Psychological Medicine

cambridge.org/psm

Original Article

Cite this article: Crowe ML, Harper KL, Moshier SJ, Keane TM, Marx BP (2023). Longitudinal PTSD network structure: measuring PTSD symptom networks over 5 years. *Psychological Medicine* **53**, 3525–3532. https://doi.org/10.1017/S0033291722000095

Received: 5 October 2021
Revised: 4 January 2022
Accepted: 6 January 2022
First published online: 28 March 2022

Key words:
DSM-5; ICD-11; network stability; posttraumatic stress disorder; veterans

Author for correspondence:
Michael L. Crowe,
E-mail: michael.l.crowe@gmail.com

© The Author(s), 2022. Published by Cambridge University Press

Longitudinal PTSD network structure: measuring PTSD symptom networks over 5 years

Michael L. Crowe[1], Kelly L. Harper[1], Samantha J. Moshier[2], Terence M. Keane[1,3] and Brian P. Marx[1,3]

[1]National Center for PTSD, Behavioral Science Division, VA Boston Healthcare System, Boston, USA; [2]Department of Psychology, Emmanuel College, Boston, USA and [3]Department of Psychiatry, Boston University School of Medicine, Boston, USA

Abstract

Background. Network modeling has been applied in a range of trauma-exposed samples, yet results are limited by an over reliance on cross-sectional data. The current analyses used posttraumatic stress disorder (PTSD) symptom data collected over a 5-year period to estimate a more robust between-subject network and an associated symptom change network.

Methods. A PTSD symptom network is measured in a sample of military veterans across four time points (*N*s = 1254, 1231, 1106, 925). The repeated measures permit isolating between-subject associations by limiting the effects of within-subject variability. The result is a highly reliable PTSD symptom network. A symptom slope network depicting covariation of symptom change over time is also estimated.

Results. Negative trauma-related emotions had particularly strong associations with the network. Trauma-related amnesia, sleep disturbance, and self-destructive behavior had weaker overall associations with other PTSD symptoms.

Conclusions. PTSD's network structure appears stable over time. There is no single 'most important' node or node cluster. The relevance of self-destructive behavior, sleep disturbance, and trauma-related amnesia to the PTSD construct may deserve additional consideration.

Posttraumatic Stress Disorder (PTSD) is a multidimensional syndrome in both its phenotypic presentation (Campbell, Trachik, Goldberg, & Simpson, 2020) and its developmental course (Dickstein, Suvak, Litz, & Adler, 2010). Although the diagnostic criteria of the construct remain controversial, the DSM-5 (APA, 2013) currently defines the construct as including intrusions, avoidance of trauma reminders, alterations in cognitions and mood, and alterations in reactivity following exposure to a traumatic event.

PTSD has historically been modeled statistically from a latent variable perspective. This 'common cause' approach allows for parsimonious modeling of symptom covariance, but the emphasis on variance shared across symptoms provides limited insight into the unique symptom-level associations (Borsboom & Cramer, 2013). Network modeling offers a complementary alternative that emphasizes understanding symptom-level associations. Network modeling may provide unique insights by directly modeling symptom correlations after accounting for common variance. Understanding these symptom-level interactions for PTSD may allow us to clarify how the disorder is maintained and identify treatment targets.

PTSD symptoms have been examined with network modeling in a range of samples but nearly all of this work relied upon cross-sectional network models (see Birkeland, Greene, & Spiller, 2020 for systematic review). Measurement error may be particularly problematic in these models, which typically emphasize conditionally dependent associations between single-item indicators (Fried & Cramer, 2017). Cross-sectional networks also cannot distinguish between- from within-subject effects (Epskamp, Waldorp, Mõttus, & Borsboom, 2018b), so observed 'edges' (i.e. item-level associations) could represent between-subject effects, within-subject effects, or a combination of the two (Epskamp et al., 2018b). The variability in both node and edge strength estimates observed in a recent review of cross-sectional network models of PTSD symptoms may be partially attributable to sources of variance such as these (Birkeland et al., 2020).

The limitations of cross-sectional data led some investigators to highlight the value of repeated measurement in the assessment of psychological networks (Costantini et al., 2019; Fried & Cramer, 2017). Longitudinal assessment of PTSD symptoms allows us to estimate a more reliable between-persons symptom network by reducing the effect of measurement error and within-subject variance. Repeated measurement data also allow us to model network stability as well as the effects of symptom change over time, both necessary steps in

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press

understanding the temporal maintenance of PTSD symptoms that are outside the scope of cross-sectional analyses.

To date, examinations of the temporal stability of the PTSD network structure are limited. Two prior studies have examined PTSD's network structure with intensive longitudinal assessment data over a period of 1 to 2 months (Greene, Gelkopf, Epskamp, & Fried, 2018; Hoffart, Langkaas, Øktedalen, & Johnson, 2019), but neither directly evaluated the stability of PTSD's network structure. Only one prior study has examined the stability of DSM-5 PTSD's network structure over the course of years (von Stockert, Fried, Armour, & Pietrzak, 2018), and several features of the sample led the authors to acknowledge limitations regarding generalizability to those seeking or receiving clinical care. Specifically, not only was the von Stockert et al. (2018) sample 90% male, but the sample was also relatively low in PTSD symptom severity, with only 8% of their sample having PCL-5 scores indicative of probable PTSD.

The Veterans After-Discharge Longitudinal Registry (Project VALOR) measured DSM-5 PTSD symptoms at four time points across 5 years in a group of veterans oversampled for trauma-related symptoms. Not only is the Project VALOR sample equally divided among men and women, but participants are also highly symptomatic, with between 61% and 69% of the sample endorsing PCL-5 scores that exceed the cut score for probable PTSD across the various time points. The current analyses use the Project VALOR sample to extend our understanding of the PTSD symptom network in two primary ways: (1) evaluate the stability of PTSD's symptom structure with additional measurement instances, over a longer period, and with a sample that is more representative of the clinical population than previous analyses, and (2) use latent growth curve modeling to generate a between-subject network for each participant's central tendency and slope over a 5-year period while limiting the influence of measurement error and within-subject variance, which have confounded previous cross-sectional network models.

Methods

Participants and procedure

Participants were a subsample of participants of Project VALOR, a longitudinal, national registry of United States veterans. For the registry, we recruited veterans of the Army or Marine Corps who had been deployed in support of Operation Enduring Freedom, Operation Iraqi Freedom, or Operation New Dawn and had undergone a mental health evaluation at a Veteran Health Administration (VHA) facility between July 2008 and December 2009. PTSD was sampled at a ratio of 3:1 (probable PTSD: not probable PTSD). Women veterans were oversampled at a ratio of 1:1 (female: male). Of the 4331 potential participants identified and contacted by phone, 2712 (62.62%) consented to participate, and 1649 (38.07%) completed the initial assessment, which included a questionnaire and a telephone-based clinical interview, between 2009 and 2012. The second wave of data collection (T2) occurred between 2013 and 2014, the third (T3) occurred between 2014 and 2015, the fourth (T4) between 2015 and 2017, and the fifth (T5) between 2018 and 2019. We administered self-report questionnaires online or by paper and pencil when requested. The second wave of data collection (T2) was the first to administer the PTSD Checklist for the *Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition* (*DSM-5*) (PCL-5; Weathers, Litz, Keane, Palmieri, and Schnurr, 2013). We therefore focused our analyses on T2 through T5. Sample characteristics for participants with at least one time point of PCL-5 data ($N = 1489$) were as follows: *Gender* – 51% female; *Age at T2* – $M = 40.66$ (S.D. = 9.8); *Race* – 75% White, 16% African American; *Ethnicity* – 12% Latino; *Education at T2* – 56% had associates degree or higher; *Treatment History* – 1212 (81%) reported seeking mental health counseling services of some kind within the past 12 months of at least one of the four measurement periods. VHA Boston's Institutional Review Board and the Human Research Protection Office of the U.S. Army Medical Research and Materiel Command approved all procedures.

Measures

Ptsd checklist for DSM-5 (PCL-5)

We used the PCL-5 (Weathers et al., 2013) to assess PTSD symptom severity at each time point. The PCL-5 is a 20-item self-report measure of PTSD symptom severity during the past-month. Items are rated on a scale from 0 to 4 (0 = *not at all* to 4 = *extremely*) and correspond to each DSM-5 symptom of PTSD. The PCL-5 has demonstrated good test-retest reliability, internal consistency, and construct validity (Bovin et al., 2016; Keane et al., 2014). In this study, the PCL-5 had excellent internal consistency ($\alpha = 0.96$ at T2, T3, T4, and T5).

Data analysis

We completed all analyses using the R program for statistical computing (R Core Team, 2020) within RStudio (R Studio Team, 2021). R code for these analyses is provided in supplemental materials. We handled missing data with listwise deletion unless otherwise noted. The final sample size at each time point was as follows: T2 = 1254; T3 = 1231; T4 = 1106; T5 = 925. For all network models, we used the *bootnet* package (Epskamp, Borsboom, & Fried, 2018a) to estimate Gaussian Graphical Models (GGM) from the Pearson correlation matrix using the least absolute shrinkage and selection operator (LASSO, Tibshirani, 1996) and extended Bayesian information criterion (EBIC; Chen and Chen, 2008) regularization. We used nonparametric bootstrapping to evaluate the reliability of edge strength and node centrality. We used expected influence (EI) and bridge EI as the primary metrics for node centrality (Robinaugh et al., 2016). A node's EI represents the sum of all its estimated edge weights while bridge EI represents the sum of only those edges connected to nodes of differing communities (i.e. diagnostic criteria clusters). The EI was selected as the primary centrality measure as it tends to outperform the strength centrality metric when negative edges are present and perform comparably when all edges are positive (Robinaugh et al., 2016). We conducted two primary analyses.

Stability of cross-sectional PTSD networks

We estimated four cross-sectional PTSD symptom networks utilizing PCL-5 data from T2, T3, T4, and T5, respectively. The stability of the PTSD network structures was evaluated using the network comparison test (NCT, van Borkulo et al., in press). Because the NCT was designed to compare two networks, we applied a series of six NCTs to evaluate differences between the network for each timepoint. The NCT applies an omnibus test of network structure invariance based on the maximum difference between edge weights in the observed networks. Failure to reject the null hypothesis for this test implies that network structure is

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press

comparable across time points. In the event of variant network structure across time, a post-hoc edge invariance test with a Benjamini and Hochberg (1995) false discovery rate correction was applied to all edge pairs to identify variant edges. Global EI invariance was also evaluated. Failure to reject the null for this test implies that the weighted sum of edges in each network is invariant across time points.

Estimation of between-person mean and between-person slope networks

Latent growth curve modeling was used to generate latent intercept and slope parameters for each of the 20 PCL items over the 5-year time period. In each model, slope loadings were fixed at −2.25, −1.25, 0.75, and 2.75 to represent the four measurements (i.e. baseline at Time 2 and 1-, 3-, and 5-year follow-ups). By centering the slope loadings we can interpret the intercept value as an average PCL-5 item score across the 5 year span and limit its correlation with the estimated latent slope. Full information maximum likelihood estimation was used for all growth curve models. Model fit for each of the 20 growth curve models was evaluated using standard fit statistics in line with the recommendations of Hu and Bentler (1999): CFI > 0.95, TLI > 0.95, RMSEA < 0.06, SRMR < 0.08. The resulting growth curve model for each item was used to predict mean (i.e. intercept) and slope values for each individual. Those values were then used to generate a person-mean network (representing the between-subject conditional correlations between average PCL-5 item scores over the 5-year span) and a person-slope network (representing the between-subject conditional correlations between person-specific linear change in PCL-5 item scores).

This method for leveraging the strengths of latent growth curve models within a network modeling framework is distinct from that recently proposed by Deserno, Sachisthal, Epskamp, and Raijmakers (under review) which focuses on examining the covariance of intercept and slope parameters within a GGM. In contrast, the current method minimizes the covariance between the latent intercept and slope parameters in favor of examining intercept and slope estimates as part of distinct network structures.

Results

Descriptive statistics for PCL-5 items at all time points can be found in Table 1. The following sample percentages had scores greater than or equal to 31[†1] (i.e. probable PTSD diagnosis; Bovin et al., 2016): Time 2 = 64%; Time 3 = 64%; Time 4 = 57%; Time 5 = 59%. There were no differences in PCL-5 total scores across gender at any of the time points. Non-White veterans had more severe PCL-5 scores relative to White veterans at all time points.

Network stability over time

Bootstrapped correlation stability[2] (CS) values were used to evaluate the reliability of the estimated networks for each individual time point. CS values indicated that network edge and centrality parameter estimates were reliable at all time points: Time 2 edge *CS* = 0.88, EI *CS* = 0.76; Time 3 edge *CS* = 0.92, EI *CS* = 0.79; Time 4 edge *CS* = 0.92, EI *CS* = 0.69; Time 5 edge *CS* = 0.88, EI *CS* = 0.60.

NCTs show stability in the network structure of PCL-5 scores over time (see Online Supplementary Table S1 for specific *p* values of all network invariance tests). No significant differences were observed in the global EI tests. We observed only one significant difference in network structure, between Time 2 and Time 5 ($n = 795$; $p = 0.031$). Post-hoc edge difference tests with a false discovery rate correction identified the connection between restricted affect (D7) and reckless behavior (E2) as the only variant edge between the networks. That edge had the following magnitudes at the two time points: Time 2 = 0.126, Time 5 = 0.007.

Latent growth curve models

All latent growth curve models had good fit (see Table 2 for all model fit indices and estimated parameters). CFI values ranged from 0.97 (B4) to 0.996 (D3). RMSEA values ranged from 0.089 (B1) to 0.027 (D3). SRMR values ranged from 0.045 (E5) to 0.018 (D3). Estimated latent intercept values ranged from 1.01 (E2) to 2.69 (E6) while estimated latent slope values ranged from −0.06 (E1) to 0 (D1). Significant covariance between the latent intercept and slope variables was observed only in item E2 [Cov(i,s) = −0.025, $p = 0.001$] and D3 [Cov(i,s) = −0.025, $p = 0.012$]. These 20 latent growth curve models were used to generate person-specific intercept and slope estimates for the between-subject person-mean and between-subject slope networks.

Person-mean network

Bootstrapped CS values indicated that network parameter estimates for the person-mean network were highly reliable: edge *CS* = 0.95, EI *CS* = 0.95, bridge EI *CS* = 0.85. Figure 1[3] panels A-C display results for the person-mean network [see Online Supplemental Fig. S1 for figure depicting all estimated edges and Online Supplementary Table S2 for values of all network parameters and bootstrapped confidence intervals (CI)]. We report the magnitudes of all edges plotted in the person-mean network model, along with their 95% CI, in Fig. 1*c*. The strongest edges in the network were those connecting avoidance of internal and external trauma reminders (C1-C2) and connecting hypervigilance and exaggerated startle (E3-E4). Generally, nodes were most strongly interconnected with other symptoms within their symptom cluster. Criterion D symptoms formed two distinct symptom clusters: negative beliefs – inappropriate blame – negative emotions (D2-D3-D4); anhedonia – detachment – restricted affect (D5-D6-D7). Tests of edge differences among Criterion D symptoms revealed that all edges within these respective Criterion D clusters were significantly greater than all possible connections spanning the two clusters. Trauma-related amnesia (D1) was poorly connected with the rest of the PCL-5 symptom network. There were 15 edges in the network with negative weight ranging in magnitude from −0.001 (C2-D2) to −0.056 (C2-E2).

Avoidance of internal (C1) and external (C2) trauma reminders had the highest predictability within the network (C1 R^2 = 0.85; C2 R^2 = 0.86), indicating that included nodes accounted for roughly 85% of the variance in avoidance symptoms. The symptom network accounted for more than 70% of the variance in all symptoms except difficulty concentrating (E5; $R^2 = 0.68$), irritability (E1; $R^2 = 0.65$), sleep disturbance (E6; $R^2 = 0.52$), self-destructive behavior (E2; $R^2 = 0.49$), and trauma-related amnesia (D1; $R^2 = 0.40$).

Node centrality should not be inferred from relative node location. Figure 1*a* displays Node EI and bridge EI, along with their

---

[†] The notes appear after the main text.

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press

Table 1. Descriptive Statistics of PCL-5 Items Across Time Points

Symptom	Label	Time 2 ($N = 1254$)		Time 3 ($N = 1231$)		Time 4 ($N = 1106$)		Time 5 ($N = 925$)	
		M	(s.d.)	*M*	(s.d.)	*M*	(s.d.)	*M*	(s.d.)
Intrusive memories	B1	2.04	(1.23)	2.03	(1.21)	1.78	(1.24)	1.87	(1.18)
Nightmares	B2	1.88	(1.30)	1.87	(1.30)	1.62	(1.31)	1.67	(1.26)
Flashbacks	B3	1.40	(1.26)	1.43	(1.27)	1.26	(1.25)	1.31	(1.23)
Emotional cue reactivity	B4	2.10	(1.23)	2.09	(1.23)	1.81	(1.28)	1.91	(1.25)
Physiological cue reactivity	B5	1.89	(1.30)	1.93	(1.32)	1.71	(1.33)	1.81	(1.28)
Avoidance of thoughts	C1	2.25	(1.36)	2.28	(1.35)	2.03	(1.39)	2.12	(1.36)
Avoidance of reminders	C2	2.21	(1.39)	2.27	(1.37)	2.02	(1.41)	2.09	(1.38)
Trauma-related amnesia	D1	1.55	(1.38)	1.58	(1.39)	1.42	(1.38)	1.54	(1.40)
Negative beliefs	D2	1.76	(1.44)	1.78	(1.44)	1.57	(1.40)	1.56	(1.38)
Blame of self or others	D3	1.66	(1.44)	1.63	(1.41)	1.45	(1.39)	1.48	(1.35)
Neg. trauma-related emotions	D4	1.93	(1.38)	1.88	(1.35)	1.70	(1.38)	1.73	(1.32)
Loss of interest	D5	2.16	(1.39)	2.18	(1.39)	2.07	(1.41)	2.12	(1.39)
Detachment	D6	2.23	(1.34)	2.28	(1.35)	2.08	(1.38)	2.17	(1.36)
Restricted affect	D7	1.93	(1.38)	1.95	(1.38)	1.78	(1.37)	1.81	(1.36)
Irritability/anger	E1	2.04	(1.28)	2.09	(1.29)	1.90	(1.32)	1.75	(1.32)
Self-destructive behavior	E2	1.02	(1.22)	1.10	(1.27)	0.91	(1.16)	0.96	(1.16)
Hypervigilance	E3	2.34	(1.40)	2.34	(1.38)	2.12	(1.45)	2.24	(1.39)
Exaggerated startle response	E4	2.16	(1.40)	2.19	(1.39)	1.98	(1.44)	2.10	(1.39)
Difficulty concentrating	E5	2.30	(1.33)	2.31	(1.34)	2.15	(1.38)	2.24	(1.34)
Sleep disturbance	E6	2.68	(1.34)	2.70	(1.34)	2.64	(1.37)	2.64	(1.36)

Note. Indicated sample size identifies the number of complete cases at each time point. A total of 605 participants had complete data across all time points.

95% CIs. Figure 2*a* shows all EI difference tests. The most influential symptom in the network, as measured by EI, was negative trauma-related emotions (D4). Along with negative trauma-related emotions, emotional and physiological cue reactivity (B4 and B5), detachment and restricted affect (D6 and D7), intrusive memories (B1), and internal and external avoidance (C1 and C2) all had EI values significantly greater than at least 50% of the nodes in the network. Self-destructive behavior (E2), Sleep disruption (E6), and trauma-related amnesia (D1) were noteworthy in that they had a significantly lower EI than all other nodes. Restriction of range is unlikely to account for the limited association between these nodes and the rest of the network as the correlation between symptom standard deviation and EI was not significant ($r = 0.11$, $p = 0.635$). Difficulty concentrating (E5) had the strongest cross-criterion connections, showing a bridge EI value significantly greater than all other nodes.

Slopes network

Bootstrapped CS values indicated that network parameter estimates for the between-person slope network were highly reliable: edge $CS = 0.92$, EI $CS = 0.88$, bridge EI $CS = 0.60$. Figure 1 panels D-F display results for the slopes network (see Online Supplementary Fig. S2 for figure depicting all estimated edges and Supplementary Table S3 for values of all network parameters and bootstrapped CIs). The magnitude of all plotted edges along with their 95% CI is depicted in Fig. 1*f*. The strongest edges in the network were again those connecting avoidance of internal and external trauma reminders (C1-C2) and connecting hypervigilance and exaggerated startle (E3-E4). Only one negative edge (B3-C1) with a weight of −0.007 was estimated in this network. Two edges estimated as > 0.1 in the person-mean network were null in the slope network: flashbacks and reckless behavior (B3-E2), avoidance of thoughts and trauma-related amnesia (C1-D1). All edges estimated as > 0.1 in the slope network were estimated in the person-mean network.

Avoidance of internal and external trauma reminders were again the most well predicted nodes in the network (C1 R^2 = .56; C2 R^2 = .57). The network accounted for at least 50% of the variance in changes in emotional cue reactivity (B4; $R^2 = 0.53$), intrusive memories (B1; $R^2 = 0.51$), and physiological cue reactivity (B5; $R^2 = 0.51$). Sleep disturbance (E6; $R^2 = 0.26$), self-destructive behavior (E2; $R^2 = 0.25$), and trauma-related amnesia (D1; $R^2 = 0.14$) were again the most poorly predicted.

Figure 1*d* displays node EI and bridge EI. Figure 2*b* displays all EI differences. Negative trauma-related emotions (D4), emotional cue reactivity (B4), and intrusive memories (B1) were the only nodes to have EI significantly greater than at least 50% of the nodes in the network. Self-destructive behavior (E2), Sleep disruption (E6), and trauma-related amnesia (D1) were again noteworthy in that they had a significantly lower EI than nearly all other nodes. Again, the correlation between EI and symptom standard deviation ($r = -0.03$, $p = 0.904$) suggests that the limited influence of these nodes is not attributable to restriction of range.

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press

Table 2. Growth curve model estimated parameters and model fit indices

	Model parameters					Fit statistics						
Item	μ_i	μ_s	ψ_i	ψ_s	$\psi_{i,s}$	χ^2	df	CFI	TLI	RMSEA	SRMR
B1	1.95*	−0.04*	0.94*	0.012*	−0.009	64.45*	5	0.973	0.967	0.089	0.041
B2	1.79*	−0.04*	1.12*	0.008*	−0.015	52.98*	5	0.981	0.977	0.080	0.036
B3	1.38*	−0.02*	1.01*	0.014*	0.002	24.48*	5	0.991	0.989	0.051	0.024
B4	2.01*	−0.04*	0.95*	0.013*	−0.004	63.32*	5	0.970	0.964	0.088	0.044
B5	1.86*	−0.02*	1.02*	0.013*	−0.010	37.07*	5	0.983	0.980	0.065	0.037
C1	2.20*	−0.03*	1.15*	0.003	−0.009	42.34*	5	0.982	0.978	0.070	0.037
C2	2.18*	−0.03*	1.20*	0.008*	−0.016	39.98*	5	0.983	0.980	0.068	0.037
D1	1.54*	0.00	1.20*	0.009*	0.003	22.25*	5	0.991	0.990	0.048	0.024
D2	1.69*	−0.04*	1.17*	0.006	−0.011	15.38*	5	0.994	0.993	0.037	0.024
D3	1.58*	−0.04*	1.08*	0.019*	−0.025*	10.68	5	0.996	0.996	0.027	0.018
D4	1.84*	−0.04*	1.07*	0.021*	−0.013	21.06*	5	0.991	0.989	0.046	0.023
D5	2.15*	−0.01	1.31*	0.007*	−0.004	21.56*	5	0.993	0.992	0.047	0.031
D6	2.21*	−0.02*	1.20*	0.006	0.001	43.55*	5	0.983	0.980	0.072	0.035
D7	1.89*	−0.03*	1.19*	0.016*	−0.012	18.81*	5	0.993	0.992	0.043	0.025
E1	1.97*	−0.06*	1.02*	0.011*	−0.002	25.21*	5	0.989	0.987	0.052	0.030
E2	1.01*	−0.02*	0.85*	0.013*	−0.025*	45.72*	5	0.976	0.971	0.074	0.038
E3	2.30*	−0.02*	1.34*	0.017*	−0.015	50.52*	5	0.983	0.979	0.078	0.034
E4	2.13*	−0.02*	1.35*	0.014*	−0.014	62.95*	5	0.979	0.974	0.088	0.041
E5	2.28*	−0.01*	1.23*	0.007*	−0.004	45.84*	5	0.984	0.980	0.074	0.045
E6	2.69*	−0.01	1.09*	0.019*	−0.015	27.61*	5	0.988	0.986	0.055	0.037

Note. i = intercept; s = slope; μ = mean; ψ = (co)variance.
* indicates $p < 0.05$.

Topological overlap

We did not consider topological overlap (i.e. excessive construct overlap across nodes; see Fried and Cramer, 2017) for these analyses as we were most interested in understanding PTSD's network structure as defined by the DSM-5. PTSD is a well-validated construct and a consensus in the non-redundancy of symptoms is implied by the diagnostic criteria. However, given the magnitude of association observed between some symptoms (e.g. C1 and C2, E3 and E4), topological overlap may be present. We completed supplemental post-hoc analyses to empirically examine this possibility. Full details and results of these analyses are provided in the Online Supplementary Appendix, Supplementary Table S4, and Supplementary Figures 3 and 4. In brief, we observed topological overlap between hypervigilance and exaggerated startle symptoms (E3 and E4) in the person-mean network. No such overlap was observed in the slope-based network. Accounting for this overlap had minimal effects on the network structure. Persistent negative trauma-related emotions (D4) and psychological distress at exposure to trauma cues (B4) continued to have the greatest EI while self-destructive behavior (E2), sleep disturbance (E6), and trauma-related amnesia (D1) remained notable for their relative lack of associations.

Discussion

Our findings expand on those from previous research by evaluating the stability of DSM-5 PTSD symptom networks over time in a sample of male and female U.S. military veterans with significant PTSD symptoms. The PTSD network was generally stable across time points, revealing only minimal changes in network structure across the 5-year time span. Across six network comparisons, only one significant difference in network structure was observed, that between T2 and T5 symptom networks. Post-hoc analyses with false discovery rate correction identified the connection between restricted positive affect (D7) and reckless behavior (E2) as the only variant edge in the networks with the relationship between the two symptoms decreasing in magnitude over time. Additional work is needed to determine whether this shift is a replicable effect. Even accounting for this minor variation, PTSD's overall between-subject network structure appears remarkably stable over a 5-year span.

In line with recent recommendations (Costantini et al., 2019), repeated measurement of PTSD symptoms was applied to better understand its network structure. We used latent growth curve modeling to estimate both a person-mean and slope network structure. To our knowledge, this is the first time between-subject mean and slope networks have been generated in this way, although it is comparable to recent analyses applying multilevel modeling to generate a baseline and random slope network from repeated measures of borderline personality disorder symptoms (von Klipstein et al., 2021). Aggregation of repeated measures in this way allowed for particularly reliable network estimates for both models, with bootstrapping methods revealing that the order of edge and EI

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press

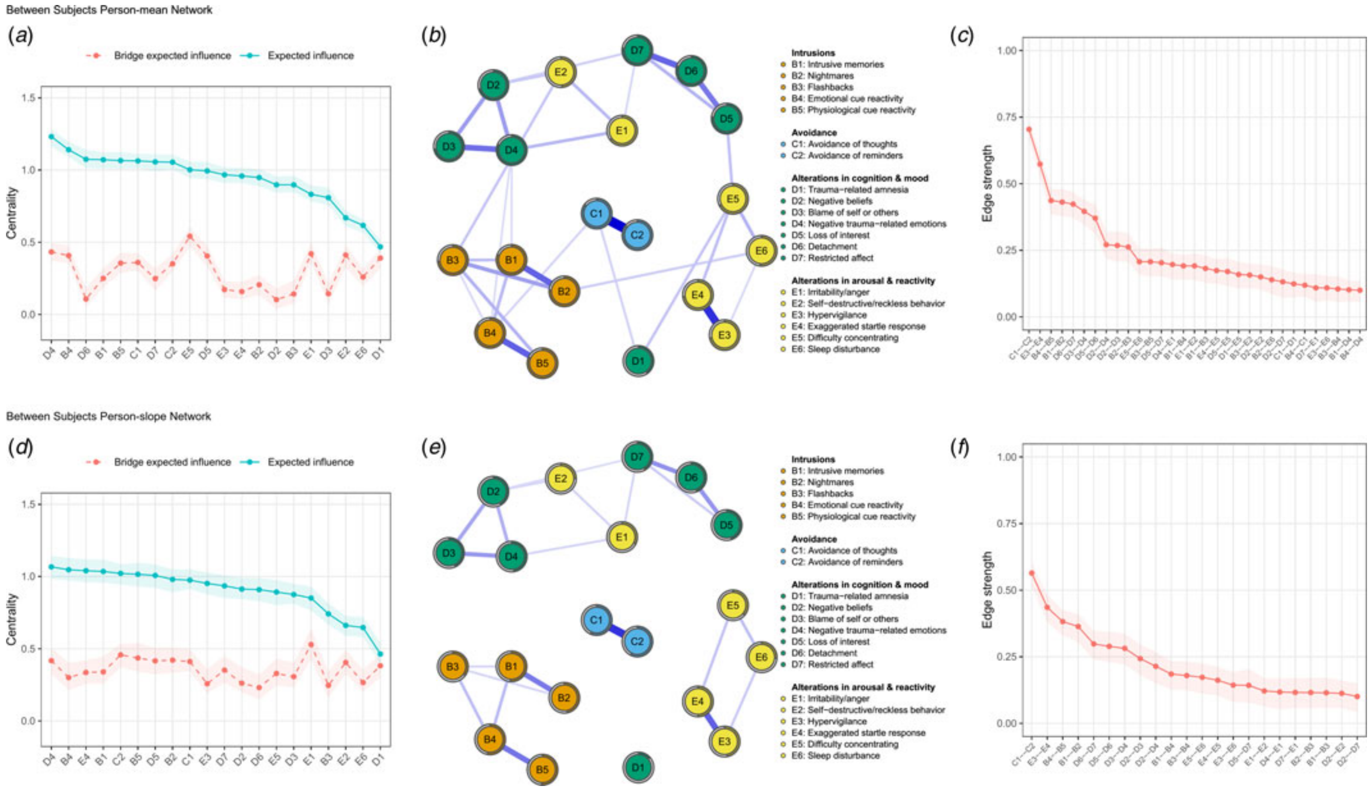

Fig. 1. PCL-5 person-mean and slopes networks.*Note.* Shaded areas reveal 95% CIs. Expected influence values reflect all estimated edges. Network figures display only edges with a magnitude greater than 0.1. Circles around nodes reflect symptom predictability and can be interpreted as variance in the symptom that can be accounted for by the rest of the network. Node location has been averaged across the person-mean and slope networks.

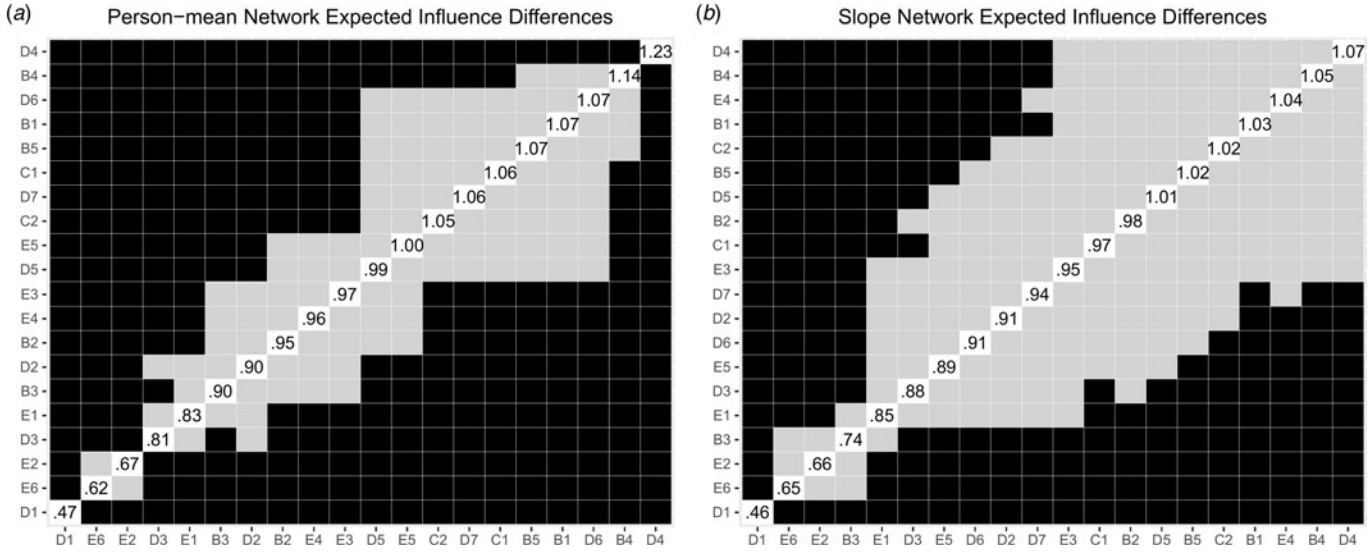

Fig. 2. Expected influence difference tests for person-mean (*a*) and slope (*b*) networks.*Note.* Expected influence difference tests based on nonparametric bootstrapping. Black cells indicate significant difference between node expected influence estimates. Plot diagonals display the observed expected influence for each node.

parameters was consistent with original estimates even after dropping 90% of the sample or more.

Both the person-mean and slope networks depict between-person symptom level associations. The person-mean network is representative of the conditional associations between mean-level differences in symptoms over the 5-year span. The connection between C1 and C2, for example, suggests that after controlling for all other symptoms in the network, individuals who reported greater than average avoidance of internal trauma-reminders also reported greater than average avoidance of external reminders. Persistent negative trauma-related emotions (D4) was the most 'central' node in the symptom network

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press

in terms of EI, suggesting that it had the greatest cumulative unique association with other PTSD symptoms. Emotional cue reactivity (B4) was also notable, with an EI greater than 15 of the 20 symptoms. This should not be interpreted as an indication that these symptoms are a central mechanism with regard to the maintenance of PTSD symptoms or that they are necessarily influential in the causal sense of the word. Self-destructive behavior (E2), sleep disturbance (E6), and trauma-related amnesia (D1) were notable within this network due to their significantly weaker associations with the rest of the network. This suggests that higher or lower levels of these symptoms, relative to the rest of the sample, were largely uninformative with regard to predicting other symptom levels after controlling for the rest of the network. These findings are consistent with Birkeland et al. (2020), who identified D4 as the most consistently strong node and E2, E6, and D1 as the most consistently weak nodes.

Our analyses are the first application of a between-subject slope-based network to understand correlated symptom change in PTSD over time. Edges in this network represent conditional between-subject associations in symptom change over time. The connection between E3 and E4, for example, suggests that after controlling for all other symptoms in the network, individuals who reported greater than average reductions in hypervigilance symptoms also reported greater than average reductions in hyperstartle symptoms. Results were largely consistent with the person-mean network. Self-destructive behavior (E2), sleep disruption (E6), and trauma-related amnesia (D1) were again identified as the least influential nodes in the network, suggesting that changes in these symptoms are relatively independent of changes in the rest of the network. The relative consistency between the person-mean and slopes network is significant as it suggests that observed between-subject contemporaneous associations are in line with between-subject associations of symptom change.

Some inconsistencies across the person-mean and slope networks were identified. Edges connecting flashbacks to reckless behavior (B3-E2) and avoidance of thoughts to amnesia (C1-D1) had notable magnitude in the person-mean network but were not observed in the slopes-based network. This suggests that although between-subject associations may be observed for these symptoms, those associations may not reflect a conditionally dependent between-subject parallel change process. Future analyses should be directed at understanding such discrepancies.

Our analyses do not permit us to identify any one most valuable treatment target. Both networks indicate that many PTSD symptoms are comparable in their overall association with the rest of the network. This is consistent with clinical trials showing that, at the between-person level, evidence-based treatment protocols are equally effective despite emphasizing the treatment of different symptom clusters (e.g. Cusack et al., 2016). The minimal associations between amnesia, risky behavior, and sleep problems and other nodes raises questions regarding the relevance of these symptoms to the PTSD construct. The presence of sleep problems among these poorly connected symptoms is perhaps the most surprising and deserves further consideration. Sleep disruption is highly prevalent among the PTSD population, and sleep problems have been identified as a prognostic indicator of PTSD severity (Koffel et al., 2016). However, relatively few associations within the person-mean network suggest that sleep disruption does not have particularly strong unique associations with other PTSD symptoms at the between-subject level and may be better understood as a non-specific indicator of distress. Similarly, the minimal associations with sleep disruption in the slopes network are consistent with longitudinal analyses showing that sleep problems are somewhat more resistant to change over the course of PTSD treatments (Gutner et al., 2013).

It is notable that the ICD-11 (WHO, 2019) excludes amnesia, risky behavior, and sleep problems from the diagnostic criteria of PTSD as well as negative trauma-related emotions (D4), the most central symptom in both networks. It is difficult to say whether this is problematic due to the correlational nature of the observed edge connections. The absence of D4 from ICD-11 diagnostic criteria could be appropriate if such negative emotionality emerges as a downstream effect resulting from symptoms present in the ICD-11 PTSD criteria. Additional analyses more closely examining the temporal association between symptoms is needed to address such questions.

These analyses should be interpreted in light of some limitations. Recent analyses suggest that item ordering effects may have an effect on PTSD symptom structure (Trachik et al., 2020). We have no way of evaluating such method effects in these analyses, but as PCL-5 items are organized based on empirical associations and common content, we would expect substantial associations between sequential items within criteria clusters to occur. Limitations associated with the extended period of time between assessments should also be considered as some symptom change dynamics will be lost with repeated measures occurring over such extended periods.

Conclusion

Self-reported PTSD symptom structure appears to be highly stable over time. Negative trauma-related emotions seem to have the greatest cumulative unique association with PTSD symptoms. Self-destructive behavior, sleep disturbance, and trauma-related amnesia stand out due to their relatively small connections with the rest of the PTSD symptom network. The PTSD symptom slope network, reflecting correlated change over time, shows a pattern of associations comparable to that of the person-mean network. Further study using longitudinal data is needed to understand the dynamic relationship between PSTD symptoms over time, but these results provide further evidence for the stability of the PTSD network and initial insights regarding symptom change over extended periods.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0033291722000095.

Financial support. The study was funded by the U.S. Department of Defense awards W81XWH-08-2-0102 and W81XWH-08-2-0100. The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the U.S. Department of Veterans Affairs or the U.S. government.

Conflicts of interest. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

A preprint version of this manuscript was posted online prior to peer review (https://osf.io/qd94v/)

Notes

1 In Bovin et al. (2016) signal detection analyses indicated that cut scores of 31-33 had equivalent efficiency for predicting a PTSD diagnosis. We use 31 here for comparative purposes.

2 The correlation stability value indicates the maximum number of cases that can be dropped from the data while retaining, with 95% probability, a

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press

correlation of at least .7 between the statistic based on the original network and the statistic computed with fewer randomly sampled cases (Epskamp, Borsboom, & Fried, 2018a). Values greater than .5 are desirable, values greater than .25 are acceptable (Epskamp, Borsboom, & Fried, 2018a).

3 NCT analyses indicated that estimated person-mean and slope network structures were invariant across race (i.e., White vs. non-White) and gender (i.e., male vs. female).

References

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders: DSM-5*. Arlington, VA: American Psychiatric Association.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B* (*Methodological*), *57*, 289–300.

Birkeland, M. S., Greene, T., & Spiller, T. R. (2020). The network approach to posttraumatic stress disorder: A systematic review. *European Journal of Psychotraumatology*, *11*, 1–14. doi: 10.1080/20008198.2019.1700614.

Borsboom, D., & Cramer, A. O. J. (2013). Network analysis: An integrative approach to the structure of psychopathology. *Annual Review of Clinical Psychology*, *9*, 91–121.

Bovin, M. J., Marx, B. P., Weathers, F. W., Gallagher, M. W., Rodriguez, P., Schnurr, P. P., & Keane, T. M. (2016). Psychometric properties of the PTSD checklist for diagnostic and statistical manual of mental disorders–fifth edition (PCL-5) in veterans. *Psychological Assessment*, *28*, 1379–1391.

Campbell, S. B., Trachik, B., Goldberg, S., & Simpson, T. L. (2020). Identifying PTSD symptom typologies: A latent class analysis. *Psychiatry Research*, *285*, 1–11. doi: 10.1016/j.psychres.2020.112779.

Chen, J., & Chen, Z. (2008). Extended Bayesian information criteria for model selection with large model spaces. *Biometrika*, *95*, 759–771.

Costantini, G., Richetin, J., Preti, E., Casini, E., Epskamp, S., & Perugini, M. (2019). Stability and variability of personality networks. A tutorial on recent developments in network psychometrics. *Personality and Individual Differences*, *136*, 68–78.

Cusack, K., Jonas, D. E., Forneris, C. A., Wines, C., Sonis, J., Middleton, J. C., … Gaynes, B. N. (2016). Psychological treatments for adults with posttraumatic stress disorder: A systematic review and meta-analysis. *Clinical Psychology Review*, *43*, 128–141.

Deserno, M. K., Sachisthal, M. S. M., Epskamp, S., & Raijmakers, M. E. J. (under review). A magnifying glass for the study of coupled developmental changes: Combining psychological networks and latent growth models. https://doi.org/10.31234/osf.io/ngfxq

Dickstein, B. D., Suvak, M., Litz, B. T., & Adler, A. B. (2010). Heterogeneity in the course of posttraumatic stress disorder: Trajectories of symptomatology. *Journal of Traumatic Stress*, *23*(3), 331–339.

Epskamp, S., Borsboom, D., & Fried, E. I. (2018a). Estimating psychological networks and their accuracy: A tutorial paper. *Behavior Research Methods*, *50*, 195–212.

Epskamp, S., Waldorp, L. J., Mõttus, R., & Borsboom, D. (2018b). The Gaussian graphical model in cross-sectional and time-series data. *Multivariate Behavioral Research*, *53*, 453–480.

Fried, E. I., & Cramer, A. O. J. (2017). Moving forward: Challenges and directions for psychopathological network theory and methodology. *Perspectives on Psychological Science*, *12*, 999–1020.

Greene, T., Gelkopf, M., Epskamp, S., & Fried, E. (2018). Dynamic networks of PTSD symptoms during conflict. *Psychological Medicine*, *48*, 2409–2417.

Gutner, C. A., Casement, M. D., Gilbert, K. S., & Resick, P. A. (2013). Change in sleep symptoms across cognitive processing therapy and prolonged exposure: A longitudinal perspective. *Behaviour Research and Therapy*, *51*, 817–822.

Hoffart, A., Langkaas, T. F., Øktedalen, T., & Johnson, S. U. (2019). The temporal dynamics of symptoms during exposure therapies of PTSD: A network approach. *European Journal of Psychotraumatology*, *10*, 1–11. doi: 10.1080/20008198.2019.1618134.

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*, 1–55.

Keane, T. M., Rubin, A., Lachowicz, M., Brief, D., Enggasser, J. L., Roy, M., … Rosenbloom, D. (2014). Temporal stability of DSM–5 posttraumatic stress disorder criteria in a problem-drinking sample. *Psychological Assessment*, *26*, 1138–1145.

Koffel, E., Khawaja, I. S., & Germain, A. (2016). Sleep disturbances in posttraumatic stress disorder: Updated review and implications for treatment. *Psychiatric Annals*, *46*, 173–176.

R Core Team (2020). *R: A language and environment for statistical computing* (4.0.2) [Computer software]. R Foundation for Statistical Computing.

Robinaugh, D. J., Millner, A. J., & McNally, R. J. (2016). Identifying highly influential nodes in the complicated grief network. *Journal of Abnormal Psychology*, *125*, 747–757.

R Studio Team (2021). *RStudio: Integrated development environment for R* (1.4.1103) [Computer software]. RStudio, PBC.

Tibshirani, R. (1996). Regression shrinkage and selection via the lasso. *Journal of the Royal Statistical Society: Series B* (*Methodological*), *58*, 267–288.

Trachik, B., Elliman, T. D., Ganulin, M. L., Dretsch, M. N., Riviere, L. A., Cabrera, O. A., … Hoge, C. W. (2020). Order effects in PTSD network analysis: Important implications for diagnostic conceptualization, treatment refinement, and research. *Psychological Medicine*, 1–8. doi: 10.1017/S0033291720004377.

Van Borkulo, C. D., Van Bork, R., Boschloo, L., Kossakowski, J., Tio, P., Schoevers, R. A., … Waldorp, L. J. (in press). Comparing network structures on three aspects: A permutation test. *Psychological Methods*. https://doi.org/10.31234/osf.io/ftx4j.

von Klipstein, L., Borsboom, D., & Arntz, A. (2021). The exploratory value of cross-sectional partial correlation networks: Predicting relationships between change trajectories in borderline personality disorder. *PLoS ONE*, *16*, 1–14. doi: 10.1371/journal.pone.0254496.

von Stockert, S. H. H., Fried, E. I., Armour, C., & Pietrzak, R. H. (2018). Evaluating the stability of DSM-5 PTSD symptom network structure in a national sample of U.S. military veterans. *Journal of Affective Disorders*, *229*, 63–68.

Weathers, F. W., Litz, B. T., Keane, T. M., Palmieri, P. A., & Schnurr, P. P. (2013). *The PTSD Checklist for DSM-5* (*PCL-5*).

World Health Organization (2019). International Statistical Classification of Diseases and Related Health Problems (11th ed.). https://icd.who.int/.

https://doi.org/10.1017/S0033291722000095 Published online by Cambridge University Press