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Dynamic networks of PTSD symptoms during conflict

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Abstract

Background. Conceptualizing posttraumatic stress disorder (PTSD) symptoms as a dynamic system of causal elements could provide valuable insights into the way that PTSD develops and is maintained in traumatized individuals. We present the first study to apply a multilevel network model to produce an exploratory empirical conceptualization of dynamic networks of PTSD symptoms, using data collected during a period of conflict.
Methods. Intensive longitudinal assessment data were collected during the Israel–Gaza War in July–August 2014. The final sample ($n = 96$) comprised a general population sample of Israeli adult civilians exposed to rocket fire. Participants completed twice-daily reports of PTSD symptoms via smartphone for 30 days. We used a multilevel vector auto-regression model to produce contemporaneous and temporal networks, and a partial correlation network model to obtain a between-subjects network.
Results. Multilevel network analysis found strong positive contemporaneous associations between hypervigilance and startle response, avoidance of thoughts and avoidance of reminders, and between flashbacks and emotional reactivity. The temporal network indicated the central role of startle response as a predictor of future PTSD symptomatology, together with restricted affect, blame, negative emotions, and avoidance of thoughts. There were some notable differences between the temporal and contemporaneous networks, including the presence of a number of negative associations, particularly from blame. The between-person network indicated flashbacks and emotional reactivity to be the most central symptoms.
Conclusions. This study suggests various symptoms that could potentially be driving the development of PTSD. We discuss clinical implications such as identifying particular symptoms as targets for interventions.

Introduction

The network perspective offers a novel way of understanding the dynamics of psychopathology (McNally, 2016; Borsboom, 2017). According to this framework, symptoms do not primarily result as passive consequences of underlying mental disorders. Rather, causally connected symptoms may interact with each other over time, potentially producing mental disorders as emergent phenomena. The new field of network psychometrics has been used in recent years to investigate the complex structure of various psychiatric disorders (Fried *et al.* 2017*b*), including depression (Fried *et al.* 2016), psychosis (Isvoranu *et al.* 2016), schizophrenia (Levine & Leucht, 2016), and anxiety (Beard *et al.* 2016), among others.

Several studies have recently used network analysis to examine the symptom-level structure of posttraumatic stress disorder (PTSD) in cross-sectional data (McNally *et al.* 2015; Bryant *et al.* 2017; Knefel *et al.* 2016; Afzali *et al.* 2017*a*, 2017*b*; Armour *et al.* 2017; Birkeland & Heir, 2017; Fried *et al.* 2017*a*; Mitchell *et al.* 2017; Spiller *et al.* 2017; Sullivan et al. 2018). These studies indicate the central roles that various symptoms may play in driving PTSD networks by being highly connected to other PTSD symptoms. For example, these studies suggest the central role of re-experiencing symptoms in the acute phase following traumatic injury (Bryant *et al.* 2017); of hypervigilance, concentration problems and foreshortened future in Chinese earthquake survivors 5 years after the disaster (McNally *et al.* 2015); and of intrusive thoughts, anger, and detachment in survivors of mass violence (Sullivan *et al.* 2018). Two studies in military veterans found that negative trauma-related emotions were among the most central symptoms (Armour *et al.* 2017; Mitchell *et al.* 2017).

Only three studies have previously assessed DSM-5 PTSD network structure (Afzali *et al.* 2017*a*; Armour *et al.* 2017; Mitchell *et al.* 2017), and, crucially, as all of these studies were cross-sectional, none of them explored the temporal dynamics of PTSD, which many researchers have described as one of the major shortcomings of the prior literature (Hamaker, 2012; Fisher, 2015; Fried & Cramer, 2017; Bos *et al.* 2017; Hamaker & Wichers, 2017; Nelson *et al.* 2017). Conceptualizing PTSD symptoms as a dynamic interacting network, rather than limiting the focus to cross-sectional associations between symptoms, allows for deeper exploration of potential causal pathways. This could provide valuable insights into the way that PTSD builds or is maintained in individuals who have traumatic experiences.

Intensive longitudinal assessments such as Experience Sampling Methodology (ESM) collect data about the daily lives of participants repeatedly over time, often using handheld computers or smartphones (Bolger *et al.* 2003; Ebner-Priemer & Kubiak, 2010; Bolger & Laurenceau, 2013). ESM has been used to investigate various psychiatric disorders, including PTSD (Chun, 2016), anxiety (Walz *et al.* 2014), and depression (Armey *et al.* 2015), among others. ESM entails multiple methodological advantages (Santangelo *et al.* 2013; Trull & Ebner-Priemer, 2013), as data are collected in real-life settings, with high ecological validity, increased accuracy, and minimized recall bias. Repeated short-term assessments can detect variations in the presence and severity of variables and reveal dynamic processes between them (Ebner-Priemer & Trull, 2009; Myin-Germeys *et al.* 2009; Bolger & Laurenceau, 2013).

Network models can be used to investigate such dynamic processes in ESM data from one participant (vector autoregression models; VAR) or data from multiple participants (multilevel VAR; Epskamp *et al.* 2016). These models produce temporal networks depicting a directed network of the lagged associations of symptoms from one time point to the next, for which Granger-causal connections between symptoms are inferred (Schuurman *et al.* 2016). Temporal networks can identify symptoms with a high 'out-strength', that is symptoms which are most predictive of other symptoms at the next time point, and those with a high 'in-strength', that is symptoms which are most predicted by other symptoms at the previous time point. Recent extensions include contemporaneous networks, for which the within-measurement associations are represented, and a between-persons network, modeling relations between the stable means of participants, for both of which 'cliques' or sub-networks of closely connected symptoms can be identified.

Using ESM data for network analysis is relatively new; ESM data have previously been used for network studies of psychiatric disorders, but almost exclusively for individual-level ($n = 1$) studies (Bak *et al.* 2016; David *et al.* 2017; Epskamp *et al.* 2017), or to investigate idiographic symptom dynamics (Fisher *et al.* 2017), although multilevel VAR using ESM data has been applied to investigate various psychological phenomena, such as positive and negative affect (e.g. Epskamp *et al.* 2016).

The current study uses ESM data from multiple individuals in a multilevel framework to investigate PTSD symptoms. As multilevel models focus on the dynamics of the relationships between symptoms over time, they could further help us to elucidate the processes by which PTSD symptoms build up and interact with each other, and potentially reinforce themselves. This could have important clinical implications (McNally *et al.* 2015; McNally, 2016; Borsboom, 2017); identifying symptoms with high out-strength, and to a lesser extent high in-strength, as well as detecting closely connected groups of symptoms, could eventually help clinicians focus on symptoms that might 'drive' PTSD in its early stages.

We present the first study to apply a multilevel network model to investigate the dynamics of symptoms that comprise the DSM-5 PTSD construct (APA, 2013), using data collected during a period of trauma exposure among Israeli civilians exposed to rocket fire. It is important to note that collecting ESM data regarding traumatic stress symptoms during a conflict situation is unparalleled in the literature, and we believe that this study, therefore, has the potential to make unique and important contributions to the understanding of mental health during ongoing trauma exposure. The study aims to produce an exploratory empirical conceptualization of dynamic networks of PTSD symptoms, with the goal to investigate the network structure of PTSD symptoms during an extended period of trauma exposure and identify symptoms that closely cluster together, as well as those with high out-strength and high in-strength.

Method

Participants and study design

The current study is part of a larger study conducted during and after the 50-day July–August 2014 Israel–Gaza armed conflict (Gelkopf *et al.* 2017; Greene *et al.* 2017; Lapid Pickman *et al.* 2017), during which more than 4500 rockets and mortar shells were fired from Gaza toward Israeli communities, and Israel Defence Forces conducted ground and air attacks on Gaza.

The sample for the current study comprised a general population sample of Israeli adult civilians living in communities exposed to rocket fire ($n = 114$). Participants were recruited via advertisements in local colleges/universities, local organizations and communities, and social networks, and via snowballing methods. Potential participants contacted the research team directly, and study explanation and oral informed consent were conducted over the telephone.

Participants entered the study gradually, between days 8 and 24 of the conflict. Participants were asked to complete ESM daily diary assessments twice a day, morning and evening at predetermined times, for 30 days, and could reply within 2 h. The questionnaires were administered via a personalized email link to participants' smartphones and referred to experiences, reactions, and symptoms occurring since the last assessment.

Participants were remunerated for their participation. The design and procedure were approved by the University of Haifa, Faculty of Social Welfare and Health Sciences Ethics Committee.

Measures

Traumatic stress symptoms were measured using the PTSD Checklist for DSM-5 (PCL-5; Weathers *et al.* 2013). This 20-item self-report tool asks participants to indicate the extent to which they experienced each PTSD symptom, on a four-point Likert scale ranging from 0 = not at all to 3 = very much. The original version was adapted for the current study so that the timeframe for experiencing each symptom was changed from 'in the past month' to 'since the last time you replied' (a minimum of 8 h gap). This measure has good psychometric properties in its original form (Blevins *et al.* 2015).

Data analysis

We included data from participants providing over 20 valid responses (one-third of potential responses). Of the sample, 84.2% ($n = 96$) met this inclusion criterion.

Demographic characteristics of the sample are presented in Table 1.

The mlVAR package (version 0.3.3) in R was used to estimate three networks (Epskamp *et al.* 2016): a contemporaneous network, which is a Gaussian graphical model (GGM) that depicts

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Table 1. Demographic characteristics of the sample

	Categories	*n*	%	Mean (S.D.)
Gender	Female	68	70.8	
	Male	28	29.2	
Age				30.1 (9.0)
Country of Birth	Israel	80	83.3	
	Outside of Israel	16	16.7	
Relationship status	Single	27	28.1	
	Has a partner	28	29.2	
	Married	39	40.6	
	Divorced/separated	2	2.1	
Have children	Yes	40	41.7	
	No	56	58.3	
Religion	Jewish	94	97.9	
	Christian and other	2	2.1	
Religiosity status	Secular	58	60.4	
	Traditional	21	21.9	
	Religious or Orthodox	17	17.7	
Education	High school (no diploma)	4	4.2	
	High school (with diploma)	34	35.4	
	Academic (including student)	54	56.3	
	Other professional training	4	4.2	
Employment	Full-time	31	32.3	
	Part-time	13	13.5	
	Temporary jobs	10	10.4	
	Student	24	25.0	
	Unemployed	5	5.2	
	Other	13	13.5	
PTSD symptoms	Endorsed PTSD DSM-5 criteria (other than duration) at least once	40	41.7	
	Per person mean PCL sum score			10.18 (7.87) Range of mean PCL sum score (0.20–32.57)

within-time-window edges (associations) between nodes (DSM-5 PTSD symptoms) that remain after controlling for temporal associations, akin to a multilevel partial correlation network; a temporal network, which is a directed network of regression coefficients that depicts the lagged associations between symptoms from one measurement point to the next and a between-persons network which is a GGM that depicts the variance–covariance structure of participants' means (Epskamp *et al.* 2016, 2017).

Decomposing the variance in these three networks allows for different insight in the covariation and potential dynamics: the temporal network shows if a deviation from a person's mean predicts a deviation from a person's mean in another variable at the next measurement occasion. As a result, temporal networks give insight into Granger causality (Granger, 1969). Contemporaneous networks show if deviations from a person's mean in two variables predict one-another in the same measurement occasion (Epskamp *et al.* 2017). Finally, the between-subjects network models the covariation between means of participants and is a more stable way of estimating networks that can be obtained from cross-sectional data, while providing a network that can be used for comparison with previous cross-sectional studies (Epskamp *et al.* 2016).

In our analysis, to make the model estimable we estimated forced random effects of incoming edges to a single node (temporal) or edges connected to the same node (contemporaneous) to be orthogonal. In the contemporaneous and between-subjects networks, we used an 'and' rule in retaining significant edges: an edge was retained if both regressions on which the edge was based were significant ($\alpha = 0.05$).

In the current analysis, the between-persons network included numerous negative edges, which are likely spurious connections given that the contemporaneous and temporal network had far fewer negative connections (see online Supplementary Material). We, therefore, conducted an alternative between-persons network analysis in the R Bootnet package using graphical LASSO and extended Bayesian information criterion to select the optimal regularization parameter, for which rather than using the mean edge scores from each individual to depict the network, we used the mean symptom scores for each participant.

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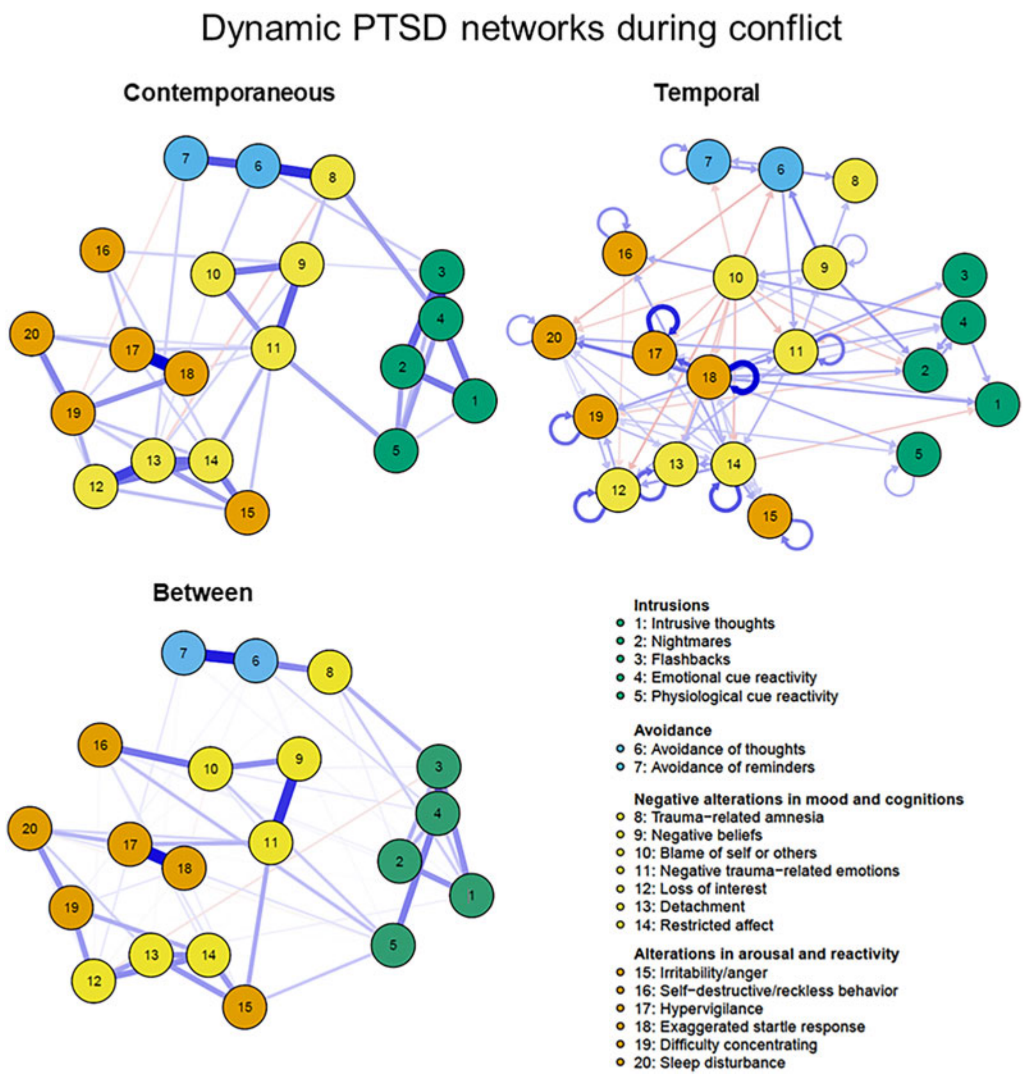

Fig. 1. Dynamic PTSD networks during the conflict. *Note*: Blue edges denote positive associations between nodes, red edges denote negative associations between nodes. Edge thickness represents the degree of association.

Results

Figure 1 depicts the contemporaneous, temporal and between-person networks.

Contemporaneous network

Several important things stand out in the contemporaneous network (Fig. 1 and Table 2). First, contemporaneous connections were nearly all positive in nature, and we identified especially strong associations between hypervigilance and exaggerated startle response (partial correlation edge weight=0.36), avoidance of thoughts and amnesia (0.30), and loss of interest and detachment (0.27).

Second, the DSM-5 symptom clusters were fairly well recovered, with strong within-cluster associations, and weaker between cluster associations.

Third, in a few cases, the contemporaneous network did not fully correspond to the DSM-5 cluster conceptualization. For example, amnesia had stronger associations to the avoidance cluster than it did to its own cluster of negative mood and cognitions, and anger had stronger associations to the negative mood and cognitions cluster than to the arousal cluster to which it belongs.

Finally, the negative mood and cognitions appear to include two 'cliques' – clusters of closely connected symptoms; the first clique comprised negative beliefs, blame, and negative emotions which were all significantly connected to each other, and the second clique was made up of loss of interest, detachment, and restricted affect.

Temporal network

There were several notable aspects of the temporal network (see Fig. 1). First, there were a substantial number of negative edges, specifically from blame, flashbacks, avoidance of thoughts, nightmares, and self-destructive behavior, which differed from the contemporaneous network. All of the lagged associations from blame to other symptoms were negative. Avoidance of thoughts had a negative lagged association with sleep disturbances.

Exaggerated startle response had by far the strongest out-strength (0.83), which is the sum of absolute significant temporal edge weights extending out from each symptom, excluding

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Table 2. Contemporaneous network: significant edge weights

	Intr. thoughts	Night-mares	Flash-backs	Emo. Reac.	Phys. React.	Avoid thoughts	Avoid remind.	Amn.	Neg. beliefs	Blame	Neg. emo.	Loss interest	Detach-ment	Res. Affect	Anger	Self-dest.	Hyper-vig.	Start.	Conc. diff.	Sleep dist.
Intrusive thoughts	.	0.19	ns	0.19	0.07	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nightmares	0.19	.	0.22	ns	0.13	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Flashbacks	ns	0.22	.	0.25	0.09	0.07	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.04	ns	ns	ns	ns
Emotional reactivity	0.19	ns	0.25	.	0.13	ns	ns	0.13	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Physiological reactivity	0.07	0.13	0.09	0.13	.	ns	ns	ns	ns	ns	0.12	ns	ns	ns	ns	ns	ns	ns	ns	ns
Avoidance of thoughts	ns	ns	0.07	ns	ns	.	0.24	0.30	ns	0.06	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Avoidance of reminders	ns	ns	ns	ns	ns	0.24	.	0.18	ns	ns	ns	ns	0.06	ns	ns	ns	ns	ns	−0.03	ns
Amnesia	ns	ns	ns	0.13	ns	0.30	0.18	.	0.08	ns	ns	ns	−0.05	ns	ns	ns	ns	ns	ns	ns
Negative beliefs	ns	ns	ns	ns	ns	ns	ns	0.08	.	0.19	0.22	ns	0.05	ns	ns	0.06	ns	ns	ns	ns
Blame	ns	ns	ns	ns	ns	0.06	ns	ns	0.19	.	0.14	ns	0.03	ns	ns	ns	ns	ns	ns	ns
Negative emotions	ns	ns	ns	ns	0.12	ns	ns	ns	0.22	0.14	.	ns	ns	0.10	0.08	ns	0.07	0.05	ns	0.05
Loss of interest	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	.	0.27	0.19	0.09	ns	ns	ns	0.11	0.05
Detachment	ns	ns	ns	ns	ns	ns	0.06	−0.05	0.05	0.03	ns	0.27	.	0.21	0.13	ns	ns	ns	0.06	ns
Restricted affect	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.10	0.19	0.21	.	0.18	ns	ns	ns	0.08	ns
Anger	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.08	0.09	0.13	0.18	.	0.06	0.06	ns	0.07	ns
Self-destructive behavior	ns	ns	0.04	ns	ns	ns	ns	ns	0.06	ns	ns	ns	ns	ns	0.06	.	0.09	ns	ns	ns
Hypervigilance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.07	ns	ns	ns	0.06	0.09	.	0.36	0.06	0.11
Startle	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.36	.	0.15	ns
Concentration difficulties	ns	ns	ns	ns	ns	ns	−0.03	ns	ns	ns	ns	0.11	0.06	0.08	0.07	ns	0.06	0.15	.	0.17
Sleep disturbance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.05	0.05	ns	ns	ns	ns	0.11	ns	0.17	.

Note: ns denotes non-significant edge

autocorrelations (see Table 3). In other words, the more startle response an individual had at one measurement, the more likely the individual was to report other symptoms at the next. Other variables with high out-strength included restricted affect (0.54), blame (0.51), negative emotions (0.34), and avoidance of thoughts (0.32).

The variables with the highest in-strength centrality – the extent to which variables are influenced by other variables in the network at the previous measurement – were sleep disturbance (0.37), and loss of interest (0.37).

Consistent with prior temporal studies of psychopathological dynamics, there were a considerable number of autocorrelations, which were stronger than the cross-lagged effects. Exaggerated startle response had the strongest autoregressive coefficient (0.27), meaning that knowing the startle response at a given timepoint has strong predictive power about startle response at the next timepoint. Hypervigilance also had a high autoregressive coefficient (0.22).

Finally, a number of interesting feedback loops emerged. For example, sleep disturbance predicted concentration difficulties, which in turn predicted restricted affect, which predicts sleep disturbance. Negative emotions predicted negative beliefs, which went to avoidance of thoughts, and back again to negative emotions.

Table 3. In-strength and out-strength of symptoms in the temporal network

Symptom	In-strength (sum of absolute values of significant edges to symptom)	Out-strength (sum of absolute values of significant edges from symptom)
Intrusive thoughts	0	0.05
Nightmares	0	0.18
Flashbacks	0.08	0.15
Emotional reactivity	0.29	0.08
Physiological reactivity	0.12	0
Avoidance of thoughts	0.28	0.32
Avoidance of reminders	0.13	0.1
Amnesia	0.16	0
Negative beliefs	0.11	0.25
Blame	0.12	0.51
Negative emotions	0.30	0.34
Loss of interest	0.37	0.08
Detachment	0	0.04
Restricted affect	0.31	0.54
Anger/irritability	0.19	0.05
Self-destructive behavior	0.17	0.04
Hypervigilance	0.31	0.19
Startle response	0.18	0.83
Concentration difficulties	0.29	0.23
Sleep disturbance	0.37	0.12

Between-persons network

The between-persons network closely resembled the contemporaneous network, albeit more sparsely connected. As with the contemporaneous network, associations between symptoms were mostly positive, with particularly strong associations between the two avoidance symptoms, between negative beliefs and negative emotions, and between hypervigilance and startle. Standardized node strength centrality was calculated (see Fig. 2), representing the sum of all edge weights of a given node. Flashbacks followed by emotional cue reactivity were the two most central symptoms in this network.

Discussion

This study assessed dynamic PTSD symptom networks in Israeli civilians during the 2014 Israel–Gaza War. There were strong positive contemporaneous associations between hypervigilance and exaggerated startle response, avoidance of thoughts and avoidance of reminders, and between flashbacks and emotional reactivity. There were some notable differences between the temporal and contemporaneous networks, which underlines the importance of analyzing both separately. These differences included the presence of a number of negative associations, particularly from blame. The temporal network also indicated the central role of startle response as a predictor of PTSD symptomatology at the next timepoint. The between-persons network showed similar patterns of associations to the contemporaneous network.

Contemporaneous associations between symptoms largely reflected the DSM-5 clusters, other than the alterations in negative mood and cognitions cluster. Previous PTSD network studies found that amnesia was only weakly associated with other PTSD symptoms (McNally *et al.* 2015; Armour *et al.* 2017; Birkeland & Heir, 2017; Fried *et al.* 2017*a*; Spiller *et al.* 2017). The current findings indicated, however, that this was not the case, but rather that amnesia was more closely related to the avoidance cluster, than to the cognitive symptoms from its own cluster, and had no significant associations with any of the negative mood items. Perhaps amnesia could be better conceptualized as an additional and perhaps involuntary form of avoidance, rather than as a negative cognition and mood symptom, at least in the context of the ongoing threat.

The pattern of connections from the remaining symptoms from the negative cognition and mood cluster supported a model in which numbing of responsiveness items (loss of interest, detachment, and restricted affect) are split from the increased negative mood and cognition items (negative mood, blame, negative cognitions), something that has also been found in previous investigations of the dimensional structure of DSM-5 PTSD (Armour *et al.* 2015; Pietrzak *et al.* 2015).

It is important to interpret the contemporaneous network in a nuanced manner (Epskamp *et al.* 2017). While 'contemporaneous' would seem to imply concurrent associations, in the current study there were relatively large time windows between assessments (8–16 h), so contemporaneous networks are not really 'contemporaneous'. Rather, they depict associations between symptoms, including potentially causal associations that took place over a number of hours, and may therefore also reflect temporal processes. To

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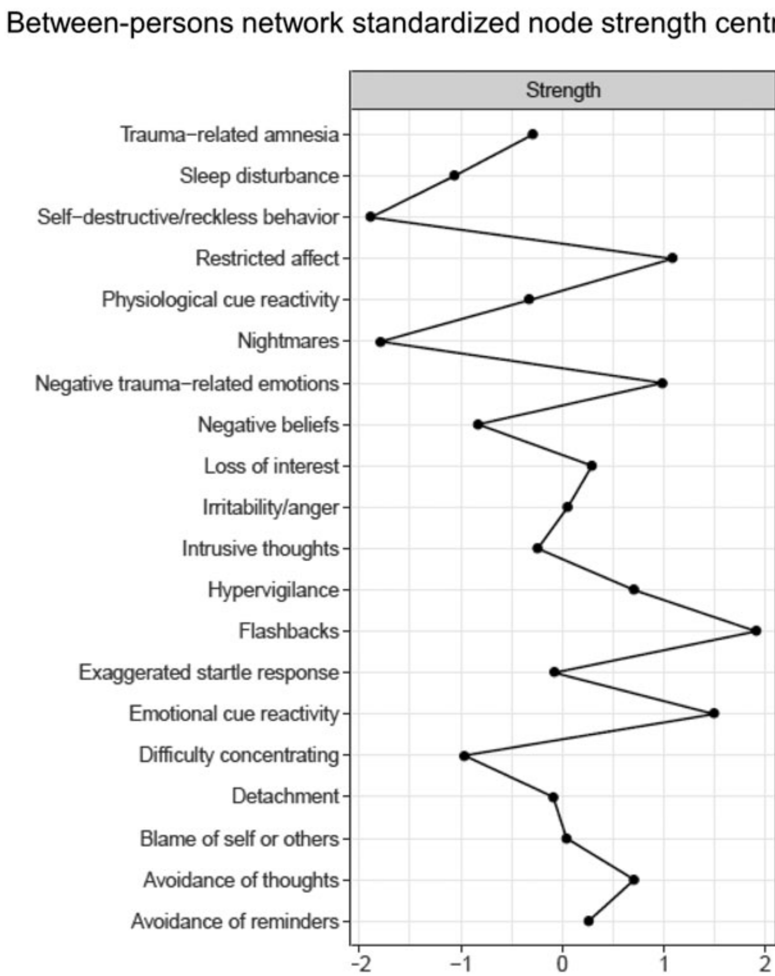

Fig. 2. Between-persons network standardized node strength centrality.

assess true contemporaneous networks, far more frequent assessments are needed, and participants should be asked how they are feeling 'right now', rather than 'since the last assessment'.

In the temporal network, the blame of self or others surprisingly predicted lower symptoms at the next measurement, in contrast to the positive associations they showed in the contemporaneous network. The blame item, which was added to the PTSD criteria in DSM-5, actually captures two very different phenomena (Greene, under review); blame of self, in which the individual gives an internal attribution to the adversity, and blame of others, which gives an external attribution to the adversity. Attributions theory posits that making external attributions for negative events is protective (Kelley & Michela, 1980). While we cannot ascertain in this study whether the participants were reporting external or internal blame, it could be speculated that in the context of war and conflict, the blame would be more likely to be externally attributed. This may then explain the negative lagged association from blame to avoidance of thoughts, avoidance of reminders, negative emotions, loss of interest, detachment, restricted affect, startle, concentration difficulties and sleep disturbance, suggesting that blaming an external source may be an effective coping mechanism.

Symptoms with strong out-strengths can be seen as those with the highest potential to impact other symptoms within the network, and are therefore likely to be particularly important in the dynamics of PTSD development. Symptoms with strong in-strength, on the other hand, are those that are most affected by other symptoms in the network. For interventions, it has been speculated that targeting symptoms with strong out-strength might provide an effective way of preventing or reducing future PTSD symptomatology (McNally, 2016; Armour *et al.* 2017; Bos *et al.* 2017).

In the current study, startle response had a greater out-strength than all other symptoms, which may suggest that targeting startle response could help reduce other symptoms. While arousal symptoms have been generally indicated as key drivers of future psychopathology in longitudinal studies of PTSD clusters (Schell *et al.* 2004; Marshall *et al.* 2006; Doron-LaMarca *et al.* 2015), startle has not specifically been found to be a central symptom in previous PTSD network studies with the exception of Spiller *et al.* (2017). It is likely that startle in the context of an ongoing threat is a different phenomenon compared with a startle when the stressor has ceased. Future studies could investigate whether startle has strong out-strength in other lower-stress environments. Additionally, restricted affect, blame, negative emotions, and avoidance of thoughts, also had high out-strength, all of which should be explored as the potential for interventions. It might also be argued that targeting symptoms that have both high in-strength and out-strength, such as sleep disturbance, could especially disrupt the network, facilitating an overall reduction in symptomatology.

Many symptoms in the temporal network had large autoregressive coefficients, i.e. predicting themselves at the next measurement, such as startle response and hypervigilance. This may indicate that these 'symptoms' may be more trait-like than others.

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It could also be that these strong autocorrelations represent the first signs of a ‘critical slowing down’, whereby pathological responses gradually crystallize (Wichers *et al.* 2016).

The between-persons network largely resembled the contemporaneous network, although with fewer and weaker connections between the symptoms. This network is the one that can be most directly compared to previous cross-sectional network studies, and there are a number of similarities between them and the current between-persons network. Hypervigiliance and startle have been found to be highly connected in a number of studies (e.g., McNally *et al.* 2015; Armour *et al.* 2017; Birkeland & Heir, 2017; Spiller *et al.* 2017). Flashbacks were identified as central symptoms by (Armour *et al.* 2017), while emotional cue reactivity was found to be the most central symptom by Spiller *et al.* (2017). Bryant *et al.* (2017) focused on early symptomatology and also noted the centrality of the re-experiencing symptoms (in a DSM-IV acute traumatic stress symptoms network). These findings are in line with our current finding of the centrality of both flashbacks and emotional cue reactivity. Interestingly, we found strong associations between the two DSM-5 avoidance symptoms, however other DSM-5 PTSD network studies do not find this strong association, relative to the associations between others symptoms. Furthermore, amnesia, while not being one of the most central symptoms, did not have especially weak connections, as found previously (Fried *et al.* 2017*a*). It is important to investigate whether these differences are because symptoms or reactions that arise during a period of trauma exposure are essentially different from those that emerge at a later stage when exposure has ceased.

There are some limitations of this study. We did not specifically include a sample with a diagnosis of PTSD, thus limiting our ability to generalize as to the associations between symptoms in those meeting DSM-5 PTSD criteria. Data were collected peritraumatically, during a conflict period, and were based on assessments conducted during both the first and second months since the traumatic stressor began, therefore the findings may not necessarily be generalizable to PTSD networks after exposure has ceased. Additionally, there are some methodological limitations with the multilevel network analysis model (Epskamp *et al.* 2016): there are no adequate fit statistics to assess the model; it only models linear processes yet there may be non-linear trends to consider; and it assumes stationarity, treating the properties of the network as constant over time, but this may not be the case, given what we know about PTSD resilience and recovery patterns (Bonanno & Mancini, 2012; Bryant *et al.* 2015), including in this particular sample (Gelkopf *et al.* 2017; Greene *et al.* 2017). Further development of time-varying multilevel network models may better clarify disorder development over time. Finally, there are other key variables that we would have liked to include in the model such as gender, trauma history, and severity of exposure to the conflict; however, power is a key limitation with these models (Fried & Cramer, 2017), and we did not have a large enough sample size to include these covariates.

This study provides a unique contribution to the PTSD research field through the novel use of ESM methodology to assess DSM-5 PTSD symptoms in individuals during a period of conflict, and through its employment of multilevel network, analyses to explore contemporaneous and temporal network connections. While this study does not depict ‘classic’ PTSD, it is certainly relevant for many people around the world who live in situations of ongoing stress and trauma exposure. This study indicates that multilevel network analyses can provide novel and useful insights into the ways that different symptoms interact with each other, as well as reinforcing themselves. More studies in this vein can elucidate the complex processes by which PTSD symptoms crystallize into disorder and indicate possible causal mechanisms that drive the development of PTSD. This, in turn, could have clinical implications for identifying the relative importance of symptoms as targets for interventions.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0033291718000351.

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Declaration 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.

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