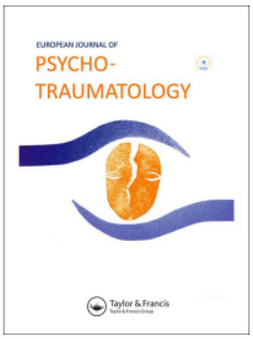

European Journal of Psychotraumatology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/zept20

Dynamic symptom associations in posttraumatic stress disorder: a network approach

Mina Stefanovic, Keisuke Takano, Charlotte E. Wittekind & Thomas Ehring

To cite this article: Mina Stefanovic, Keisuke Takano, Charlotte E. Wittekind & Thomas Ehring (2024) Dynamic symptom associations in posttraumatic stress disorder: a network approach, European Journal of Psychotraumatology, 15:1, 2317675, DOI: 10.1080/20008066.2024.2317675

To link to this article: https://doi.org/10.1080/20008066.2024.2317675

EUROPEAN JOURNAL OF PSYCHOTRAUMATOLOGY
2024, VOL. 15, NO. 1, 2317675
https://doi.org/10.1080/20008066.2024.2317675

CLINICAL RESEARCH ARTICLE

OPEN ACCESS Check for updates

Dynamic symptom associations in posttraumatic stress disorder: a network approach

Mina Stefanovic [a], Keisuke Takano [a,b], Charlotte E. Wittekind [a] and Thomas Ehring [a]

[a]Department of Psychology, LMU Munich, Munich, Germany; [b]Human Informatics and Interaction Research Institute, The National Institute of Advanced Industrial Science and Technology (AIST), Ibaraki, Japan

ABSTRACT

Background and objective: The current study aimed to investigate the within-day symptom dynamics in PTSD patients, specifically focusing on symptoms that most predict changes in other symptoms. The study included a baseline diagnostic assessment, followed by an assessment using the experience sampling method (ESM) via a smartphone.

Method: Participants answered questions related to their PTSD symptoms four times per day for 15 consecutive days (compliance rate 75%). The clinical sample consisted of 48 treatment-seeking individuals: 44 with PTSD as a primary diagnosis, and four patients with subsyndromal PTSD, all of whom had not yet begun trauma-focused treatment. The ESM assessment included the 20 items from the PTSD Checklist for DSM-5, five items from the International Trauma Questionnaire (ITQ) assessing disturbances in relationships and functional impairment, and two items from the Clinician-Administered PTSD Scale for DSM-5 assessing symptoms of depersonalization and derealization.

Results: Temporal networks (prospective associations between symptoms) showed that changes in *hypervigilance* predicted changes in the greatest number of symptoms at the next time point. Furthermore, *hypervigilance* showed temporal connections with at least one additional symptom from each of the DSM-5 PTSD symptom clusters.

Conclusions: Results show that the contemporaneous network (representing the relationship between given symptoms within the same assessment occasion) and the temporal network (representing prospective associations between symptoms) differ and that it is important to estimate both. Some findings from earlier research are replicated, but heterogeneity across studies remains. Future studies should include potential moderators.

Asociaciones dinámicas de síntomas en el trastorno de estrés postraumático: una aproximación de redes

Antecedentes y objetivo: El presente estudio buscó investigar las dinámicas de los síntomas dentro de un día en pacientes con TEPT, centrándose específicamente en los síntomas que más predicen los cambios en otros síntomas. El estudio incluyo una evaluación diagnostica inicial, seguida de una evaluación mediante el método de muestreo de experiencias (ESM en su sigla en inglés) a través de un teléfono inteligente.

Método: Los participantes contestaron preguntas relacionadas con sus síntomas del TEPT cuatro veces al día por 15 días consecutivos (tasa de cumplimiento 75%). La muestra clínica consistió en 48 individuos que buscaban tratamiento: 44 con TEPT como diagnóstico principal, y cuatro pacientes con TEPT subclínico, todos los cuales aún no habían empezado un tratamiento centrado en el trauma. La evaluación del ESM incluyó los 20 ítems de la Lista de Chequeo de TEPT para el DSM-5, cinco ítems del Cuestionario Internacional de Trauma (ITQ en sus siglas en ingles) que evalúa las alteraciones en las relaciones y el deterioro funcional, y dos ítems de la Escala de TEPT administrada por el clínico según el DSM-5 que evalúa los síntomas de despersonalización y desrealización.

Resultados: Las redes temporales (asociaciones prospectivas entre síntomas) mostraron que los cambios en hipervigilancia predijeron los cambios en la mayor cantidad de síntomas en el siguiente momento. Además, la hipervigilancia mostró conexiones temporales con al menos un síntoma adicional de cada grupo de síntomas de TEPT del DSM-5.

Conclusiones: Los resultados muestran que las redes contemporáneas (que representa la relación entre los síntomas dados dentro de la misma ocasión de evaluación) y la red temporal (que representa las asociaciones prospectivas entre síntomas) difirieren y que es importante estimar ambas. Se replican algunos hallazgos de investigaciones previas, pero persiste la heterogeneidad entre los estudios. Futuras investigaciones deberían incluir potenciales moderadores.

ARTICLE HISTORY
Received 30 May 2023
Revised 22 December 2023
Accepted 2 January 2024

KEYWORDS
Posttraumatic stress disorder; ESM; network analysis; multilevel VAR; contemporaneous; temporal

PALABRAS CLAVE
Trastorno de estrés postraumático; ESM; análisis de redes; VAR de multiniveles; contemporáneo; Temporal

HIGHLIGHTS

- We investigated within-day symptom dynamics in PTSD patients using experience sampling technology.
- Temporal and contemporaneous symptom networks differed; thus, it is important to estimate both.
- Changes in hypervigilance were an important predictor of symptoms at the next time point.

CONTACT Thomas Ehring thomas.ehring@lmu.de Department of Psychology, LMU Munich, Leopoldstr. 13, 80802, Munich, Germany
Supplemental data for this article can be accessed online at https://doi.org/10.1080/20008066.2024.2317675.

Two out of three people in a general population worldwide experience a traumatic event during their lifetime (Kessler et al., 2017). A substantial subgroup of trauma-exposed individuals develop PTSD (Atwoli et al., 2015), which is related to high disability and considerable socioeconomic burden (Warth et al., 2020). However, the definition of PTSD is rather complex. For example, the Diagnostic and Statistical Manual of Mental Disorders (DSM-5: American Psychiatric Association, 2013) defined PTSD as four symptom clusters comprising 20 specific symptoms to which a complex algorithm is applied. As a consequence, PTSD is far from being a homogenous disorder; instead, a very large number of different symptom combinations are possible that ultimately lead to a PTSD diagnosis (Galatzer-Levy & Bryant, 2013). On the other hand, the newly proposed criteria for PTSD of the International Classification of Diseases, 11th edition (ICD-11) only include symptoms of re-experiencing, avoidance, and persistent perceptions of heightened current threat to diagnose PTSD as the primary diagnosis (World Health Organization, 2021). Furthermore, the ICD-11 has introduced a separate diagnostic category for complex PTSD, which – in addition to the three core elements of PTSD comprises enduring disturbances in the domains of affect, self, and interpersonal relationships as additional symptoms of psychopathology (World Health Organization, 2021). There is an ongoing debate about which approach is more valid and more useful from clinical and theoretical perspectives.

In recent years, network theory has emerged providing an alternative conceptualization to the latent construct approach of disorders; it instead proposes that disorders are an emergent property of symptoms that interact in a dynamic way (Fried & Robinaugh, 2020). From this perspective, studying symptom dynamics thus helps to understand PTSD as a disorder. In addition, studying symptom networks may help in identifying promising treatment targets. To better understand inter-relationships between symptoms, researchers have used network analysis, which informs us about the pattern of co-occurrence between symptoms (Borsboom & Cramer, 2013; Epskamp et al., 2016; Hofmann et al., 2016). However, most earlier studies have focused on cross-sectional networks representing symptom co-occurrence across a group of individuals at one point of assessment (e.g. patients who experience hypervigilance are easily startled; those who often experience nightmares tend to suffer from intrusive thoughts) (Birkeland et al., 2020; Fried et al., 2018; Isvoranu et al., 2021).

Although cross-sectional networks are relevant as they may provide information on the underlying causal structure of PTSD symptoms (Hofmann et al., 2016), one crucial limitation of this approach is that it does not tap into the dynamic interplay between symptoms (Birkeland et al., 2020; Isvoranu et al., 2021). To address this limitation, researchers have recently started to use intensive longitudinal assessments to capture day-to-day (or even shorter, e.g. half-a-day) changes in symptoms and to estimate temporal associations between symptoms within an individual (Epskamp et al., 2018).

A temporal network is typically configured as a series of lag-1 auto-regressive vector models, where levels of symptoms are predicted by the other symptoms at the previous timepoint. The symptom-to-symptom associations are, therefore, estimated as directional paths, which help identify how strongly a symptom predicts other symptoms in the network (i.e. out-strength). It can be argued that in order to properly study symptom dynamics over time (e.g. to identify possible treatment targets), it is essential to assess temporal associations between symptoms, even in the absence of external interventions. PTSD symptoms show some variability even in the absence of an intervention or other external influences. For example, key symptoms of the disorder, e.g. flashbacks, intrusive memories, are discrete events that are not persistently present. Studying a symptom network informs us how an emergence or temporary presence of such a momentary symptom influences the other symptoms and experiences, e.g. a flashback may increase negative affect and arousal, which may further influence avoidance behaviour.

Following the seminal work by Greene and colleagues on Israeli civilians exposed to rocket fire (Greene et al., 2018), temporal networks of PTSD symptoms have been estimated for traumatized individuals in an acute post-trauma phase (Price et al., 2020), for PTSD patients undergoing exposure treatment (Hoffart et al., 2019), and for a mixed group of individuals meeting the criteria for PTSD (Reeves & Fisher, 2020).

In these temporal networks, central symptoms that were most predictive of other symptoms at a later time point (i.e. high out-strength) were identified, namely *exaggarated startle response* (Greene et al., 2018), *hypervigilance* and *physiological reactivation* (Hoffart et al., 2019), *low interest* (Price et al., 2020), and *negative trauma-related emotions* (Reeves & Fisher, 2020).

Thus, research focusing on temporal networks in the context of PTSD has not produced stable findings across studies with regard to central symptoms (possibly due to the different population studies, different timings of temporal associations, differences regarding symptom severity, and small sample sizes). However, in all studies, different shapes emerged for temporal (within-person) networks than for cross-sectional (between-person) networks (Birkeland et al., 2020; Isvoranu et al., 2021). For example, Greene et al. (2018) found a larger number of negative edges in the temporal network than in the contemporaneous

one; Price et al. (2020) showed that the temporal network was sparser than the contemporaneous one. It has therefore been suggested that studying temporal dynamics in symptom networks should have a high priority in this field of research.

These two networks assess symptom dynamics on different time scales. In the contemporaneous network, activation of the symptoms at the same moment are represented, whereas temporal networks allow examining symptom prediction over time. Of note, the contemporaneous network captures the relations that are not captured by the temporal network. This could mean that the contemporaneous network captures temporal relations on a faster time scale compared to the temporal network. Due to pragmatic reasons, past research has mainly focused on contemporaneous networks. Current findings on differences between contemporaneous and temporal networks suggest that we can not easily generalize from one to the other. Focusing on temporal – in addition to contemporaneous – associations might be particularly important for clinical purposes as symptoms with high predictive power for other symptoms may be promising targets for intervention.

Building on the four prior studies described above, the primary focus of the current study was to examine the dynamic interplay between symptoms in PTSD patients, this time using a more intensive assessment approach than in these earlier studies (four times per day for 15 consecutive days). Previous studies have typically used a less frequent assessment schedule with longer assessment-to-assessment intervals (e.g. once or twice per day or per week). This appears necessary since acute changes in symptoms can take place within hours, particularly in vulnerable individuals (Schuler et al., 2021).

Furthermore, PTSD symptoms can easily be triggered by situational and environmental factors (e.g. loud noises; Naragon-Gainey et al., 2012), therefore, it appears crucial to obtain a time series of symptoms with high temporal resolution and high ecological validity. In order to extent previous network studies, additional complex symptoms related to PTSD (e.g. disturbances in relationships, functional impairment, and depersonalization and derealization) were included in addition to the DSM-5 symptom criteria for PTSD.

We decided to include all symptoms defined by either DSM-5 or ICD-11 that belong to PTSD or complex PTSD. As the PCL is a frequently used instruments in the literature and – although based on DSM-5 – comprises most symptoms included in both conceptualization of PTSD, we used the PCL items as the basis for our ESM assessment. We then additionally included items related to depersonalization and derealization and only those items from the ITQ that were not sufficiently approximated PCL items, i.e. disturbances in relationships and functional impairment. In this way, we were able to cover all symptoms defined by both DSM-5 and ICD-11.

While from traditional disorder-focused perspective, this approach may be regarded as lacking stringency, our rationale was based on network theory and therefore aimed to include all symptoms that have been suggested to constitute (complex) PTSD across the DSM and ICD conceptualizations. Importantly, network theory assumes that disorders are not latent constructs but can best be described by dynamic symptom networks. Therefore, it is not uncommon practice for network studies to include related symptoms within the same network. The question of whether and how the additional symptoms taken from ICD then fit within the PTSD network (otherwise comprising DSM-5 items) is then an empirical question.

Using this data, we estimated two types of networks: *contemporaneous networks* representing the partial correlations between symptoms recorded at the same time of measurement, and *temporal networks* illustrating how symptoms influence each other at the subsequent measurement (Epskamp et al., 2018). Given the heterogenous findings in the literature, it was difficult to build a priori hypothesis for the current analyses – furthermore, as we added items that were not covered in the previous studies (e.g. disturbances in relationships), we tested the temporal and contemporaneous associations between symptoms in an exploratory manner. Our primary focus was on how each network could be characterized, and thus, we interpreted the centrality indices: the strength for the contemporaneous network (how strongly a symptom is associated with other symptoms within a timepoint) and out-strengths for the temporal network (how well a symptom predicts other symptoms).

1. Method

1.1. Participants

Participants were recruited between September 2019 and August 2021 via advertisements and flyers distributed in two in-patient and three outpatient treatment centres in Munich, Germany, through flyers distributed at a counselling service for trauma survivors, as well as through online advertisements. The inclusion criteria for participants were: age between 18 and 60 years; fluency in German; and exposure to a traumatic event based on DSM-5 criteria (American Psychiatric Association, 2013) with PTSD (or sub-syndromal PTSD that did not meet the full DSM-5 criteria, which was the case for $n = 4$ participants[1]) as a primary diagnosis. Additionally, participants had to be attending a PTSD treatment centre but could not yet have started receiving trauma-focused treatment, as we wanted to avoid any ongoing treatment impacting

the symptom networks. Participants were not eligible if they had no memory of the trauma, had a current or lifetime diagnosis of schizophrenia or borderline personality disorder, had substance use disorder within the past month, or acute suicidality. The final sample comprised 48 participants (for detailed sample characteristics, see Table 1; the flow of participants is provided in Figure S1 in the supplementary material).

1.2. Measures

1.2.1. Baseline measures

The Structured Clinical Interview for DSM-5 (SCID-5-CV)[2] (Beesdo-Baum et al., 2019) or the *Clinical Administered PTSD Scale for DSM-5 (CAPS-5)* (Schnyder, 2013; Weathers et al., 2018) were used to verify a diagnosis of PTSD. Comorbid disorders were assessed with the SCID-5-CV for all participants.

The PTSD Checklist for DSM-5 (PCL-5) (Krüger-Gottschalk et al., 2017; Weathers, Litz, et al., 2013) is a 20-item DSM-5-based self-report measure for PTSD that was used to assess PTSD symptom severity in the past month.

The Life Events Checklist (LEC-5) (Weathers, Blake, et al., 2013) was used as a self-report measure to assess trauma exposure to 16 specific traumatic events plus one additional open item.

1.2.2. Experience sampling method (ESM) items

At each ESM assessment occasion, participants rated 27 items, including the 20 items from the PCL-5 assessing all DSM-5 symptoms of PTSD, and two items adapted from the CAPS-5 to assess depersonalization and derealization symptoms. In addition, five items from the International Trauma Questionnaire (ITQ: Cloitre et al., 2018) assessing disturbances in interpersonal relationships (2 items; feeling distant or cut off from other people; difficulties staying emotionally close to other people), and functional impairment (3 items; impairments of relationships and social life; work; and in other areas of life) were used (for details see supplementary material Table S5). Participants reported the intensity of their symptoms on a 5-point scale (0 = *absent* to 4 = *extremely*). The wordings for all items were modified to assess PTSD symptoms experienced since the previous ESM assessment occasion. One exception was the first occasion of each day, which targeted symptoms since waking up in the morning. The two sleep-related items from the PCL-5 were used only on the first assessment of each day as they were related to the sleep during the night (for detailed explanation see supplementary material, Figure S2). Sleep-related items were analysed and published in another manuscript (Werner et al., 2022).

Table 1. Sample characteristics ($N = 48$).

Characteristics	*Mean (SD)* or *N (%)*
Age (years, *M*, *SD*)	38.89 (13.51)
Gender (*n*, %)	
Women	35 (72.92%)
Men	13 (27.08%)
Education (*n*)[a]	
Middle school or equivalent	21 (43.75%)
High school degree	13 (27.08%)
University degree	12 (25%)
Type of traumatic event experienced (*n*)[a]	
Accident	3 (6.25%)
Physical assault	11 (22.92%)
Sexual assault	28 (58.33%)
Life-threatening illness or injury	2 (4.17%)
Any other very stressful event or experience	2 (4.17%)
Comorbidity disorders (*n*)	
Depression	12 (25%)
Obsessive compulsive disorder	4 (8.3%)
Substance use disorder	4 (8.3%)
Anxiety disorder	4 (8.3%)
ADHD[b]	1 (2.08%)
Treatment setting (*n*)[c]	
Inpatients	15 (31.25%)
Outpatients	26 (54.17%)
Not in treatment	7 (14.58%)

Note: [a]Data of two participants was missing.
[b]ADHD = Attention Deficit Hyperactivity Disorder.
[c]Participants were in an assessment phase and had not yet begun any trauma focused treatment.

1.3. Procedure

Participants were first contacted via phone to assess eligibility and were then invited for the first face-to-face assessment where they received information about the study and provided informed consent. We then conducted the clinical interviews to verify PTSD diagnosis and other comorbid disorders. Afterwards, participants completed the sociodemographic and symptom questionnaires, received instructions about the procedure for the smartphone assessments, and installed the ESM app on their own smartphone or on a smartphone provided by the research team. During the course of assessments (15 consecutive days), notifications were sent 4 times per day, scheduled in semi-randomized timing, each separated by approximately four hours. In response to each notification, participants were asked to rate their levels of PTSD symptoms since the previous ESM assessment occasion.

Depending on their sleep habits, participants could choose the start time of each day at around 8:30, 9:30, or 10:30 AM. If participants did not respond to a notification, they received a reminder 20 min later. If the reminder was also missed, participants were instructed to respond to the next notification. After completing all smartphone assessments, participants were invited for another appointment and received 35€ as a fee for participating. This study was approved by the local research ethics committee (Department of Psychology, LMU Munich; Code: 06_Stefanovic_f).

1.4. Statistical analyses

We estimated two types of networks (i.e. contemporaneous and temporal) on ESM-assessed PTSD

symptoms. Contemporaneous networks represent the relationship between given symptoms within the same assessment occasion, whereas temporal networks represent prospective associations between symptoms (Epskamp et al., 2018). We used a two-step estimation approach (Bringmann et al., 2013; Epskamp et al., 2019). First, we estimated the temporal network using multilevel, lag-1 vector autoregressive (VAR) models, in which each symptom was predicted by itself, and other symptoms were assessed using the previous occasion. Second, the contemporaneous network was specified as another set of multilevel VAR models on the residuals of the temporal network. It is recommended to exclude the potential influences of the symptoms observed at the previous time point and thus to focus solely on the within-moment effects.[3] The estimated fixed effects were mapped onto each network as edges connecting PTSD symptoms represented as nodes. Participants' responses made in the first assessment occasion of each day (and thus the two sleep items) were excluded from the network analyses because a VAR model assumes a constant interval between proximate time points. We assumed the orthogonal covariance structure for the random effects as we encountered convergence problems with the assumption of the correlated structure (Epskamp et al., 2019). To describe the network characteristics, centrality indices were computed for each type of network. For the contemporaneous network, standardized strength centrality was estimated for each node, which is given by the sum of the absolute values of the edge weights connected with the node. For the temporal network, we defined in- and out-strength for each node in order to identify the symptoms that were most predicted by other symptoms (in-strength) and symptoms that mostly predicted other symptoms (out-strength). These network analyses were performed using the R package, mlVAR (Epskamp et al., 2019).

2. Results

2.1. Sample characteristics and compliance

The mean number of valid ESM responses per person was 41.47 (SD = 14.64; Range = 5–60) out of a total of 60 notifications. Most participants received notifications in a range from 57 to 60 (N = 42). The remaining 6 participants received the notifications in a range from 21-45. As we did not find a systematic pattern in the missingness (e.g. no significant correlation between the PCL score and compliance[4]), all participants were included in the network analyses. Additionally, we confirmed that results were unchanged overall when we excluded participants with low compliance (e.g. 4 participants were below 18 or fewer valid responses, please see Figure S4 in supplementary material).

For a detailed description of the measures please see Table S4 and Figure S3 in the supplementary material.

2.2. Contemporaneous network

Figure 1 (Panel A) shows the estimated contemporaneous network, while Figure 2 (Panel A) illustrates standardized node strength centrality for the contemporaneous network. Information about partial correlation for the contemporaneous network is provided in the supplementary material (Table S1). First, the strongest edges were found between the following nodes: *feeling distant or cut off from other people* and *difficulties staying emotionally close to people* (partial correlation edge weight = .34); *hypervigilance* and *exaggerated startle response* (.34); *impairment of work* and *impairment in other areas of life* (.33); and *depersonalization* and *derealization* (.32). Second, items belonging to the symptom cluster 'changes in mood and cognition' fell into two sub-groups: one sub-group was closely related to the two nodes in the category 'disturbances in relationships', and the other sub-group shows associations with the cluster 're-experiencing'. Third, the node with the highest strength centrality was *feeling distant or cut off from other people.* On the other hand, *amnesia* showed the lowest strength.

2.3. Temporal network

Figure 1 (Panel B) shows the temporal network, and Figure 2 (Panel B) illustrates out- and in-strength centrality for the temporal network. Detailed information about temporal fixed effects and standard errors for temporal network fixed effects is provided in the supplementary material (Table S2, Table S3). First, the estimated temporal network showed significant auto-regressive effects for most of the symptoms, which suggests that PTSD symptoms were generally inert and only changed gradually over time. Second a larger number of negative edges emerged in the temporal network (12) compared with the contemporaneous network (3). Third, the highest out-strength centrality was found for *hypervigilance*, which was followed by *derealization* and *feeling distant from other people.* These results imply that, for example, the more hypervigilant a person is at one moment, the higher the levels of other symptoms they experience at the next moment. The nodes with the highest in-strength centrality (i.e. the nodes that are the most predicted by other nodes) were *avoidance of thoughts* and *loss of interest in activities*. The temporal network comprised more negative correlations than the contemporaneous network, and the nodes with the most negative correlations in the temporal network were *emotional cue reactivity* and *flashbacks*, respectively.

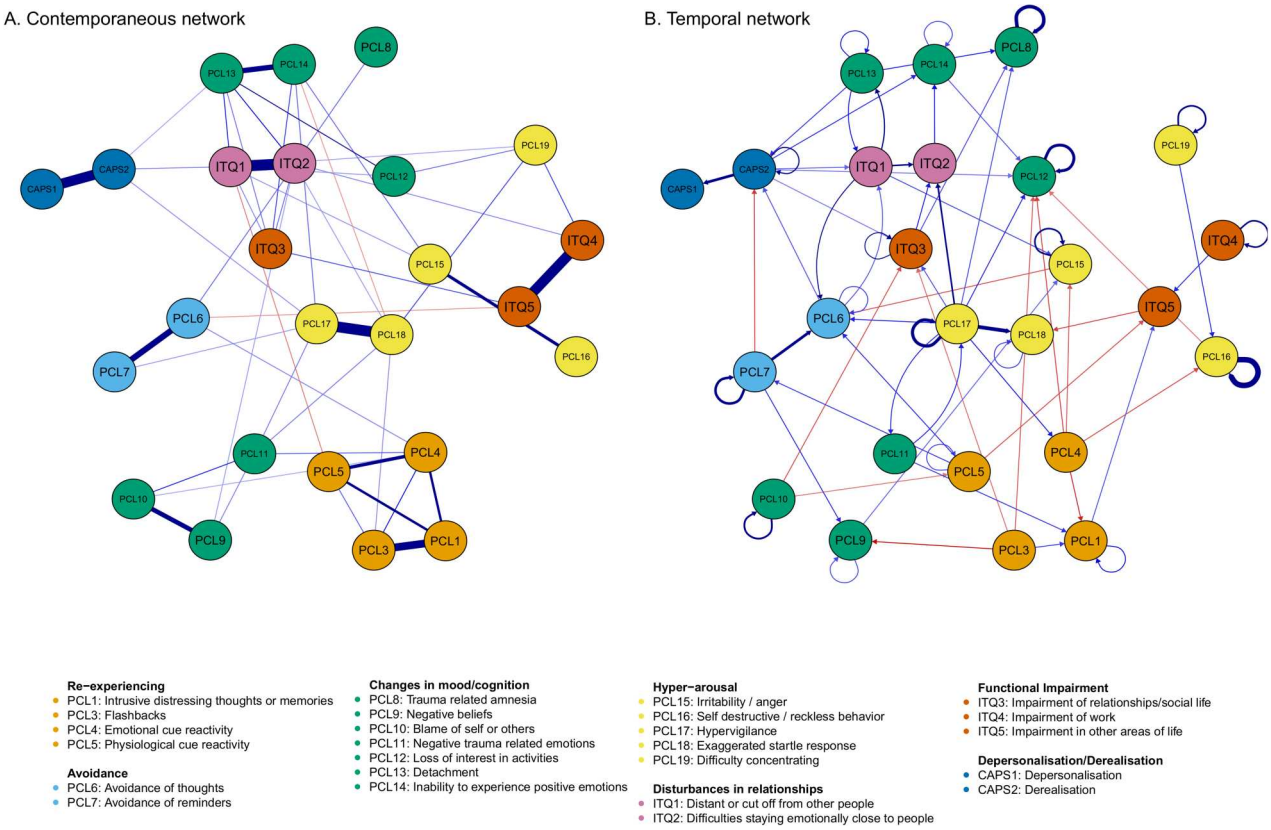

Figure 1. Estimated symptom networks – contemporaneous (Panel A) and temporal (Panel B).

Note: Red edges represent negative associations whereas blue edges represent positive associations between symptoms. A self-directed edge indicates an auto-regressive effect of a symptom on the same symptom at the next time point.

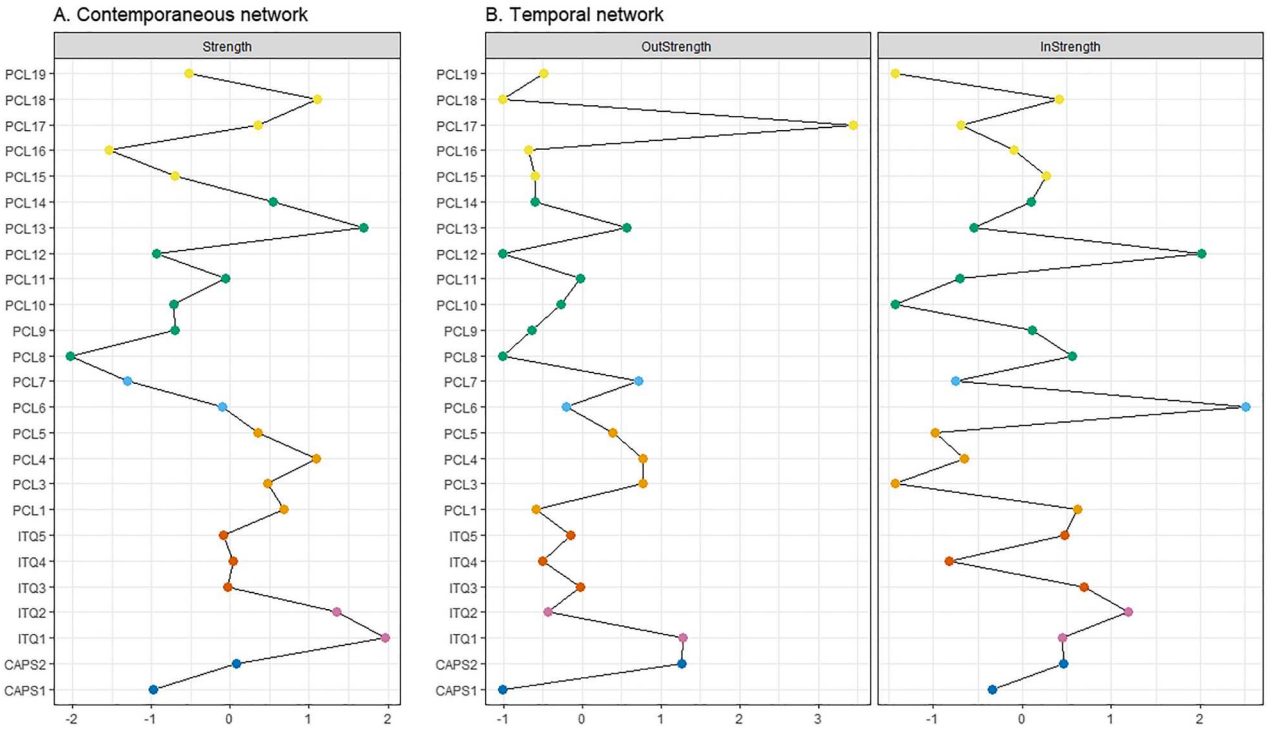

Figure 2. Standardized node strength centrality for the contemporaneous network (Panel A) and out- and in-strength centrality for the temporal network (Panel B).

Note: See Figure 1 for the symptom labels and clusters (coloured).

3. Discussion

We investigated dynamic PTSD symptom networks in patients attending specialized treatment centres – but before they had received trauma-focused treatment – by estimating contemporaneous and temporal networks. Building on and extending previous studies, the current study applied more intensive assessments and included additional symptoms associated with complex PTSD. Analysing the centrality and association between nodes, there was a markable difference between contemporaneous and temporal networks. Importantly, the temporal network comprised more negative correlations. Increase in *emotional cue reactivity* led to decrease of *intrusive distressing thoughts or memories*, *self-destructive behaviour*, *irritability/anger* and *loss of interest in activities*. Furthermore, increase in *flashbacks* precede decrease in *negative beliefs*, *impairment of relationships* and *loss of interest in activities* at the next time point and vice versa. In the contemporaneous network, on the other hand, symptoms showed a stronger synchronization with only a few negative correlations. Thus, the main finding from earlier research that temporal networks differ substantially from contemporaneous ones could clearly be replicated in the current study. It therefore appears important to always consider both types of networks when investigating the symptom structure in PTSD. It is important to note that the contemporaneous network captures the relations that are not captured by the temporal network. This could mean that the contemporaneous network captured temporal relations on a faster time scale compared to the temporal network. It is important to consider the time intervals more closely in future research. Differences between contemporaneous and temporal networks illustrate that PTSD dynamics differ even within hours which shows that there are different types of symptom interreations. Contemporaneous networks illustrate which symptoms are activated and deactivated within the same time. However, the core assumptions of network theory is that symptoms dynamics develop over time. This can more adequately be tested using temporal networks, both for theoretical as well as clinical purposes.

Some additional findings from previous studies were replicated. First, the items included in the DSM-5 cluster *changes in mood and cognition* fell into two subgroups, consistent with the study by Greene et al. (2018) and the dimensional structure of PTSD according to DSM-5 (Armour et al., 2015; Pietrzak et al., 2015). One group could be characterized as 'avoidance, detachment, recued responding' where the other group is more focused on 'negatively valenced thoughts and feelings'. This could implicate that Cluster D may be more heterogeneous than suggested by DSM-5, which should be investigated in the future research.

Second, in the contemporaneous network, amnesia was found to be the node with the lowest strength, which has been found repeatedly in earlier cross-sectional networks studies (Birkeland et al., 2020; Isvoranu et al., 2021). However, the finding is not in line with two previous PTSD dynamic network studies (Greene et al., 2018; Reeves & Fisher, 2020).

The changes around the within-person centred mean of *hypervigilance* predicted changes in most other symptoms at the next measurement. It has been argued that these temporal associations identified in a network analysis may be interpreted as indicators of the Granger causality (Epskamp et al., 2018), a term originating from the economic literature that signifies a potential indicator of causality (Granger, 1969). From a clinical perspective, it appears relevant to test whether targeting symptoms with the highest out-strength is related to higher treatment efficacy than targeting other symptoms, which may ultimately lead to defining symptoms of primary and secondary focus (Hoffart et al., 2019; Wichers et al., 2017). Hyperarousal occurs when a person suddenly goes into a state of increased alertness: even though there is no real danger, the person behaves as if they were confronted with threat. Identifying *hypervigilance* as the symptom with the highest out-strength is in line with the key components of prolonged exposure treatment where in-vivo exposure can be seen as directly targeting this symptom (Foa et al., 2007). In an earlier study conducted during exposure therapy with PTSD patients, *hypervigilance* and *physiological reactivity* were indeed found to be symptoms with the highest out-strengths (Hoffart et al., 2019). Even if not directly targeting hypervigilance, it may be informative to at least closely monitor it during treatment for PTSD as it may predict subsequent symptom reduction due to its high out-strength.

In the current study, *feeling distant or cut off from other people* was additionally found to have many direct connections to other nodes in the contemporaneous network, and to have effects on many other nodes in the temporal network; thus, this variable potentially also plays an important role in PTSD maintenance. Of note, current evidence-based interventions do not routinely target this symptom in a direct or specific way. If findings on a central role of these symptoms in the PTSD symptom network are replicated in future research, this could suggest that targeting this important interpersonal symptom – or at least closely monitoring it during treatment – may be promising. However, it is important to note that centrality measures are indeed difficult to interpret, particularly if the network consists of the positive and negative edges. Even though there is currently criticism of the use of any centrality measures (Bringmann et al., 2019), due to the aspect of

comparability to the previous studies on longitudinal networks, centrality measures were used.

Several limitations of the study and directions for future studies are noteworthy. First, although our sample size is within the range of earlier studies investigating temporal PTSD networks based on intensive ESM sampling in a patient population (e.g. Hoffart et al., 2019; Reeves & Fisher, 2020), recent considerations regarding the stability of the networks (Mansueto et al., 2023) suggest that our findings need to be replicated using larger samples. Second, not all participants in our sample satisfied the usually recommended criterion of 20 observation per person, known as a rule of thumb (the number of observations should be higher than the number of estimated parameters) (Ramseyer et al., 2014). Third, network models depend on the symptoms included in the network. We based our model on PTSD symptoms according to DSM-5 and additionally included symptoms related to dissociation, interpersonal problems, and functional impairment according to ICD-11, as these cover a wide spectrum of PTSD characteristics. Nevertheless, other variables may be important to consider, such as frequent comorbid symptoms (e.g. depressive symptoms; substance use) and information on external variables (e.g. environmental risk factors (Borsboom, 2017; Isvoranu, 2021)). Fourth, we tested a heterogenous sample of trauma survivors with PTSD. However, there is a first indication from a cross-sectional network study that trauma type may be a moderator (Stefanovic et al., 2022). Therefore, future studies should include other variables such as frequent comorbid symptoms (e.g. depressive symptoms; substance use), external variables (e.g. environmental risk factors) (Borsboom, 2017; Isvoranu, 2021) and trauma type as a moderator in temporal network studies. Fifth, our sample may not be representative as patients with comorbid borderline personality disorder were excluded. Sixth, complex PTSD according to ICD-11 may not be adequately assessed as we did not include all ITQ items in the analyses. Finally, although mlVAR assumes multivariate normality on residuals, the package does not allow testing this assumption. This should be addressed in future research and software development.

To conclude, despite the limitations, our study provided information about the within-day dynamics of PTSD symptoms in a clinical sample. Results show that contemporaneous and temporal networks differ and that it is important to estimate both. Some findings from earlier research are replicated, but heterogeneity across studies remains. Future studies should include potential moderators in the model (e.g. trauma type), and estimate idiographic networks following the work from Reeves and Fisher (2020) as a possible starting point for using temporal networks as a basis for personalized interventions.

Notes

1. These four participants attended one of the specialized treatment centers for their PTSD symptomatology but did not meet full DSM-5 criteria in the structured interviews.
2. When data collection for this study started, SCID-5-CV was not yet available in all outpatient centers. With the intention of simplifying the process for the patients, if a diagnostic was already provided with the SCID-IV and CAPS, we did not repeat the diagnostic part, as all patients were diagnosed according to DSM-5 criteria.
3. As a VAR model assumes the stationarity for each time series, we confirmed that there was no significant time trend on the PCL, ITQ, or CAPS scores.
4. Compliance rate was computed as the number of valid ESM responses divided by total number of beeps. Then, the compliance rate was correlated with the PCL score (both specified at the person level), which was not statistically significant.

Acknowledgements

Experience sampling data was collected with the Tellmi App, which was developed with support from a grant from the German Research Foundation to Felix Schönbrodt (SCHO 1334/5-1).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

MS was supported by scholarship from BAYHOST – Bavarian Academic Center for Central, Eastern and Southeastern Europe.

Data availability statement

The data that support the findings of this study and the R Code are accessible for reviewers in OSF at https://osf.io/upaxk/, and will be made openly accessible via OSF upon publication.

ORCID

Mina Stefanovic http://orcid.org/0000-0002-9340-456X
Keisuke Takano http://orcid.org/0000-0003-0406-8654
Charlotte E. Wittekind http://orcid.org/0000-0002-5841-0067
Thomas Ehring http://orcid.org/0000-0001-9502-6868

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed). https://doi.org/10.1176/appi.books.9780890425596

Armour, C., Tsai, J., Durham, T. A., Charak, R., Biehn, T. L., Elhai, J. D., & Pietrzak, R. H. (2015). Dimensional structure of DSM-5 posttraumatic stress symptoms: Support for a hybrid Anhedonia and externalizing behaviors

model. *Journal of Psychiatric Research*, *61*, 106–113. https://doi.org/10.1016/j.jpsychires.2014.10.012

Atwoli, L., Stein, D. J., Koenen, K. C., & McLaughlin, K. A. (2015). Epidemiology of posttraumatic stress disorder: Prevalence, correlates and consequences. *Current Opinion in Psychiatry*, *28*(4), 307–311. https://doi.org/10.1097/YCO.0000000000000167

Beesdo-Baum, K., Zaudig, M., & Wittchen, H.-U. (2019). *SCID-5-CV Strukturiertes Klinisches Interview für DSM-5-Störungen–Klinische Version: Deutsche Bearbeitung des Structured Clinical Interview for DSM-5 …* https://scholar.google.de/citations?user = qqp2lfiaaaaj&hl = fr&oi = sra.

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), 1700614. https://doi.org/10.1080/20008198.2019.1700614

Borsboom, D. (2017). A network theory of mental disorders. *World Psychiatry*, *16*(1), 5–13. https://doi.org/10.1002/wps.20375

Borsboom, D., & Cramer, A. O. (2013). Network analysis: An integrative approach to the structure of psychopathology. *Annual Review of Clinical Psychology*, *9*, 91–121. https://doi.org/10.1146/annurev-clinpsy-050212-185608

Bringmann, L. F., Elmer, T., Epskamp, S., Krause, R. W., Schoch, D., Wichers, M., Wigman, J. T. W., & Snippe, E. (2019). What do centrality measures measure in psychological networks? *Journal of Abnormal Psychology*, *128*(8), 892–903. https://doi.org/10.1037/abn0000446

Bringmann, L. F., Vissers, N., Wichers, M., Geschwind, N., Kuppens, P., Peeters, F., Borsboom, D., & Tuerlinckx, F. (2013). A network approach to psychopathology: New insights into clinical longitudinal data. *PLoS One*, *8*(4), e60188. https://doi.org/10.1371/journal.pone.0060188

Cloitre, M., Shevlin, M., Brewin, C. R., Bisson, J. I., Roberts, N. P., Maercker, A., Karatzias, T., & Hyland, P. (2018). The International Trauma Questionnaire: Development of a self-report measure of ICD-11 PTSD and complex PTSD. *Acta Psychiatrica Scandinavica*, *138*(6), 536–546. https://doi.org/10.1111/acps.12956

Epskamp, S., Deserno, M. K., & Bringmann, L. F. (2019, October 21). *mlVAR: Multi-level vector autoregression*. https://cran.r-project.org/web/packages/mlVAR/index.html.

Epskamp, S., Maris, G. K. J., Waldorp, L. J., & Borsboom, D. (2016, September 9). *Network psychometrics*. http://arxiv.org/pdf/1609.02818v2.

Epskamp, S., van Borkulo, C. D., van der Veen, D. C., Servaas, M. N., Isvoranu, A–M, Riese, H., & Cramer, A. O. J. (2018). Personalized network modeling in psychopathology: The importance of contemporaneous and temporal connections. *Clinical Psychological Science*, *6*(3), 416–427. https://doi.org/10.1177/2167702617744325

Foa, E. B., Hembree, E., & Rothbaum, B. O. (2007). *Prolonged exposure therapy for PTSD: Emotional processing of traumatic experiences*. Oxford University Press.

Fried, E. I., Eidhof, M. B., Palic, S., Costantini, G., Huisman-van Dijk, H. M., Bockting, C. L. H., Engelhard, I., Armour, C., Nielsen, A. B. S., & Karstoft, K–I. (2018). Replicability and generalizability of posttraumatic stress disorder (PTSD) networks: A cross-cultural multisite study of PTSD symptoms in four trauma patient samples. *Clinical Psychological Science*, *6*(3), 335–351. https://doi.org/10.1177/2167702617745092

Fried, E. I., & Robinaugh, D. J. (2020). Systems all the way down: Embracing complexity in mental health research. *BMC Medicine*, *18*(1), 205. https://doi.org/10.1186/s12916-020-01668-w

Galatzer-Levy, I. R., & Bryant, R. A. (2013). 636,120 ways to have posttraumatic stress disorder. *Perspectives on Psychological Science*, *8*(6), 651–662. https://doi.org/10.1177/1745691613504115

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society*, *37*(3), 424–438. https://doi.org/10.2307/1912791

Greene, T., Gelkopf, M., Epskamp, S., & Fried, E. (2018). Dynamic networks of PTSD symptoms during conflict. *Psychological Medicine*, *48*(14), 2409–2417. https://doi.org/10.1017/S0033291718000351

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), 1618134. https://doi.org/10.1080/20008198.2019.1618134

Hofmann, S. G., Curtiss, J., & McNally, R. J. (2016). A complex network perspective on clinical science. *Perspectives on Psychological Science*, *11*(5), 597–605. https://doi.org/10.1177/1745691616639283

Isvoranu, A–M. (2021). *From syndromes to symptoms: Networks models of psychosis and beyond*. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl = http%3A%2F%2Fwww.adelaisvoranu.com%2FPhDThesisAdelaIsvoranu.pdf&chunk = true.

Isvoranu, A–M, Epskamp, S., & Cheung, MW–L. (2021). Network models of posttraumatic stress disorder: A meta-analysis. *Journal of Abnormal Psychology*, *130*(8), 841–861. https://doi.org/10.1037/abn0000704

Kessler, R. C., Aguilar-Gaxiola, S., Alonso, J., Benjet, C., Bromet, E. J., Cardoso, G., Degenhardt, L., Girolamo, G. d., Dinolova, R. V., Ferry, F., Florescu, S., Gureje, O., Haro, J. M., Huang, Y., Karam, E. G., Kawakami, N., Lee, S., Lepine, J–P, … Koenen, K. C. (2017). Trauma and PTSD in the WHO world mental health surveys. *European Journal of Psychotraumatology*, *8*(sup5), 1353383. https://doi.org/10.1080/20008198.2017.1353383

Krüger-Gottschalk, A., Knaevelsrud, C., Rau, H., Dyer, A., Schäfer, I., Schellong, J., & Ehring, T. (2017). The German version of the Posttraumatic Stress Disorder Checklist for DSM-5 (PCL-5): Psychometric properties and diagnostic utility. *BMC Psychiatry*, *17*(1), 379. https://doi.org/10.1186/s12888-017-1541-6

Mansueto, A. C., Wiers, R. W., van Weert, J. C. M., Schouten, B. C., & Epskamp, S. (2023). Investigating the feasibility of idiographic network models. *Psychological Methods*, *28*(5), 1052–1068. https://doi.org/10.1037/met0000466

Naragon-Gainey, K., Simpson, T. L., Moore, S. A., Varra, A. A., & Kaysen, D. L. (2012). The correspondence of daily and retrospective PTSD reports among female victims of sexual assault. *Psychological Assessment*, *24*(4), 1041–1047. https://doi.org/10.1037/a0028518

Pietrzak, R. H., Tsai, J., Armour, C., Mota, N., Harpaz-Rotem, I., & Southwick, S. M. (2015). Functional significance of a novel 7-factor model of DSM-5 PTSD symptoms: Results from the National Health and Resilience in Veterans study. *Journal of Affective Disorders*, *174*, 522–526. https://doi.org/10.1016/j.jad.2014.12.007

Price, M., Legrand, A. C., Brier, Z. M. F., Gratton, J., & Skalka, C. (2020). The short-term dynamics of

posttraumatic stress disorder symptoms during the acute posttrauma period. *Depression and Anxiety*, *37*(4), 313–320. https://doi.org/10.1002/da.22976

Ramseyer, F., Kupper, Z., Caspar, F., Znoj, H., & Tschacher, W. (2014). Time-series panel analysis (TSPA): Multivariate modeling of temporal associations in psychotherapy process. *Journal of Consulting and Clinical Psychology*, *82*(5), 828–838. https://doi.org/10.1037/a0037168

Reeves, J. W., & Fisher, A. J. (2020). An examination of idiographic networks of posttraumatic stress disorder symptoms. *Journal of Traumatic Stress*, *33*(1), 84–95. https://doi.org/10.1002/jts.22491

Schnyder, U. (2013). Clinician-administered PTSD Scale for DSM-5-past month version.

Schuler, K., Ruggero, C. J., Mahaffey, B., Gonzalez, A. L., Callahan, J., Boals, A., Waszczuk, M. A., Luft, B. J., & Kotov, R. (2021). When hindsight is not 20/20: Ecological momentary assessment of PTSD symptoms versus retrospective report. *Assessment*, *28*(1), 238–247. https://doi.org/10.1177/1073191119869826

Stefanovic, M., Ehring, T., Wittekind, C. E., Kleim, B., Rohde, J., Krüger-Gottschalk, A., Knaevelsrud, C., Rau, H., Schäfer, I., Schellong, J., Dyer, A., & Takano, K. (2022). Comparing PTSD symptom networks in type I vs. type II trauma survivors. *European Journal of Psychotraumatology*, *13*(2), 2114260. https://doi.org/10.1080/20008066.2022.2114260

Warth, R. v. d., Dams, J., Grochtdreis, T., & König, H–H. (2020). Economic evaluations and cost analyses in posttraumatic stress disorder: A systematic review. *European Journal of Psychotraumatology*, *11*(1), 1753940. https://doi.org/10.1080/20008198.2020.1753940

Weathers, F. W., Blake, D., Schnurr, P., Kaloupek, DG[DG], Marx, BP[BP], & Keane, T. M. (2013a). *The Life Events Checklist for DSM-5 (LEC-5)*. National Center for PTSD website: http://www.ptsd.va.gov.

Weathers, F. W., Bovin, M. J., Lee, D. J., Sloan, D. M., Kaloupek, D. G [Danny G.], Keane, T. M., Marx, B. P [Brian P.], & Schnurr, P. P. (2018). The Clinician-administered PTSD Scale for DSM-5 (CAPS-5): Development and initial psychometric evaluation in military veterans. *Psychological Assessment*, *30*(3), 383–395. https://doi.org/10.1037/pas0000486

Weathers, F. W., Litz, B. T., Keane, T. M., Palmieri, P. A., Marx, B. P [B. P.], & Schnurr, P. (2013b). *The PTSD Checklist for DSM-5 (PCL-5)*. National Center for PTSD website: http://www.ptsd.va.gov.

Werner, G. G., Göhre, I., Takano, K., Ehring, T., Wittekind, C. E., & Stefanovic, M. (2022). Temporal associations between trauma-related sleep disturbances and PTSD symptoms: An experience sampling study. *Psychological Trauma: Theory, Research, Practice, and Policy*, Advance online publication. https://doi.org/10.1037tra0001386

Wichers, M., Wigman, J. T. W., Bringmann, L. F., & Jonge, P. d. (2017). Mental disorders as networks: Some cautionary reflections on a promising approach. *Social Psychiatry and Psychiatric Epidemiology*, *52*(2), 143–145. https://doi.org/10.1007/s00127-016-1335-z

World Health Organization. (2021). *ICD-11 Coding Tool*. World Health Organization. https://icd.who.int/ct11/icd11_mms/en/release.