The interrelationships of post-traumatic stress symptomatology in trauma-survivors across development: A comparative network analysis of children, adolescents and adults

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Abstract

Background

The defining symptoms of Post traumatic stress disorder has undergone considerable revision with each iteration of the DSM. Indeed, PTSD represents a unique diagnosis in that it uniquely identifies developmental differences. Previous research has identified longitudinal changes in PTSD symptoms but currently no research has investigated whether develop influences this. Similarly, the challenges associated with diagnosis also extend to differences that exist between caregiver and self-report. Newly developed statistical methods which allow for the interactions between symptoms to be investigated may better elucidate such differences.

Methods

PTSD symptom networks was estimated in two samples of caregiver reported symptoms of 516 very young children, and 681 school aged children. Three samples of self-reported PTSD symptom networks of 1213 school aged children, 1131 adolescents and 1013 adults were also estimated. The two caregiver reported networks were compared to one another as well as the self-reported networks.

Results

The PTSD symptom network of the caregiver reported network of very young children and school aged children did not show significant differences, with the most central symptoms being symptoms most easily observed. Significant differences in the symptom networks were observed between the self-reported networks indicative of developmental changes in symptom presentation. Whilst longitudinal changes in the network were observed in the adult network, which were not observed in the child and adolescent network.

Psychological distress following the experience of a traumatic event has long been recognised throughout history. Only in the 1980's was this constellation of psychological symptoms following a traumatic event formally recognised as Post-traumatic stress disorder (PTSD). PTSD is unusual among DSM syndromes in that the diagnostic criteria specify an etiologic event, in that the symptoms must begin or worsen after the event. The defining symptoms of PTSD have evolved extensively, between DSM III and DSM 5 with an overall increase in the number of symptoms from 12 to 20 and in the number of symptom groups from 3 to 4. Overall, such changes appear to reflect the research on PTSD which has been notable for controversy as well as progress.

Establishing the symptom structure of PTSD is important for understanding the aetiology and maintenance of PTSD. Cognitive theories share a core assumption that is the attempt to assimilate new information (traumatic experience) within an individual's pre-existing set of beliefs and models of the world characterize the post traumatic reaction (Dalgleish, 1999). The symptoms which represent the post traumatic reaction have varied considerably, representative of the challenge of identifying what symptoms best identify the syndrome. Reflective of this are the contrasting approaches of the two major classification systems (DSM and ICD), where the ICD has focused on the core symptom clusters (re-experiencing, avoidance and hyperarousal) the DSM believed it prudent to still include other non-specific symptom clusters that are found in other conditions (e.g. negative alterations in cognition and mood) (Stein et al., 2014). Revision of these symptom clusters have relied on guidance from factor analytic research in order to determine the most parsimonious symptom groups (Armour et al., 2016; Friedman, 2013; Rasmussen et al., 2018). However, Network Theory has argued that the focus on factors has concealed important information concerning the relationships between symptoms (Borsboom, 2017).

Network theory conceptualises mental disorders as a series of dynamic interactions between symptoms (Borsboom & Cramer 2013; Borsboom, 2017). This framework has been used as a means to complement traditional analytic methods to further our understanding of PTSD. For example, McNally et al., (2015) first used network analysis to investigate the causal system constitutive of PTSD. The authors found broad support of a casual structure consistent with the Ehlers and Clarke model of PTSD (2000), in that hypervigilance emerged as a highly central system. Studies investigating different populations have found differences in the centrality of symptoms. For example in motor vehicle survivors, Bryant et al., (2017) found intrusions and physiological reactivity as most central, whilst in Ross et al's., (2018) investigation in combat veterans, detachment and recurrent thoughts were the most central items. With concerns about the replicability and power issues within the network field (Borsboom et al., 2017; Epskamp, Borsboom, & Fried, 2017; Forbes et al., 2017a; Fried & Cramer, 2017), Fried et al (2018) investigated the structure of PTSD in four different trauma samples. Whilst each of the networks showed moderate to high correlations, there were differences among the networks most acutely amongst the associations between symptoms. Furthermore, network methods have been used to explore how gender (Cao et al., (2019) and trauma type (Benfer et al., 2018) influences the network structure. However, to date, the preponderance of research has focused on adults.

The network analysis literature on children and adolescence and PTSD is gradually increasing in scope (Cao et al., 2019; de Haan et al., Bartels et al., 2019., Pfeiffer et al., 2019). This research has generally reflected findings in the adult literature, which highlights the centrality of the re-experiencing symptoms (Pfieffer et al., 2019; de Haan et al.,2019 and Cao et al., 2019). However, in an investigation of DSM-5 PTSD symptoms in children Bartel et al., (2019) found that trauma related cognitions and persistent negative emotional state to be more central, different to what has been found in adults. This difference may reflect previous research, which has indicated that PTSS are experienced differently and change with development (Pynoos & Goenjian., 1996; Salmon & Bryant, 2002). Indeed, Russell et al (2017) who compared symptom networks in children and adolescents found differences in symptom associations. Whilst no significant differences were observed in the overall strength and structure of the network, the differences in sample sizes may have resulted in their being not enough power to investigate this difference (van Borkulo, 2017). This highlights the need for further research within this domain.

Network analysis has been used to investigate dynamic changes in network structure across time. For example, in a longitudinal investigation of PTSS in adults, Bryant et al (2017) found changes in symptom dynamics and overall network strength across time, which conformed to fear conditioning models of PTSD. To date only two other studies have investigated changes in the dynamic network structure of PTSD symptoms. Segal et al., (2019) who compared networks of combat soldiers pre (6 months) and post (6 months) deployment and found that following deployment symptoms of reactivity to triggers and avoidance symptoms became more closely associated. In a study of PTSD symptoms of children and adolescents measured at 2 weeks, 3 months and 6 months after a traumatic event, Ge et al., (2019) found a strengthening of connectivity in the symptoms and the centrality of re-experiencing symptoms. Given the differing timescales, more longitudinal investigations are required to determine whether similar processes are occurring in different populations.

The current researched aimed to investigate differences in symptom associations and network structure between different age groups. In addition to this the current research aimed to investigate the effects of the reporter on the network structure. Finally, the research also sought to explore changes in the network structure across time and determine whether differences existed as a function of age.

Methods

Participants and Procedure

Data were collated from multiple studies investigating PTSD symptomatology (Bryant et al., 2017; De Young et al., 2011; Hitchcock et al., 2021; Kassam-Adams et al., 2020; Meiser-Stedman et al., 2008; Scheeringa et al., 2012). Five different samples were derived from these datasets based on pre-defined age groupings. Two of the samples involved caregiver reports of symptoms while the remaining three involved self-report. All participants were assessed using standardized measures designed to assess post-traumatic stress symptoms according to the Diagnostic and Statistical Manual for Mental Disorders: Fourth Edition (DSM-IV; APA, 2000). A summary of the sample characteristics for the five datasets is provided in Table 1.

Table 1. An overview of the characteristics of each sample

Description	Sample 1 Caregiver Report of Very Young Children	Sample 2 Caregiver Report of children and adolescents	Sample 3 School Aged Children self-reported symptoms	Sample 4 Adolescent self-reported symptoms	Sample 5 Adult self-reported Symptoms
Age	4.74 (1.11) Range 2- <6.5	10.24 (2.46) Range 6.5- <18	10.13 (1.50) Range 6.5- <12.5	14.78 (1.41) Range 12.5- <18	38.00 (13.70) Range 18-71
Female (%)	219(42.4%)	246 (36.12%)	484 (39.9 %)	399 (35.3%)	266 (26.2%)
Sample Size	516	681	1213	1131	1013
Assessment Time Point (days)	144.76 (71.38)	142.04 (72.72)	138.07 (100.24)	106.80 (67.27)	111.32 (56.81)
%Met PTSD Criteria	DSM-IV 43[8.3%%] AA 155 [30%]	DSM-IV = 21 (3.1%) AA = 68 (10%)	DSM-IV 85[7%] AA 190 [15.7%]	DSM-IV 92 [8.1%] AA 174 [15.4%]	DSM-IV 99 [9.6%] AA 163 [16.1%]
Number of participants endorsing 0 items	145 [28.1%]	223 [32.75%]	386 [31.82%]	430 [38.02%]	281 [27.74%]
Trauma	Unintentional Injury = 151 (29.3%) Acute medical event (non-injury) = 61 (11.8%) MVA / RTA = 109 (21.1%) Interpersonal Violence = 73 (14.1%) Disaster = 120 (23.3%) Other = 1 (0.2%) Missing = 1 (0.2%)	Unintentional Injury = 449 (65.9%) Acute medical event (non-injury) = 18 (2.6%) MVA / RTA = 146(21.4%) Interpersonal Violence = 46(6.5%) Disaster = 17(2.4%) Other = 5 (0.7%%)	Unintentional Injury = 719 (59.3%) Acute medical event (non-injury) = 20 (1.6%) MVA / RTA = 187(15.4%) Interpersonal Violence = 14 (1.2%) Disaster = 247 (20.4%) Other = 26 (2.1%)	Unintentional Injury = 730 (64.5%) Acute medical event (non-injury) = 14 (1.2%) MVA / RTA = 157 (13.9%) Interpersonal Violence = 90 (8%) Disaster = 117 (10.3%) 1000- Other = 4 (0.4%) Missing = 19 (1.7%)	Unintentional Injury = 246 (24.3%) MVA / RTA = 639(63.1%) Interpersonal Violence = 62 (6.1%) Other = 64 (6.3%) Missing = 2 (0.2%)

Measures	The Anxiety Disorders Interview Schedule for Children – Parent Version = 6 (1.2%) Diagnostic Infant and Preschool Assessment DIPA = 125 (24.2%) PCL-PR PTSD Checklist for Children - Parent Report = 46 (8.9%) [PTSD Semi-Structured Interview and Observational Record for Infants and Young Children] = 47(9.1%) The Preschool Age Psychiatric Assessment = 292 (56.6%) -	The Anxiety Disorders Interview Schedule for Children – Parent Version = 279 (40.97%) Diagnostic Infant and Preschool Assessment = 26 (3.8%) PTSD Checklist for Children - Parent Report = 152 (22.32%) PTSD Semi-Structured Interview and Observational Record for Infants and Young Children = 60 (8.8%) The Preschool Age Psychiatric Assessment = 40 (5.9%) UCLA PTSD Reaction Index for DSM-IV – Parent Version = 124 (18.21%)	The Anxiety Disorders Interview Schedule for Children – Child Version = 130 (10.7%) Clinician-Administered PTSD Scale = 303 (25%) Child PTSD Symptom Scale CPSS = 527 (43.4%) UCLA PTSD Reaction Index for DSM-IV =253 (20.9%)	CADIS = 7 (.6%) CAPS = 257 (22.7%) CPSS = 574 (50.8%) UCLA PTSD Reaction Index for DSM-IV =293 (25.9%)	Clinician-Administered PTSD Scale = 985 (97.1%)) UCLA PTSD Reaction Index for DSM-IV = 28 (2.8%)

Caregiver-report samples

Sample one comprised data from 516 trauma-exposed children aged between 2 and 6.5 years (M_{age} = 4.74 years, SD=1.11; Sex_{female} = 219, 42.4%). Of these very young children, 43 (8.3%) met criteria for DSM-IV PTSD, with 155 (30%) meeting developmentally-appropriate criteria for PTSD according to the Alternative Algorithm – a precursor of the Preschool PTSD diagnosis in the DSM-5 developed for this age group (Scheeringa et al., 2011; see Supplementary Materials for an overview of the algorithm and its relationship to the DSM-5 PTSD preschool subtype), based on caregiver-report.

Sample two comprised 681 older trauma-exposed children and adolescents aged between 6.5 and 18 years of age (M_{age} = 10.24; SD=2.46; Sex_{female} = 246, 36.12%) for whom we also had caregiver reports. Of this sample, 21 (3.1%) met criteria for DSM-IV PTSD using the appropriate adult-based algorithm. Of note, even in this older sample, more children – 68 (10.8%) – met criteria using the Alternative Algorithm (Scheeringa et al., 2011; Woolgar et al., in press).

Self-report samples

Sample three overlapped with Sample Two and comprised self-reported symptoms of post-traumatic stress in 1213 elementary-school aged children aged between 6.5 and 13 years (M_{age} = 10.13, SD = 1.5; Sex_{female} = 484, 39.9%). Of this sample, 85 (7%) met criteria for DSM-IV PTSD. Of note, 199 (15.7%) met criteria using the Alternative Algorithm (Scheeringa et al., 2011).

Sample four also overlapped with Sample two and comprised 1131 adolescents aged between 13 and 18 years (M_{age} = 14.78, SD=1.41; Sex_{female} = 399, 35.3%) with self-reported posttraumatic stress symptoms. Of these, 92 (8.1%) met criteria for DSM-IV PTSD and 174 (15.4%) would have met criteria using the Alternative Algorithm (Scheeringa et al., 2011).

Finally, sample five was an adult sample, comprising 1013 individuals aged 18 and older (M_{age} = 38.00, SD=13.70; Sex_{female} = 266; 26.3%), who self-reported their symptoms of post-traumatic stress. Of these, 99 (9.8%) met criteria for a PTSD diagnosis. Of note, in this adult sample 163 (16.1%) met criteria for the Alternative Algorithm (Scheeringa et al., 2011).

Details of the inclusion criteria and recruitment flow for each of the different samples is summarised in the Supplementary Materials (S1). Briefly, the majority of the Sample One very young child dataset was obtained from these four studies (Scheeringa et al. 2012; Meiser-Stedman et al., 2008; De Young et al,. 2012; Hitchcock et al., 2020) in conjunction with the Prospective Studies of Acute Child Trauma and Recovery Data Archive (PACT/R)(ref). PACT/R is an international collaborative effort to share and preserve child trauma data. Information about the studies included in this data archive can be found here: https://childtraumadata.org/datasets-pactr-archive. Samples two and three were comprised of data acquired from PACT/R in addition to participants in the previously aforementioned studies whose age was above 6.5 years. Sample four was mainly comprised of data from PACT/R and from Bryant et al (2017) were a participant to be under 18 years of age. Finally, sample five was comprised mainly from Bryant et al., (2017) study and participants from the PACT/R database who were above 18 years of age. A summary of the data extraction process is provided in the Supplementary Material.

Participants for longitudinal network evaluations

Two longitudinal samples (see Table 2) of children and adolescents (Sample Six; *N*=551) and adults (Sample Seven; N=805) were extracted from the three self-report cross-sectional samples to include participants for whom we had repeated measures of post-traumatic stress symptoms across at least two time points. For Time 1 we required that participants be assessed within 28 days of having experienced a trauma. This criterion was utilised given it has been defined within the DSM-IV-TR as the point in time in which acute stress reactions occur (American Psychiatric Association, 2000). We required a minimum time difference of three months (90 days) between Time 1 and follow-up at Time 2 as it has been observed that after three months allows for 'natural recovery' to occur following acute symptoms in children and young people (Meisser-Stedman et al., 2017; Le Brocque et al., 2010).

Table 2. An overview of the characteristics of the two longitudinal samples

Description	Sample 6 Child and adolescents self-report symptoms	Sample 7 Adult self-report symptoms
Total Sample (*N*)	551	805
Time 1 Days (SD)	12.34 (8.71)	5.94 (5.94)
Time 2 Days (SD)	253.51 (71.16)	365
Age in years	11.76 (3.67)	39.03 (13.51)
Female (n; %)	200 (36.3%)	215 (26.6%)
n (%) meeting PTSD Criteria Time 1	DSM-IV = 85 (15.4%) AA = 144 (26.1)	DSM-IV 32 (4%) AA = 78 (9.7)
n (%) meeting PTSD Criteria Time 2	DSM-IV = 42(7.6%) AA = 70 (12.7%)	DSM-IV 78 (9.7%) AA = 127 (15.8%)
Measures	ADIS = 132(24%) CPSS = 346 (62.8%) CUCL = 73 (13.2%)	Clinician-Administered PTSD Scale = 805 (100%)
Trauma types n (%)	Unintentional Injury = 322 (58.45%) Acute medical event (non-injury) = 8 (1.5%) MVA / RTA = 152 (27.6%) Interpersonal Violence = 52 (9.4%) Other = 16 (2.9%) Missing = 1 (0.2%)	Unintentional Injury = 133 (16.52%) MVA / RTA = 528 (65.59%) Acute medical event (non-injury) = 51 (6.35%) Interpersonal Violence = 41 (5.09%) Other = 52 (6.4%) Missing = 4(0.5%)

Harmonization of posttraumatic stress measures across samples

The different post-traumatic stress measures used in the source studies for the 5 cross-sectional samples are presented in Table 1. A harmonization guide was used to create a standardised database across these different assessment measures. This guide was created as part of the PACT/R project and involved a panel of international leaders in PTSD research identifying the degree to which each question of each assessment measure assessed the relevant DSM-IV PTSD symptom (Kassam-Adams et al., 2020) To standardize across measures each item was binarized to indicate whether the person had either met or did not meet the criteria. See Supplementary Materials for details on the harmonization process and the derivation of diagnoses for each measure and sample (S2).

Overview of analytic approach

Cross-sectional regularized partial correlation networks

Cross-sectional networks were estimated for Samples one to five using Ising Models (Ising, 1925). Ising Models estimate weighted, undirected networks among a set of binary items. The pairwise interactions represent conditionally independent relationships between nodes, which are equivalent to partial correlations. Using the IsingFit package in R (http://cran.r-project.org/web/packages/IsingFit/IsingFit.pdf) we adopted a regularization technique which applies the graphical Least Absolute Shrinkage and Selection Operator (LASSO) algorithm in combination with an Extended Bayesian Information Criterion (EBIC). The hyperparameter for regularization was set at .25, the default in IsingFit (van Borkulo, 2014). The LASSO shrinks all edge-weights towards zero and sets small weights to exactly zero. The R package qgraph (Epskamp et al., 2012) was used to visually represent the network structure. In network graphs, thicker links between nodes indicate stronger partial correlations (edge weights) which can be either positive (blue) or negative (red). The absence of a line indicates zero correlation.

Network Inference

To quantify the importance of each symptom node in a given network, three centrality metrics that are often investigated are Strength, Betweenness, and Closeness. Given concerns surrounding the Betweenness and Closeness metrics (Hallquist et al., 2019), only the Strength Metric was computed for the current study. The R package bootnet (Epskamp & Fried., 2018) was used to compute the normalized Strength value for each node. The Strength metric reflects the sum of the absolute value of edge weights for a given node, thus higher Strength for a symptom reflects a combination of the strength of the edge weights and the quantity of edges (Barrat, Barthelemy, Pastor-Satorras, & Vespignani, 2004; Newman, 2004).

The shared variance between each node and all of its neighbours – the node's Predictability – was computed using the mgm package in R (Haslbeck & Waldorp 2015; Haslbeck & Waldorp 2018). In contrast to Strength which is a relative metric of how interconnected a node is, Predictability provides an absolute measure of interconnectedness (Haslbeck & Waldorp 2018). In the network graphs this is denoted by the *rings* around the nodes which indicate the proportion of explained variance in that node by all other nodes.

Stability

Network Stability for each of the respective networks was computed using the procedures outlined by Epskamp, Borsboom and Fried (2017). The r package bootnet (Epskamp & Fried., 2018) was used to determine the stability of the Strength and Predictability metrics. In alignment with these recommendations, bootnet completed 1000 bootstraps of the metrics with progressively smaller, random subsets of the sample. Conventionally, the correlation-stability coefficient should ideally be around 50% and not below 25% (Epskamp et al., 2017). We also computed the edge-weights difference test and the centrality difference test for each network. Both of these tests involve taking the difference between bootstrapped values of on edge-weight or centrality and another edge-weight or centrality and constructing a bootstrapped CI around those difference scores (Epskamp et al., 2018).

Visualization

To visualize the outputs produced by qgraph the layout of the nodes was supervised using the Fruchtermann-Reingold algorithm (Frutcherman & Reingold, 1991). For ease of visual comparison, the layout of the networks was restricted using the 'Average Layout' command in qgraph so each network had a comparable layout.

Network Comparison

Networks were compared using two methods. The first involved correlating the edge weights across the networks. In line with previous work (Borsboom et al., 2017; Fried et al., 2018), Spearman correlation was used to calculate the measure of similarity between the networks. The difference between networks were then statistically tested using the Network Comparison Test (NCT), a permutation-based test via the R package NetworkComparisonTest (van Borkulo et al., 2017). This test compares networks based on their topology, global network strength and differences in edge strength. To avoid biases caused by differences in sample sizes, van Borkulo et al (2017) recommend repeated subsampling of the largest group as a robustness check. Based on Fried et al. (2017) this procedure was computed five times for each set of comparisons. Due to the exploratory nature of this investigation the multiple comparisons were not controlled for, as whilst it was anticipated there would be developmental differences, it was unknown where such differences would exist.

Missing Data

For the network analysis, participants were only included if there was a completed measure of each post traumatic stress symptom and age-related information was available (see Tables 1 and 2).

Results

Cross-sectional comparisons of caregiver-report and self-report networks

Table 3 presents the post-traumatic stress symptom data broken down by individual DSM-IV symptoms for the different samples for the cross-sectional comparisons.

Table 3. Frequency (*n* (%)) of PTSD DSM-IV symptom endorsement by sample.

DSM-IV PTSD Symptom	Sample 1: Caregiver Report Very young children (n=516)	Sample 2: Caregiver report children & adolescents (n=681)	Sample 3: Self Report School Aged Children (n=1213)	Sample 4: Adolescent Self Report (n=1131)	Sample 5: Adult Self Report (n=1013)
B1: Intrusions	147 (28.5%)	178(26.1%)	195(16.1%)	154 (13.6%)	144 (14.2%)
B2: Nightmares	134 (26%)	67 (9.8%)	143(11.8%)	88 (7.8%)	124 (12.2%)
B3: Flashbacks	66 (12.8%)	64 (9.4 %)	132 (10.9%)	104 (9.2%)	60 (5.9%)
B4: Psychological reactivity	235 (45.5%)	100 (14.7%)	215 (17.7 %)	179(15.8%)	157 (15.5%)
B5: Physiological reactivity	66 (12.8%)	47 (6.9%)	132 (10.9%)	110(9.7%)	123 (12.1%)
C1: Avoidance of thoughts/feelings	98(19.0%)	109 (16.0%)	291 (24%)	185 (16.4%)	144 (14.2%)
C2: Avoidance of situations	151 (29.3%)	115 (16.9%)	179 (14.8%)	135 (11.9%)	99 (9.8%)
C3: Amnesia	27 (5.2%)	104 (15.3%)	315(26%)	321 (28.4%)	367 (36.2%)
C4: Disinterest	39 (7.6%)	80 (11.8%)	109 (9.1%)	102 (9%)	154 (15.2%)
C5: Feeling detached	42 (8.1%)	42 (6.2%)	77 (6.4%)	91 (8.5%)	138 (13.6%)
C6: Emotional numbing	52 (10.1%)	46 (6.8%)	109 (9%)	120 (10.6%)	104(10.3%)
C7: Foreshortened future	2 (.4%)	28 (4.1%)	88 (7.3%)	95 (8.4%)	51 (5.0%)
D1: Sleep problems	174 (33.7%)	88 (12.9%)	218 (18%)	220 (19.5%)	411 (40.6%)
D2: Irritability	190 (36.8%)	144 (21.2%)	198 (16.3%)	225 (19.9%)	267(26.4%)
D3: Concentration problems	101(19.6%)	104(15.3%)	209 (17.2%)	203 (18%)	238 (23.5%)
D4: Hypervigilance	118 (22.9%)	146 (21.4%)	293(24.2%)	278 (24.6%)	190 (18.8%)
D5: Startle response	135 (26.2%)	93 (13.7%)	215 (17.7%)	176 (15.6%)	111 (11%)

Caregiver networks

Sample 1: Caregiver report on very young Children aged between 2 and 6.5 years

The regularized Ising Graphical Model for Sample one is depicted in Figure 1. As can be seen, DSM-IV symptom B4 (*psychological distress)* seemed to have both the most and strongest associations. For example, with C1 (*Avoidance of thoughts*), C2 (*Avoidance of situations*), C6 (*emotional numbing*). Symptoms D2 (*Irritability*) and D3 (*Concentration problems*) were also positively inter-correlated. The strength Metric indexing the centrality of the different symptoms is depicted in Figure 2. This indicated that the strongest symptom (standardized estimates nearing/exceeding 1) was B4 (*Psychological reactivity)*. The mean Predictability of the network was 22.09%, indicating that, on average, 22.09% of the variance of each symptom node across the network was explained by its neighbours. This was substantially lower than in previous studies in adults (Fried et al., 2018).

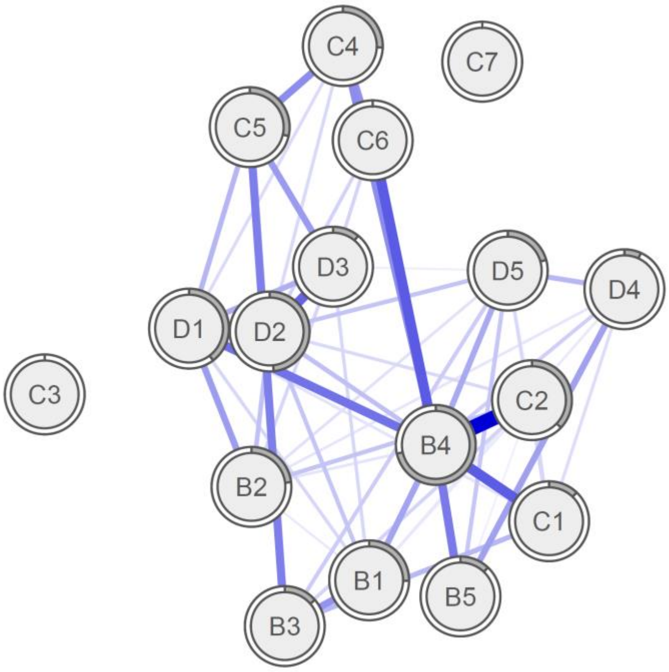
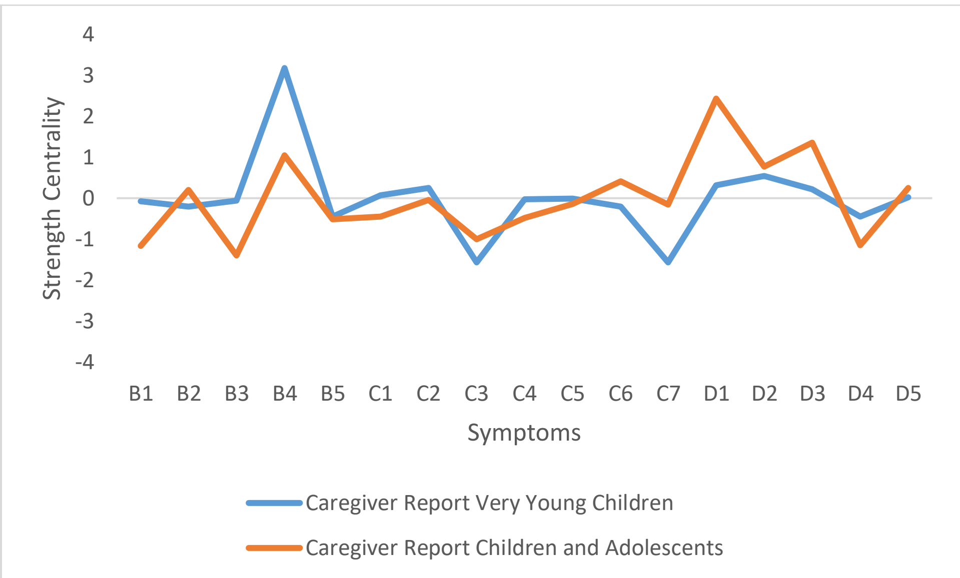


Figure 1. Network depicting the Caregiver report on very young Children aged between 2 and 6.5 years



B1: Recurrent and intrusive distressing recollections; B2: Recurrent distressing dreams of the event, B3: Acting or feeling as if the traumatic event were recurring, B4: Intense psychological distress at exposure to internal or external cues, B5: Physiological reactivity on exposure to internal or external cues, C1: Efforts to avoid thoughts, feelings or conversations associated with the trauma, C2: Efforts to avoid activities, places or people that arouse recollections of the trauma, C3: Inability to recall an important aspect of the trauma, C4: Markedly diminished interest or participation in significant activities, C5: Feeling of detachment or estrangement from others, C6: Restricted range of affect, C7: Sense of a foreshortened future, D1: Difficulty falling or staying asleep, D2: Irritability or outburst of anger, D3: Difficulty concentrating, D4: Hypervigilance, D5: Exaggerated startle response

Figure 2. Strength centrality metrics of caregiver-reported PTSD DSM-IV symptom networks across the age range (Samples 1 and 2).

Sample 2: Caregiver report on school-age children and adolescents aged between 6.5 and 18 years

The regularized Ising Graphical Model based on caregiver reports of the older school-age children and adolescents is depicted in Figure 2. As can be seen, the strongest edge associations were among symptoms D2 (*Irritability)* and D3 *(Concentration problems)* and between B2 (*Nightmares) and* D1 (*Sleep problems).* The Strength metrics (Figure 7) indicated that items, B4 (*Psychological reactivity*), D1 (*Sleep problems)* and D3 (*Concentration problems)* exceeded the standardized estimation of 1. The mean Predictability of the network was 16.17%,

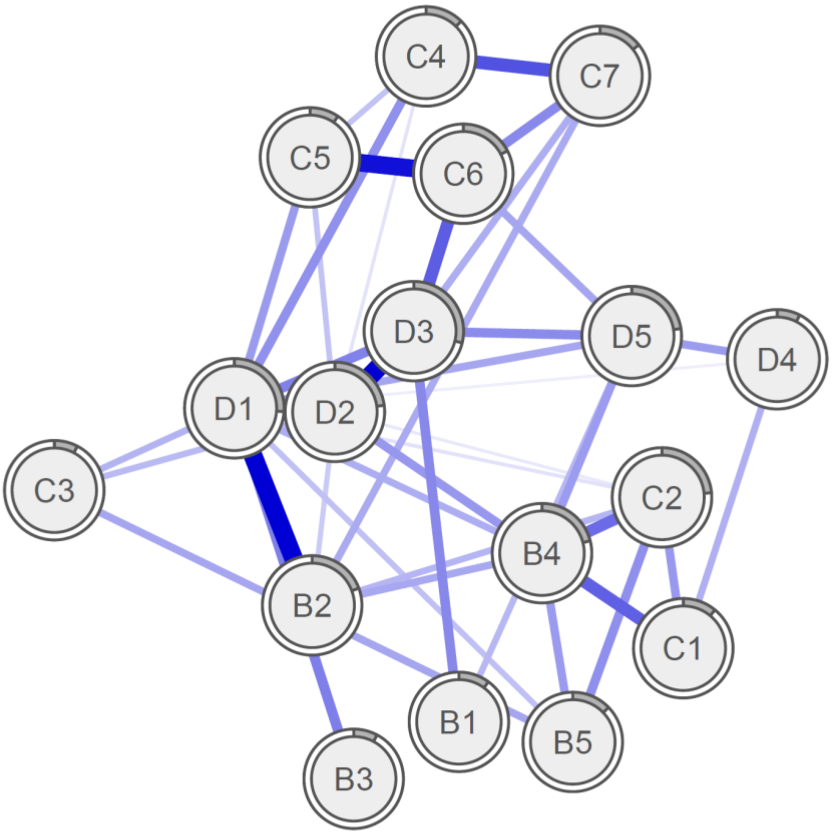


Figure 3. Network depicting the Caregiver report on school-age children and adolescents aged between 6.5 and 18 years

Self-report networks

Sample 3: Self-reports from school-aged children aged between 6.5 and 13 years

The network based on the self-report school-aged child data (Figure 4) showed strong edge associations between symptom C5 (*Feeling detached*) and symptoms B3 (*Flashbacks*), C4 (*Disinterest)* and C6 (*emotional numbing*). A strong edge association was also observed between symptoms B1 (*Intrusions*), B2 (*Nightmares*) and B4 (*Psychological reactivity)*. The symptoms that had standardized estimates exceeding 1 for the Strength metric were B4 (*Psychological reactivity*), B5 (*Physiological reactivity*) and C6 (*Restricted range of affect*) (Figure 7). The mean Predictability of the network was 15.05%,

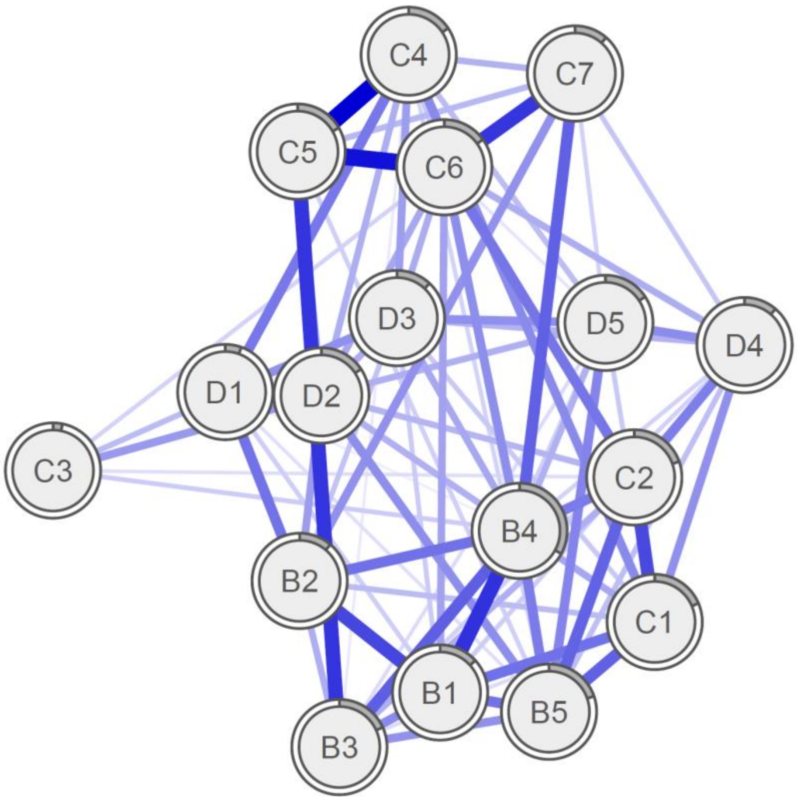


Figure 4. Network depicting the *self-reports from school-aged children aged between 6.5 and 13 years*

Sample four: Self-reports from adolescents aged between 13 and 18 years

The Network for adolescent self-reported symptoms (Figure 5) showed that the strongest edge associations were between symptom C6 (*emotional numbing*) and symptom C5 (*Feeling detached)*. A strong association was also evident between symptoms D4 (*Hypervigilance)* and D5 (*Startle response*). The only symptom with a Strength metric exceeding 1 was item B1 (*Intrusions*), and C6 (*emotional numbing*)*)* see Figure 7. The mean Predictability of the network was 21.44%,

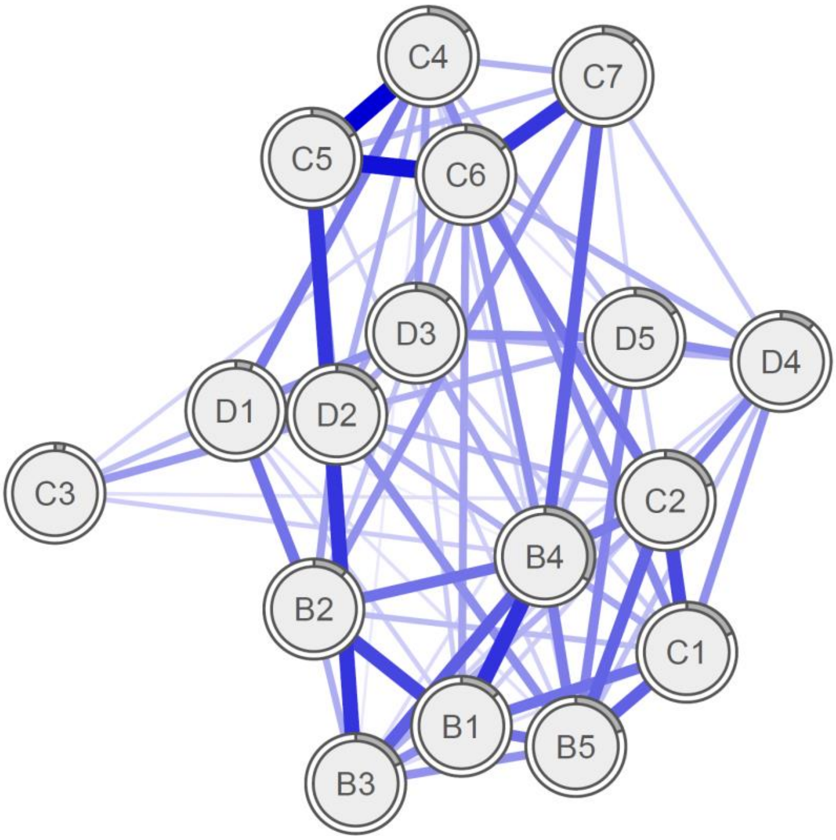


Figure 5. Network depicting the Self-reports from adolescents aged between 13 and 18 years

Sample 5: Self reports from adults aged 18 and older

The network for adult self-reported symptoms (Figure 6.) shows that the strongest edge associations were between symptom C6 (*emotional numbing*) and symptoms C5 (*Feeling detached*) and symptom C4 (*Disinterest*). A strong edge association was also observed between symptom B5 (*Physiological reactivity*), B3 (*Flashbacks*) and B4 (*Psychological reactivity)*. Symptoms which exceed 1 on the Strength metric in the standardized estimation were symptoms, B5 (*Physiological reactivity) and C4 (Disinterest)* see Figure 7*.* The mean Predictability of the network was 21.26%,

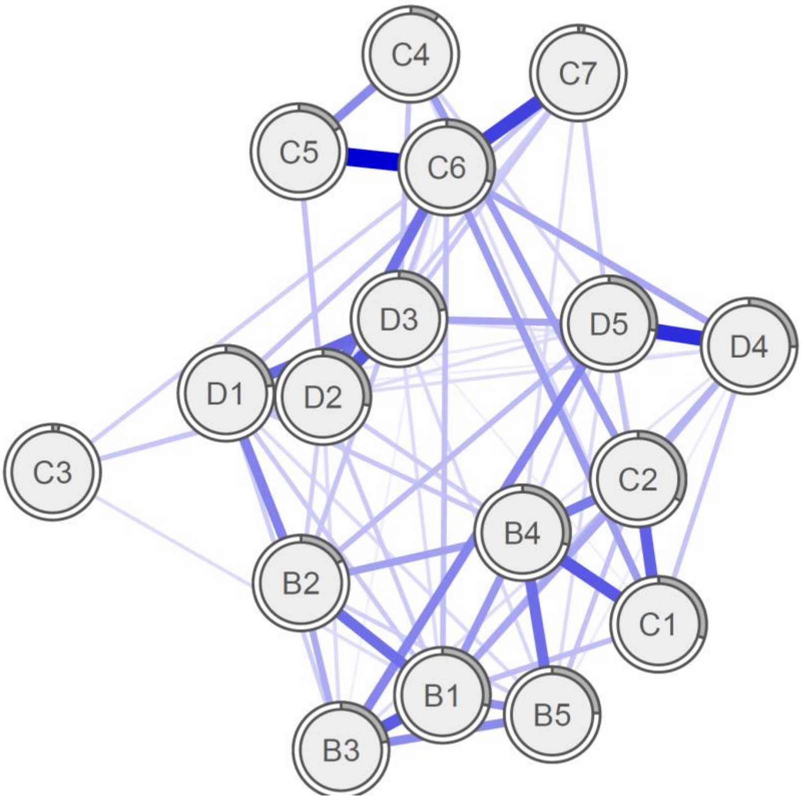
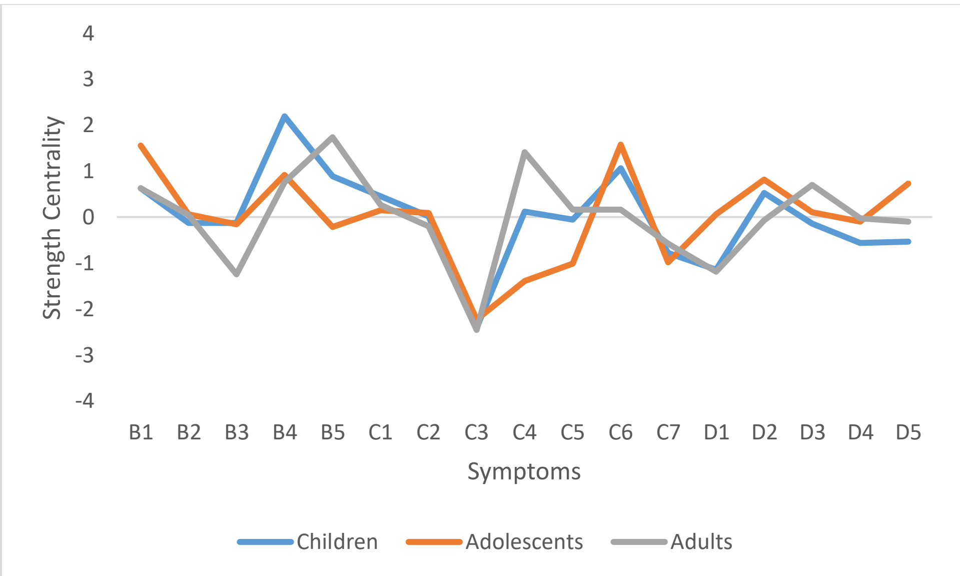


Figure 6. Network depicting the Self reports from adults aged 18 and older

Figure 7. Strength centrality metric of self-reported DSM-IV PTSD symptoms across children adolescents and adults.



B1: Recurrent and intrusive distressing recollections; B2: Recurrent distressing dreams of the event, B3: Acting or feeling as if the traumatic event were recurring, B4: Intense psychological distress at exposure to internal or external cues, B5: Physiological reactivity on exposure to internal or external cues, C1: Efforts to avoid thoughts, feelings or conversations associated with the trauma, C2: Efforts to avoid activities, places or people that arouse recollections of the trauma, C3: Inability to recall an important aspect of the trauma, C4: Markedly diminished interest or participation in significant activities, C5: Feeling of detachment or estrangement from others, C6: Restricted range of affect, C7: Sense of a foreshortened future, D1: Difficulty falling or staying asleep, D2: Irritability or outburst of anger, D3: Difficulty concentrating, D4: Hypervigilance, D5: Exaggerated startle response

Network stability estimates

Strength stability

The Strength correlation-stability coefficient exceeded the threshold of .25 for each network except for Sample 2 – the caregiver report of children and adolescents (see Table 4 and Table 5). This suggests that for all networks except this network, the Strength metrics provided a reliable estimation. As outlined by Epskamp & Fried (2018), the lower coefficient for Sample 2 means that the centrality estimates need to be interpreted with caution (Fried et al., 2020).

Table 4: Correlation-stability coefficients for the Strength centrality indices

	Caregiver Report Very Young Children	Caregiver Report Children & Adolescents	Self-report School Aged Children	Self-report Adolescents	Self-report Adults
Strength correlation-stability coefficient	.52	.21	.36	.44	.52

Edge-weight

Non-parametric bootstrapping was used to calculate the confidence intervals around the edge weights and showed significant overlap across all the networks. This suggests that although certain edged appear stronger their difference is not statistically significantly different given they have overlapping confidence intervals. The order of the edge-weights should therefore be interpreted with caution. Furthermore, comparisons of node strength and edge differences were also completed for each network (Supplementary Figure s3-s38)

Cross-sectional network comparisons

Correlations between networks

The edge weights of each of the respective networks from the five samples were correlated to determine the extent of similarity. The two caregiver-reported networks (Samples 1 and 2) were moderately correlated ($r_s = 0.35$; Hinkle et al., 2003). For the self-report networks, the weakest correlation existed between the self-report adult (Sample 5) and self-report adolescents (Sample 4) networks which showed a moderate correlation ($r_s = 0.27$) and the strongest correlation existed between the self-report adolescents and self-report school-aged children (Sample 3) which showed a moderately large positive correlation ($r_s = 0.46$). The small to moderate sizes of correlations suggest that there exist key differences between the networks.

Table 5: Spearman correlations between each of the respective networks.

	Sample1: Caregiver-report for Very Young Children	Sample 2: Caregiver-report for older Children and Adolescents	Sample 3: Self-report School Aged Children	Sample 4: Self-report Adolescents	Sample 5: Self-report Adults
Sample1: Caregiver report very young children	1	.35	.35	.28	.28
Sample 2: Caregiver report older children and adolescents	–	1	.32	.33	.25
Sample 3: Self-report school aged children	–	–	1	.46	.37
Sample 4: Self-report adolescents	–	–	–	1	.41
Sample 5: Self-report adults	–	–	–	–	1

Comparison of caregiver report networks in very young children (Sample 1) compared to caregiver report of older-children and adolescents (Sample 2)

The NCT showed a non-significant difference between the topology of the two caregiver-report networks ($p = 0.43$). A comparison of the global network strength revealed a non-significant difference ($p = .39$) between the caregiver report of very young children ($M_{Strength} = 30.50$) and caregiver report of school aged children ($M_{Strength} = 27.42$). A total of 17 edges were significantly different from one another, details of which are provided in the Supplementary Materials. Taken together this suggests that the two caregiver reported networks were broadly similar.

Comparison of self-report networks of school-aged children (Sample 3) and adolescents (Sample 4)

A non-significant difference existed in the topology between school-aged children self-report and adolescent self-report ($p = 0.38$). A comparison of the global network strength between the school aged children (($M_{strength} = 38.61$) and adolescents ($M_{strength} = 41.05$) revealed a non-significant difference ($p = 0.45$). In total, 10 edges were significantly different from one another, details of which are provided in the Supplementary Materials. The results highlight that the two networks were similar in the nature and strength of the connection between the symptoms.

Comparison of self-report networks of school-aged children (Sample 3) with adults (Sample 5)

The NCT revealed a significant difference between the topologies of school-aged children and adult self-report networks (p = 0.04). However, there was not a significant difference in the global network strength between school aged children ($M_{strength}$ = 38.61) and adults ($M_{strength}$ = 42.30) , p = 0.41. Across the two networks, 15 edges were significantly different, details of which are provided in the Supplementary Materials. This shows that the two networks showed key differences in relation to the nature of the inter-relationship amongst the symptoms and may suggest evidence of developmental differences that are present in the symptom networks.

Comparison of self-report networks adolescents (Sample 4) with adults (Sample 5)

The NCT revealed that the topology of the two networks were not significantly different, although there was a trend towards significance (p = 0.08). The comparison of global network strength between adolescents ($M_{strength}$ = 41.05) and adults ($M_{strength}$ = 42.30) indicated the adult network was not significantly different, p = 0.89. In all, 13 edges were significantly different, details of which are provided in the Supplementary Materials.

Longitudinal self-report networks

Table 6. Frequency (*n* (%)) of post-traumatic stress DSM-IV symptom endorsement by sample.

DSM-IV PTSD Symptom	Sample 6: Self - Report Children and Adolescents Time 1 N = 551	Sample 6: Self-Report Children and Adolescents Time 2 N = 551	Sample 7: Self-Report Adults Time 1 N = 805	Sample 7: Self-Report Adults Time 2 N=805
B1: Intrusions	146 (26.5%)	69 (7.5%)	98 (12.2%)	97 (12.1%)
B2: Nightmares	88 (16%)	38 (6.9%)	91 (11.3%)	91 (11.3%)
B3: Flashbacks	113 (20.5%)	57 (10.3%)	47 (5.8%)	49 (6.1%)
B4: Psychological Reactivity	147 (26.7%)	63 (11.4%)	92 (11.4%)	114 (14.2%)
B5: Physiological Reactivity	118 (21.4%)	56 (10.2%)	69 (8.6%)	107 (13.3%)
C1: Avoidance of thoughts/feelings	181 (32.9%)	101 (18.3%)	94 (11.7%)	104 (12.9%)
C2: Avoidance of situations	116 (21.1%)	76 (13.8%)	21 (2.6%)	99 (12.3%)
C3: Amnesia	135 (24.5%)	115 (20.9%)	288 (35.8%)	265 (32.9%)
C4: Disinterest	75 (13.6%)	47 (8.5%)	49 (6.1%)	95 (11.8%)
C5: Feeling detached	56 (10.2%)	35 (6.4%)	37 (4.6%)	113 (14%)
C6: Emotional numbing	83 (15.1%)	54 (9.8%)	37 (4.6%)	99 (12.3%)
C7: Foreshortened future	58 (10.5)	20 (3.6%)	25 (3.1%)	56 (7%)

D1: Sleep problems	172 (31.2%)	78 (14.2%)	427 (53%)	286 (35.5%)
D2: Irritability	115 (20.9%)	82 (14.9%)	143 (17.8%)	183 (22.7%)
D3: Concentration Problems	117 (21.2%)	73 (13.23%)	151 (18.8%)	160 (19.9%)
D4: Hypervigilance	184 (33.4%)	151 (27.4%)	38 (4.7%)	176 (21.9%)
D5: Startle response	112 (20.3%)	67 (12.2%)	52 (6.5%)	117 (14.5%)

Children and adolescents

Sample 6: Self reports from children and adolescents

The Network at Time 1 (Figure 8) shows that the strongest edge associations were between symptom B3 (*Flashbacks*) and symptoms B2 (*Nightmares) and C2 (Avoidance of situations).* Symptoms which exceed 1 on the Strength Metric in the standardized estimation were symptoms B1 (*Intrusions)*, and B5 (*Physiological reactivity)* see Figure 6*.* The mean predictability of the network was 25.79%.

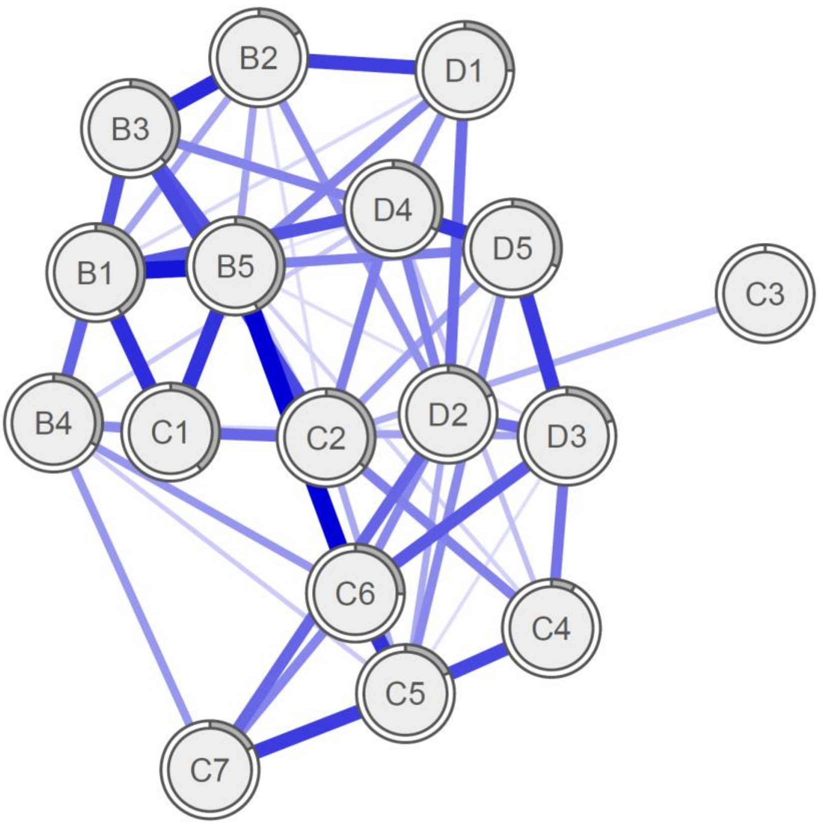


Figure 8. Network depicting Self reports from children and adolescents at time 1

The network at Time 2 (Figure 9.) showed that the strongest association with symptoms B1 (Intrusions) and symptoms B2 (Nightmares), and B4 (Psychological reactivity). Strong associations also existed between the symptoms D4 (Hypervigilance) and D5 (Startle response) as well as symptoms D3 (Concentration problems) and D1 (Sleep problems). Symptoms which exceed 1 on the Strength Metric in the standardized estimation were B1, C1 and C6 (see Figure 12). The mean Predictability of the network was 23.52%.

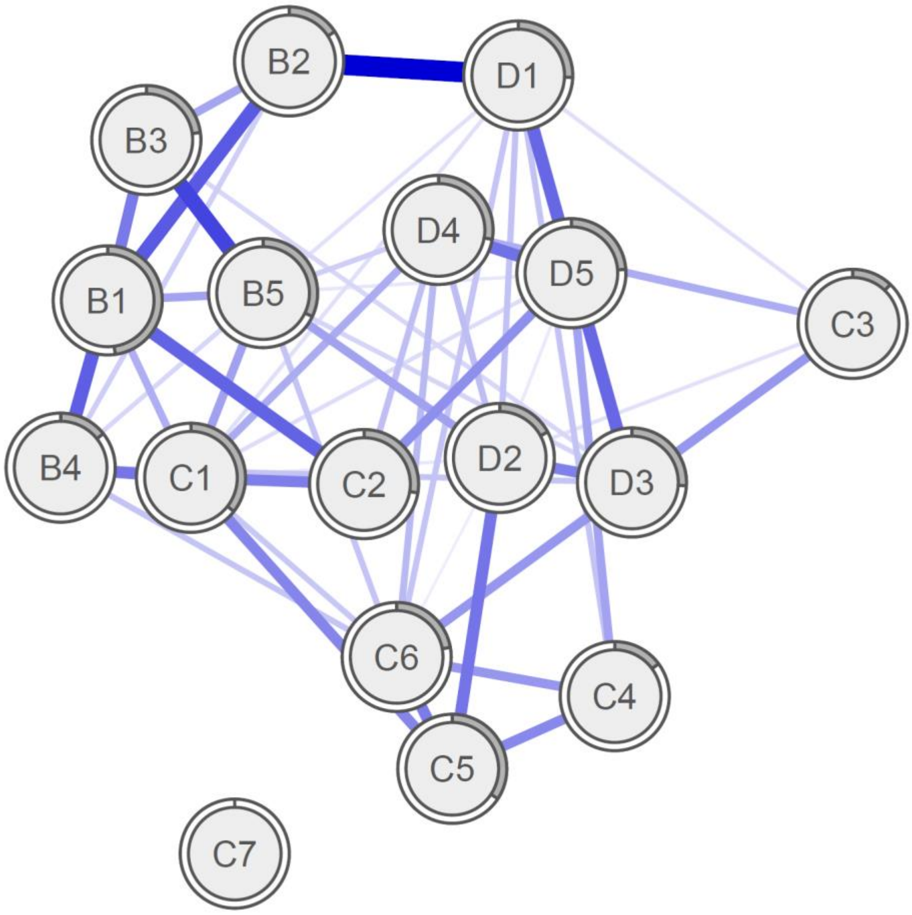


Figure 9. Network depicting Self reports from children and adolescents at time 2

Sample7: Self reports from adults

The network for adult self-reported symptoms of PTSD across Time 1 is depicted in Figure 10. The network showed that the strongest associations with symptoms B1 (Intrusions) and B4 (Psychological reactivity), B3 (Flashbacks) and C1 (Avoidance of thoughts/feelings). Symptoms which exceeded 1 on the Strength metric in the standardized estimation were B1, B5 and C1 (see Figure 12.). The mean Predictability of the network was 16.01%.

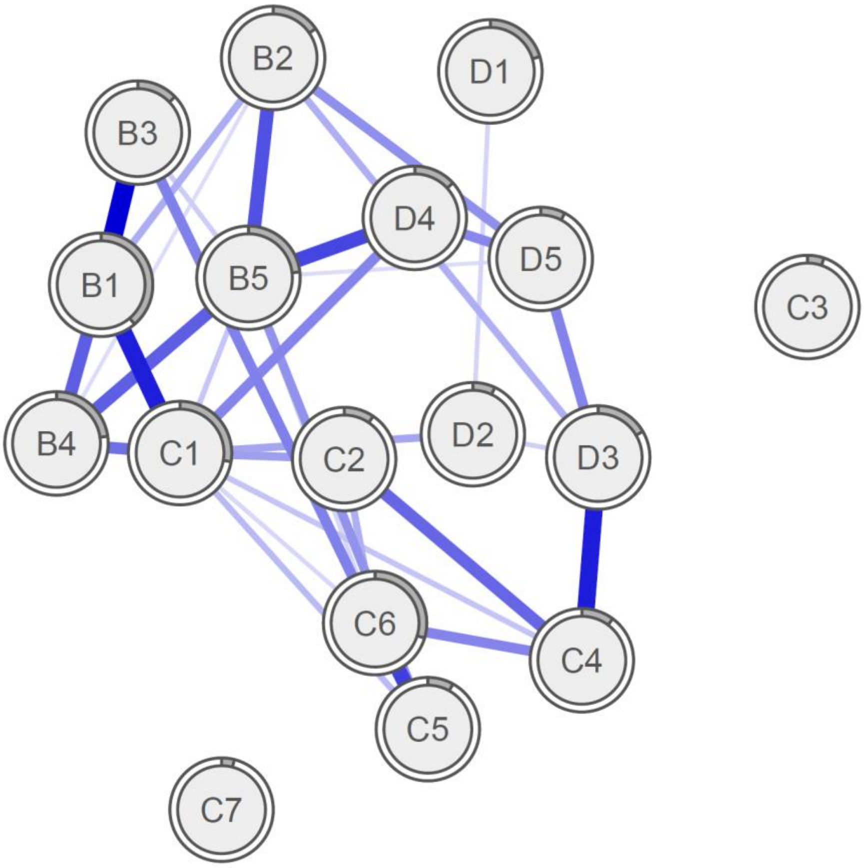


Figure 10. Network depicting adult self-report network at Time 1

The adult self-report network at Time 2 (Figure 11.) showed the strongest associations with symptoms B1 (Intrusions) and B2 (Nightmares), and B4 (Psychological reactivity) symptoms D4 (Hypervigilance)and D5 (Startle response) and symptoms B4 (Psychological reactivity) and B5 (Physiological reactivity). Symptoms which exceed 1 on the Strength metric in the standardized estimation were C5 and D2. The mean Predictability of the network was 29.93%.

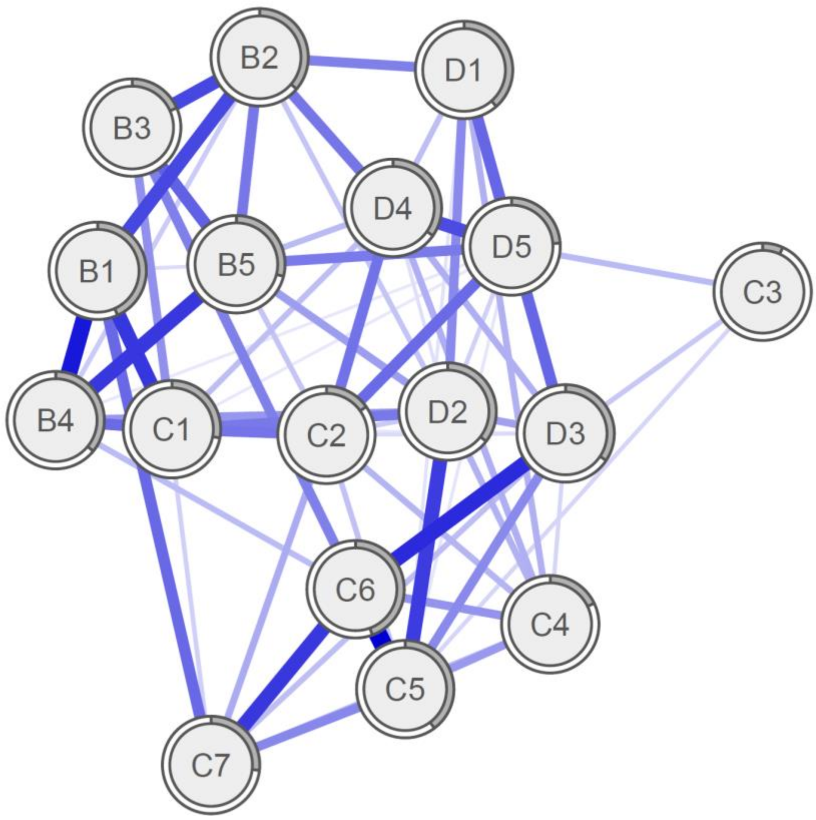
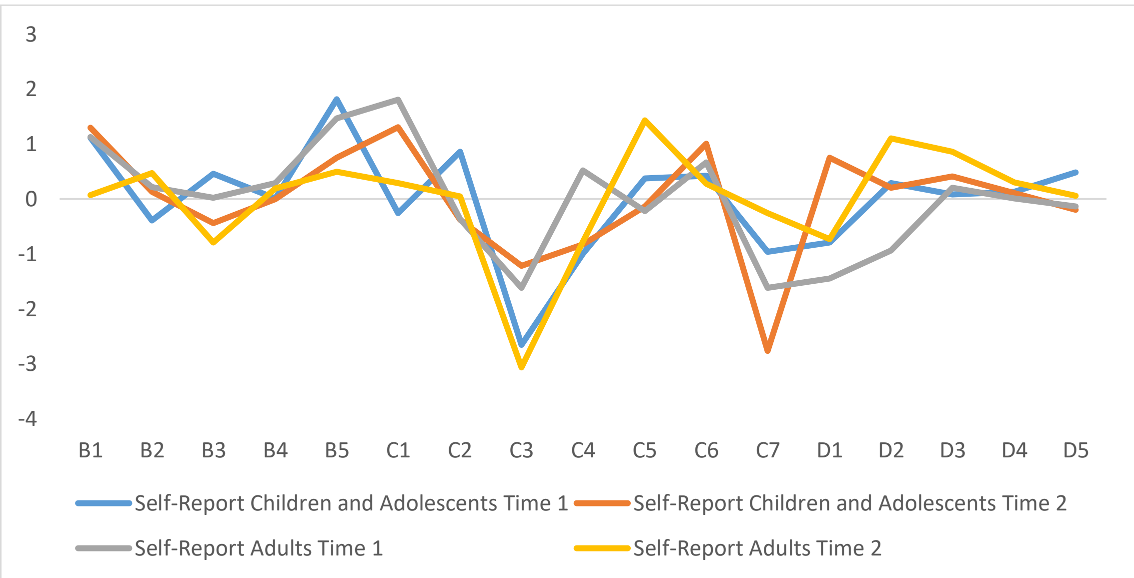


Figure 11. Network depicting adult self-report network at Time 2

Figure 12. Standardized Strength Centrality of Longitudinal Self-Reported PTSS Networks



B1: Recurrent and intrusive distressing recollections; B2: Recurrent distressing dreams of the event, B3: Acting or feeling as if the traumatic event were recurring, B4: Intense psychological distress at exposure to internal or external cues, B5: Physiological reactivity on exposure to internal or external cues, C1: Efforts to avoid thoughts, feelings or conversations associated with the trauma, C2: Efforts to avoid activities, places or people that arouse recollections of the trauma, C3: Inability to recall an important aspect of the trauma, C4: Markedly diminished interest or participation in significant activities, C5: Feeling of detachment or estrangement from others, C6:

Restricted range of affect, C7: Sense of a foreshortened future, D1: Difficulty falling or staying asleep, D2: Irritability or outburst of anger, D3: Difficulty concentrating, D4: Hypervigilance, D5: Exaggerated startle response

Stability

The Strength metric stability coefficients exceeded the threshold of .25 for each network except for Time 2 self-report children and adolescents. This suggests that the stability analysis of the strength indices provided a reliable estimation except for this network and the results for that network must therefore be interpreted with caution.

Table 8: Correlation-Stability Coefficients for the Strength Centrality Indices

	Time 1: Self-Report Children and Adolescents	Time 1: Self-Report Adults	Time 2: Self-Report Children and Adolescents	Time 2: Self-Report Adults
Strength Correlation-Stability Coefficient	.28	.36	.13	.28

Network Comparisons

The edge weights of each of the respective networks from the four samples were correlated to determine the extent of similarity. Across time 1 and time 2 both the self-report children and adolescent networks (r_s = 0.34 and the adult networks (r_s = 0.30) showed moderate correlations (Hinkle et al., 2003).

Table 9: Spearman correlations between each of the respective networks.

	Sample1: Children and Adolescents Time 1	Sample 2: Children and Adolescents Time 2	Sample 3: Adults Time 1	Sample 4: Self-Adults Time 2
Sample1: Children and Adolescents Time 1	1	.34	.27	.37
Sample 2: Children and Adolescents Time 2	–	1	.40	.40
Sample 3: Adults Time 1	–	–	1	.30

Sample 4: Self-Adults Time 2	–	–	–	1

Network Comparison Test Between Self Report of Children and Adolescents at Time 1 compared to Time 2

The NCT revealed that the topologies of the two networks were not significantly different (p = 0.71). The comparison of global network strength at Time 1 ($M_{strength}$ = 32.75) and Time 2 ($M_{strength}$ = 33.92) indicated the networks was not significantly different, p = 0.79. In all, 9 edges were significantly different, details of which are provided in the Supplementary Materials.

Network Comparison Test Between Self Report of Adults at Time 1 compared to Time 2

The NCT revealed that the topology of the two networks was significantly different (p = 0.03). The comparison of global network strength at Time 1 ($M_{strength}$ = 27.12) and Time 2 ($M_{strength}$ = 43.25) also indicated that the networks were significantly different, p < 0.001. In all, 14 edges were significantly different, details of which are provided in the Supplementary Materials.

Discussion

The current study investigated for the first time, the networks of very young children, school-aged children, adolescents and adults concurrently. As expected, differences in the network structure were observed across development, which appeared to be sequential in nature. Consistent with previous research the networks which were estimated in the current study showed differences to previous research investigating these populations. Comparisons between longitudinal changes in networks between adults and children & adolescents showed differences in the changes in PTSD symptoms across time.

Cross Sectional Caregiver report Networks

In the comparison of caregiver reported networks, the differences were non-significant. A corollary of this finding is that the child and adolescent caregiver reported network did not meet the stability requirements outlined by Fried and Epskamp (2017) due to the low endorsement rate of symptoms. The results therefore need to be interpreted with caution, however the low endorsement rate is representative of caregivers reporting on internalized symptoms of their child (Scheeringa., 2011). This may account for why in the stable caregiver reported network of very young children the most central items are those of which are more easily observed (*psychological reactivity*). A key consideration of caregiver reporting, is the mental health of the parent, given as

Dyregrov & Yule (2006), noted that children are attuned to their parent's reactions to the event and the appropriateness of discussing the trauma and therefore may modulate their response to the event based on this. In the current study, we were not able to control for the mental health of the caregiver, however the network approach may be informative to Clinicians as it provides a nuanced understanding of what symptoms caregivers notice in their children and ultimately help guide diagnostic considerations.

Cross Sectional Self Report Networks

Across the self-reported networks there existed interesting dynamics between item centrality and edge strengths. For example, in all of the self-report networks, symptoms in the re-experiencing cluster were most central. Interestingly, the items that were most strongly connected to these re-experiencing symptoms were from the avoidance cluster. These findings appear to be consistent with our understanding of PTSD. That is at its core a distorted representation of trauma memory and the maintaining processes of avoidance and maladaptive appraisal (Ehlers & Clark, 1999). As the traumatic images are avoided, they never become associated within their proper context (Ehlers & Clark, 1999). That this was consistent across the cross-sectional networks supports findings that trauma focused CBT is effective irrespective of age however requires adjustments to be developmentally appropriate (e.g. Goodall et al., 2017; Smith et al., 2019).

Developmental differences were observed among the networks, which changed incrementally with age. For example, the only differences between the child and adolescent network were edge related differences, a finding consistent with Russel et al., (2017). The edge related differences were mainly confined to cluster differences between and within C (Avoidance) and D (Arousal). This finding is consistent with Corrion et al., (2002) who found increased segregation of clusters with pubertal development, which the authors attributed to differences in symptom expression. In line with this explanation, such differences appeared to be more pronounced between the child and adult network.

Salmon & Bryant (2002) provided an overview of how developmental differences in language, memory and emotion need to be recognized as a factor in the presentation and internal representation of PTSD. This appears to be reflected in the current findings, where the most significant differences existed between the child and adult network, which differed in terms of topology. The majority of edge differences occurred within the adult avoidance cluster which was not as present in the child cluster. For example, there were stronger edges which linked the avoidance items C1 & C2 to numbing items C4 (disinterest), C5 (detachment) and C6 (restricted range affect) in the adult sample. These results provide examples of 'vicious cycles' present within

PTSD, which may be absent because children do not have the same autonomy as adults in being able to control what they avoid.

Differences between the adult and adolescent network were less pronounced. The adolescent and adult network only showed significant differences in relation to particular edges. These differences in edges were mainly confined to the avoidance cluster (5/13) specifically items which suggest negative alterations in cognition and mood (negative emotional state; detachment; foreshortened future). Indeed, the diminished interest symptom was more central in the adult network compared to the adolescent network. It could be that adults having more experience and life history have more pronounced difficulty in ameliorating the trauma in a congruent manner.

Longitudinal Networks

As previously explored in Bryant et al., (2017) the network structure of PTSS changed across time. Specifically, in the acute phase, re-experiencing symptom were more central and highly connected, and at the 12 month follow up the associations of these re-experiencing symptoms were strengthened with the addition of associations with the startle response and hypervigilance. This finding was similar to what was observed in the child and adolescent network; however avoidance symptoms were more central at time 2. Whilst such a finding needs to be interpreted with caution due to the instability of the network, this finding underscores the importance of avoidance in the maintenance and exacerbation of this disorder. For Bryant et al., (2019) such findings support the view of the fear circuitry system being the core element in PTSD. That this was also found in a younger sample provides further support for this interpretation.

In the adult sample the comparison between time 1 and time 2 showed that not only did the network strengthen its associations over time but also the network's topology changed. This is in direct contrast to the child and adolescent sample which showed neither changes in the strength nor changes in the network topology. It must be noted that the network for the younger sample at time 2 did not meet requirements for a stable network attributable to the low endorsement rates of items. This highlights a key sample difference, in that the adult sample consisted of a higher proportion of people who did not recover from their trauma whereas a greater proportion of children and adolescents did.

Considerations and limitations

A key limitation of the current investigation is that there was a focus on exploration at the expense of controlling for multiple comparisons. This means that the results of the comparison may not be replicated. However, this decision was made given the size of each of the samples and the issues of stability that were present in some samples. A key limitation of the network approach is the requirement for substantial datasets given the amount of comparisons that are conducted. New methods, such as moderate network models (Haslbeck, 2020), may conceivably be used to help address this limitation.

Another limitation relates to the lack of controlling for the severity of each of the different samples. Previous studies have explored this using an additional measure of severity however this was not possible in the current study. To overcome this issue, participants who were asymptomatic across all criteria of PTSD were removed, the networks re-estimated and comparisons re-conducted. The details of this is provided in the supplementary materials, but as a brief summary the comparisons broadly replicated the findings. Whilst this suggests severity is not a confound the lack of an external measure of severity is a limitation of the current investigation.

A key limitation of the current investigation relates to the reliance on DSM symptoms to estimate the networks. The DSM and the associated symptoms have been designed to ensure individuals are accurately and reliably diagnosed. This is not entirely commensurable with the view that symptoms represent a dynamic system. It therefore may be more informative to instead investigate psychological models, such as the Ehler’s and Clarke model of PTSD (Ehlers & Clarke, 1999), which describes the PTSD ‘system.’

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