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Changes in the dynamic network structure of PTSD symptoms pre-to-post combat

Adva Segal[1], Ilan Wald[1], Gad Lubin[2], Eyal Fruchter[2], Keren Ginat[2], Ariel Ben Yehuda[2], Daniel S. Pine[3] and Yair Bar-Haim[1,4]

[1]School of Psychological Sciences, Tel Aviv University, Tel Aviv, Israel; [2]Division of Mental Health, Medical Corps, Israel Defense Forces, Ramat Gan, Israel; [3]National Institutes of Mental Health, Bethesda, Maryland, USA and [4]Sagol School of Neuroscience, Tel Aviv University, Tel Aviv, Israel

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Author for correspondence:
Adva Segal, E-mail: advasegal@tau.ac.il

Abstract

Background. Combat exposure is associated with elevated risk for post-traumatic stress disorder (PTSD). Despite considerable research on PTSD symptom clustering, it remains unknown how symptoms of PTSD re-organize following combat. Network analysis provides a powerful tool to examine such changes.

Methods. A network analysis approach was taken to examine how symptom networks change from pre- to post-combat using longitudinal prospective data from a cohort of infantry male soldiers (M_{age} = 18.8 years). PTSD symptoms measured using the PTSD Checklist (PCL) were assessed after 6 months of combat training but before deployment and again after 6 months of combat (Ns = 910 and 725 at pre-deployment and post-combat, respectively)

Results. Stronger connectivity between PTSD symptoms was observed post-combat relative to pre-deployment (global strength values of the networks were 7.54 pre *v.* 7.92 post; $S = .38$, $p < 0.05$). Both the re-experiencing symptoms cluster (1.92 *v.* 2.12; $S = .20$, $p < 0.03$) and the avoidance symptoms cluster (2.61 *v.* 2.96; $S = .35$, $p < 0.005$) became more strongly inter-correlated post-combat. Centrality estimation analyses revealed that psychological reaction to triggers was central and linked the intrusion and avoidance sub-clusters at post-combat. The strength of associations between the arousal and reactivity symptoms cluster remained stable over time (1.85 *v.* 1.83; $S = .02$, $p = .92$).

Conclusions. Following combat, PTSD symptoms and particularly the re-experiencing and avoidance clusters become more strongly inter-correlated, indicating high centrality of trigger-reactivity symptoms.

Introduction

Post-traumatic stress disorder (PTSD) affects anywhere between 5% and 30% of combat deployed soldiers (Thomas *et al.*, 2010; Wald *et al.*, 2013), with many soldiers experiencing sub-clinical symptoms associated with considerable psychological and behavioral disability (Stein *et al.*, 1997). The Diagnostic and Statistical Manual (DSM) has traditionally conceptualized PTSD as involving re-experiencing, avoidance, and hyperarousal clusters, with the addition of altered mood and cognition in DSM-5 (American Psychiatric Association, 2013). Despite considerable research and debate on symptom clustering in patients (Friedman *et al.*, 2016; Guina, 2016; Hoge, 2016; Hoge *et al.*, 2016), work that examines changing relations among PTSD symptoms as a function of intense combat stress in otherwise healthy participants is scarce.

A network analysis approach provides a tool to examine changes in PTSD symptom clusters as these transform over time and as a function of designated events (e.g. Armour *et al.*, 2017; Bryant *et al.*, 2017). Network analysis is designed to examine the interplay between symptoms that constitute the presumed clinical space of a disorder. The network is comprised of nodes representing the observed variables (e.g. the different symptoms of PTSD), and edges representing the associations among these symptoms. The network is graphically visualized and statistically analyzed. The relative importance of a specific symptom in a network can be inferred by its location within the network, with symptoms that are highly correlated with other symptoms located at the center and symptoms with lessor weaker associations located more peripherally (Borsboom and Cramer, 2013; Boschloo *et al.*, 2015).The strength of a network can be estimated, and the relative connectivity of different networks can be compared (van Borkulo, 2015).

Network analysis approaches assume that a disorder is defined by a causal system of psychopathological symptoms that are mutually dependent. As these associations get stronger a clinical disorder might emerge (Hofmann *et al.*, 2016). For example, combat can lead to stress reactions, which could influence other symptoms such as emotional distress, which may in turn increase arousal and trigger nightmares or other re-experiencing symptoms. As these symptoms

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become more strongly inter-related, a full-blown PTSD may surface. Theories of PTSD have attempted to capture the complexity of relations between symptoms emerging following traumatic exposure (Keane *et al.*, 1985; Foa and Rothbaum, 1998; Ehlers and Clark, 2000; Friedman *et al.*, 2007). For example, Horowitz (1986) suggested that traumatic exposure involves an intrusive phase associated with arousal and re-experiencing symptoms, and a denial phase characterized by efforts to avoid such intrusive repetitions combined with numbness and amnesia. According to this theory, fluctuations between intrusion and avoidance allow processing of the trauma and as a result the intensity of symptoms decrease over time. Failure in these processes may lead to persistent post-traumatic reactions. Network analyses can contribute to the understating of complex interplays between different PTSD symptoms, shedding light on the unique roles of particular symptoms, and characterize the associations between them.

To date, network analysis studies of PTSD symptoms typically focused on patients. Specifically, two prior cross-sectional studies applied networks analysis to chronic PTSD symptoms. A study of earthquake survivors revealed high centrality for hypervigilance and foreshortened future, while also noting associations among other clusters (McNally *et al.*, 2015). Another study of network structure found clinically significant DSM-5 PTSD symptoms in veterans to involve high centrality of negative trauma-related emotions, flashbacks, detachment, and physiological cue reactivity (Armour *et al.*, 2017). Only one prior study applied network analysis in a longitudinal design (Bryant *et al.*, 2017), comparing network structure 1 week following trauma and 12 months later. Re-experiencing symptoms were central to other symptoms in the acute phase, with intrusions and physiological reactivity being the most central symptoms in the networks. Overall network connectivity was significantly stronger at 12 months than in the acute phase. In addition, the network associations among the re-experiencing symptoms strengthened at 12 months, and physiological reactivity was strongly associated with exaggerated startle response, which was also associated with hypervigilance.

Here, for the first time, we longitudinally describe how associations between PTSD symptoms evolve over time in newly recruited infantry soldiers preparing for combat deployment and then after combat. The first assessment occurred following 6 months of intensive combat training (see below for description) but before deployment to real combat. Soldiers were assessed again after 6 months of combat deployment where they were exposed to a wide array of combat experiences. Comparing the associations between PTSD symptoms at these unique time points in the deployment cycle can provide insights as to how stress symptoms develop under different levels of military-related stress and demands. Network analysis theory assumes that strength of inter-relation between symptoms can give rise to clinical psychopathology. Therefore, although network analyses are somewhat exploratory in nature, we tentatively hypothesized that network strength would be greater post-combat than at pre-deployment, given that some PTSD symptoms may be more loosely related when stress levels are moderate during pre-deployment training relative to their association post real combat exposure.

Methods

Participants

Participants were newly recruited Israel Defense Force (IDF) infantry soldiers (all male, M_{age} = 18.8 years, S.D. = 1.0, range = 18–24). In total, 84.8% of the participants were born in Israel (5.4% in the USA, 1.8% in Russia, and 7.9% in other countries). Participants were physically and mentally healthy and eligible for mandatory military service in the IDF. Mean number of years of formal education was 12.09 (S.D. = .77, 80% with matriculation). Participants were asked to rate their levels of PTSD symptoms at two time points: (a) following a 6 months of basic and advanced combat training prior to their first combat deployment (pre-deployment, n = 910); and (b) following 6 months of combat (post-combat, n = 725). These two time points involved progressive increase in military-related stress, with milder stress at training, followed by much higher stress in deployment while performing combat missions on daily bases. In total, 604 participants had a full data set without any missing data for both time points.

Combat experiences

Self-reported combat experiences were collected using the Combat Experiences Scale (Hoge *et al.*, 2004; Wald *et al.*, 2013). Data were collected between 2008 and 2010. The pre-deployment data refer to 6 months of intensive basic and advanced combat training. During the training period, soldiers were assigned to occasional guarding and patrol missions, typically in calm and less challenging areas, hence, some minor reporting of combat experiences may be noted for this pre-deployment assessment. However, at this pre-deployment assessment, the participants were not yet exposed to real combat. The participants were then deployed to routine security missions in intensive conflict zones. Their activity during combat deployment included close-quarter arrests and take-downs, patrol, and riot containment (i.e. thrown stones, Molotov cocktail bombs, stabbing attempts, and occasionally receiving incoming rocket, mortar, or small-arms fire). Participants provided written informed consent at each of the data collection points. The Institutional Review Boards of Tel Aviv University, the IDF, and the Israeli Ministry of Health approved the study.

Measurement of PTSD symptoms

Following Hoge *et al.* (2004), symptoms of PTSD were evaluated with the PTSD Checklist (PCL, specific stressor version; Blanchard *et al.*, 1996) in relation to the combat training epoch and the combat deployment epoch for pre-deployment and post-combat, respectively. This self-report questionnaire consists of 17 items assessing the presence and severity of PTSD symptoms corresponding to DSM-IV criteria, reflecting three clusters of symptoms: intrusion, avoidance, and hyperarousal. Scores range from 17 to 85, with higher scores reflecting greater symptom severity. Cronbach's α of the PCL in the current study was 0.90 pre-deployment and 0.93 post-combat.

Data analysis

Data analyses were conducted between October 2017 and February 2018. The data were analyzed using the free software environment R, and was carried out in four steps: (1) we first estimated the pre-deployment and post-combat network structures and provide visualization of these; (2) we then computed the differences in connectivity between the pre-deployment and post-combat networks using the Network Comparison Test; (3) we evaluated the importance of nodes by computing centrality

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indices; and (4) we estimated the stability and accuracy of the networks.

Handling of missing data

Routines for handling of missing data in networks analysis are still underdeveloped. For overall networks connectivity estimation ($n = 910$ pre-deployment and $n = 725$ post-combat), we followed Briganti *et al.* (2018) and Santos *et al.* (2018), applying pairwise complete observations, such that for each computed partial correlation, the full available data were used. For the longitudinal comparison (NCT), we included only participants that provided complete data on PTSD symptoms at both measurement time points ($n = 604$).

Network estimation

We estimated the networks' partial correlation coefficients at pre-deployment and post-combat using the Gaussian Graphical Model (EBICglasso) option in the *R*-package qgraph. This structural network is composed of 'nodes' representing PTSD symptoms and 'edges' representing the partial correlations between them (Friedman *et al.*, 2008). This information is visualized to exhaust the relevant information in a simple and efficient way using the Fruchterman–Reingold's algorithm (Fruchterman and Reingold, 1991) that places nodes close to each other or further apart according to the degree of their partial correlation. Controlling for all symptoms, the EBICglasso function employs a LASSO regularization method, which minimizes false edge detection by setting small edges to zero (Tibshirani, 2011; Van Borkulo *et al.*, 2014). The size of partial correlations between symptoms is visualized by edge thickness, which we used to explore changes between symptoms associations within a network and between the two networks. The maximum edge value was set to 0.45, the strongest value identified across networks; the minimum edge value was set to 0.03, to simplify interpretation of the networks graph.

Our primary analyses were guided by the DSM definition of the PTSD clusters (re-experiencing, avoidance, and arousal). However, to empirically identify communities of symptoms in the networks, we also applied the spinglass algorithm that is based on the notion that nodes of the same community would be connected by edges, whereas nodes of different communities would not (Yang *et al.*, 2016). To enhance stability, we run our data through the algorithm 1000 times and extracted the communities with the highest frequency. Online Supplementary Fig. S1 depicts communities of PCL symptoms in pre-deployment and post-combat networks.

Longitudinal comparisons between networks

Longitudinal comparisons were conducted using the Network Comparisons Tests (NCT; van Borkulo, 2015). This test requires complete data sets without missing data for both compared time points. Therefore, for these specific comparisons, 604 participants with fully complete data were used. Specifically, we longitudinally compared pre-deployment and post-combat: (1) general network strength connectivity; and (b) specific PTSD clusters (intrusion, avoidance, and hyperarousal). These comparisons used a permutation technique with 1000 iterations to index significant difference in network strength values.

Centrality estimation

Centrality estimation was used to identify the importance of specific symptoms in the networks. Three measures were computed: *betweenness*, reflecting the degree to which a node is located in the shortest path between any two nodes; *closeness*, estimating the average distance from a node to all other nodes, as reflected by the inverse of all shortest path lengths between one node and all other nodes; and *strength*, the sum of all weighted edges of a node with other nodes. The higher the degree of a centrality measure, the more central a given node is in a network (Opsahl *et al.*, 2010).

Accuracy and stability estimation

A major challenge in networks analysis is estimating a network's stability and accuracy. We adopted the method developed by Epskamp *et al.* (2018). First the accuracy of the edged weights of the network is estimated by drawing bootstrapped 95% confidence intervals (CIs) around the edged weights. Smaller CIs represent greater accuracy in estimation. A second analysis relates to the stability of the order of the centrality measures applying a sub-setting bootstrap technique in which participants are dropped from the network analysis and a re-estimation of the network is conducted, producing acentrality stability coefficient (CS-coefficient), where values are considered sufficient when they are $\geqslant 0.25$ and preferably $\geqslant 0.50$. Finally, to complement these two analyses, we used the bootstrapped difference test that compares edge-weights and nodes' strength and show whether they differ significantly from each other. All bootstrapping routines used 1000 iterations.

Results

Combat exposure and severity of PTSD symptom

In total, 645 participants had a full data set for both time points. Only 16% of the soldiers reported experiencing more than a single combat event at pre-deployment. In contrast, 45% of the soldiers reported serious combat exposure post-deployment. Indeed, the two time points differed markedly on the Combat Experiences Scale, $t_{(644)} = 21.5$, $p < 0.0001$ (see Table 1 for combat experiences).

Soldiers reported average PCL scores of 25.35 (S.D. = 9.51) and 25.30 (S.D. = 10.67) at pre-deployment and post-combat, respectively. These relatively low PCL scores reflect the generally healthy character of this cohort of young infantry soldiers. Of note, all participants had successfully passed rigorous psychological screens and received clean bills of mental health prior to the pre-deployment assessment. Nevertheless, 3.3% reported symptoms at a probable PTSD level (defined by having one intrusion symptom, three avoidance symptoms, two hyperarousal symptoms, and a total PCL score $\geqslant 50$) in the pre-deployment assessment. Probable PTSD frequency increased to 4.8% post-combat, $\chi^2(1) = 28.73$, $p < 0.0001$.

PTSD symptoms networks

Figure 1 depicts PCL symptom network structures pre-deployment and post-combat. Analyses also reveal changes in cross-cluster connections following combat. Overall, positive connections emerged between all symptoms within the two networks, with stronger global network connectivity post-combat (7.92) relative to pre-deployment (7.54), $S = .38$, $p < 0.05$. For parsimony, we highlight the three PTSD clusters measured by the PCL: intrusion, avoidance, and hyperarousal.

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Table 1. Frequency of specific combat experiences pre-deployment and post-combat

Combat experience	Pre-deployment	Post-combat
	Number/total number (percent)	
Being attacked or ambushed	5/645 (0.8)	22/643 (3.4)
Receiving incoming artillery, rocket, or mortar fire	45/645 (7)	100/642 (15.6)
Being shot at receiving small-arms fire	9/644 (1.4)	34/643 (5.3)
Shooting or directing fire at the enemy	8/645 (1.2)	78/642 (12.1)
Being responsible for the death of an enemy combatant	2/645 (0.3)	4/642 (0.6)
Being responsible for the death of non-combatant	1/645 (0.2)	5/643 (0.8)
Seeing dead bodies or human remains	46/645 (7.1)	71/642 (11.1)
Handling or uncovering human remains	13/645 (2)	16/642 (2.5)
Seeing dead or seriously injured Israelis	37/644 (5.7)	69/641 (10.8)
Knowing someone seriously injured or killed	184/644 (28.6)	221/643 (34.4)
Participating in demining operations	3/644 (0.5)	7/641 (1.1)
Seeing ill or injured women or children whom you were unable to help	21/644 (3.3)	51/642 (7.9)
Being wounded or injured	26/644 (4)	30/642 (4.7)
Had a close call, was shot Had a close call, was shot or hit, but protective gear saved you	8/644 (1.2)	16/640 (2.5)
Had a buddy shot or hit who was near you	9/644 (1.4)	15/641 (2.3)
Clearing or searching homes or buildings	5/644 (0.8)	108/642 (16.8)
Engaging in hand-to-hand combat	4/643 (0.6)	9/641 (1.4)
Saved the life of a soldier or civilian	16/643 (2.5)	35/641 (5.5)
Being at a place where stones or explosive devices were thrown	56/643 (8.7)	223/640 (34.8)
Arresting wanted individuals	3/644 (0.5)	192/640 (30)

Within-cluster connections

Overall connectivity among the five intrusion symptoms (cluster B) of the PCL (intrusive thoughts, nightmares, flashbacks, upset by reminders, and physiological cue reactivity) became stronger from pre-to-post combat (the global strength values were 1.92 *v.* 2.12; $S = .20$, $p < 0.03$). Specifically, the connections between trauma-triggered symptoms – upset by reminders (B4) and physiological cue reactivity (B5) strengthened following combat. Enhanced connections between symptoms also appeared within the avoidance cluster (cluster C), with stronger connections following combat relative to pre-deployment (the global strength values were 2.96 *v.* 2.61; $S = .35$, $p < 0.005$). Furthermore, the architecture of the avoidance cluster changed following combat. Pre-deployment involved two distinct sub-clusters. One consisted of avoidance of thoughts (C1), avoidance of situations (C2), and trauma-related amnesia (C3), whereas the other encompassed disinterest in activities (C4), detachment (C5), emotional numbing (C6), and foreshortened future (C7). In contrast, post-combat all these symptoms align together as a single and more tightly connected cluster. Specifically, strong connection emerged between trauma-related amnesia (C3) and both disinterest in activities (C4), and foreshortened future (C7).

Finally, connections between the arousal and reactivity symptoms (cluster D) were stable over time (the global strength values were 1.85 *v.* 1.83; $S = .02$, $p = .92$). This specific network appears to be comprised of two separate sub-clusters: sleep disturbance (D1), irritability/anger (D2), and difficulty concentrating (D3) on the one hand; and hypervigilance (D4) and exaggerated startle response (D5) on the other hand.

Stable connections between symptoms not affected by combat exposure

The edge-weight bootstrapped difference test revealed that some PTSD symptoms appear to be strongly connected regardless of combat exposure, as illustrated in the summary plot (online Supplementary Fig. S2). Specifically, nightmares (B2) and flashbacks (B3); avoidance of thoughts (C1) and avoidance of situations (C2); detachment (C5) and emotional numbing (C6); irritability/anger (D2) and difficulty concentrating (D3); and hypervigilance (D4) and exaggerated startle response (D5).

Centrality analysis

The centrality stability coefficient of strength showed acceptable stability (0.52). Lower CS-coefficients were noted for betweenness (0.13) and closeness (0.21; online Supplementary Fig. S4). Therefore, our centrality interpretations are based on the strength index. Additional accuracy and stability analyses are available in Supplementary Materials (online Supplementary Figs S2–S5).

The centrality estimation analyses revealed that symptom B4 (upset by reminders) is central in the two networks but acts as a bridge symptom between the intrusion and avoidance subclusters only post-combat (Fig. 2). In addition, the centrality bootstrapped difference test indicated that across time, the nodes with the highest centrality strength values were: flashbacks

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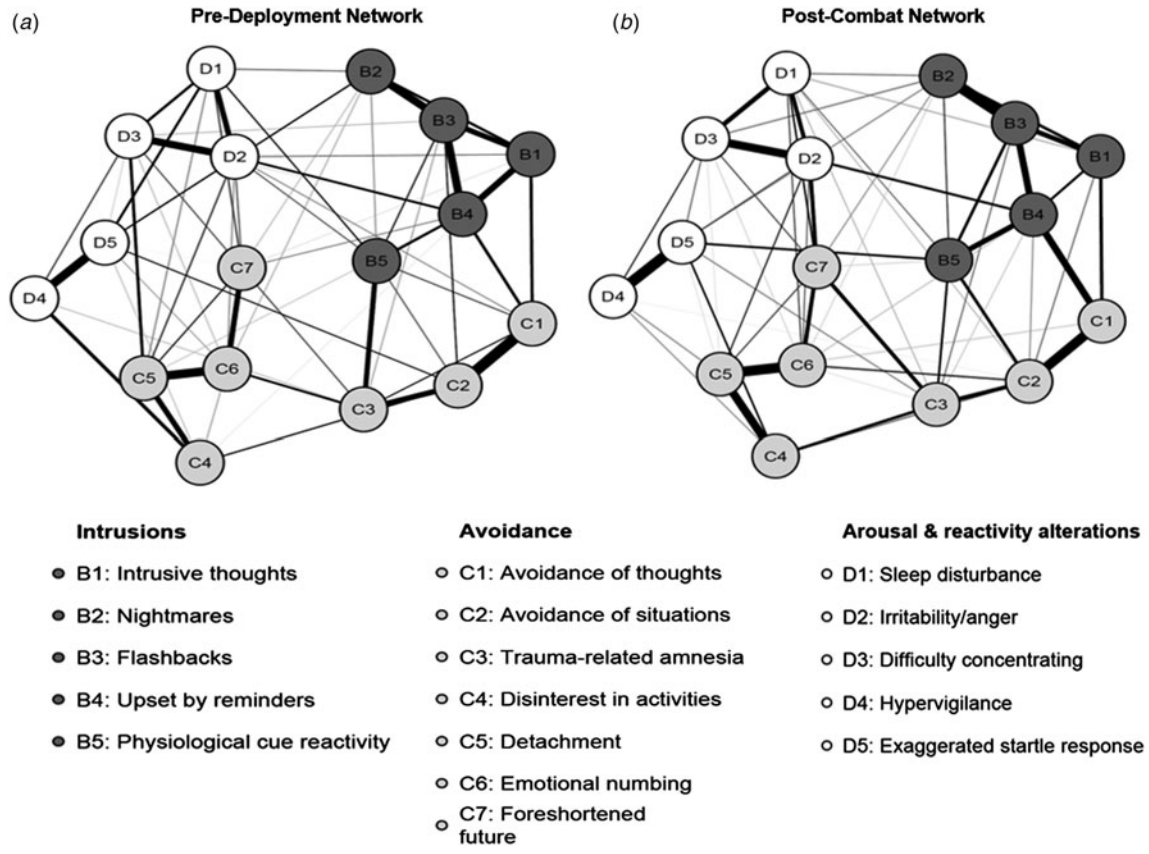


Fig. 1. Network structures of PTSD symptoms (PCL): (*a*) pre-deployment; and (*b*) post-combat. Each network consists of 17 nodes representing the 17 symptoms of PTSD per DSM-IV, and edges (lines) represent the partial correlation coefficients between these nodes (symptoms), that is, the connections between two nodes after controlling for all other connections in the network. Black edges represent positive associations and red edges represent negative associations. Edge thickness and brightness reflect the association's (edge) strength (e.g. the B4–B5 edge is thicker at post-combat relative to pre-deployment indicating a stronger partial correlation between these two symptoms post-combat). To simplify interpretation and network visualization, the locations of the nodes have been kept to identical positions between the two networks by taking the mean coordinators of nodes' locations in the individual layout networks. Symptom numbers and their abbreviated descriptions are provided in the figure.

(B3 = 1.31 and 1.12, respectively, for pre-deployment and post-combat) and upset by reminders (B4 = 1.27 and 1.43), which were significantly larger than almost half of the other symptoms in the network. The nodes with the lowest values were hypervigilance (D4 = −1.89 and −2.43) and disinterest in activities (C4 = −1.95 and 1.19; Fig. 2), which were significantly smaller than almost all other symptoms (online Supplementary Fig. S5).

Discussion

The current study examined PTSD symptom dynamics following combat exposure. A network analysis approach contrasted correlation systems to generate data on changes in PTSD symptom associations and organization. Results indicate that intrusion symptoms became more tightly connected following combat, suggesting a consolidation process of sorts. Specifically, symptoms of reactivity to triggers (i.e. upset by reminders – B4 and physiological cue reactivity – B5) became more strongly connected to each other and central in the PTSD symptoms network. These changes suggest that reaction to triggers represents a key factor in PTSD symptom evolution following potentially traumatic exposure. This finding is consistent with prior results indicating centrality of such symptoms after exposure to trauma (Bryant *et al.*, 2017). We assessed PTSD symptoms following 6 months of combat. It would be of interest to assess whether the centrality of reaction to triggers remains dominant following a longer period. It is conceivable that in cases of prolonged and chronic PTSD (e.g. several years) other sets of symptoms (e.g. avoidance) may become centralized, or alternatively, network strength may again reduce as most soldiers may come to healthy terms with their combat experiences. Future longitudinal research is needed to unveil such developmental trajectories.

Avoidance symptoms also became more closely associated following combat. Interestingly, trauma-related amnesia (C3) linked what appeared to be two separate avoidance sub-clusters at the pre-deployment baseline. Trauma-related amnesia may in fact play a central role in symptom evolution, despite suggestions from some models of PTSD (Rubin *et al.*, 2008), which view this particular symptom as less central. The division of the avoidance cluster into two separate sub-clusters received support in previous studies showing that avoidance of thoughts and situations (C1 and C2) reflected one cluster, and the other avoidance symptoms, C3–C7, may be part of a separate numbing/dysphoric cluster (e.g. King *et al.*, 1998; Simms *et al.*, 2002; Elhai *et al.*, 2011). Indeed, DSM-5 now defines the avoidance cluster as distinct from a cluster of negative mood and cognition. Our findings suggest that when stress level is high (i.e. combat deployment), trauma-related amnesia (C3) may form a bridge between the two avoidance sub-clusters per DSM-IV or possibly the two distinct clusters per DSM-5.

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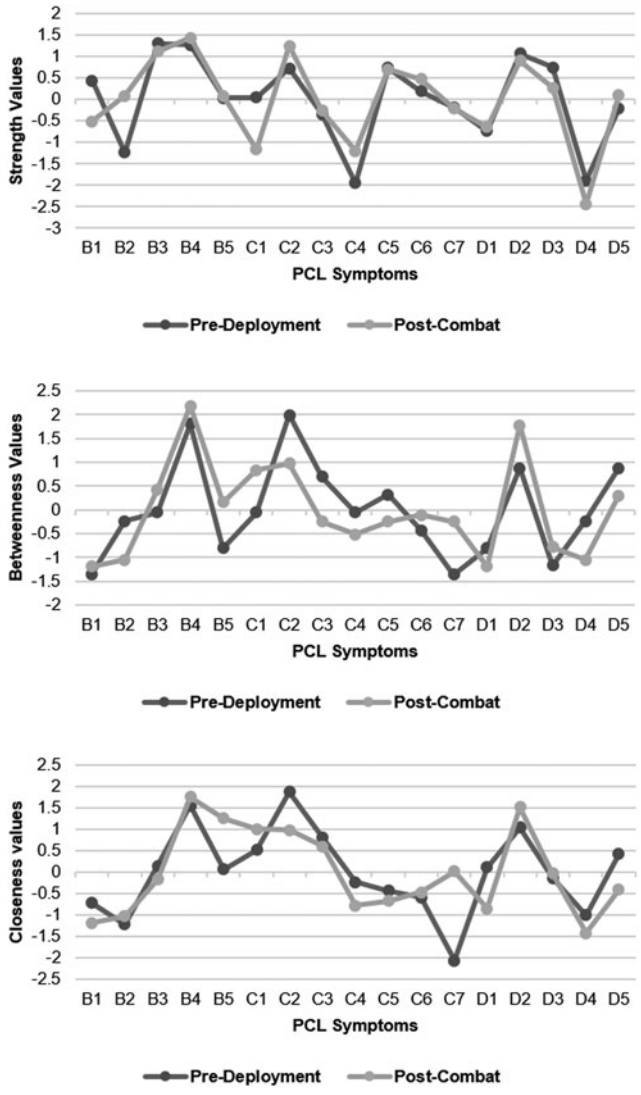


Fig. 2. Centrality estimates: strength, betweenness, and closeness at pre-deployment and post-combat. Centrality indices show that across time the most central nodes are flashbacks (B3) and upset by reminders (B4), which have the highest values of node strength (positive scores), whereas the least central nodes are hypervigilance (D4) and disinterest in activities (C4) with the lowest strength values (negative scores). The centrality interpretations are based on the strength index that had a good stability across time. Centrality indices are shown as standardized *z*-scores.

The results also find a modified structure of associations between the intrusions and avoidance clusters following combat, primarily via strengthened connections with reactivity to triggers. As in other work, this suggests that intrusion and avoidance symptoms are inherently linked (e.g. Bryant *et al.*, 2017). The intrusion-avoidance dynamic plays a central role in the definition of PTSD since DSM-III (American Psychiatric Association, 1987). The common assumption is that the tendency to avoid trauma reminders is a response to the distress caused by the re-experiencing symptoms. Although avoidance reduces the distress in the short run through negative reinforcement, it impedes the processing of trauma information and might prevent opportunities to change negative beliefs and perceptions relating to it (Keane *et al.*, 1985; Foa and Rothbaum, 1998; Ehlers and Clark, 2000). Disrupting this vicious intrusion-avoidance cycle is a prime focus of current evidence-based treatments for PTSD, such as prolonged exposure (Foa *et al.*, 2007). The current findings again highlight the close associations between re-experiencing and avoidance in combat deployed soldiers.

Surprisingly, the arousal and reactivity cluster structure did not change in the current study. Moreover, data found evidence of separated arousal sub-clusters, each strongly interconnected. One sub-cluster consists of sleep disturbance (D1), irritability/anger (D2), and difficulty concentrating (D3). The other sub-cluster consists of hypervigilance (D4) and exaggerated startle response (D5). These results may be unique to infantry soldiers who extensively train for combat, expect deployment, and then deploy. Thus, symptoms related to sleep, irritability/anger, and concentration (D1, D2, and D3), and their interconnectedness may be already dominant and meaningful following 6 months of pre-deployment combat training. The current results also correspond with previous network studies in PTSD (McNally *et al.*, 2015; Bryant *et al.*, 2017; Spiller *et al.*, 2017), where hypervigilance (D4) and exaggerated startle response (D5) were strongly associated and located peripherally in the network. It was suggested that this connection may reflect a self-reinforcing feedback loop, where hypervigilance predisposes to exaggerated startle response and it in turn may trigger and preserve hypervigilance (McNally *et al.*, 2015). The current findings are also in line with model fit studies of DSM-5 PTSD symptoms suggesting the best fit is achieved in a model that differentiates the arousal cluster to two separate factors: hypervigilance (D4) and exaggerated startle response (D5) as part of anxious arousal, and the other arousal symptoms (D1–D3) as part of externalizing behaviors and dysphoric arousal (Elhai *et al.*, 2009, 2011; Liu *et al.*, 2014; Armour *et al.*, 2015; Tsai *et al.*, 2015).

The findings of stronger network connectivity in the re-experiencing and avoidance sub-clusters following combat also correspond with cross-sectional research on PTSD symptom structure (Engdahl *et al.*, 2011), and with literature indicating that the dominance of these different sub-clusters and their interconnectedness may fluctuate at different time points following traumatic exposure (e.g. Shalev *et al.*, 1998; Solomon and Mikulincer, 2006; Solomon *et al.*, 2009). Intrusion symptoms appear to play a central role in the early development of the disorder (Yehuda *et al.*, 1998; Solomon *et al.*, 2012; Bryant *et al.*, 2017), whereas avoidance symptoms become more dominant as time passes, presumably as afunction of a defense strategy that contains the distress generated by the intrusion symptoms (McFarlane, 1992; Shalev *et al.*, 1996).

The current results should be considered in light of potential limitations. First, we used self-report assessments of PTSD symptoms severity. Although previous research indicates that PCL scores are correlated strongly with standardized clinician ratings [e.g. the Clinically Administered PTSD Scale (CAPS); Blanchard *et al.*, 1996], future studies may wish to assess symptom network structures using clinician ratings. Second, participants in the current study had 6 months of military training before the pre-deployment measurement. This training, although highly stressful and entailing both combat simulation and some routine security missions, does not reflect a clear-cut trauma as does real combat experience. As such, the pre-deployment PCL scores relating to this pre-deployment training epoch may lack the intensity of combat-related trauma, raising a question about the validity of the reported symptoms. Importantly however, this limitation is inherent to longitudinal designs exploring changes in symptom networks structure from pre- to post-combat and therefore must rely on pre-combat reports. Third, the current study reveals PTSD symptoms structure in a highly homogeneous cohort

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(18-year-old male infantry soldiers) and a very specific traumatic context – combat. For better insight on generalizability of the current results, it would be important to test more divergent populations as well as different traumatic contexts. Fourth, the sample of this study is a non-selected sample of young healthy soldiers that were exposed to potential traumatic combat events. This affords a longitudinal developmental view of PTSD symptoms associations over time following traumatic exposure. However, it is still unclear whether the networks studied here be similar to those of clinical samples of soldiers with PTSD. Such longitudinal research would require a much larger sample than was available to the current study. Finally, the current study used the PCL, which relates to DSM-IV criteria for PTSD. Although many of the symptoms are the same as in the previous DSM, new symptom items were added to the DSM-5 diagnosis (American Psychiatric Association, 2013). Thus, while some important inferences can be drawn from the current analyses, future studies using DSM-5 symptoms are needed.

In conclusion, the present study offers a new insight into the dynamic associations between networks of PTSD symptoms as it evolves in soldiers from pre-to-post combat exposure. The longitudinal results highlight the importance of interaction between intrusive and avoidance symptom clusters, which integrate into a more tightly correlated unit of symptoms following combat. If close associations between re-experiencing symptoms and avoidance symptoms are cemented following combat exposure, a potential target for intervention may be reduction of the strength of these associations in the acute phases following trauma and before chronic pathology develops. Knowledge on the dynamics of PTSD symptoms association over time could clarify the impact of traumatic exposure on mental health and offer focused targets for therapy.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0033291719000539.

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