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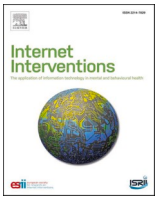

Pathological network changes in patients with social anxiety disorder before and after an Internet-based CBT

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ABSTRACT

A network perspective may shed light on the understanding of Internet-based CBT efficacy for social anxiety disorder. Previous cross-sectional evidence revealed a densely interconnected network for individuals with social anxiety. Yet, longitudinal network changes before and after ICBT are lacking. This study aimed to investigate pathological network changes with Graphical Gaussian Model among patients with social anxiety disorder (n = 249). Social phobia scale (SPS) and Social interaction anxiety scale (SIAS) were measured before and after 8 weeks Internet-based CBT. Results revealed the connection between symptom tension when speaking and symptom awkward when being watched was the most robust edges during ICBT interventions. The pathological network benefited from ICBT and exhibited modification in several prominent interconnections. The overall network connectivity continues to exhibit comparable strength after ICBT. This study represents the first examination of social anxiety network changes after patients with SAD completed a systematic ICBT. Changes in critical edges and nodes provide valuable insights for the design and efficacy assessment of ICBT interventions.

1. Introduction

Network perspectives provide a radically novel perspective to comprehend the pathology of mental disorders (Borsboom and Cramer, 2013; Borsboom, 2017). In network theory, nodes represent symptoms and edges represents correlation between symptoms, network connectivity depicts how strong the connections among symptoms are, and various centrality indices imply the importance and influence of symptoms (Borsboom, 2017). From network perspectives, a mental disorder emerges from causal interaction between nodes. Meanwhile, cross-sectional network studies have found that symptoms are highly interconnected for most disorders (Robinaugh et al., 2020). Network comparison between the clinical group and the healthy group revealed greater network connectivity in the clinical group for multiple mental disorders. For example depression, Pe et al., 2015, Santos et al., 2017; social anxiety, Heeren and McNally, 2018; and schizophrenia, van Rooijen et al., 2018.

Social Anxiety disorder (SAD), characterized by extreme fear of negative evaluations that cause significant distress or avoidance of social activities (American Psychiatric Association, 2013). Previous research found that SAD is a prevalent and disabling disorder and increases the risk of other psychiatric disorders (especially other anxiety disorders, mood disorders and substance abuse disorders) (Wittchen and Fehm, 2003). Epidemiological findings present a high prevalence and comorbidity of SAD (Fehm et al., 2005; Kessler et al., 2012). Mayo et al. (2014) systematically reviewed interventions for SAD and found that CBT is associated with large effect size and is recommended as the initial treatment for SAD. In the last decades, Internet-based cognitive behavior therapy (ICBT) has developed into one of the most effective treatments for social anxiety disorder (Berger et al., 2011; Kishimoto et al., 2016; Chen et al., 2020). The efficacy of ICBT was shown to remain stable from 3 months to 3 years with respect to the long-term symptom reduction (Boettcher et al., 2013; Hedman et al., 2016). Compared to traditional face to face CBT, ICBT offers significant advantages in terms of convenience and accessibility (El Alaoui et al., 2015).

Like the understanding of corona-virus disease as being caused by

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the corona-virus, social anxiety disorder is often assumed to be a latent entity, which consequences extreme fear of negative evaluations and significant distress or avoidance. However, from the network perspective, abundant connections among nodes in the network are more likely to create an episode of social anxiety (Borsboom, 2017). Specifically, densely interactions of social anxiety symptoms, rather than an entity called social anxiety disorder, emerge a social anxiety attack in social situations. Heeren and McNally (2018) compared network connectivity differences between individuals with or without SAD and found that compared to healthy persons, individuals with SAD exhibited a densely interconnected network of fear and avoidance of the social situation. The understanding SAD from the network theory perspective could also be used to help in detecting critical symptoms and treatment targets (Borsboom et al., 2011). With the help of centrality measures, the connectedness of a given SAD symptom with all other symptoms could be accessed (Opsahl et al., 2010). For example, Rodebaugh et al. (2018) identified intervention targets depending on centrality indices in a group of SAD patients, then found that changes in these central symptoms were more related to overall symptom change in another separate group of SAD patients.

Although cross-sectional comparison indicated that patients with mental disorders show higher network connectivity, one primary subject with respect to pathological networks is concerned with longitudinal network changes before and after treatments (McNally, 2021). From cross-sectional data, a reasonable speculation is that perhaps after CBT treatment, the global network connectivity of patients with SAD will move from the SAD network side to the healthy network side, that is, from a densely interconnected network to a less interconnected network. However, until 2021, most empirical network studies focused on treatment efficacy declared no changes in global network connectivity after a CBT treatment (e.g., Levine and Leucht, 2016; Schuler et al., 2018). Moreover, few studies reported a prodigious increase in global network connectivity after a systematic CBT treatment (Beard et al., 2016, Fried et al., 2016, Bryant et al., 2017, Bos et al., 2018). It should be pointed out that increase in global network connectivity does not indicate invalidation of CBT, because all these studies reported significant reductions in symptom severity after CBT intervention.

To date, no research has examined the post-treatment social anxiety network and the partial correlations between social anxiety symptoms after ICBT treatments. Furthermore, no study has contrast the pathological network changes before and after ICBT treatment in a large group of SAD patients. Using network analysis, the aim of the present study is to estimate the pathological network in SAD patients both before and after ICBT, and to explore the specific impact of ICBT on influential symptoms, significant edges, and global strength. Based on the results of previous treatment studies, this study hypothesized that (1) the centrality of symptoms and their interconnections in SAD network would change after ICBT treatment; (2) the global network connectivity would maintain or even increase after ICBT treatment; (3) SAD symptoms would be relieved after ICBT treatment.

2. Material and methods

2.1. Participants

Participants were recruited from an ICBT program at Peking University which targeted at adult SAD patients across China. The current study utilized self-reported data collected before and after ICBT treatment from 2018 to 2021. These data were selected because all participants received the same ICBT treatment program during this treatment period, and all participants were measured by Social Interaction Anxiety Scale and Social Phobia Scale before and after ICBT. All of 249 participants who completed the ICBT treatment and met the inclusion criteria were selected. Over half of the sample (61.8 %) was female, and average age was 25.37 ± 4.70.

The inclusion criteria were as follows: (1) Participants were older than 18 years. (2) They met the DSM-IV diagnosis of SAD and did not comorbid other mental disorders except for mood disorder. (3) One year prior to the ICBT, they did not take psychiatric medication or receive counseling or psychotherapy treatment. (4) Their score on the Social Interaction Anxiety Scale was higher than 32 or the score on the Social Phobia Scale was higher than 26.

2.2. Measurements

The Chinese version of Mini International Neuropsychiatric Interview (MINI; Si et al., 2009; developed from Sheehan et al., 1998) was used to diagnose SAD. Patients were interviewed by graduate students for approximately 30 min. All interviewers were ongoing a clinical internship and had practiced MINI under the guidance of a psychiatrist.

The Chinese version of MINI has high internal reliability (0.94) and test-retest reliability (0.97) (kappas range from 0.89 to 1.0; Si et al., 2009). The MINI has strong reliability and validity with the Structured Clinical Interview for DSM-IV.

The Chinese version of Social Phobia Scale is a 20-item scale that assesses the fear and avoidance in social situations (Ye et al., 2007, developed from Mattick and Clarke, 1998). The Chinese version of Social Interaction Anxiety Scale is a 19-item scale used to evaluate the degree of an individual's feelings of anxiety and fear in a social interaction situation, such as being at a party or talking to others (Ye et al., 2007, developed from Mattick and Clarke, 1998). Both scales show high internal reliability (0.90 for SPS and 0.87 for SIAS) and retest reliability (0.85 for SPS and 0.86 for SIAS). We previously found certain predictors of the ICBT improvement were significant only in either SPS or SIAS scores (Chen et al., 2020). Thus, using both scales together provides a more comprehensive assessment of ICBT efficacy. In the current study, the Cronbach's α for the SPS was 0.87 and for SIAS was 0.72. Because each node is a symptom, Table 1 profiles the symptoms measured by the two scales.

2.3. ICBT procedure

This ICBT program was first developed at the University of Bern (Berger et al., 2011). The original materials were translated and revised twice by nine clinical psychologists at Peking University (Kishimoto et al., 2016).

The 8-week courses can roughly be divided into five parts:1. Motivation arousing and relaxation training, which guides the participants to think about and write down why they want to change and what life would be like if social anxiety symptoms would reduce. 2. Psychoeducation, which explains the relevant theories of SAD, the concepts of negative thoughts, safety behaviors, self-focus attention, and their relationships, which helps participants gradually construct the case formulation of their own. 3. Analysis of cognitive construct, which instructs participants to identify and re-examine their nonadaptive negative thoughts and to take notes on the rational thinking form, which will guide them to replace nonadaptive thoughts with adaptive ones. 4. Attention training, which helps participants to focus more on the external environment than self-focused attention. 5. Exposure and problem solving, which aim to help participants to confront the situations that may cause anxiety, to try behavioral experiments, and to solve problems. This study was approved by the local ethics committee and registered in Peking University.

2.4. Data analysis

We employed Graphical Gaussian Model (GGM) to estimate four networks, two for the SIAS network and two for the SPS network. For each network, nodes represent the social anxiety symptoms and edges represent partial correlations between symptoms (Epskamp et al., 2017). We regularized partial correlation network and eliminated spurious associations by running graphical LASSO algorithm (Friedman

Table 1
Symptoms measured by SPS and SIAS.

	SPS	SIAS
Symptom1	I become anxious if I have to write in front of other people	I get nervous if I have to speak with someone in authority
Symptom2	I become self-conscious when using public toilets	I have difficulty making eye contact with others.
Symptom3	I can suddenly become aware of my own voice and of others listening to me	I become tense if I have to talk about myself or my feelings.
Symptom4	I get nervous that people are staring at me as I walk down the street	I find it difficult to mix comfortably with the people I work with.
Symptom5	I fear I may blush when I am with others	I tense up if I meet an acquaintance in the street.
Symptom6	I feel self-conscious if I have to enter a room where others are already seated	When mixing socially, I am uncomfortable
Symptom7	I worry about shaking or trembling when I'm watched by other people	I feel tense if I am alone with just one other person.
Symptom8	I would get tense if I had to sit facing other people on a bus or a train	I am at ease meeting people at parties, etc.
Symptom9	I get panicky that others might see me to be faint, sick or ill	I have difficulty talking with other people.
Symptom10	I would find it difficult to drink something if in a group of people	I find it easy to think of things to talk about.
Symptom11	It would make me feel self-conscious to eat in front of a stranger at a restaurant	I worry about expressing myself in case I appear awkward.
Symptom12	I am worried people will think my behavior is odd	I find it difficult to disagree with anther's point of view
Symptom13	I would get tense if I had to carry a tray across a crowded cafeteria	I have difficulty talking to attractive persons of the opposite sex.
Symptom14	I worry I'll lose control of myself in front of other people	I find myself worrying that I won't know what to say in social situations
Symptom15	I worry I might do something to attract the attention of others	I am nervous mixing with people I don't know well.
Symptom16	When in an elevator I am tense if people look at me	I feel I'll say something embarrassing when talking.
Symptom17	I can feel conspicuous standing in a queue	When mixing in a group, I find myself worrying I will be ignored
Symptom18	I get tense when I speak in front of other people	I am tense mixing in a group.
Symptom19	I worry my head will shake or nod in front of others	I am unsure whether to greet someone I know only slightly.
Symptom20	I feel awkward and tense if I know people are watching	

et al., 2008). For network visualization, the thickness of the edges represents the strength of the correlation. The blue edges represent positive correlations, while the red edges represent negative correlations. According to the Fruchterman-Reingold algorithm, nodes with stronger average associations are arranged close to the center of the graph (Fruchterman and Reingold, 1991). The latest version of R package qgraph (Version 1.6.9) was used to calculate and visualize the networks.

We calculated expected influence indices to identify which symptoms are more influential in the network (Opsahl et al., 2010). Expected influence retains the sign of edge weights and summing them up (Robinaugh et al. 2020). A higher expected influence suggests increased importance of the symptom. Compared to other centrality indices, expected influence was a better centrality index when there were negative edges as well as a better predictor of symptoms changes of network over time (McNally, 2021).

Edge comparison test and network stability were examined by the bootnet procedure (Costenbader and Valente, 2003). Edge comparison tests were conducted to assess whether a specific edge in the network is significantly stronger or weaker than other edges. 1000 bootstrap iterations were employed to evaluate the robustness of edges and the overall stability of the network (Epskamp et al., 2017).

Global strength and the stability of node centrality between pre- and post-treatment networks were tested by R-package Network Comparison Test (NCT) (van Borkulo et al., 2015). By summing up all the edges in the network, the global strength can be used to estimate the network connectivity of the pathological network(Epskamp et al., 2017). The NCT procedures randomly switched half of pre- and post-treatment data, constructed networks, compare networks and repeated for 10,000 times.

3. Results

To visualize the changes in the SAD symptom network, we estimated four networks for pre-treatment social interaction, post-treatment social interaction, pre-treatment social phobia, post-treatment social phobia, respectively.

3.1. Networks analysis for SPS

From the SPS perspective, Fig. 1 depicts both pre- and post treatment SPS networks. In pre-treatment network, 97 edges were maintained after regularization. Node S16 (tensed if others look at me in elevator) emerged as the most central and influential symptom within the network. The edge comparison test revealed that the edge connecting node S14 (worry of losing control) and node S15 (worry about attracting attention) is significantly stronger than 80.4 % edges, making it the strongest edge in the network. Additionally, the edge between S18 (Tension when speaking) and S20 (awkward when being watched) was also stronger than 79.4 % edges. Other noteworthy edges including S8-S11 (stronger than 57.7 % of other edges, etc.), S11-S16 (52.5 %), S13-S16 (50.5 %), S10-S11 (38.1 %), S2-S10 (33.0 %), S4-S16 (33.0 %).

For the post-treatment SPS network, 101 edges remained after regularization. According to the centrality plot, node S16 continues to be the most central and influential symptom in the network. The edge comparison test revealed that the edge between node S18 (Tension when speaking) and S20 (awkward when being watched) is still significantly and stronger than 80.2 % other edges, making it the most robust edge in the pathological network. An emergent edge between S16 (tensed if others look at me in elevator) and S17 (conspicuous in a queue) was also noteworthy, being stronger than 61.4 % edges. Additional noteworthy edges including S7-S19 (36.6 %), S12-S14 (28.7 %), S6-S20 (19.8 %).

NCT revealed that the global strength was not significantly greater in the post-treatment group (gs = 7.78) than in the pre-treatment group (gs = 7.98, P = 0.45). Centrality invariance test showed that the centrality of nodes “X1, X3, X6, X9, X20 significantly changed after ICBT treatment (Ps < 0.05).

3.2. Network analysis for SIAS

From the social interaction perspective, Fig. 2 depicts both pre- and post-treatment networks in social interaction perspective. Only six edges were maintained after regularization. According to the centrality plot, node S4 (difficult to mix comfortably with colleagues) was the most central and influential symptom for the SAD network. The edge comparison test revealed the edge between the nodes S4 and S9 (difficult to talk with others) edge was significantly stronger than all other edges.

For post-treatment networks, plenty of edges emerged and 89 edges were maintained after regularization. Node S8 (at ease meeting others) and node S10 (easy to think of topics) became the central and influential nodes. The edge comparison test revealed that the edge between node S8 and S10 is significantly stronger than 97.8 % of other edges, making it the strongest edges in the post-treatment SIAS network. Additionally, the edge between S7 (alone with one person) and S15 (nervous with unfamiliar person) was stronger than 71.9 % of the edges. Other noteworthy edges include S4-S9 (57.3 %), S5-S6 (50.6 %), S14-S15 (36.0 %), S6-S14 (34.8 %).

Network comparison test revealed that the global strength was

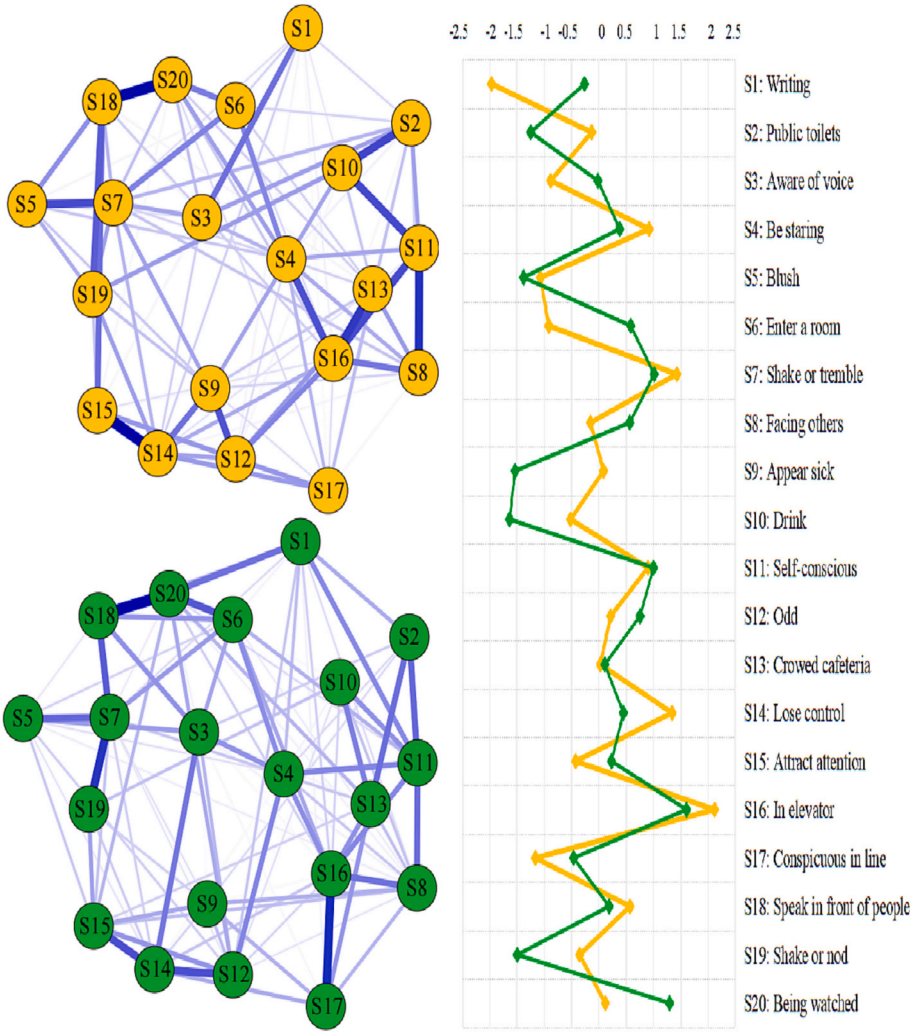

Fig. 1. SPS network models using EBICglasso model selection strategy. The orange model above is pre-treatment model and the model below is post-treatment model. Nodes represent symptoms and edges represent partial correlation. Blue edges represent positive correlation, Parameter: cut = 0, minimum = 0. The vertical line graph on the right represents the expected influence of nodes. Orange line represents pre-treatment and green line represents post-treatment.

significantly greater in post-treatment group (gs = 7.29) than in pre-treatment group (gs = 0.61, P < 0.001). Centrality invariance test showed that the centrality of all nodes, except for X8 and X10, significantly changed after ICBT treatment (Ps < 0.001).

3.3. Robustness of networks estimation

Fig. 3 provides the results of network stability. The bootstrapped CIs for the edges indicate that the edges are fairly stable and several edges exhibit values significantly greater than zero, providing an estimate of the certainty and precision of the edges for the pre- and post-treatment group.

3.4. Overview of scores on SIAS and SPS

The last set of questions aimed to investigate SIAS and SPS score changes during ICBT. Table 2 presents an overview of patient scores on the SIAS, SPS before and after ICBT treatment. Paired-samples *t*-tests revealed that total scores of SIAS, SPS significantly decreased from pre-treatment to post-treatment (Ps < 0.001). The pre-treatment Pearson correlation between SPS and SIAS was 0.364 (P < 0.01), while the post-treatment Pearson correlation between SPS and SIAS increased to 0.602 (P < 0.01).

4. Discussion

Our study was the first to investigate social anxiety network changes after a systematic Internet-based CBT intervention among patients diagnosed with SAD. Further in-depth examinations on changes of influential nodes, significant edges and global strength within the SPS and SIAS network were conducted from a network perspective.

4.1. Influential symptoms and interconnections in post-treatment SAD networks

The post-treatment SAD network could identify dominant symptoms and strong interconnections that remain influential among SAD patients after ICBT interventions (Borsboom, 2017). In post-treatment SPS network, significant connections between “Tension when speaking” and “awkward when being watched” and the most influential symptom “tensed if others look at me in elevator” sustained the dominant influence after ICBT. This result aligns with previous studies indicating the stability and persistence of social anxiety symptoms (Beesdo et al., 2012), indicating that SAD patients who complete ICBT may continue to experience tension when they perceive themselves as the focus of attention. In post-treatment SIAS network, the most prominent interaction in post-treatment SIAS network was dealing with unfamiliar people. This finding is consistent with developmental models of SAD

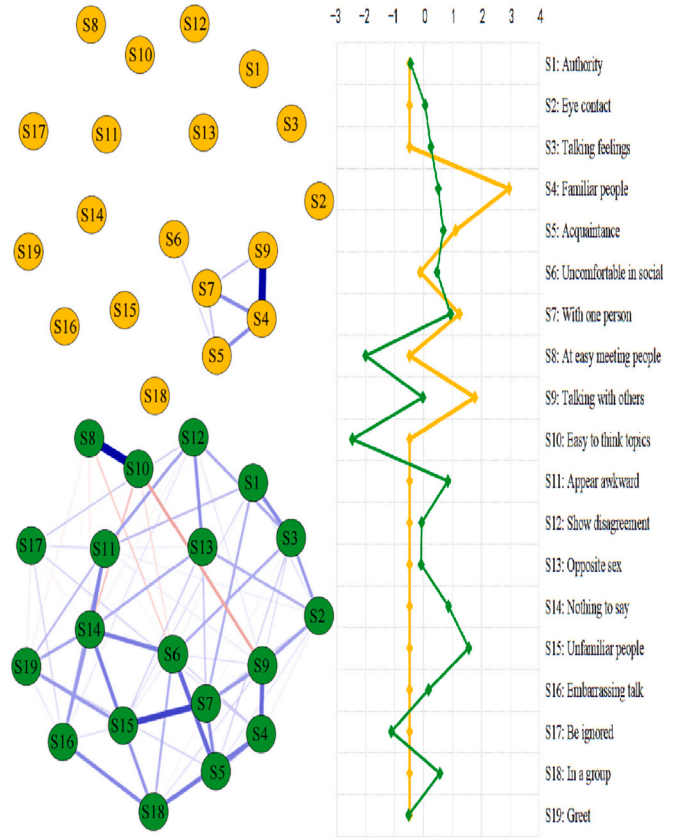

Fig. 2. SIAS network models using EBICglasso model selection strategy. The orange model above is pre-treatment model and the green model below is post-treatment model. Nodes represent symptoms and edges represent partial correlation. Blue edges represent positive correlation and red edges represent negative correlation. Parameter: cut = 0, minimum = 0. The vertical line graph on the right represents the expected influence of nodes. Orange line represents pre-treatment and green line represent post-treatment.

that hold that uneasiness in social situations involving unfamiliar people is important in the maintenance of SAD (Hofmann and DiBartolo, 2014). These persistent nodes and edges can provide valuable insights for enhancing the efficacy of ICBT and for designing more comprehensive ICBT interventions (Borsboom et al., 2011).

Additionally, the interaction between two positive nodes exhibited significant impact. A possible explanation for the increasing expected influence of two reverse items might be a huge therapeutic advance considering SAD patients showed significant distress and uneasiness in social interaction (APA, 2013).

4.2. *Beneficial modifications in SAD networks*

By comparing the pre- and post-treatment SPS networks, it can be observed that the connectivity within the network experienced beneficial modifications. Specifically, the prominent interaction in pre-treatment SPS network was between "being focused" and "losing control". The high interconnection is in line with previous pathological models of SAD (Spurr and Stopa, 2002; Pineles and Mineka, 2005; Amir et al., 2005), which emphasized that attentional bias and interpretation bias maintained social anxiety symptoms. Possible reasons for the diminishment of this interaction after ICBT include: Cognitive restructuring could help patients establish alternative connections (Taylor et al., 1997); Attention training could shift their self-focused attention to external attention (Schmidt et al., 2009); Exposure could aid in confronting and attenuating the catastrophic association (Rodebaugh et al., 2004).

With the help of psychoeducation and cognition restructuring components, patients with SAD could enhance the understanding of SAD and develop alternative thoughts which replace previous anxious thoughts (Taylor et al., 1997). These new understandings and cognitions manifest in the post-treatment SPS network as newly established edges. For example, in the pre-treatment SPS network, the symptoms "I worry about shaking or trembling when I'm watched by other people" and "I worry my head will shake or nod in front of others" were weakly connected. Patients could gained insights into self-focused attention and underwent attentional training during ICBT. As a result, they recognized that both symptoms stem from the same psychological mechanism, leading to a newly established strong connection between these symptoms in the post-treatment SPS network (Schmidt et al., 2009).

Table 2
Mean scores for SPS and SIAS before and after treatment.

Group	SPS mean (SD)	SIAS mean (SD)
Pre-treatment (n = 249)	42.24 (13.56)	54.20 (8.36)
Post-treatment (n = 249)	19.92 (10.10)***	32.49 (9.74)***

*** P < 0.001.

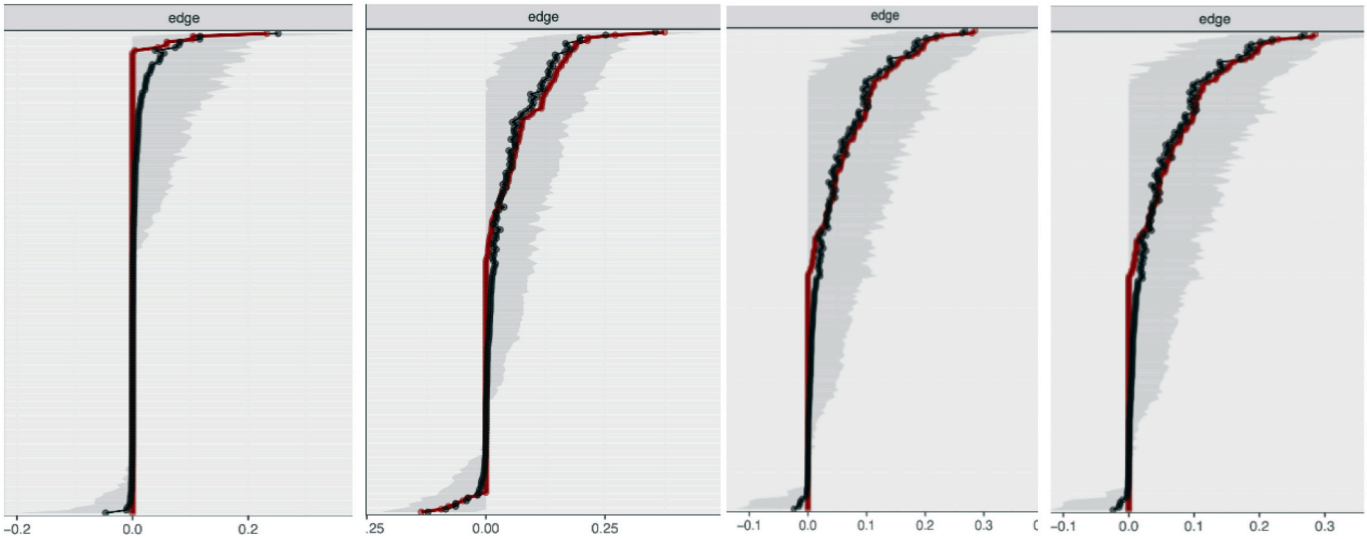

Fig. 3. Bootstrapped CIs for networks. Four CIs are pre-treatment SIAS, post-treatment SIAS, pre-treatment SPS, post-treatment SPS from left to right.

These beneficial modifications can help researchers and therapists better understand the efficacy of ICBT, advantageous changes occurred in the social anxiety network, and provide valuable insights for future treatment strategies.

4.3. The network connectivity for SAD networks

The sustained global strength for the SPS network aligns with previous network studies (Levine and Leucht, 2016; Schuler et al., 2018), and could be caused by the diversity of responses to treatment (McNally, 2021). Specifically, significant edges remains, the emerging edges counterbalance the reduction of previously prominent edges, resulting in no significant change in global strength.

The significant increase in global strength of the post-treatment SIAS network is attributable to a ceiling effect observed in the pre-treatment SIAS network. Directly comparing the change in global strength between pre- and post-treatment SIAS networks could lead to erroneous conclusions.

4.4. Ceiling effect on pre-treatment SIAS network

A weird result is that the pre-treatment SIAS network was weakly interconnected and very different from the social anxiety network measured by SPS in this study or by LASA in previous studies (Heeren and McNally, 2018). Despite Network Theory suggesting that symptoms are more likely to escalate into a disorder episode when networks are strongly interconnected (Borsboom, 2017), the movement in the opposite direction in global strength has also been observed in previous studies (Beard et al., 2016). This counterintuitive observation of increased network density may be attributable to heightened symptom variance. In the baseline assessment, SIAS scores appear to be higher and internal consistency coefficient appears to be lower than what has been reported in prior research (Kishimoto et al., 2016). In collectivist cultures, individuals may be more motivated to maintain group harmony through increased social interaction (Hofmann et al., 2010). As a result, individuals with SIAS scores may be more motivated to participate and complete ICBT, thereby producing a ceiling effect that limits variance, attenuates edge weights, and consequently suppresses network density (McNally, 2021). After ICBT interventions, the treatment responses lead to an elevation in symptom variance, thereby resulting in an increase of network density in post-treatment network.

4.5. SIAS and SPS scores changes

Consistent with the findings of prior ICBT studies (Berger et al., 2011; Kishimoto et al., 2016; Chen et al., 2020), both SIAS and SPS scores exhibited significant reductions after ICBT interventions, proving the efficacy of ICBT in the treatment of SAD.

4.6. Berkson's bias and other limitation

All participants in present study met a certain inclusion criteria. The stringent inclusion criteria may inadvertently affect the network edges in unpredictable ways, also called Berkson's bias (De Ron et al., 2021). To illustrate, consider an investigation into a group of professional singers. An absence of correlation between pitch accuracy and the popularity of singers, given that professionals typically have near-perfect pitch accuracy. Such a conclusion might be misleading when generalized to amateur singers, where Berkson's bias could result in an underestimation of the correlation between pitch accuracy and popularity. Furthermore, prior studies on the efficacy of ICBT indicated that symptom severity can predict treatment adherence (Chen et al., 2020). Therefore, exercising caution and expanding the research to encompass diverse SAD patient populations could minimize the potential for incorrect generalization.

Besides, the networks in this study were derived from convenience samples, and the absence of a control group further limits the interpretation of the results. Borsboom (2017) highlights that there is a pressing need for rigorously designed studies investigating pathological networks to enhance the validity of network analyses. Future studies could modify ICBT interventions based on significant edges identified in SAD networks, and assess various forms of treatment and SAD patients under multiple including criteria and cultural backgrounds.

5. Conclusion

This study set out to investigate pathological network changes before and after Internet-based CBT treatments. The post-treatment SAD network revealed influential symptoms and connections among SAD patients who completed ICBT interventions. Additionally, the pathological network in SAD patients exhibited beneficial modifications in several prominent interconnections after ICBT interventions. Despite a significant reduction in post-treatment social anxiety scores, the overall network connectivity continues to exhibit comparable strength. The limitations related to the patient sample and the generalization call for further experimental research to enrich the understanding of SAD and ICBT from a network perspective.

Declaration of competing interest

None declared.

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