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Network Structure of Childhood Trauma, Bodily Disturbances, and Schizotypy in Schizophrenia and Nonclinical Controls

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***Background and Hypothesis*: Exposure to childhood trauma has been linked to the development of psychosis and bodily self-disturbances, 2 hallmarks of schizophrenia (SZ). Prior work demonstrated that bodily disturbances serve as a bridge between childhood trauma and SZ symptomatology, but the diagnostic specificity of these connections remains unknown. This study uses network analysis to bridge this gap by comparing the interplays between childhood trauma, bodily self-disturbances, and schizotypy in clinical and general populations. *Study Design*: Networks were constructed to examine the relationships between schizotypy (Schizotypal Personality Questionnaire; SPQ), bodily self-disturbances (Perceptual Aberration Scale; PAS), and childhood trauma (Childhood Trauma Questionnaire, CTQ) in 152 people with SZ and 162 healthy comparison participants (HC). The Fused Graphical Lasso was used to jointly estimate the networks in the 2 groups and the structure and strength of the networks were compared. Node centrality and shortest paths between CTQ, PAS, and schizotypy were examined. *Study Results*: When comparing SZ and HC, the network of bodily self-disturbances, childhood trauma, and schizotypy were similarly structured, but the network was significantly stronger in SZ than HC. In both groups, bodily self-disturbances were on one of the shortest paths between childhood trauma to schizotypal experiences. *Conclusions*: Our findings revealed reliable associations between childhood trauma, bodily self-disturbance, and schizotypy, with bodily disturbances acting as a bridge from childhood trauma to schizotypy. The elevated strength of the SZ network indicates a more highly interconnected, and therefore reactive network in which exposure to childhood trauma can more easily activate bodily disturbances and schizotypy.**

Key words: schizophrenia/schizotypy/bodily self-disturbances/childhood trauma/network analysis

Introduction

Exposure to childhood trauma is one of the most consistently documented risk factors for psychopathologies such as post-traumatic stress disorder (PTSD), mood disorders, eating disorders, and psychosis.[1–4] In the 19th century, physicians became perplexed by the physical and psychological symptoms reported by victims of railway accidents who did not sustain physical injuries.[5] French neurologist Jean-Martin Charcot proposed that the observed "hysteria" was caused by trauma, an invisible "wound" resulting from the subjective experience of distressing events.[6] This conceptualization ties back to the ancient Greek origin of the word trauma (τραῦμα: "wound"), which frames it a "hidden wound,"[7] thereby clearly connecting trauma with the body. Today, sensitization of the hypothalamic–pituitary–adrenal (HPA) axis is recognized as a primary mechanism underlying emotion dysregulation and development of psychopathology in those who have experienced trauma.[8] Exposure to adverse experiences during childhood, a critical period for brain development, can have particularly deleterious effects.[9]

Beyond the brain, exposure to trauma has been linked to transdiagnostic disturbances of the subjective experience of the body. In fact, one of Charcot's main collaborators, Pierre Janet, coined the word "dissociation," which he described as a "disaggregation of the psyche" and considered a defense mechanism in the face of trauma.[10] Dissociations are currently conceptualized as a disruption in the typical integration of the awareness one's body, cognition, emotions, and behavior.[11] Although characteristic of trauma-related disorders, dissociative experiences occur in a variety of psychiatric conditions.[12] Notably, two-thirds of individuals with a primary psychotic disorder experience frequent dissociation.[13] Dissociative experiences are in fact qualitatively

close to the bodily self-disturbances characteristic of schizophrenia (SZ) phenomenology.[14–17] Although close, the unclear boundaries of the self and the erosion of the first-person perspective characteristic of self-disturbances distinguishes them from dissociative experiences.[18] In addition, exposure to trauma is thought to contribute to the development of self-disturbances.[19] Contemporary investigations of self-disturbances in SZ have largely focused on bodily aspects of self-awareness (eg, body ownership, agency), which are more easily captured by empirical methods. Importantly, bodily self-disturbances precede and predict transition to psychosis in prodromal populations.[20] As such, bodily disturbances, which have been tied to trauma exposure, might be an important risk marker for SZ.

Schizotypy was first introduced as a set of inherited personality traits that yields a vulnerability for SZ.[21] In fact, increased levels of schizotypy were reliably identified in first-degree relatives of patients with SZ.[22] More recently, a review confirmed that schizotypy increases with genetic liability for SZ.[23] Schizotypy is multidimensional, and its factors mirror the 3 major symptom clusters in SZ: positive, negative, and disorganized.[24] Though the nature of the schizotypy construct (ie, dimensional vs categorical) remains debated, there is a broad consensus that schizotypy correlates with SZ liability.[25] As such, research on schizotypy can facilitate the identification of causal, resilience, and compensating factors at play in the development of SZ, and offers a multidimensional structure that captures etiological heterogeneity.[26] As a latent personality organization, the study of schizotypy in clinical and nonclinical groups allows for important comparisons.

Schizotypy has been linked to childhood trauma and bodily disturbances in the general population. In line with early models of SZ, anomalous bodily experiences, and self-disturbances were also regarded as central to schizotypy by early investigators.[21,27,28] In fact, one of the earliest measures of schizotypy focuses on bodily aberrations.[27] The link between childhood trauma and schizotypy in nonclinical populations is also well documented.[29] Recent studies further showed that self-disturbances mediate the relationship between childhood trauma and psychotic-like experiences (PLEs) in the general population.[30–33] Though schizotypy and PLEs are sometimes used interchangeably, they capture different phenomenon. One of the key differences between these 2 concepts is that schizotypy is thought to be stable over time while PLEs are transient experiences.[34] Thus, though the relationships between schizotypy and childhood trauma, and schizotypy and bodily self-disturbances are independently well documented, the potentially complex interplays between these 3 constructs remain understudied. Furthermore, these connections have never been compared in clinical and nonclinical populations.

The network framework offers a novel, data-driven approach to the study of psychopathology that can be used to bridge these gaps. It considers disorders as dynamic systems consisting of various symptoms and biological, psychological, social, and environmental factors.[35] Recent network investigations documented a link between childhood trauma and multidimensional schizotypy in a nonclinical population[36] as well as links between childhood trauma and psychotic symptoms[37,38] and dissociative experiences[39] in clinical samples. Another recent network study found that bodily disturbances serve as a bridge between childhood trauma and SZ symptomatology,[40] but the diagnostic specificity of these connections remains unexplored. The network framework can be applied to different populations and used to compare the specificity of connections, as well as vulnerability for a disorder. For instance, the networks of childhood trauma and schizotypy were found to be similar in people with high and low schizotypy, though the network of individuals with elevated schizotypy was more strongly connected.[36] The overall strength of a network sheds light on its connectivity: nodes of highly connected networks are more likely to activate each other, which makes for a more vulnerable network.

The current study aims to compare the structure and connectivity of networks of childhood trauma, schizotypy, and bodily disturbances in people with and without SZ. More specifically, we aim to (1) investigate the links between different types of childhood trauma, bodily disturbances, and multidimensional schizotypy in a sample of individuals with SZ and healthy controls, (2) compare the structure and strength of these networks, and (3) identify pathways that may be involved in the relationship between childhood trauma, schizotypy, and bodily self-disturbances in the 2 groups. Given the lack of prior work in this area, this work is exploratory.

Methods

Participants

One hundred sixty-two control participants (HC) and 152 individuals with a primary non-affective psychotic disorder (SZ) were included in this study. The SZ group included 77 individuals with schizophreniform disorder, 53 individuals with schizophrenia, and 22 individuals with schizoaffective disorder. One hundred-one of the SZ participants were identified as first episode, defined as being within the first 2 years since an index psychotic episode. The duration of illness for our SZ participants ranged from 0 to 31.4 years, with an average of 4.7 years. Diagnoses were confirmed (SZ) or ruled out (HC) using the Structured Clinical Interview for DSM-IV[41] or 5.[42] SZ were recruited from the Psychotic Disorders Program at Vanderbilt Psychiatric Hospital in Nashville, TN and HC were recruited by advertisement from the same community. All participants were 18–65 years old. Exclusion criteria included estimated premorbid IQ lower than 70, the presence of a systemic medical illness (eg, cancer) or

central nervous system disorder (eg, multiple sclerosis, epilepsy), a history of significant head trauma, psychotropic drug use (HC only), substance abuse within last 3 months (SZ) or lifetime history of substance abuse/dependence (HC). HC participants with a history of psychiatric illness, first-degree relative with a psychotic disorder, or treatment with psychotropic medication were excluded. All participants provided written informed consent prior to enrolling in the study and were compensated for their time. The study was approved by the Vanderbilt Institutional Review Board. Demographic and clinical information for study participants is presented in table 1.

Measures

Bodily Disturbances. Participants were administered the Perceptual Aberration Scale,[27] a 35 true/false items questionnaire assessing 5 types bodily disturbances (ie, unclear body boundaries, feelings of unreality or estrangement of the body, feelings of deterioration of one's body parts, perceptions of the change of size of one's body parts, and changes in the appearance of the body). The PAS yields a total score that quantifies bodily disturbances and is suitable for use with both healthy and clinical populations. It has been shown to have good to excellent reliability.[27]

Childhood Trauma. Exposure to childhood trauma was evaluated using the Childhood Trauma Questionnaire, Short-Form (CTQ-SF[43]). The CTQ-SF is a retrospective assessment tool comprised of 5 subscales: emotional neglect, emotional abuse, physical neglect, physical abuse, and sexual abuse. It consists of 28 items, each rated on a 5-point Likert scale. The CTQ-SF is a widely used instrument to measure childhood trauma, and its validity has been demonstrated in diverse clinical and nonclinical samples.[43]

Schizotypy. Schizotypal traits were measured using the Schizotypal Personality Questionnaire (SPQ[44]), a 74-item true/false questionnaire. The SPQ is the most widely used tool to assess schizotypy in research settings and has been shown to have excellent psychometric properties.[45,46] It yields 9 subscales: Ideas of Reference, Excessive Social Anxiety, Odd Beliefs/Magical Thinking, Unusual

Table 1. Participants demographic and clinical information

	SZ (N = 152)	HC (N = 162)	Statistics		
	N	N	X^2	df	P
Sex (M/F)	107/45	102/60	1.63	1	.20
Race					
Asian	2	5	2.13	3	.55
Black	43	40			
White	103	110			
Other	4	7			
Hispanic Y/N	3/149	6/156	0.40	1	.53
	Mean (SD)	Mean (SD)	t	df	P
Age	25.47 (8.84)	27.02 (9.71)	1.48	312	.14
PAS	6.43 (6.27)	1.81 (1.86)	−8.72	175.8	<.0001*
CTQ					
Emotional Abuse	5.39 (5.02)	1.67 (2.45)	−8.28	216.1	<.0001*
Emotional neglect	5.25 (4.17)	2.64 (3.11)	−6.27	278.65	<.0001*
Physical Abuse	2.89 (3.75)	1.41 (2.05)	−4.31	231.26	<.0001*
Physical neglect	2.76 (3.03)	1.02 (1.95)	−5.10	164.3	<.0001*
Sexual abuse	1.91 (3.98)	0.22 (0.86)	−6.02	255.18	<.0001*
SPQ					
Ideas of reference	4.47 (3.06)	1.02 (1.67)	−12.30	230.62	<.0001*
Social anxiety	3.99 (2.85)	1.84 (2.34)	−7.30	292.43	<.0001*
Odd beliefs	2.23 (2.29)	0.29 (0.67)	−10.05	174.84	<.0001*
Unusual perception	3.28 (2.75)	0.48 (0.92)	−11.94	182.51	<.0001*
Odd behavior	3.06 (2.39)	0.96 (1.73)	−8.88	273.51	<.0001*
No close friends	3.95 (2.72)	1.52 (1.95)	−9.04	271.95	<.0001*
Odd speech	3.89 (2.85)	1.71 (1.88)	−7.96	259.45	<.0001*
Constricted affect	3.06 (2.38)	1.00 (1.23)	−9.56	222.83	<.0001*
Suspiciousness	3.59 (2.82)	0.85 (1.48)	−10.69	224.86	<.0001*
PANSS					
Positive	17.94 (7.63)	—	—		
Negative	16.90 (7.88)				
General	32.14 (9.57)				
Duration of illness	4.70 (7.50)				

Perceptual Experiences, Odd/Eccentric Behavior, No Close Friends, Odd Speech, Constricted Affect, and Suspiciousness.

Data Analysis

Statistical analyses were implemented in R (Version 4. 2. 2).

Networks Construction. The Fused Graphical Lasso (FGL[47]) was used to jointly estimate networks in SZ and HC using the *EstimateGroupNetwork* package.[48] The FGL is an extension of the "graphical least absolute shrinkage and selection operator" (glasso[49]) that allows for joint estimation of multiple Gaussian Graphical Models (GGMs[50]). In these networks, edges represent partial Spearman correlations between nodes. The glasso uses a tuning parameter (λ1) to regulate the density penalty. FGL improves edge estimation by exploiting similarities between the 2 groups while simultaneously allowing true differences to emerge. In addition to λ1, the FGL includes a second tuning parameter (λ2), which regulates the penalty on differences between corresponding edges in the 2 networks. *K*-fold cross-validation was used to empirically select the optimal values of λ1 and λ2. In order to facilitate visual comparison, the layout was kept consistent across the 2 networks.

Networks Comparison. We first computed a coefficient of similarity to index the similarity between the jointly estimated networks. Specifically, a Spearman correlation was used to assess the relation between the network parameters (eg, edge weights and node strength) of the jointly estimated SZ and HC networks. We then formally tested the differences between the 2 networks using the *NetworkComparisonTest* (NCT) package,[51] which adopts a nonparametric permutation test to assesses differences between 2 networks' structure and strength. We note that this package currently does not allow for comparison of jointly estimated networks and no existing function achieves this goal. Consistent with previous studies,[52,53] we hence used the individually estimated networks instead for this test, after establishing high similarity between the jointly- and individually estimated networks. Due to this methodology and software constraint, the results of this test will be descriptive and interpreted with caution.

Networks Stability. The *boonet* package[54] was used to assess the accuracy and stability of the networks. Correlation Stability coefficients (CS coefficient) were computed via bootstrapping the sample 1000 times. CS coefficients above 0.5 indicate stable and interpretable networks.[54] The *bootnet* package does not yet allow for accuracy and stability assessment of jointly estimated networks either. Instead, we estimated the CS coefficients for the individually estimated networks, which provides a lower-bound estimate of the stability of the jointly estimated networks[52] (Plots representing bootstrapped edge means and 95% CIs are provided in the supplementary material).

Shortest Path. Dijkstra's algorithm[55] was used to identify the shortest paths between childhood trauma and schizotypy. For details on this method, see Isvoranu, Borsboom, van Os, and Guloksuz.[56] A shortest path represents the most efficient route from 1 node to another (ie, the minimum number of steps needed to get from 1 node to the other). As such, shortest paths can help identify potential factors mediating the relationship between exposure to trauma and schizotypy.

Centrality. Centrality indices were generated to identify influential nodes in the networks. The s*trength* of a node represents the absolute sum of all edge strengths directly connected to it. The *betweenness* index indicates the number of times a given node lays on the shortest path between 2 other nodes. The *closeness* index is the inverse of the weighed sum of distances of a given node from all other nodes in the network, quantifying how easily all other nodes can be linked from a given node.

Results

Similarity and Strength

Group differences in schizotypy (SPQ), bodily disturbances (PAS), and childhood trauma (CTQ-SF) are presented in table 1 and the jointly estimated networks are visualized in figure 1. The CS coefficient for edge weights was 0.63 for SZ and 0.54 for HC, indicating that both networks are stable and interpretable. As expected, the schizotypy subscales were generally strongly correlated to each other. The childhood trauma subscales were also strongly correlated to each other. In both networks, bodily disturbances were directly connected to many schizotypy subscales as well as several childhood trauma experiences, particularly those measuring abuse.

Interestingly, the HC and SZ networks were found to be highly similar between the 2 groups, with a coefficient of correlation of 0.93. The omnibus test in fact revealed no significant difference between the 2 networks, $P = .39$.

Despite this similarity, eleven unique edges were also identified in the SZ network (ie, PAS—Odd Beliefs, PAS—No Friends, PAS—Sexual Abuse, Sexual Abuse—No Friends, Sexual Abuse—Physical Abuse, Sexual Abuse—Physical Neglect, Physical Abuse—Emotional abuse, Odd Beliefs—Emotional Abuse, Ideas of Reference—Suspiciousness, Odd Speech—Social Anxiety, Social Anxiety—Constricted Affect) and 2 in the HC network (ie, Physical Neglect—Unusual Perception, Physical Neglect—Emotional Abuse). These differences are illustrated in supplementary figure 2.

Comparing the global strength estimates, the SZ network (average edge strength = 0.055) was found to be significantly stronger than the HC (average edge

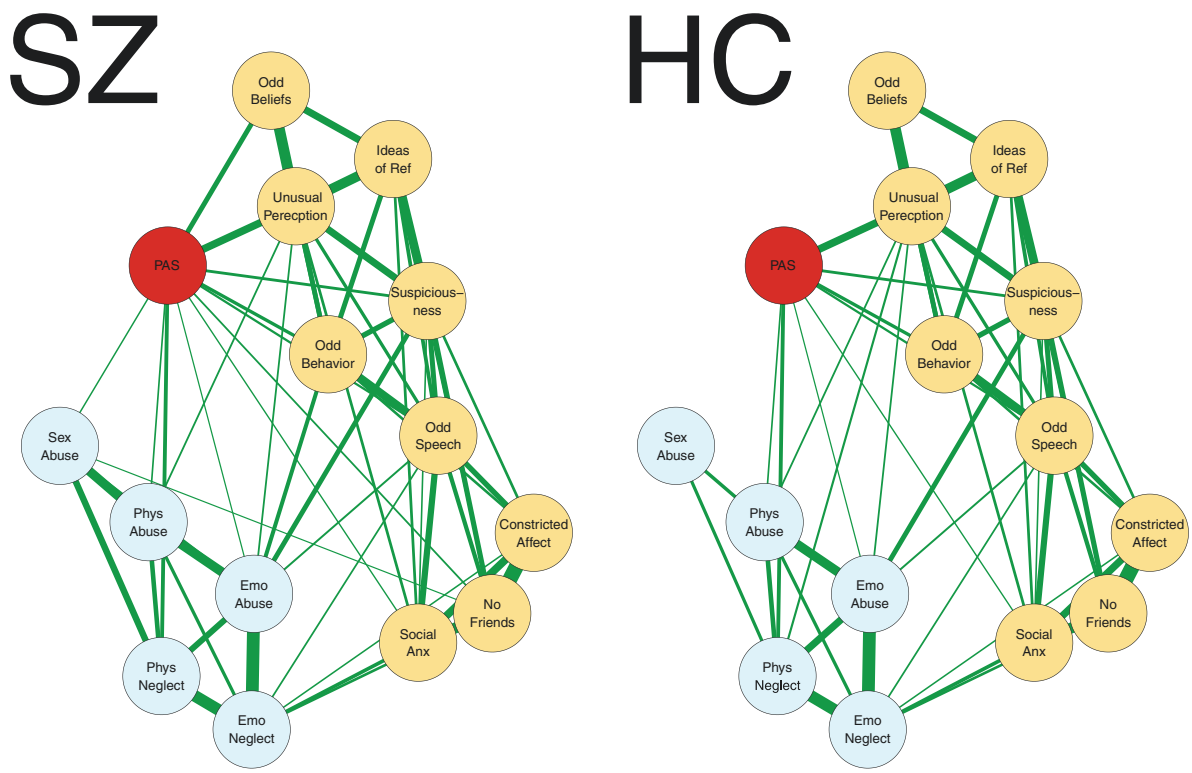

Fig. 1. Jointly estimated networks of schizotypy (SPQ), bodily disturbances (PAS), and childhood trauma (CTQ-SF) for SZ and HC. Nodes represent SPQ subscales (yellow), PAS (red), and CTQ-SF subscales (light blue). Edges represent regularized partial Spearman correlations; edges thickness represents the strength of the association. Green edges represent positive relations.

strength = 0.050) network, $P = .004$. This suggests that while the structure of the networks was not significantly different between groups, the nodes are more strongly interconnected in SZ, as compared to HC.

Shortest Paths

Three shortest paths from childhood trauma and schizotypy were identified in both samples: 1 connected physical neglect to unusual perception through bodily disturbances, 1 linked emotional abuse to suspiciousness, and 1 linked emotional neglect to social anxiety (figure 2). An additional shortest path from childhood trauma to schizotypy was found in SZ, linking emotional abuse to odd behavior.

Centrality

Centrality indices of the jointly estimated networks are reported in figure 3. Centrality indices revealed unusual perception and suspiciousness from the schizotypy scale as the most central nodes in the 2 networks. More specifically, unusual perception was the strongest node. Suspiciousness was found to have the highest betweenness and closeness index, revealing it as a critical node to facilitate the flow of information through the network (betweenness) and having a short average distance with the remaining nodes in the network (closeness).

Discussion

This study leveraged the Fused Graphical Lasso to compute and compare the networks of bodily disturbances, childhood trauma, and schizotypy in people with and without SZ. The structure of the networks was found to be highly consistent between the 2 samples. This suggests reliable associations between childhood trauma, bodily self-disturbances, and schizotypy phenomena extending beyond the SZ spectrum.

In these networks, bodily self-disturbances were found to directly relate to the 3 dimensions of schizotypy (ie, cognitive/perceptual, interpersonal, and disorganized), as well as a variety of childhood trauma experiences, particularly abuse. In both networks, a shortest path between childhood trauma and schizotypy was identified through bodily disturbances, indicating that bodily disturbances serve as a bridge between exposure to childhood trauma and the clinical phenomena of schizotypy.

Comparison of the overall edge strength between the 2 networks revealed a more strongly connected network in SZ. This elevated connection is indicative of a highly reactive network in which childhood trauma, bodily disturbances, and schizotypy easily activate each other. We however note that the width of the bootstraped CIs of edges in the 2 networks (see supplementary figures 4 and 5), limits our interpretation of strengths, such that

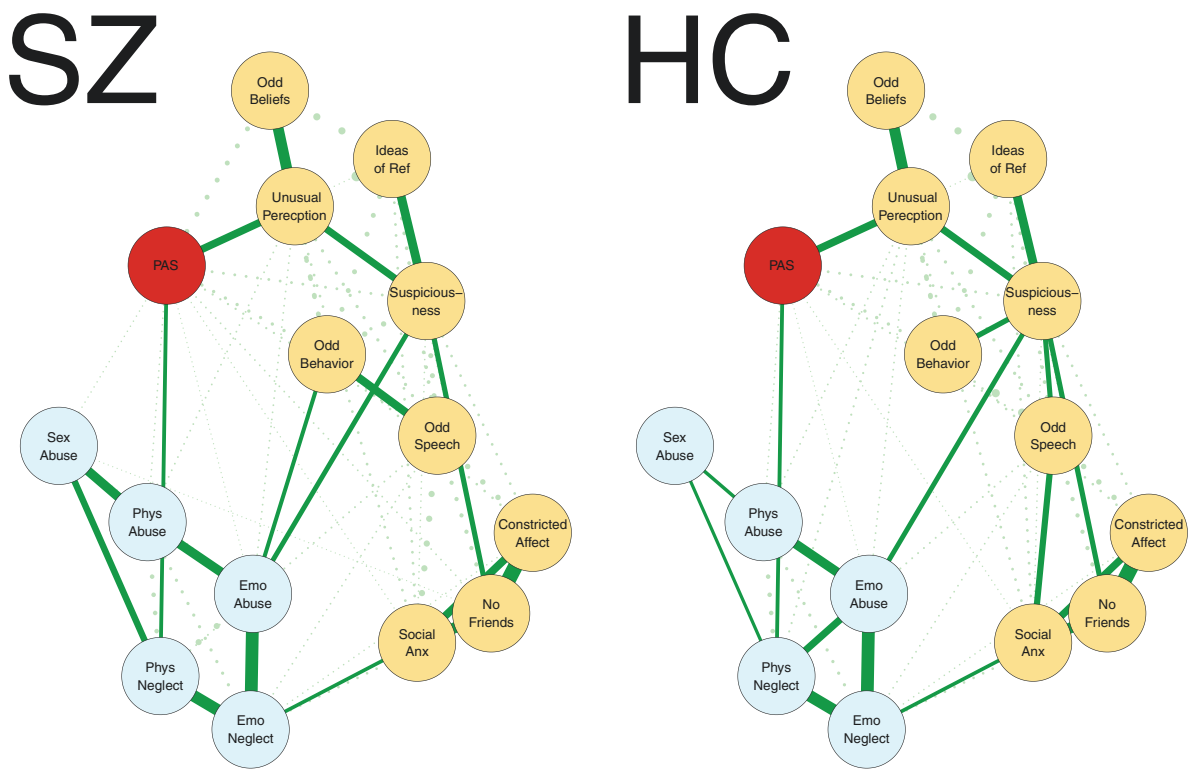

Fig. 2. Shortest paths between childhood abuse (eg, all CTQ-SF nodes) and schizotypy (all SPQ subscales) in SZ and HC. Lines represent the shortest paths between childhood abuse and schizotypy.

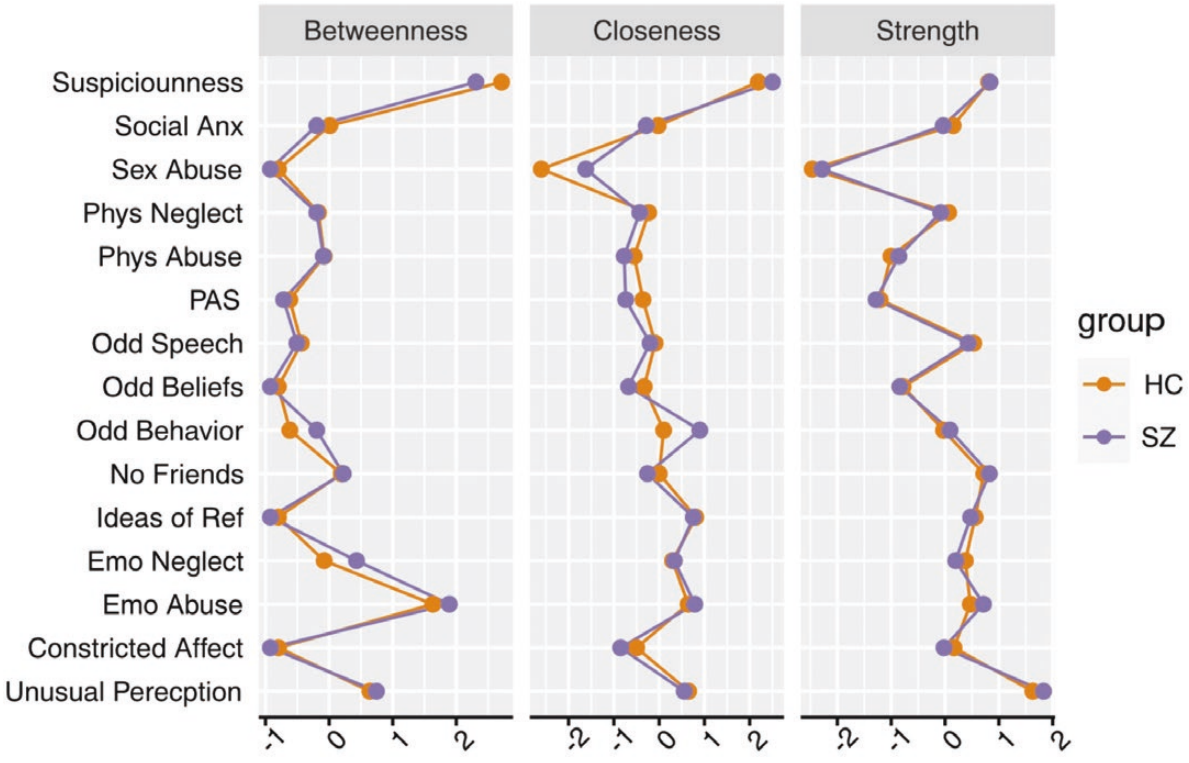

Fig. 3. Standardized centrality measures (eg, betweenness, closeness, and strength) for each of the nodes of the jointly estimated networks in SZ and HC.

we focus the remainder of our discussion on the presence, rather than strength, of edges.

Eleven unique edges were identified in the SZ network vs 2 in the control network, which indicates a denser network in SZ. As such, although the networks of childhood trauma, bodily disturbances, and schizotypy are equivalent in people with and without SZ, the heightened connectivity and density of the SZ network indicates a more vulnerable network in which bodily disturbances might play an important role.

Unusual perception was found the be the most influential node in the networks. In addition, the shortest path linking childhood trauma to schizotypy through bodily disturbances specifically connected physical neglect to unusual perception. In interpreting these results, we note that the instrument used to measure bodily disturbances (PAS) conceptualizes body aberrations as a subtype of unusual perception. In addition, current computational models of psychosis highlight the role of unusual perceptions in the development of delusions.[57] It is thus notable that unusual perception, which plays a central role in the network of childhood trauma, bodily disturbances, and schizotypy, has also been demonstrated to play a role in the etiology of psychotic symptoms.

Taken together, we note the potential implications these findings have for understanding SZ-spectrum phenomenology. The diathesis-stress model of psychopathology posits that genetic and environmental risk factors interact to yield a vulnerability to a given disorder.[58] In the case of SZ, schizotypy represents genetic liability,[21] and childhood trauma has been identified as a major environmental risk factor.[59,60] Our work suggests that bodily disturbances, which are characteristic of SZ phenomenology and precede psychosis, exist at the junction of these 2 etiological factors.

Our work also adds to a growing body of literature using the network framework. A recent study documented relationships between various types of childhood trauma and multidimensional schizotypy.[36] This study noted that the strength of the network was higher in people with high schizotypy than those with low schizotypy. Our work extends these findings in 2 important ways. First, our addition of bodily disturbances helped reveal an important mechanistic pathway linking childhood trauma to positive schizotypy (ie, unusual perception) through bodily disturbances. A similar mechanistic pathway linking childhood trauma to psychotic symptoms (ie, hallucinations) through bodily disturbances was recently identified.[37] We note an important difference between these pathways such that while bodily disturbances bridged childhood *abuse* to positive symptoms, they linked physical *neglect* to positive schizotypy in the present study. Thus, it is possible that experiences of deprivation (ie, neglect) play an important role in activating schizotypal experience while threat experiences (ie, abuse) are related to psychotic symptoms. Lastly, our work extends the relations between childhood trauma and schizotypy beyond the nonclinical realm by documenting similar networks in people with and without SZ.

A few limitations should be acknowledged. First, our measures relied on self-report instruments, which increases the risk of response bias, which might differentially impact people with SZ and control individuals. Relatedly, the PAS, although originally developed as a measure of bodily aberrations in SZ, is part of the Wisconsin Schizotypy Scales. As such, it is possible the PAS and some of the SPQ subscales tapped into some similar experiences. Second, group differences in variability of measures might have contributed to our results. In particular, it is possible that the relatively low CTQ-SF scores in HC might contribute to the observed difference in network strength between the 2 samples. We however note that the FGL has been used to compare clinical and nonclinical samples in numerous recent studies with no reported concerns of heterogeneity of variance. Lastly, we note a software constraint that prevented us from testing the comparison between the jointly estimated networks. Our comparison of the individually estimated networks is however consistent with other studies. Methodological limitations also prevented us from assessing the stability of the shortest paths, and the CS coefficients of the closeness and betweenness centrality indices, such that these should be interpreted with caution and would benefit from replication in independent samples.

In sum, our work documented a reliable network of childhood trauma, bodily disturbances, and multidimensional schizotypy in people with and without SZ. Unusual perception appears to play a particularly central role in this network, and bodily disturbances lay on one of the shortest paths from childhood trauma and schizotypal experiences. Lastly, we found that although structurally identical, the network was stronger in the SZ sample than the control sample, suggesting a more highly reactive network in which experiences of childhood trauma, bodily disturbances, and schizotypy more readily activate each other, thereby increasing risk for psychopathology.

Supplementary Material

Supplementary data are available at *Schizophrenia Bulletin Open* online.

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