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Network analysis of depressive and anxiety symptoms with well-being in students during the COVID-19 pandemic: a repeated cross-sectional study

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The university student population is particularly vulnerable to depression, which was identified during the COVID-19 pandemic. Understanding how depressive symptoms are interrelated with mental and physical health in students is essential. The aim of this study was to reveal the network of depressive and anxiety symptoms with respect to well-being (life satisfaction, physical health, physical activity, and perceived stress) during a difficult situation—the COVID-19 pandemic—at two measurement points of different pandemic severities. A repeated cross-sectional study was conducted in June 2020 (T1) (lower pandemic severity) and March 2021 (T2) (higher pandemic severity) among 592 and 1230 Czech university students, respectively. The measurements used were the PHQ-9, GAD-7, PSS-10, SWLS, self-rated physical health (SRH), and sociodemographic survey. The network analysis approach was utilized. For the significance of differences, the χ^2 test, Student's *t* test, and ANOVA were performed. The results revealed that scale-level depression, stress, and worse SRH increased over time, whereas life satisfaction decreased. Scale-level anxiety and physical activity were stable over time. PHQ2 Sad mood was the most central and influential node at T1 and T2. PHQ9 Suicidal Ideation was closely related to other variables at T1, whereas PHQ1 Anhedonia was closely related to other variables at T2. The most influential risk factors were the PHQ-2 score and the GAD-2 score, which are associated with uncontrollable worrying, whereas life satisfaction, physical health, and physical activity were the most protective factors. It is crucial to recognize and decrease the PHQ2 score and increase life satisfaction to improve the mental health of university students.

Abbreviations

COVID-19	Coronavirus disease 2019
PSS-10	The 10-item Perceived Stress Scale
GAD-7	The 7-item Generalized Anxiety Disorder scale
PHQ-9	The 9-Item Patient Health Questionnaire
SRH	Self-Rated Health
SWLS	Satisfaction With Life Scale
WHO	World Health Organization

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which is responsible for coronavirus disease 2019 (COVID-19), was first detected in China in December 2019. It has spread rapidly worldwide, resulting in a global pandemic[1,2]. During the first year and a half of this pandemic, the virus infected more than 180,000,000 people and caused almost 4,000,000 deaths[3].

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The authorities of most countries around the world introduced significant restrictions in subsequent waves of the pandemic. There is growing evidence that restrictions such as lockdowns, quarantines, and curfews, as well as other COVID-19-related stressors (infection fears, boredom, frustration, financial loss, inadequate information), negatively affect mental health. Most studies report posttraumatic stress symptoms, confusion, anger, emotional exhaustion, and lack of interest, together with highly elevated anxiety and depressive symptoms. Moreover, depressive symptoms and COVID-19 concerns are positively associated with pandemic-related employment loss and more stringent self-quarantine behavior, which was proven in a sample of almost 2500 adults from English-speaking countries[4,5].

One of the strategies used to prevent the rapid spread of SARS-CoV-2 was the introduction of online-only education at most universities worldwide, which did not involve in-person communication between students and lecturers[6]. According to the meta-analysis, the satisfaction rate with online education among students was significantly higher in the prepandemic era (79.7%) than in the postpandemic era (50.7%). The abovementioned rapid transformation of the educational system in response to worldwide quarantine was a source of great stress for students[7,8].

Many studies confirm that being a student predisposes one to stress reactions due to periodic overloads, permanent awareness of the threat, pressure to perform at the best possible level, and concerns about the future. Interestingly, stress related to the university environment has a greater contribution to depressive symptoms than personal stressors alone, which can be connected with specific, unusual situation of students: they are treated as responsible adults, but on the other hand, they have duties for which they do not receive direct remuneration[9,10]. Moreover, although almost half of the students experienced at least one mental health problem that persisted for longer than two years, the majority of them (60%), did not receive appropriate treatment[11]. The prevalence of stress, depression, and anxiety among students is constantly increasing, and depression rates are now significantly higher than those reported in the general population (30.6%). Furthermore, cross-national prospective research conducted during the COVID-19 pandemic among representative samples of young adults revealed that student status is a risk factor for depression and suicidal ideation, whereas younger age is not[12]. Therefore, students constitute a vulnerable population prone to the development of psychopathology[13–15].

A previous study on mental health among students from nine countries revealed that the prevalence of depressive symptoms (cutoff score ≥ 10) during the first wave of the pandemic among Czech university students was 21%[16], which was lower than that among students from Turkey, Poland, Russia, Colombia, Slovenia, Israel, Germany, and Ukraine[17]. The risk factors for depressive symptoms differ according to country, and for Czech students, the relevant factors were exposure to COVID-19 and worse comparative physical health[17]. Life satisfaction among Czech university students at that time was significantly greater than that of students from Turkey, Poland, and Russia, while it was similar to that of students from Germany, Slovenia, Colombia, and Israel[18]. Czech students at the master's level were almost three times more likely to have higher satisfaction with life than those at the bachelor's level; moreover, those who did not experience exposure to COVID-19 infection perceived their comparative physical health better, were physically active (over 150 min per week), and were more satisfied with life (0.4, 0.3, and 1.9 times, respectively)[18].

The relationship between physical activity and well-being during the COVID-19 pandemic has also been well established in other populations of students[19–23] and the general population[24–26].

A recent systematic review and meta-analysis revealed that depression was linked to quality of life among university students during the COVID-19 pandemic[27]. The relationship between satisfaction with life and depressive symptoms is bidirectional[28]. A longitudinal study confirmed that in the three-year lag analysis, the relationship between satisfaction with life and depressive symptoms was bidirectional; however, in the six-year lag analysis, satisfaction with life was a predictor for future depressive symptoms, but not inversely[29].

Nevertheless, most of the literature focuses on depression and anxiety at the scale level, and little is known about the relationships between different factors and specific symptoms of depression and anxiety.

The network theory of mental health disorders focuses on the premise that symptoms of psychopathology are causally connected via diverse (biological, psychological, and societal) mechanisms[30]. Activated symptoms triggered by disruptive experiences can lead to psychopathology[31] and remain activated long after the triggering external factor disappears[32]. The analysis of individual symptoms and their patterns is recommended because, compared with the analysis of sum score results, better insight into and possibilities for improving mental health are needed[33]. Thus, it is crucial to understand not only how symptoms are interconnected but also how they are connected to other factors.

Research shows that specific nodes in the network of depressive and anxiety symptoms have the highest centrality strength; however, the results are not consistent and depend on a sample characteristic. Among the symptoms with the highest centrality strength, Sad mood (depressive symptom, PHQ2) and Worry too much (anxiety symptom, GAD3) are revealed[33–35]. Additional central nodes are Depressed affect and Nervousness (GAD1) during the beginning of the pandemic[36] and Irritability (GAD6) and Guilty (PHQ6) during the later stage of the COVID-19 pandemic[37] in Chinese adolescents. In college Chinese students, Sad mood (PHQ2) played an activating role for other symptoms[38], whereas Irritability (GAD6), Uncontrollable worry (GAD2), Trouble relaxing (GAD4), and Sad mood (PHQ2) are the most central nodes among nursing students[39]. Other studies have shown that Fatigue is the most central node in the network in early treatment response[40].

However, little is known about the relationships between the network of symptoms and other factors. Relationships between depressive symptoms and distress and empathy in university students[41], grades in adolescents[37], or 14 subdomains of subjective well-being among South Korean adults[42] and between life satisfaction and neuroticism in Chinese college students[43] have been analyzed via a network approach. Nevertheless, there is still a gap in understanding the links between depressive and anxiety symptoms and life satisfaction, physical health, and stress. Moreover, the cultural context plays a role in reactions to stressful

experiences, as the COVID-19 pandemic and mental health indicators differ among university students depending on the country[17].

The present study

The aim of this study was to reveal the network of depressive and anxiety symptoms with respect to physical health (self-rated health and physical activity), satisfaction with life, and perceived stress. We expect to reveal the most central symptoms among Czech university students by applying network analysis with two measurements over a 10-month period during the COVID-19 pandemic. To our knowledge, this is the first repeated cross-sectional study among Czech students within a network theory of mental health frames.

Network analysis (NA) enables the visualization and interpretation of complex interactions between different types of data by creating a network represented by variables (nodes) and relationships between them (edges). The variables are often classified into various categories, so information can be integrated from different data sources, which is important in health psychology. Indeed, this field of science deals mostly with interactions between social, biological, and psychological factors in determining widely understood mental health[18,19]. Therefore, the NA method fits well with our repeated cross-sectional research based on a holistic definition of health.

To date, most studies on students' mental health during the COVID-19 pandemic have focused on medical or dentistry students[20–23], whereas research on the Czech population has been dominated by analyses of the whole population, working adults, elderly individuals, and health care professionals[24–27]. Therefore, to fill this knowledge gap, the current study was conducted among students at Mendel University in Brno, which offers a wide range of nonmedical courses, such as those in the fields of agriscience, forestry, horticulture, business, and economics.

We were also interested in the low prevalence of depressive symptoms in Czech students during the first wave of the COVID-19 pandemic compared with students from other countries[16]. However, this time, we wanted to research a larger sample of participants to enable the generalization of the results. The main research question refers to the stability of the mental health network and the centrality of symptoms in two different external circumstances caused by the COVID-19 pandemic.

During the first measurement (Time 1, June 2021), the number of daily newly confirmed COVID-19 cases was relatively low ($M = 65.71$), whereas ten months later, during the second measurement (Time 2, May 2021), the number reached over 12,000 cases ($M = 10,154.89$)[44]. Even though the percentage of the vaccinated population increased during Time 2 (Fig. 1), the pandemic situation still fluctuated.

Thus, we expected that, owing to the increase in daily COVID-19 cases, the psychological response of participants would be more acute during Time 2, after the third wave of the pandemic. Importantly, e-learning was introduced regularly before the pandemic, so the changes in learning style evoked by obligatory quarantine in the studied sample may not have been harmful to well-being.

Overall, it is crucial to establish the network connectivity and centrality of depressive and anxiety symptoms during external challenges among those particularly vulnerable to depression, such as students. Moreover, we expect to reveal links between the network of depressive and anxiety symptoms and life satisfaction, self-rated physical health, physical activity, and perceived stress.
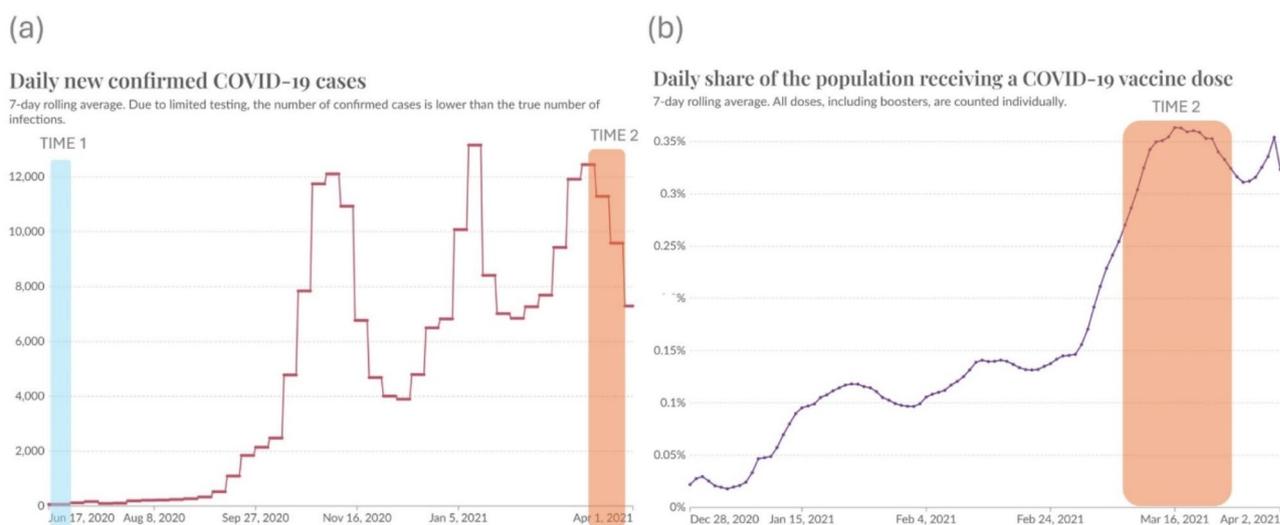

Fig. 1. Daily number of newly confirmed COVID-19 cases (**a**) and the daily share of the population receiving a COVID-19 vaccine (**b**) during two measurements: Time 1 (June 2020) and Time 2 (March 2021) in the Czech population. Data source (**a**) WHO COVID-19 Dashboard. Data source (**b**) official data collated by Our World Data[44].

Results
Participants

The sample size at Time 1 (T1) was 592 participants, whereas at Time 2 (T2), it was 1230 participants. The proportion of female students was the same across the two samples (72.30%). The students in sample 1 were slightly younger ($M = 22.41$) than the students in sample 2 were ($M = 22.84$), $t(1820) = -4.23$, $p < 0.001$. The effect size measured by Cohen's d was $d = -0.21$, indicating a small effect. The proportion of participants differed due to the place of residence in the two samples. In sample 1, a greater proportion of participants lived in rural areas (48.30%) than in sample 2 (38.10), while a smaller proportion lived in a city (28.00%) than in sample 2 (35.30%). The participants were more frequently students at the bachelor's level than at the master's level of education in the two samples; however, there were slightly more students at the bachelor's level in sample 1 than in sample 2. Descriptive statistics for sociodemographic characteristics and χ^2 test results for the two samples are presented in Table 1.

Moreover, at T1, 89% of the students experienced symptoms of COVID-19, but none of them were hospitalized. Only 7% of the close friends and family members of the students were infected. Unfortunately, two students lost friends or family members to COVID-19 during this time. Moving on to T2, fewer than half of the students (47%) experienced symptoms, and four of them were hospitalized. The infection rate among friends and family members was significantly higher at 87%. Sadly, 19% of the students experienced the death of a close family member by T2.

Differences over time

The prevalence of depressive and anxiety symptoms (moderate, cutoff score ≥ 10) was 41.70% and 37.50%, respectively, at T1. During the second measurement, the risk of moderate depression was 50.40%, whereas the risk of anxiety was 43.30%. High stress prevailed among 66.00% of the students at T1 and 76.30% at T2.

Depressive symptoms at the scale level significantly increased at T2 compared with those at T1; however, the effect size was negligible. Among depressive symptoms, the PHQ4 (Energy), PHQ7 (Concentration), and PHQ9 (Suicide ideation) scores significantly increased at T2, but the effect sizes were negligible. Only PHQ1 (Anhedonia) and PHQ2 (Sad Mood) significantly increased, with small effect sizes.

Variable	Sample 1 Total ($N = 592$)				Sample 2 Total ($N = 1230$)				
	N	%	M	SD	N	%	M	SD	χ^2
Gender									
Man	164	27.70			341	27.70			n.s
Woman	428	72.30			889	72.30			
Age (20–30)			22.41	1.82			22.84	2.11	
Place of residence									
Village	259	43.70			469	38.10			
Town	167	28.20			327	26.60			9.92**
City	166	28.10			434	35.30			
Education level									
Bachelor	453	76.50			875	71.10			5.86*
Master	139	23.50			355	28.90			
Year of study									
First	248	41.90			525	42.70			
Second	153	25.80			319	25.90			
Third	123	20.80			213	17.30			n.s
Fourth	27	4.60			77	6.30			
Fifth	30	5.10			75	6.10			
Sixth	11	1.90			21	1.70			
Faculty									
Agronomy	188	31.80			499	40.60			
Regional development and international	56	9.50							
Lifelong learning	10	1.70			679	55.20			
Forestry and wood technology	83	14.00							
Business and economics	178	30.10			52	4.20			
Horticulture	77	13.00							

Table 1. Sociodemographic characteristics of the samples and χ^2 test results. *M* mean, *SD* standard deviation, *n.s.* nonsignificant *p* level, p > 0.05. **$p < 0.01$, ***$p < 0.001$.

Anxiety symptoms at the scale level did not significantly change. At the individual symptom level, only GAD3 (Worry too much) increased with a small effect, whereas GAD2 (Uncontrollable Worrying) and GAD6 (Irritability) also increased significantly but with negligible effect sizes.

The increase in perceived stress and decrease in life satisfaction were significant, with a small effect size.

Physical activity did not significantly change. The mean score for physical activity at T1 and T2 was less than 150 min; thus, the mean score can be interpreted as being physically inactive.

We present the descriptive statistics of the included variables and differences due to the time of measurement in Table 2.

Network analysis
On the basis of the literature review, well-being indices, understood as mental (perceived stress and life satisfaction) and physical (physical activity and self-rated health) health, were included in the network model of depressive and anxiety symptoms at two measurement time points.

After controlling for all variables in the network, a visualization of relationships (edges) among nodes was generated. There were 20 nodes, the number of nonzero edges was 109/190, and the sparsity was 0.426 at T1. The graph visualization of the network analysis of depressive and anxiety symptoms with respect to well-being in Czech students at T1 is presented in Fig. 2.

At T2, there were 40 nodes, the number of nonzero edges was 114/190, and the sparsity was 0.400. A visual graph of the network analysis results at T2 is shown in Fig. 3.

Network centrality nodes
The centrality of nodes indicates their relative importance in the context of the other nodes in the network[45].

Betweenness
The betweenness centrality metric reveals a node's pivotal role as a bridge in the network. Nodes with higher betweenness centrality are essential for the flow of information or resources among other nodes.

PHQ2 Sad mood exhibited the highest betweenness centrality in the two analyzed networks. This indicates its critical role in connecting other nodes within the networks, potentially serving as a gatekeeper or bridge with other symptoms and well-being indices. On the other hand, physical activity had the lowest betweenness centrality in both networks, along with GAD6 Irritability and GAD7 Feeling afraid during T1 and T2, respectively.

Closeness
Closeness centrality refers to proximity to other nodes in the network; thus, higher closeness means shorter paths and thus quicker interaction within the network.

The highest closeness centrality was associated with the PHQ2 Sad mood in both networks. Additionally, PHQ9 Suicidal ideation also had high closeness centrality during T1, while PHQ1 Anhedonia had high closeness centrality during T2. The node with the lowest degree of closeness was self-rated health at T1 and physical activity at T2.

Strength
The strength centrality node value reflects the connectivity or influence of each variable in the network (on the basis of the weighted number and strength of all edges of the node linked to other nodes). Higher strength denotes a greater number of connections or stronger connections to other nodes. Thus, high strength reflects the importance or influence of a specific node within the network.

The PHQ2 Sad mood score had the highest centrality strength in the two estimated networks, whereas the lowest strength score was for self-rated health and physical activity at T1 and only physical activity at T2.

Expected influence
A greater expected influence indicates a more influential role of a node as a risk factor if the scores are positive or as a protective factor if the scores are negative. The closest-to-zero scores represent the lowest expected influence[46].

Again, PHQ2 Sad mood was the most influential risk factor in the network, whereas life satisfaction had the lowest negative score, thus constituting the most protective factor. Therefore, to deactivate the network, life satisfaction, self-rated physical health, and physical activity should be enhanced, while activating PHQ2 negatively influences the network. The outcomes were consistent at T1 and T2. The second influential risk factor was GAD2 Uncontrollable worry at T1 and T2, whereas GAD1 Nervousness was a more influential risk factor at T2.

Details regarding node centrality are presented in Fig. 4 for sample 1 and Fig. 5 for sample 2.

Network accuracy and stability
The accuracy of the centrality indices, determined via a subset bootstrap of 1000, was very good. Better stability is indicated by higher values of centrality estimates. The correlation stability (CS) coefficient was greater than 0.5 for betweenness and closeness and greater than 0.75 for strength during T1 in sample 1. The CS for sample 2 during T2 was greater than 0.5 for betweenness and greater than 0.75 for closeness and strength. The outcome of CS over 0.75 suggests that the evaluation of centrality indices is consistent in the vast majority of cases, even when three-quarters of the data are removed, whereas for CS 0.5, this is true when half of the data are removed. Details regarding the case-dropping bootstrap analysis, which estimated average correlations between centrality indices in the total sample and centrality indices in a random subsample, retaining only a certain portion of cases (90%-100%), are presented in Fig. 6 for sample 1 and Fig. 7 for sample 2.

| | Time 1 | | | | | | Time 2 | | | | | | |
| Variable | Range | M | SD | 95% CI | | Range | M | SD | 95% CI | | F(1,1820) | η² |
				LL	UL					LL	UL		
Depressive symptoms	0–27	9.14	6.23	8.63	9.64	0–27	10.32	6.54	10.68	9.95	13.42***	0.007
PHQ1 Anhedonia	0–3	1.15	1.00	1.07	1.23	0–3	1.54	1.05	1.48	1.60	56.07***	**0.030**
PHQ2 Sad Mood	0–3	1.06	1.02	0.98	1.14	0–3	1.42	1.03	1.37	1.48	50.50***	**0.027**
PHQ3 Sleep	0–3	1.37	1.12	1.24	1.43	0–3	1.26	1.12	1.20	1.32	n.s.	
PHQ4 Energy	0–3	1.56	0.99	1.48	1.64	0–3	1.69	1.03	1.64	1.75	6.84**	0.004
PHQ5 Appetite	0–3	1.20	1.04	1.12	1.29	0–3	1.27	1.10	1.20	1.33	n.s.	
PHQ6 Guilty	0–3	1.11	1.06	1.03	1.20	0–3	1.13	1.10	1.02	1.19	n.s.	
PHQ7 Concentration	0–3	0.92	1.06	0.83	1.00	0–3	1.08	1.06	1.02	1.14	9.34**	0.005
PHQ8 Motor	0–3	0.45	0.77	0.38	0.51	0–3	0.46	0.79	0.42	0.51	n.s.	
PHQ9 Suicide ideation	0–3	0.35	0.73	0.29	0.41	0–3	0.46	0.84	0.41	0.51	7.64**	0.004
Anxiety	0–21	8.32	5.32	7.89	8.75	0–21	8.82	5.58	8.51	9.13	n.s.	
GAD1 Nervousness	0–3	1.41	0.95	1.33	1.48	0–3	1.47	1.02	1.41	1.53	n.s.	
GAD2 Uncontrollable Worrying	0–3	1.21	0.95	1.14	1.29	0–3	1.11	1.00	1.06	1.17	4.09*	0.002
GAD3 Worry too much	0–3	1.32	1.00	1.24	1.40	0–3	1.61	1.01	1.56	1.67	34.36***	**0.019**
GAD4 Trouble relaxing	0–3	1.31	1.04	1.23	1.40	0–3	1.30	1.06	1.24	1.26	n.s	
GAD5 Restlessness	0–3	0.81	0.94	0.73	0.88	0–3	0.82	0.98	0.76	0.87	n.s	
GAD6 Irritability	0–3	1.27	0.96	1.20	1.35	0–3	1.44	1.00	1.39	1.50	11.98***	0.007
GAD7 Feeling afraid	0–3	0.98	1.03	0.90	1.06	0–3	1.06	1.07	1.00	1.12	n.s	
Perceived Stress	7–33	21.33	4.72	20.95	21.71	0–40	24.43	7.32	24.02	24.84	88.60***	**0.046**
Satisfaction with Life	5–35	21.79	6.42	21.27	22.30	5–35	20.13	6.53	19.77	20.50	25.79**	**0.014**
Self-Rated Health	1–5	2.27	0.88	2.20	2.35	1–5	2.37	0.89	2.32	2.42	4.59*	0.003
Physical Activity (min. per week)	0–1260	129.84	155.46	117.29	142.39	0–1260	128.44	150.82	120.01	136.88	n.s	

Table 2. Variable characteristics and results of one-way ANOVA. *M* mean, *SD* standard deviation, *CI* confidence interval. Small-sized effects are bolded (0.01–0.06). *$p < 0.05$, and ***$p < 0.001$.
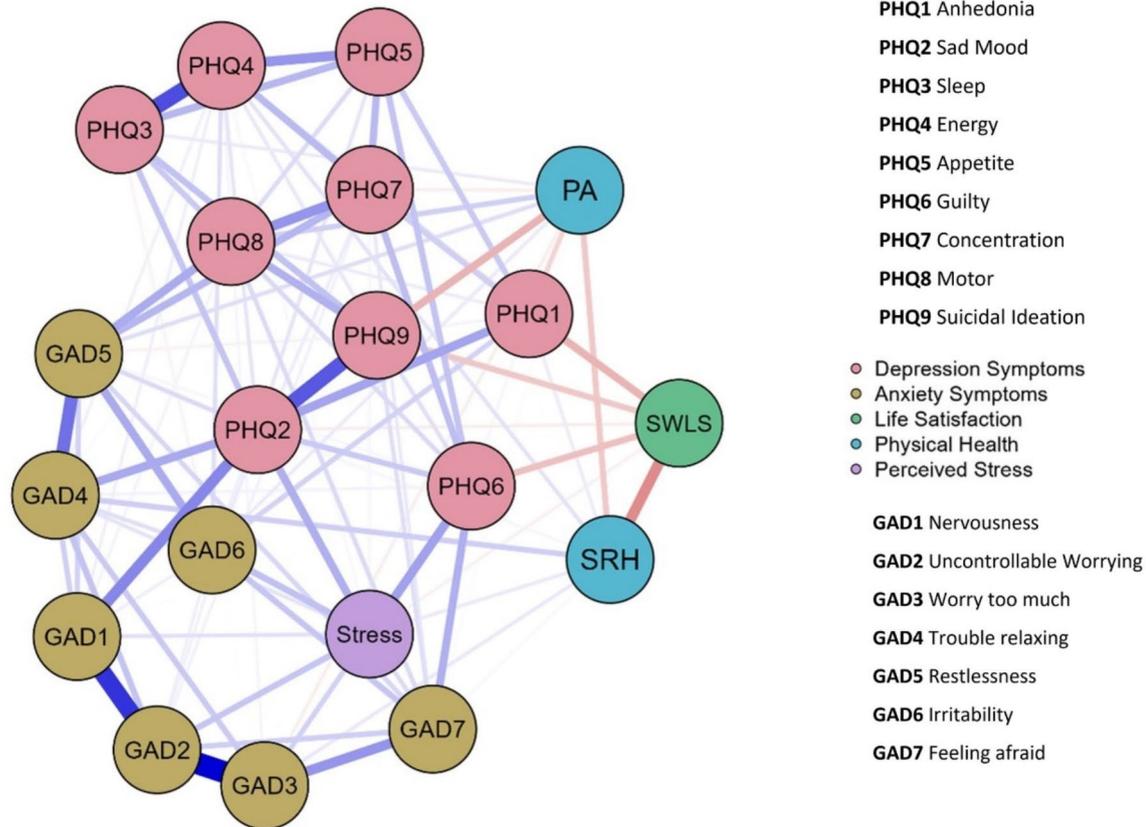
Fig. 2. Sample 1 Network of depressive and anxiety symptoms with well-being in Czech university students ($N = 592$) at T1. Nodes represent the following variables: blue edges represent positive relationships; red edges represent negative relationships. The thickness of the edges represents the strength of the relationships between the nodes.

Edge stability was calculated with 1000 nonparametric bootstrap samples for edge weight estimation in both samples. The nonparametric bootstrap analysis shows that both network models, at T1 and T2, exhibit high stability and accuracy in estimating centrality measures. The close alignment of the bootstrap means and the narrow confidence intervals reveal that the two networks' parameters are robust and reliable. The findings support the use of the current network models to further explore the psychological constructs under study. The results are presented in Fig. S1 for sample 1 at T1 and Fig. S2 for sample 2 at T2 in the Supplementary Materials.

Discussion

This was a unique network analysis study of depressive and anxiety symptoms with well-being in Czech university students during the COVID-19 pandemic involving two measurements.

We revealed significant changes in mental health and well-being over ten months and revealed that the symptom with the greatest degree of centrality for depression and anxiety was the PHQ2-Sad mood. The proposed network model of depressive and anxiety symptoms with respect to well-being was accurate, stable, and robust.

Differences over time

We revealed that during a more difficult pandemic situation, depressive symptoms at the scale level and individual symptoms increased significantly. Even though vaccination for COVID-19 was accessible during the second measurement, there was a profound increase in daily cases of COVID-19 infection. The new daily confirmed COVID-19 case rate was 154 times higher at T2 than at T1. Moreover, even though students experienced COVID-19 symptoms less frequently at T2, the proportion of infected friends and family members was greater. Additionally, almost every fifth student in this study experienced bereavement at T2. Thus, the pandemic situation during the second measurement was more challenging at many levels.

The risk of moderate depression was already high at T1, reaching 41.70%. This rate is twice as high as that reported in a previous study conducted with a similar sample of Czech university students (21%) at that
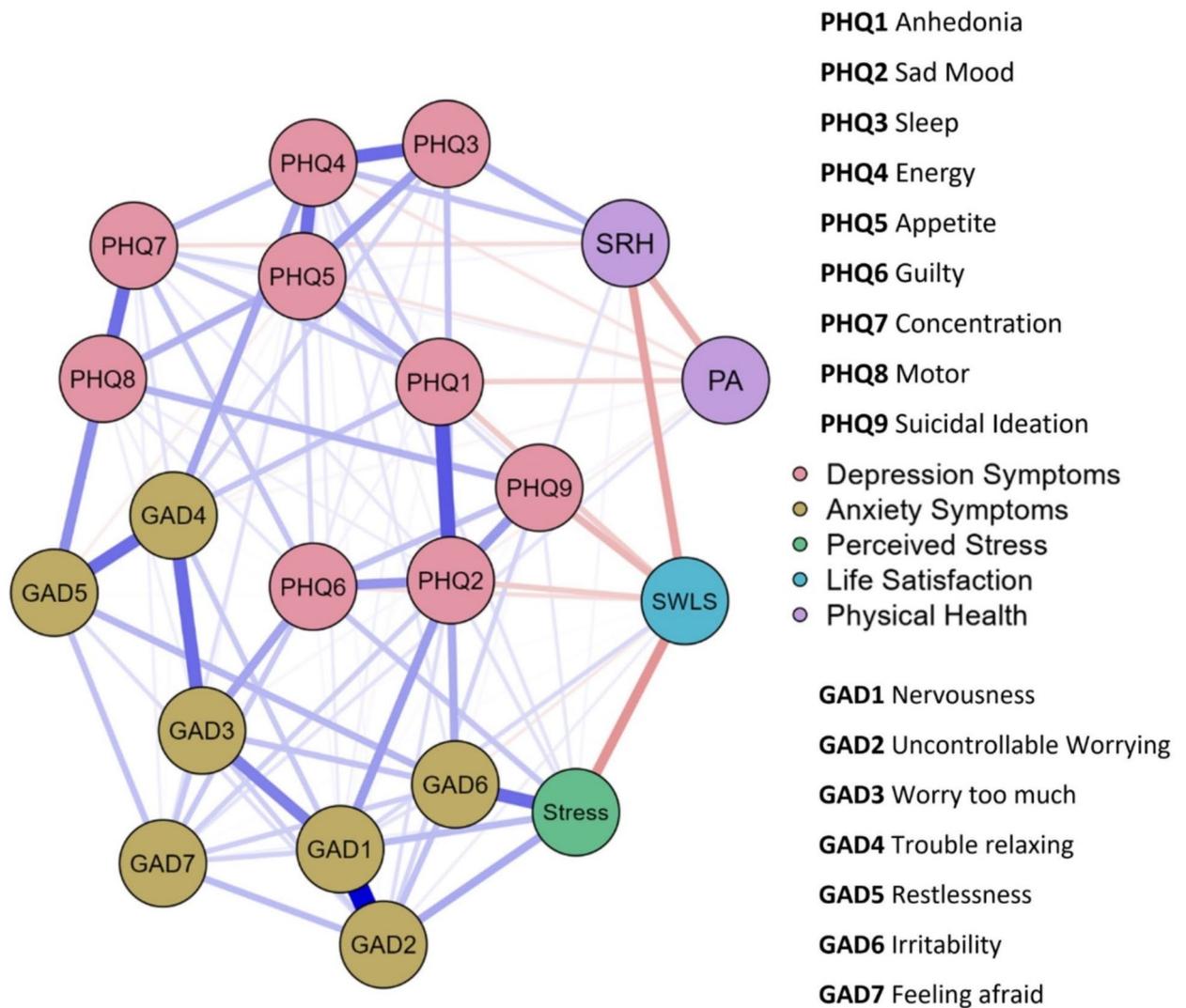
PHQ1 Anhedonia
PHQ2 Sad Mood
PHQ3 Sleep
PHQ4 Energy
PHQ5 Appetite
PHQ6 Guilty
PHQ7 Concentration
PHQ8 Motor
PHQ9 Suicidal Ideation

- Depression Symptoms
- Anxiety Symptoms
- Perceived Stress
- Life Satisfaction
- Physical Health

GAD1 Nervousness
GAD2 Uncontrollable Worrying
GAD3 Worry too much
GAD4 Trouble relaxing
GAD5 Restlessness
GAD6 Irritability
GAD7 Feeling afraid

Fig. 3. Sample 2 Network of depressive and anxiety symptoms with well-being in Czech university students ($N = 1230$) at T2. Nodes represent the following variables: blue edges represent positive relationships; red edges represent negative relationships. The thickness of the edges represents the strength of the relationships between the nodes.

time[16]. The higher prevalence might be due to the almost twofold larger sample size in this study. The moderate depression rate at T2 was higher, as expected, and reached over 50.00%. This means that during the third wave of the pandemic in Czechia, more than half of the students experienced at least moderate depressive symptoms. The increase between the two measurements was indeed significant, although the effect size was small. We noted that the moderate anxiety rate was 37.50% at T1 and 43.30% at T2. However, anxiety did not significantly increase at the scale level. Thus, when the scale-level results for depressive and anxiety symptoms were analyzed, there was a significant difference in depression but not anxiety levels. This result confirms previous results on depression among students with respect to the pandemic which indicate that students are particularly vulnerable to depression but not to anxiety. Moreover, previous longitudinal research has shown that in nationally representative samples from four countries, the prevalence of anxiety and depression did not change, regardless of changes in the pandemic situation[12]. Similar results were shown in a 12-measurement Dutch study during the pandemic[47]. Research has shown that fear of COVID-19 has changed significantly due to the pandemic situation[48], particularly with respect to the mortality rate[47], but depression and anxiety have stabilized over time. Our study confirmed that the student population is particularly vulnerable to increases in depression, unlike the general population[47,48]. Thus, further disturbances in external situations may negatively affect depression levels in students.

Analysis of differences in symptoms over time revealed changes in particular depressive and anxiety symptoms. The most pronounced change (although with a small effect) was observed with respect to the PHQ2 Sad score. A significant increase was observed in the PHQ4 Energy, PHQ7 Concentration, and PHQ9 Suicidal
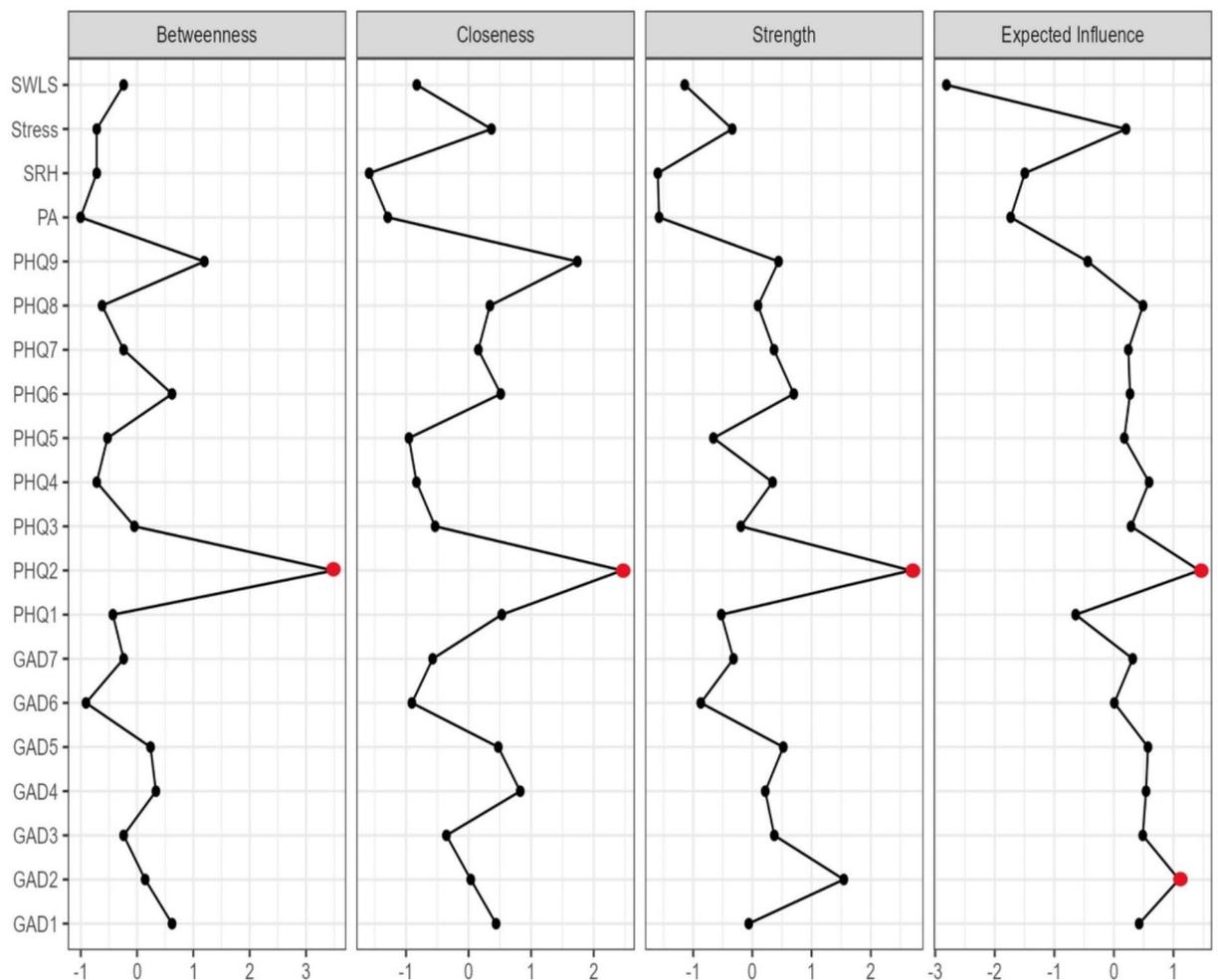
Fig. 4. Standardized centrality and expected influence values of nodes in the estimated networks in sample 1 (*N* = 592). The red dots denote the highest estimations. The red dots indicate the highest values.

Ideation scores, but the difference was negligible. With respect to anxiety symptoms, the students more strongly reported Uncontrollable worry (GAD2), Worry too much (GAD3), and Irritability (GAD6). Other symptoms of depression and anxiety were stable over time.

Life satisfaction decreased in a more difficult pandemic situation, whereas perceived stress increased. However, the change in perceived stress was more pronounced, similar to previous research in students[49]. Changes in stress over time during the COVID-19 pandemic were revealed in previous work in a representative sample of young adults from four countries. The perceived stress prevalence was lower in an improved pandemic situation[12]. This shows that changes in perceived stress due to the severity of the pandemic situation have occurred both in the student population and in a nationally representative population.

The students rated their physical health slightly more poorly during the second measurement, even though their physical activity was the same over time.

Centrality indices

The network analysis revealed that regardless of the severity of the external situation, the most central factor was the PHQ2 Sad mood. It played a crucial role as a bridge between the other nodes, had the shortest proximity and thus the possibility of prompt interaction, and had the strongest connectivity in the verified model at two measurements. Furthermore, it has the highest expected influence and can be treated as the strongest risk factor in the network. Previous research also noted the highest centrality strength for PHQ2[33,34,38,50]. We showed that PHQ2 Sad mood (feeling down, depressed, or hopeless) is a depressive symptom that exacerbates other symptoms regardless of the severity of the external situation.

However, some symptoms play different roles depending on the pandemic situation. At T1, PHQ9 Suicidal Ideation had the highest closeness, presenting the shortest paths (after PHQ2) with other nodes in the network. Moreover, it has high betweenness centrality, enabling information flow between the other nodes. However, during T2, those functions were transferred to PHQ1 Anhedonia. Thus, during a relatively safer pandemic situation (T1), suicidal thoughts were much quicker to interact with other variables in the network, whereas
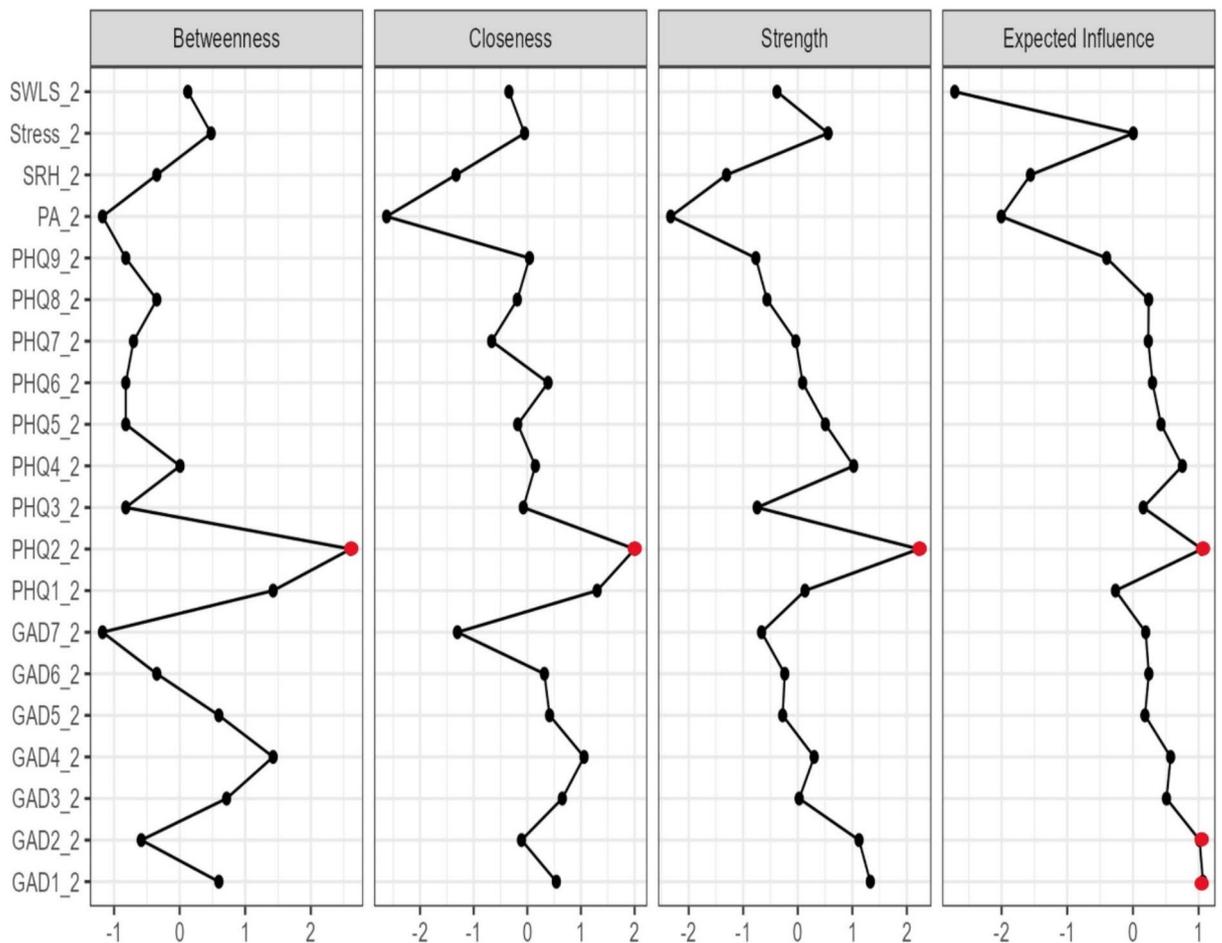
Fig. 5. Standardized centrality and expected influence values of nodes in the estimated networks in sample 2 ($N = 1230$). The red dots denote the highest estimations. The red dots indicate the highest values.

during a more challenging situation, anhedonia was a stronger risk factor for students' mental health and well-being. Thus, specific symptoms can play a different role depending on external situational circumstances.

Although suicidal ideation was the least common depressive symptom, it was closely related to other variables in the network. Thus, in a more stable external situation, even low levels of suicidal ideation may significantly and quickly affect other symptoms. Therefore, it is crucial to recognize and deactivate PHQ9, even when it rarely appears.

Moreover, perceived stress was a more pivotal node during the second measurement and less important during the first measurement. The least impactful nodes in the networks, regardless of the pandemic situation, were physical activity and self-rated health. Additionally, life satisfaction scored low in centrality indices in the networks. However, the lowest expected influences of life satisfaction, self-rated physical health, and physical activity were the most influential protective factors in the network. Thus, enhancing life satisfaction should deactivate risk factors. Unfortunately, the centrality analysis revealed that protective factors are closely connected with depressive and anxiety symptoms. Moreover, the strongest risk factor, PHQ2 Sad mood, increased during a more stressful situation at T2. Thus, during difficult situations, the PHQ2 score increases, resulting in the development of other depressive and anxiety symptoms.

Therefore, it is crucial to recognize the pivotal role of PHQ2 Sad mood as the strongest risk factor for mental health and well-being in students.

Network of depressive and anxiety symptoms with well-being

Satisfaction with life was directly related to depressive symptoms, self-rated health, and perceived stress. The relationships with anxiety were very sparse or nonexistent, particularly at T2. The most robust direct links for life satisfaction in both networks were self-rated physical health and suicidal ideation (PHQ9). This means that, regardless of the pandemic situation, life satisfaction decreased when students rated their physical health as lower and more often had suicidal thoughts.

Previous research among South Korean adults revealed strong relationships between life satisfaction and anhedonia (PHQ1) and sad mood (PHQ2)[42]. In our study, those links also appeared, although a link to anhedonia
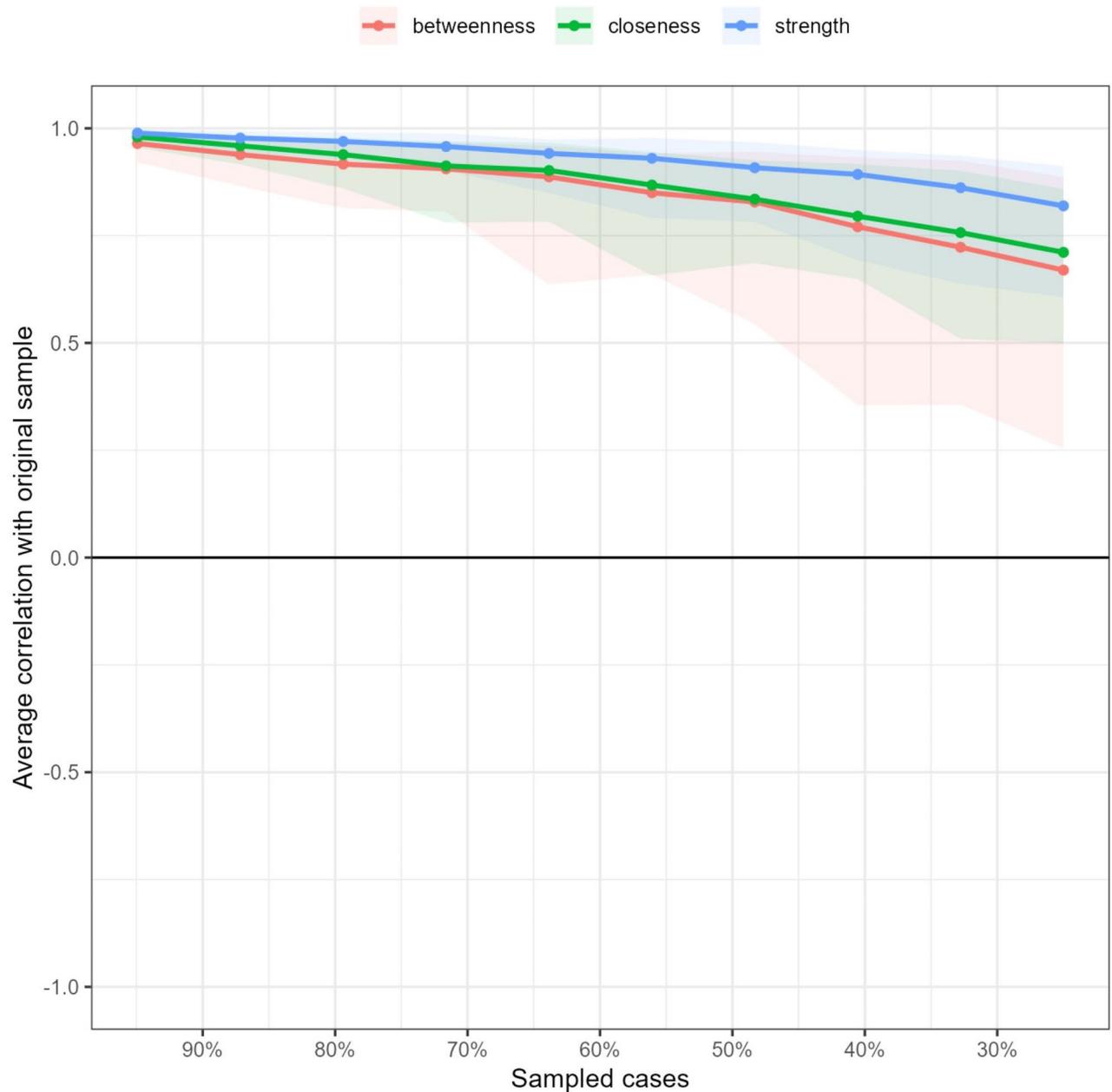
Fig. 6. Stability of the centrality indices (betweenness, closeness, and strength) in the estimated networks in sample 1 ($N = 592$). The shaded area indicates 95% confidence intervals of correlation estimates resulting from 1000 bootstraps.

was stronger at T2. We also found a link between life satisfaction and guilt (PHQ6) at two measurement points, although again, it was stronger at T2.

Stress was linked directly and positively to uncontrollable worrying (GAD2) and irritability (GAD6) over time. During relatively safe pandemic circumstances, stress was also strongly related to increased depressive symptoms (PHQ2 Sad mood; PHQ6 Guilty). During a more severe pandemic situation, there is greater nervousness (GAD1) and lower life satisfaction.

The direct link between physical activity and physical health was stable over time. Physical activity was additionally linked to suicidal ideation (PHQ9) at T1 but not at T2. Thus, in a less stressful situation, physical activity could directly decrease suicidal ideation levels, but not during a more severe pandemic situation. A recent meta-analysis did not find a significant decrease in suicidal ideation due to physical activity; however, it confirmed a significant decrease in suicide attempts[51]. Our results revealed a significant negative link, but it faded when the pandemic worsened. It seems that during more challenging external circumstances, physical activity is not enough to alleviate suicidal ideation.
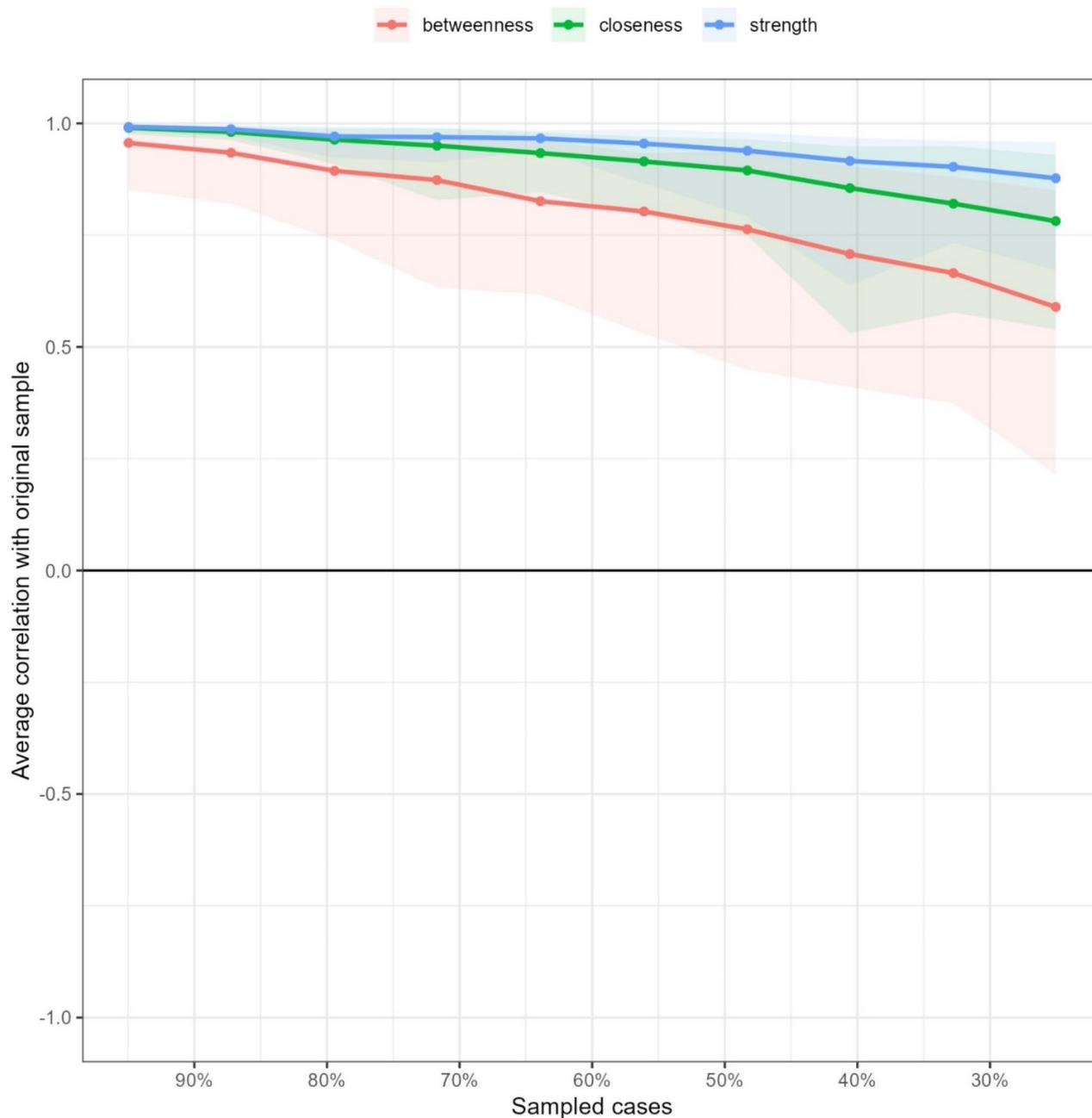
Fig. 7. Stability of the centrality indices (betweenness, closeness, and strength) in the estimated networks in sample 2 ($N = 1230$). The shaded area indicates 95% confidence intervals of correlation estimates resulting from 1000 bootstraps.

The most crucial node, PHQ2 Sad mood, was strongly related to nervousness (GAD1), anhedonia (PHQ1), and problems with sleep (PHQ3). Previous research[33,34,38,50] has also shown that central symptoms include depressive and anxiety symptoms. In our study, the links between depressive and anxiety symptoms (such as PHQ2 and GAD1) were stronger than those between depressive symptoms (e.g., no link between PHQ2 and PHQ7 or PHQ8 at T1) or anxiety symptoms (e.g., no link between GAD3 and GAD5 at T1 and T2).

Moreover, we found that during the second measurement, suicidal ideation (PHQ9) was alleviated by feeling tired (PHQ4). Even though the strength of this link was low, we revealed a negative direction that did not appear during the first measurement.

Thus, even though the network was relatively stable over time, the relationship between symptoms and their role may differ due to changes in the external environment.

Conclusions

We revealed that the PHQ2 Sad mood score among Czech students was the most influential node during two measurements in the COVID-19 pandemic. It plays the role of a bridge between other factors, has the shortest proximity to other nodes, and is the most connected node in the research network. Sad mood is also the highest risk factor, together with the GAD2 score, which is associated with uncontrollable worrying. These two factors constitute the highest risk factors in the network of mental health symptoms and well-being.

Furthermore, we showed that the protective factors are life satisfaction, physical activity, and self-rated physical health, which are stable over time. However, these factors had low centrality indices.

Even though the networks were stable over time, we revealed that in different external circumstances, the relationships between particular depressive and anxiety symptoms and other factors changed. Thus, we can recognize one symptom (Sad mood) as the riskiest and most influential in diverse external circumstances.

It is important to understand the mechanism behind depression and anxiety symptoms to create and promote effective interventions. For example, an intervention can be framed as focused on one's strengths[52]. Understanding which specific symptoms activate the network of depressive/anxiety symptoms allows for the introduction of more precise programs and interventions. Including techniques that help alleviate perceived stress and sad mood in the students' curriculum is crucial.

The strength of this study was that it revealed a complex network of depressive and anxiety symptoms with respect to well-being in two samples of Czech university students over time during the COVID-19 pandemic. However, this study has several limitations. The design of this study was repeated cross-sectional; thus, we could not identify causal relationships. Furthermore, this is a self-reported study. Unfortunately, we did not control the students' previous medical history. Moreover, on the one hand, the results for a group of nonmedical university students reveal the Czech context, but on the other hand, they lack a more generalized, cross-cultural context. Previous research revealed significant variations in students' mental health issues among countries during the COVID-19 pandemic[17]. Therefore, it is crucial to thoroughly comprehend these differences and consider the cultural context. Building on previous research[33,34,38,50] and the network's stability over time, as well as its resilience to various external challenges, we can assume that the centrality of depressive and anxiety symptoms can be universally applicable. However, the relationships with other nodes may vary due to cultural differences. Therefore, further validation of the model in a cross-cultural context is needed.

Methods

Study design

This study was conducted in a repeated cross-sectional design among students from Mendel University of Brno in Czechia at two measurement points. The first measurement (T1) was taken between 17 June and 24 July 2020, whereas the second (T2) was taken after 10 months, between 7 and 31 March 2021. The inclusion criteria were being a student at the bachelor's or master's level of the stationary mode of study and an age ranging from 20 to 30 years.

The online survey was prepared in the Czech language. Common biases were controlled by providing a variety of possible responses, both visually and relating to content. The answers were constructed from higher to lower and from lower to higher to avoid biases. The participants could stop at any time and return to finish the survey when desired, and there was no time limit on survey completion. The students were not rewarded for their participation in the study.

The survey at T1 was distributed among 673 students, among whom 666 signed an informed consent form to participate in the study. For the purpose of this study, students in nonstationary mode were excluded ($N = 74$). The final sample size at T1 was 597.

During the second measurement, the survey was distributed among 1304 students. At T2, 1294 students agreed to participate in the study. The final sample of students who met the inclusion criteria of stationary study mode was 1230.

Ethics statement

The University Research Committee at the University of Opole, Poland, approved the study protocol with decision no. 1/2020. The study received the Ethics Waiver from Mendel University in Brno, Czech Republic, as it followed the ethical standard of the 1964 Helsinki Declaration and its amendments and adhered to specific obligatory regulations in the Czech Republic.

The study followed the ethical requirements of anonymity and voluntary participation. Each person provided written informed consent. In accordance with the Declaration of Helsinki, written informed consent was obtained from each participant before inclusion. All methods were carried out under relevant guidelines and regulations.

This study was a part of the international project "Mental health of undergraduates during the COVID-19 pandemic"[53].

Statistical analysis

The statistical analyses were performed via JASP 0.18.3 computer software (network analysis) and IBM SPSS Statistics for Windows 29.0 (χ^2 test, Student's t test, one-way ANOVA, descriptive statistics). A chi-square (χ^2) test was performed for frequencies of descriptive variables.

The χ^2 test of independence was used to verify whether the proportion of participants significantly differed due to sociodemographic variables in the two samples. Student's t test was used to compare the mean age of the two samples. The effect size was measured by Cohen's d coefficient, described as low if $d \geq 0.20$, medium if $d \geq 0.50$, and large if $d \geq 0.80$. One-way analysis of variance (ANOVA) was performed to reveal the significance

of differences in mental health and well-being over time. The effect size for ANOVA was evaluated by η^2 (low if $\eta^2 \geq 0.01$, medium if $\eta^2 \geq 0.06$, and large if $\eta^2 \geq 0.14$).

For the calculation of moderate depression and anxiety prevalence, the PHQ-9 and GAD-7 scores were coded with cutoff scores equal to or above 10[54,55]. As there is no cutoff score for the measurement of perceived stress by the PSS-10, the recommended level for high perceived stress over 20 was utilized[56].

The final step was network analysis. We chose the EBICglasso estimator with the extended Bayesian information criterion (EBIC) tuning parameter at the recommended value of 0.5 to compute a sparse Gaussian graphical model (GGM) with a graphical lasso[57]. All 20 continuous and ordinal variables were introduced to the model, which was applied to the two samples of university students. The model was signed, weighted, and estimated via (penalized) maximum likelihood estimation[50].

Centrality stability was calculated to assess the degree to which centrality estimates were subject to sampling error. The accuracy of the centrality indices was determined with 1000 bootstrap samples. The correlation stability (CS) coefficient should not be less than 0.25 and should preferably be greater than 0.5. Edge stability was investigated via a subset of 1000 bootstrapping operations.

Network analysis is a unique method used to explore complex systems that combine environmental, behavioral, and psychological data. We assumed a mutualistic model. A network is a system that consists of nodes (visually represented by circles) connected by edges (lines) that reflect the strength of the relationship between nodes, typically after controlling for all variables in the network[58]. The blue edges represent positive associations, whereas the red edges represent negative associations. The thickness and saturation of the edges represent the strength of the relationships between the nodes. The centrality measures were standardized as z scores for betweenness, closeness, strength, and expected influence.

Sample size
A large sample is expected to establish a stable and accurate network. However, predicting network structure and edge weights is difficult, as little evidence exists for a priori power analysis guidance[58]. Thus, we assumed at least 500 participants.

Measurements
Depression
The 9-item Patient Health Questionnaire (PHQ-9)[54] was used to evaluate depressive symptoms in the preceding two weeks. The participants respond on a 4-point scale (from 0 = not at all to 3 = nearly every day). The PHQ-9 can be used as a unidimensional scale with scores ranging from 0 to 27 (higher scores indicate greater depression risk). This study's reliability coefficient (Cronbach's α) was 0.87 and 0.88 for T1 and T2, respectively.

Anxiety
For anxiety symptom measurement, we used the 7-item Generalized Anxiety Disorder (GAD-7) scale[55]. This instrument is used to evaluate anxiety symptoms during the preceding two weeks. The participants used a 4-point response scale (from not at all = 0 to nearly every day = 3). The GAD-7 can be used as a unidimensional scale, with scores ranging between 0 and 21 (higher scores indicate a greater risk of general anxiety disorder). In the current study, Cronbach's α was 0.89 at T1 and T2.

Perceived stress
We utilized the 10-item Perceived Stress Scale (PSS-10) to measure the frequency of stressful events in the previous month[56]. The participants evaluate their answers on a 5-point Likert scale (from 0 = never to 4 = very often). The higher the score (ranging from 0 to 40), the greater the perceived stress. In this study, Cronbach's α was 0.56 at T1 and 0.85 at T2.

Life satisfaction
Life satisfaction was evaluated by the Satisfaction with Life Scale (SWLS)[59]. The SWLS evaluates a global cognitive aspect of subjective well-being. The scores range from 5–35, and participants respond to a 7-point Likert scale (from 1 = Strongly disagree to 7 = Strongly agree). Higher scores indicate greater life satisfaction. In the current study, Cronbach's α = 0.84 and 0.84 for T1 and T2, respectively.

Physical health
Physical health was evaluated by one-item self-rated health (SRH)[60]. The participants rated their health on a 5-point Likert scale (from Excellent = 1 to Poor = 5). The higher the scores, the worse the self-rated physical health.

Physical activity
Physical activity was measured by a self-report questionnaire on physical activity frequency during the previous week. The outcome was calculated by multiplying the number of days and minutes per day during the last week. According to the World Health Organization[61], those who take at least 150 min per week are considered physically active, whereas those under this threshold are considered physically inactive.

Sociodemographic data
The sociodemographic survey referred to gender, age, place of residence, year of study, mode of study (stationary vs. nonstationary), and faculty type.

Data availability

The measurements and the database are accessible at the Centre for Open Science OSF upon reasonable request[53] to the corresponding author, Dominika Ochnik.

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Author contributions

D.O. conceptualized and supervised the study. I.B. organized the data collection. D.O. and E.R. wrote the first draft of the manuscript. D.O. performed the statistical analysis and figure generation. All the authors (D.O., E.W., Z.C., H.N., M.S., M.S., A.S., N.S.-G., M.W., and I.B.) contributed to the writing and interpretation of the results.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics declarations

The University Research Committee at the University of Opole, Poland, approved the study protocol with decision no. 1/2020. The study received the Ethics Waiver from Mendel University in Brno, Czech Republic, as it followed the ethical standard of the 1964 Helsinki Declaration and its amendments and adhered to specific obligatory regulations in the Czech Republic. The study followed the ethical requirements of anonymity and voluntary participation. Each person provided written informed consent. In accordance with the Declaration of Helsinki, written informed consent was obtained from each participant before inclusion. All methods

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Additional information

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