

Supplemental Materials

S1. Gaussian Graphical Models (GGMs) Analyses

S2. Sensitivity Analysis with One Standard Deviation Perturbation

S3. Ising Model Supplemental Materials

S1. Gaussian Graphical Models (GGMs) Analyses

S1.1. Methods: Gaussian Graphical Model Network Analyses

First, Gaussian graphical models (GGMs) were used to estimate depressive symptom networks for early, middle, and late adolescence. In these networks, nodes represented depressive symptoms and edges represented the partial correlations between pairs of symptoms [1]. The *EBICglasso* was applied to reduce spurious edges. All network estimations were implemented using the *qgraph* package.

Second, the expected influence (EI) centrality index was employed to assess the importance of each depressive symptom within the networks. EI is defined as the sum of the edge weights connecting a given symptom to all others. The EI value of each symptom was calculated using the *bootnet* package [2]. Symptoms were ranked by their EI values within each stage of adolescence.

Third, network comparison tests (NCTs) were conducted using the *NetworkComparisonTest* package to examine differences in network structure, edge strength, global expected influence, and symptom centrality (*i.e.*, EI) between any two networks [3].

Fourth, the accuracy and stability of the networks were assessed via the *bootnet* package [4]. The accuracy of edge weights was evaluated by estimating 95% confidence intervals (CIs) with 1000 nonparametric bootstraps. The stability of the EI centrality indices was examined by calculating correlation stability (CS) coefficients. The CS coefficients should ideally be above 0.5 and not below 0.25.

S1.2. Results

S1.2.1. Network Structures and Central Depressive Symptoms

Figure S1 presents network structures of depressive symptoms across different stages of adolescence. In the three networks, the number of non-zero edges was 151, 137, and 141, respectively, out of 190 possible edges. In early adolescence, the strongest edge was between “feeling unhappy” (CESD12R) and “can’t enjoy life” (CESD16R), with an edge weight of 0.52. In middle adolescence, the strongest edge was between “crying” (CESD17) and “feeling sad” (CESD18), with an edge weight of 0.52. In late adolescence, the strongest edge was again between “feeling unhappy” (CESD12R) and “can’t enjoy life” (CESD16R), with an edge weight of 0.55. The mean edge weight was 0.05 in each network, indicating the presence of many weak edges across all three networks.

“Feeling sad” (CESD18) exhibited the highest EI centrality in early, middle, and late adolescence, emerging as the most central depressive symptom across all stages. “Feeling depressed” (CESD6) has one of the top three highest EI values across these period, indicating its consistently high centrality within the three networks. The full EI centrality results for all depressive symptoms are available in Figure S2.

All three networks demonstrated adequate accuracy. The CS coefficients for EI was 0.75 in each network. Detailed results regarding the networks’ accuracy and stability are presented in Figures S3 and S4.

S1.2.2. Central Symptoms of GGMs and Ising Models

The results of the *Ising* model analysis showed that “feeling sad” (CESD18) in

early adolescence and “feeling depressed” (CESD6) in middle and late adolescence had the highest EI values. These two symptoms were identified as the most central symptoms in their respective developmental stages. “Feeling sad” (CESD18) emerged as the most central symptom in both the GGM and the *Ising* networks in early adolescence. In middle and late adolescence, “feeling depressed” (CESD6) and “feeling sad” (CESD18) were the two most central symptoms in both the GGM and *Ising* networks.

References

1. Epskamp S, Fried EI. A tutorial on regularized partial correlation networks. *Psychol. Methods* **2018**, 23, 617–634. DOI:10.1037/met0000167
2. Robinaugh DJ, Millner AJ, McNally RJ. Identifying highly influential nodes in the complicated grief network. *J. Abnorm. Psychol.* **2016**, 125, 747–757. DOI:10.1037/abn0000181
3. Van Borkulo CD, Van Bork R, Boschloo L, Kossakowski JJ, Tio P, Schoevers RA, et al. Comparing network structures on three aspects: A permutation test. *Psychol. Methods* **2023**, 28, 1273–1285. DOI:10.1037/met0000476
4. Epskamp S, Borsboom D, Fried EI. Estimating psychological networks and their accuracy: A tutorial paper. *Behav. Res. Methods* **2018**, 50, 195–212. DOI:10.3758/s13428-017-0862-1

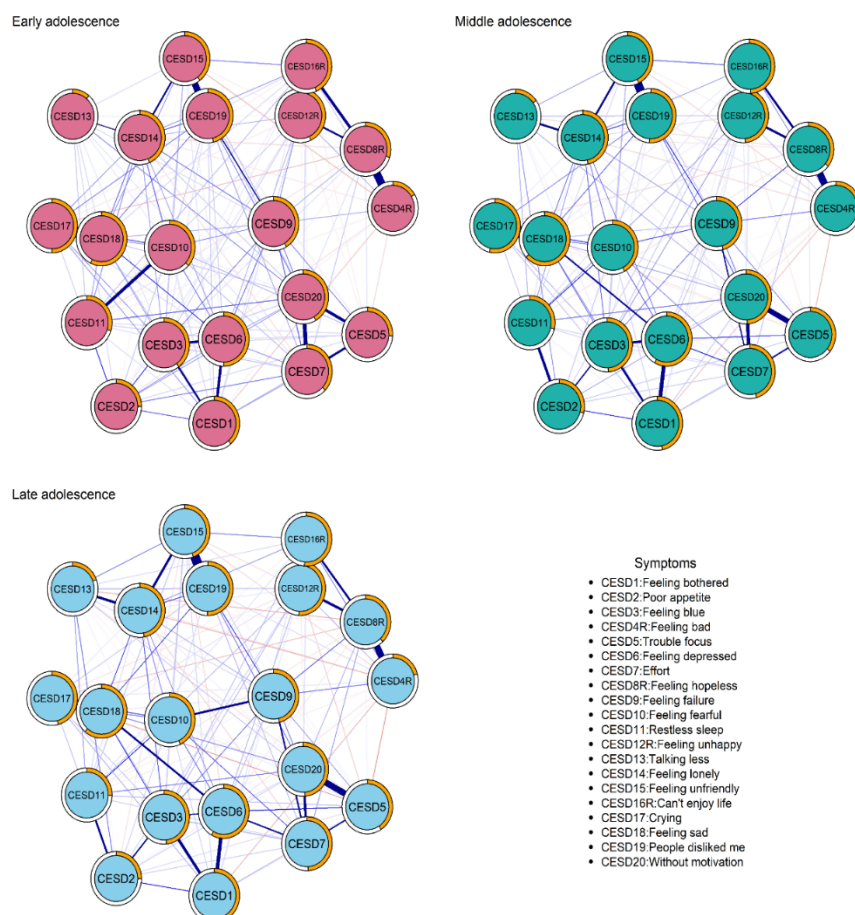


Figure S1. GGM network structures of depressive symptoms at different stages of adolescence. Note: Each node represents a depressive symptom. Blue edges represent positive connections and red edges represent negative connections. Thicker edges indicate stronger connections. The ring around each node indicates its predictability by all other nodes in the network. A larger orange sector corresponds to higher predictability.

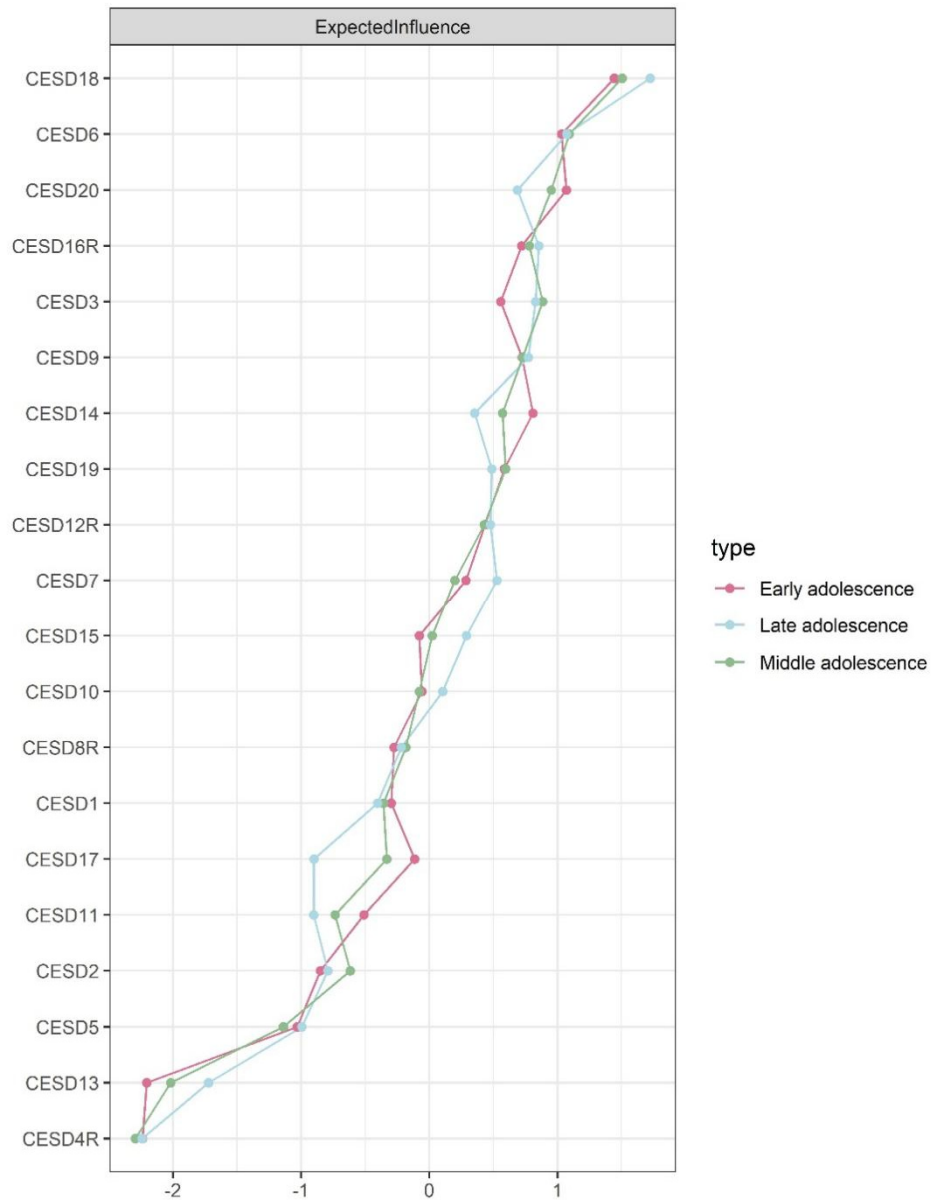


Figure S2. EIs of depressive symptoms in GGM networks for different stages of adolescence. Note: The red line represents the EIs of depressive symptoms in early adolescence. The green line represents the EIs of depressive symptoms in middle adolescence. The blue line represents the EIs of depressive symptoms in late adolescence. Symptoms were ordered by their EI values.

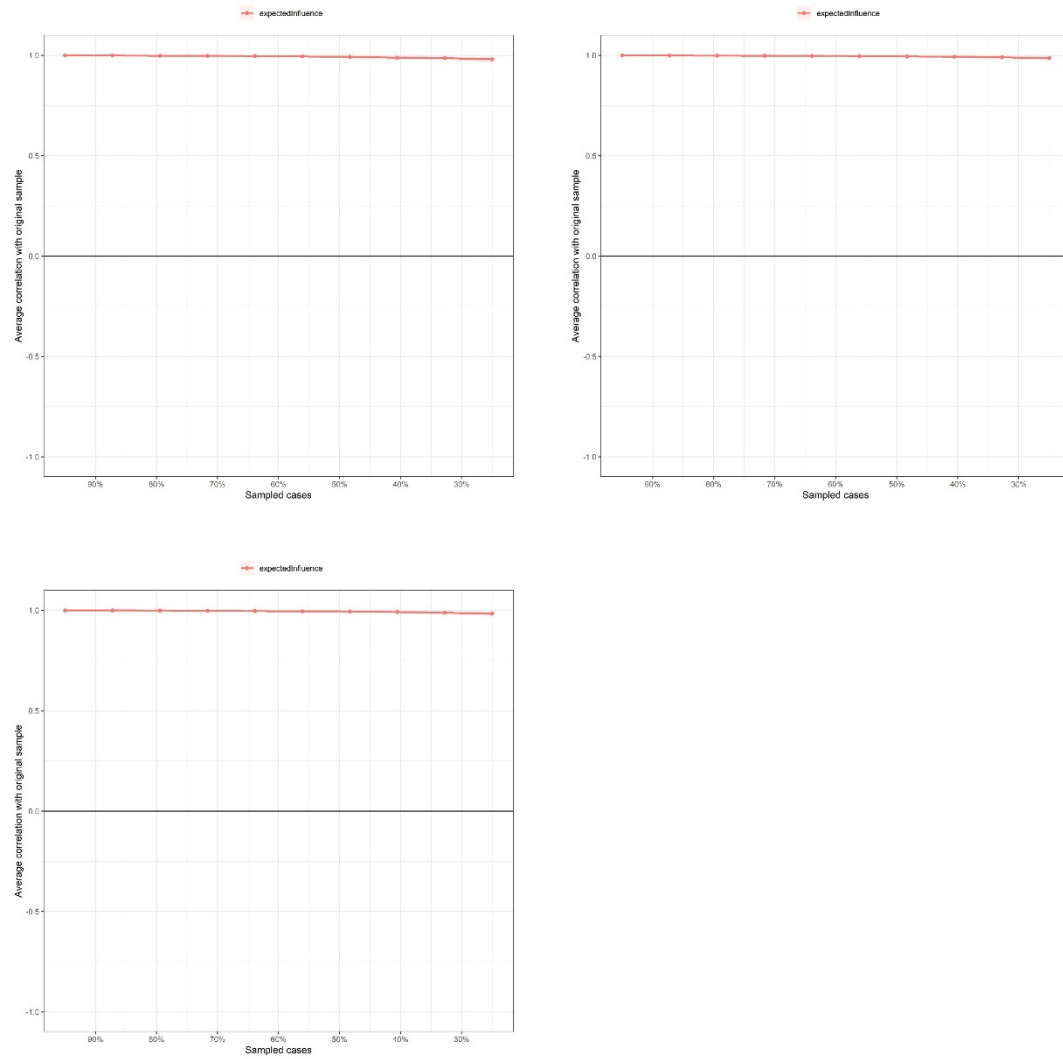


Figure S3. Centrality stability in GGM networks across different stages of adolescence. Note: This figure shows the different proportion of cases that can be dropped, such that with 95 % probability the correlation between original centrality indices and centrality of networks based on subsets is 0.7 or higher. The proportion of dropped cases is 0.75% for three networks.

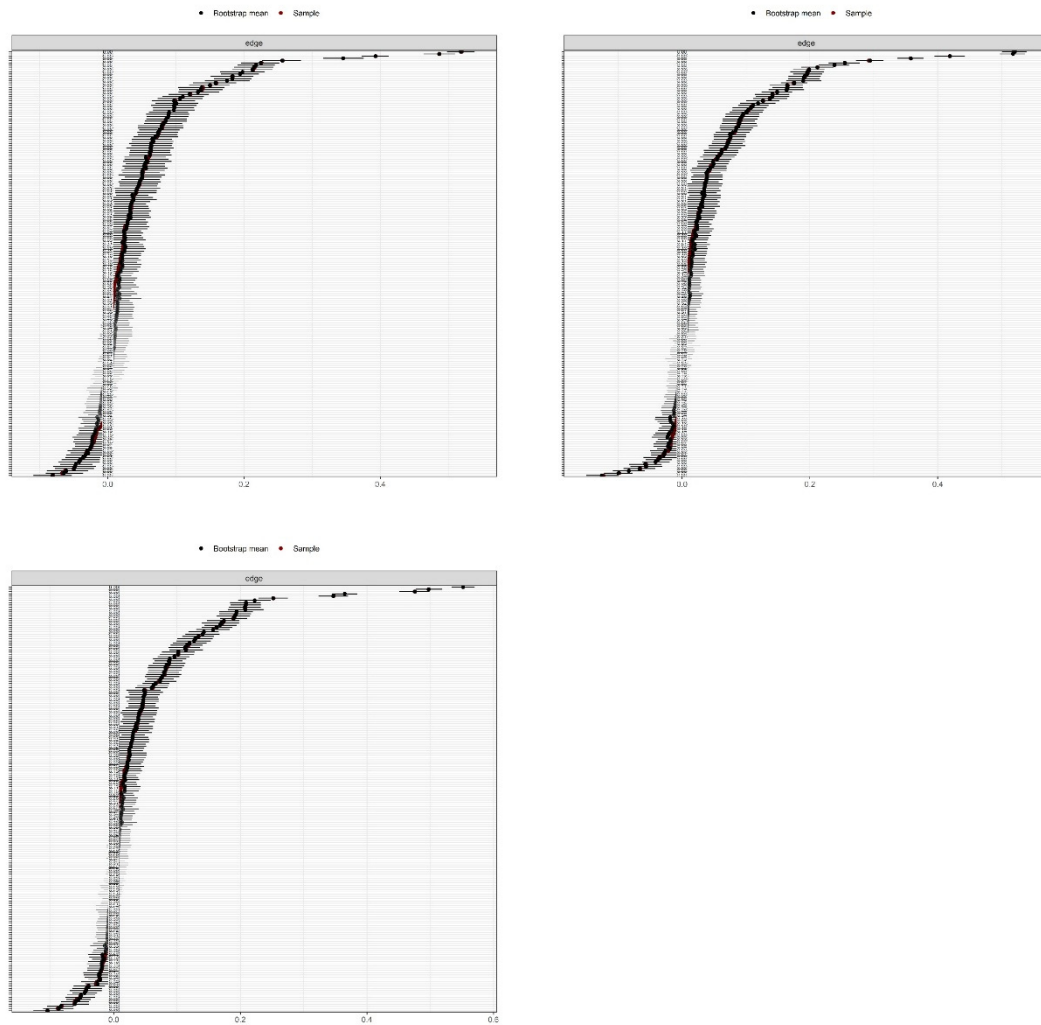


Figure S4. Edge weight accuracy in GGM networks for different stages of adolescence. Note: The figure presents the edge weight accuracy estimated via 1000 bootstraps for early, middle, and late adolescence. It can be observed that the narrow range of the 95% confidence intervals indicates a relatively accurate estimation of the edge weights.

S2. Sensitivity Analysis with One Standard Deviation Perturbation

The Alleviating and Aggravating Interventions

Figure S5 presents the results of alleviating and aggravating interventions in early, middle, and late adolescence. Depressive symptoms exhibited distinct projected effects on the whole network states across different stages of adolescence. In early adolescence, the alleviating intervention targeting “crying” (CESD17) had the greatest projected effect on the overall network state. Deactivating this symptom reduced the sum score mean from 4.61 to 3.88 (NIRA score = 0.73). In the aggravating intervention, “feeling sad” (CESD18) exhibited the greatest projected effect on the network state. Worsening this symptom increased the sum score mean from 4.57 to 5.61 (NIRA score = 1.04). Moreover, the confidence intervals for the effects of worsening “feeling depressed” (CESD6) and “feeling sad” (CESD18) largely overlapped. Worsening “feeling depressed” (CESD6) increased the sum score mean from 4.57 to 5.60 (NIRA score = 1.03).

Simulation interventions in middle and late adolescence exhibited aligned outcomes. The alleviating intervention targeting “feeling depressed” (CESD6) had the greatest projected effect on the whole network state, reducing the sum score mean from 7.22 to 5.86 (NIRA score = 1.36) in middle adolescence and from 7.53 to 6.11 (NIRA score = 1.42) in late adolescence. In the aggravating intervention, “feeling sad” (CESD18) showed the greatest projected effect, increasing the sum score mean from 7.17 to 8.73 (NIRA score = 1.56) in middle adolescence and from 7.58 to 9.11 (NIRA score = 1.54) in late adolescence.

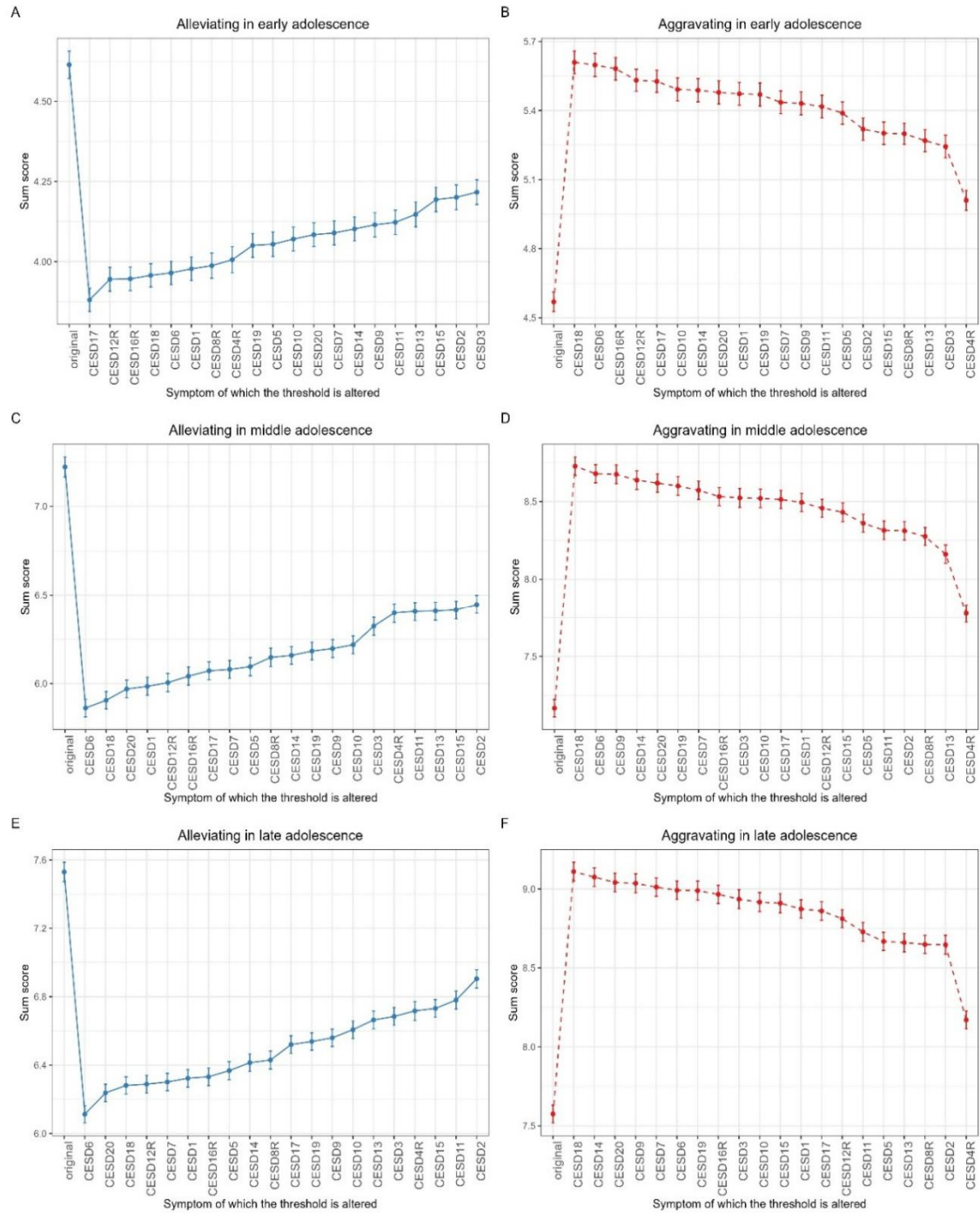


Figure S5. Results of alleviating and aggravating interventions for early, middle, and late adolescence. Note: The figure presents the simulated intervention used one standard deviation perturbation. This figure comprises six subplots. In each subplot, the x-axis displays individual depressive symptoms whose thresholds were altered and the y-axis shows the sum score of the network following each intervention. (A) alleviating interventions in early adolescence; (B) aggravating interventions in early adolescence; (C) alleviating interventions in middle adolescence; (D) aggravating interventions in middle adolescence; (E) alleviating interventions in late adolescence; (F) aggravating interventions in late adolescence.

S3. Supplemental Materials of Ising Models

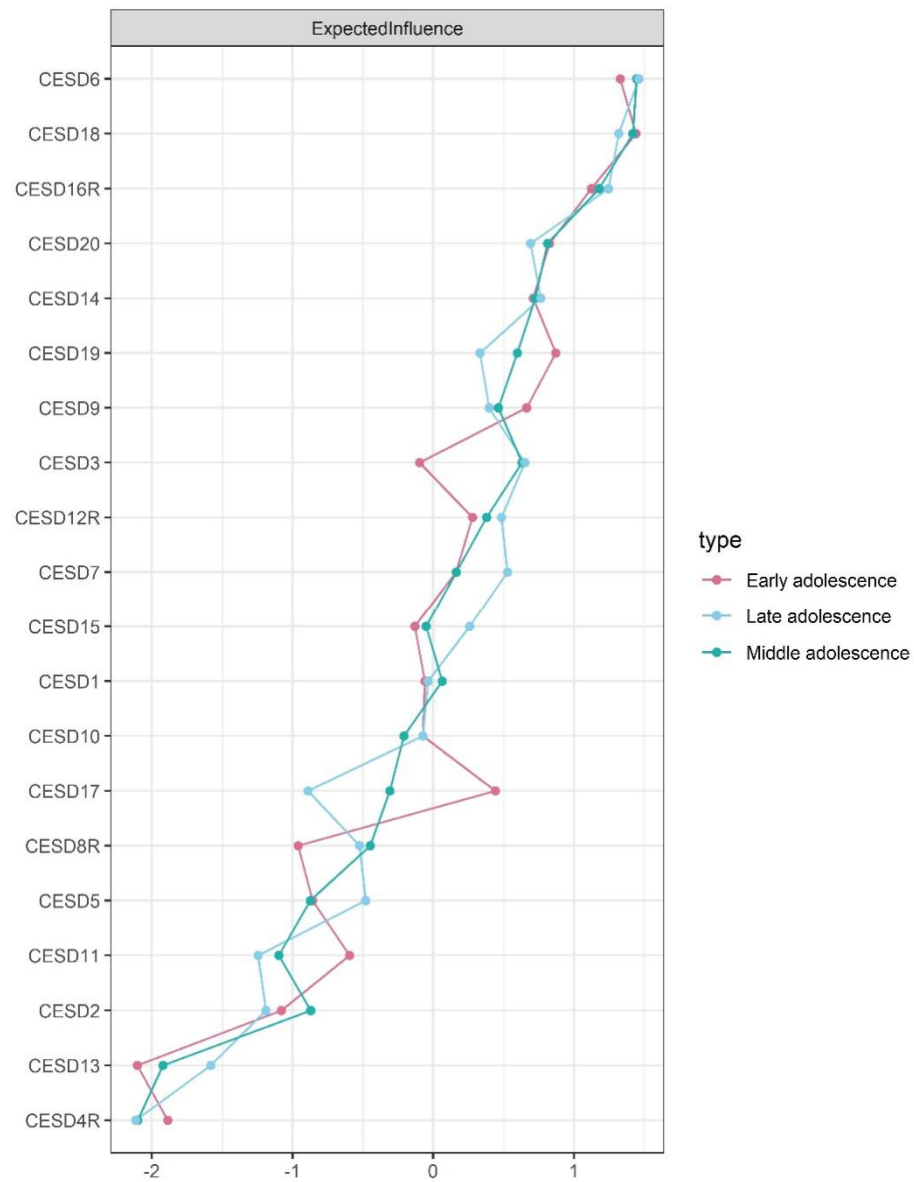


Figure S6. EIs of depressive symptoms in Ising networks across different stages of adolescence. Note: The red line represents the EIs of depressive symptoms in early adolescence. The green line represents the EIs of depressive symptoms in middle adolescence. The blue line represents the EIs of depressive symptoms in late adolescence. Symptoms were ordered by their EI values.

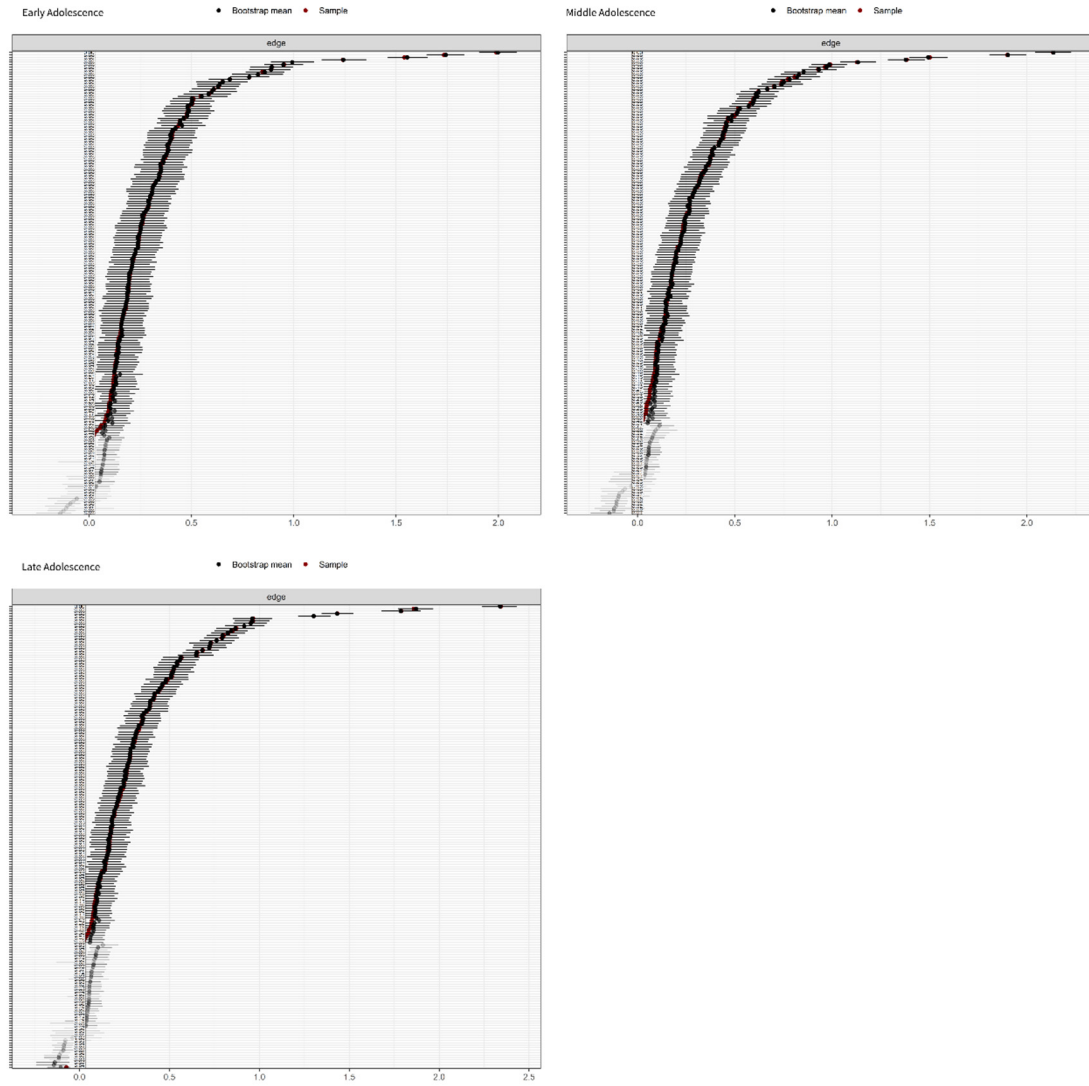


Figure S7. Edge weight accuracy of Ising networks across different stages of adolescence. Note: The accuracy of edge weights was evaluated by estimating 95% confidence intervals (CIs) with 1000 nonparametric bootstraps. A narrower confidence interval is often interpreted as indicating higher accuracy of edge weights.

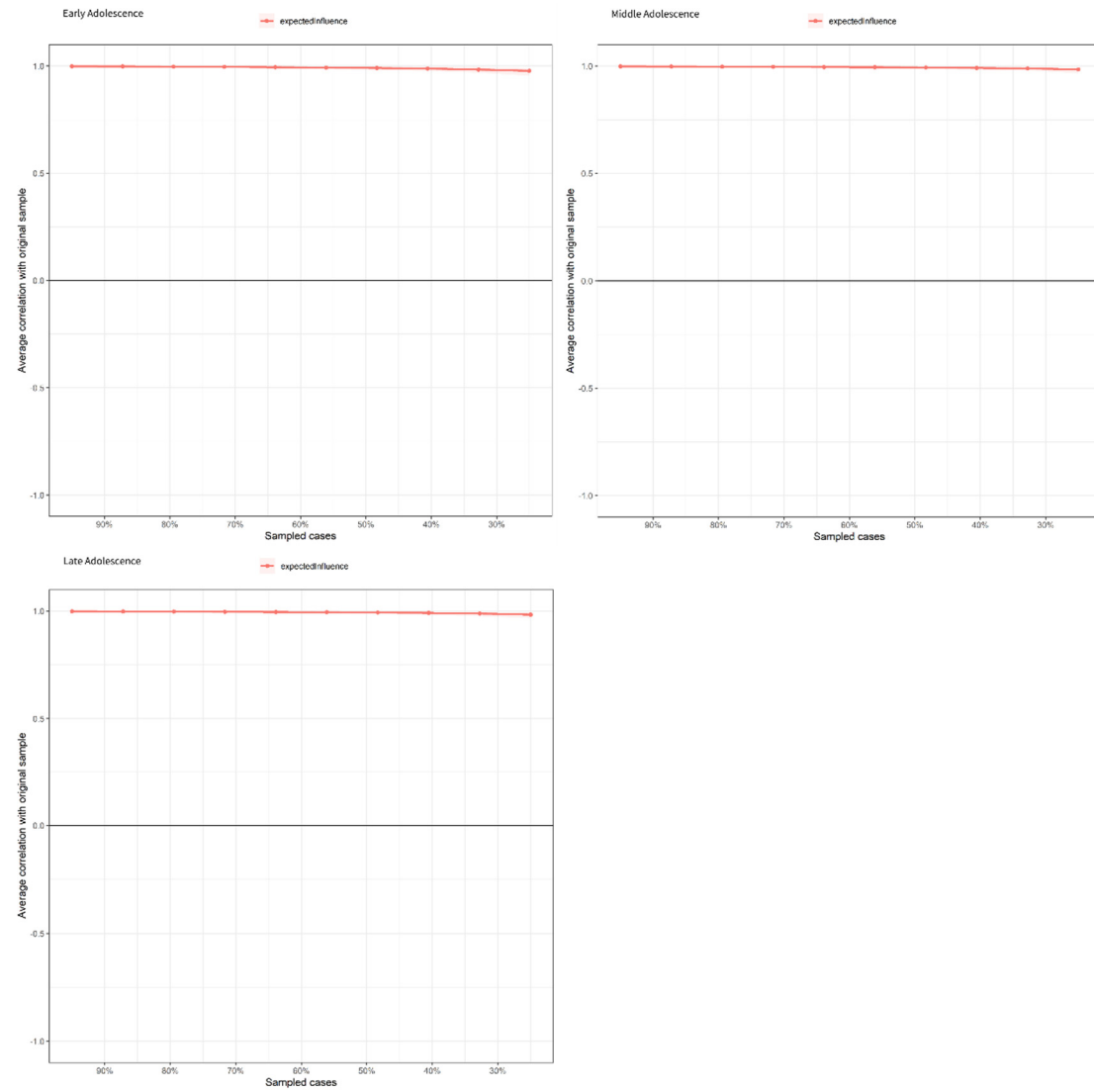


Figure S8. Centrality stability of Ising networks across different stages of adolescence. Note: The stability of the EI centrality indices was examined by calculating correlation stability (CS) coefficients. The CS coefficient was 0.75 in each Ising network.

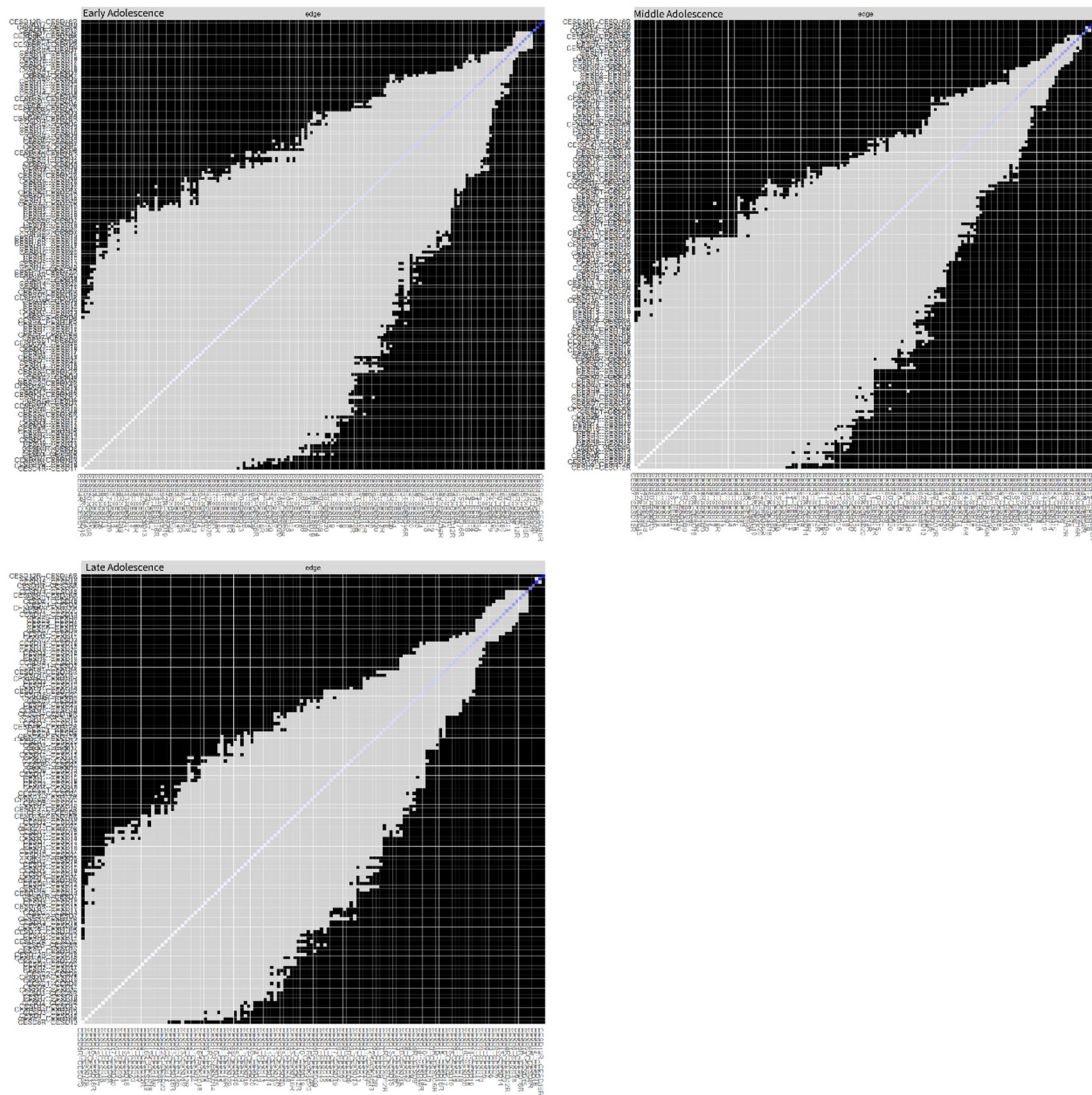


Figure S9. Edge weight differences of Ising networks across different stages of adolescence. Note: Black cells indicate that there is a significant difference between the two edge weights, and grey cells indicate the absence of a significant difference.

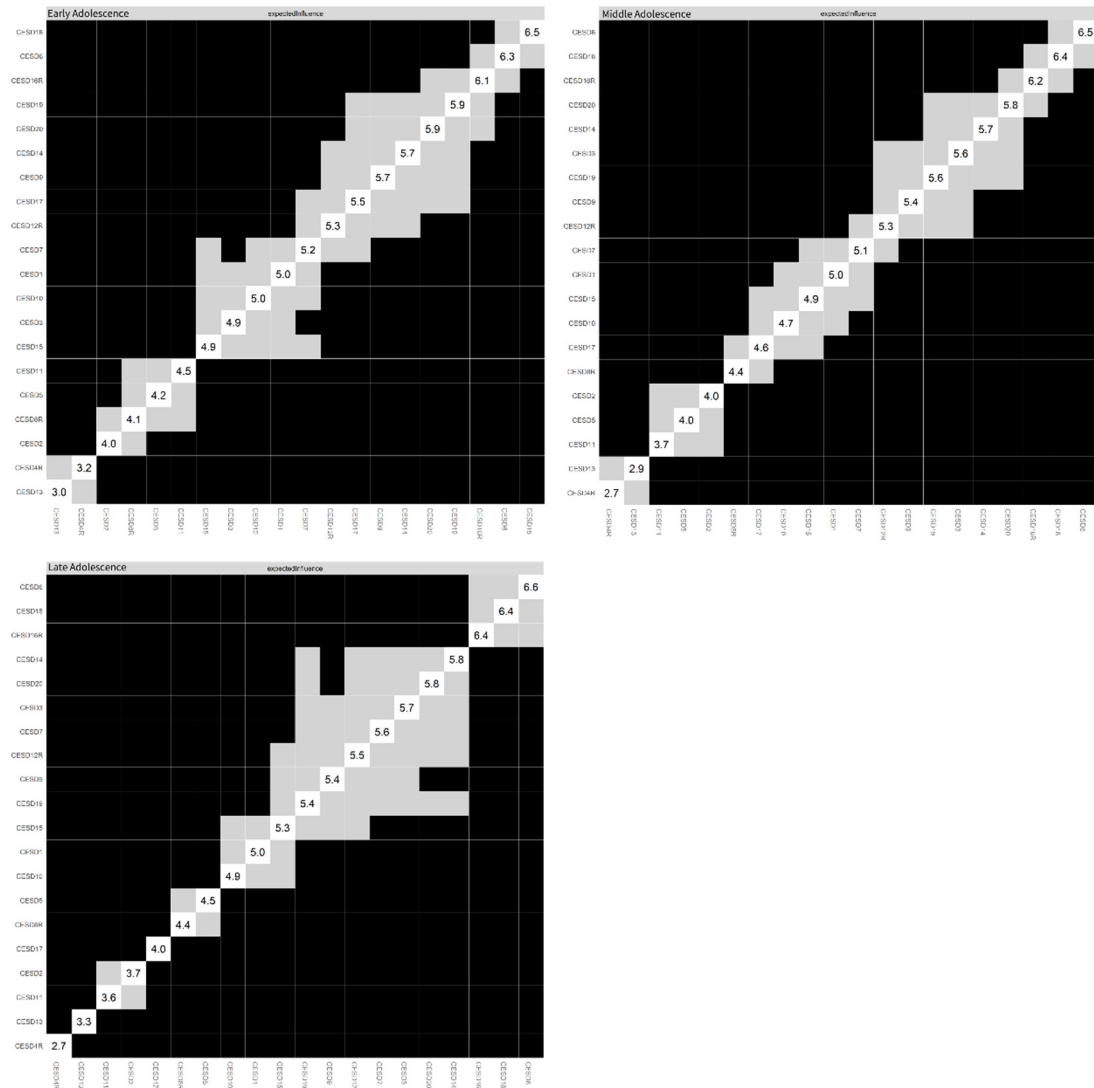


Figure S10. EI differences of Ising networks across different stages of adolescence. Note: Black cells indicate that there is a significant difference in EI centrality between the two nodes, and grey cells indicate the absence of a significant difference.

Table S1. Pearson correlation coefficients among symptoms in early adolescence.

	CESD1	CESD2	CESD3	CESD4	CESD5	CESD6	CESD7	CESD8	CESD9	CESD10	CESD11	CESD12	CESD13	CESD14	CESD15	CESD16	CESD17	CESD18	CESD19	CESD20
CESD1																				
CESD2	0.36																			
CESD3	0.474	0.377																		
CESD4	0.062	0.048	0.077																	
CESD5	0.312	0.261	0.31	0.051																
CESD6	0.52	0.375	0.517	0.103	0.354															
CESD7	0.376	0.329	0.381	0.087	0.402	0.44														
CESD8	0.163	0.138	0.184	0.39	0.143	0.192	0.19													
CESD9	0.386	0.297	0.424	0.133	0.343	0.479	0.425	0.235												
CESD10	0.372	0.31	0.364	0.079	0.303	0.452	0.357	0.15	0.408											
CESD11	0.334	0.325	0.329	0.063	0.273	0.388	0.325	0.14	0.344	0.429										
CESD12	0.286	0.228	0.3	0.237	0.196	0.34	0.257	0.412	0.339	0.261	0.265									
CESD13	0.19	0.171	0.201	0.033	0.166	0.222	0.195	0.075	0.221	0.205	0.195	0.142								
CESD14	0.394	0.306	0.42	0.088	0.285	0.474	0.344	0.174	0.455	0.429	0.371	0.329	0.281							
CESD15	0.361	0.259	0.387	0.058	0.274	0.42	0.362	0.155	0.416	0.362	0.308	0.275	0.216	0.48						
CESD16	0.286	0.224	0.295	0.232	0.198	0.328	0.269	0.416	0.326	0.259	0.271	0.606	0.15	0.338	0.306					
CESD17	0.435	0.327	0.425	0.079	0.288	0.491	0.348	0.143	0.412	0.452	0.362	0.269	0.212	0.465	0.391	0.278				
CESD18	0.465	0.341	0.469	0.087	0.308	0.548	0.39	0.174	0.465	0.469	0.399	0.318	0.244	0.517	0.456	0.327	0.668			
CESD19	0.401	0.296	0.408	0.091	0.311	0.465	0.379	0.176	0.486	0.406	0.34	0.31	0.229	0.492	0.546	0.32	0.465	0.517		
CESD20	0.383	0.334	0.402	0.089	0.416	0.456	0.494	0.197	0.449	0.375	0.364	0.288	0.237	0.415	0.39	0.299	0.384	0.438	0.443	

Note: All correlations were statistically significant. ($p < 0.001$), $N = 15,299$.

Table S2. Pearson correlation coefficients among symptoms in middle adolescence.

	CESD1	CESD2	CESD3	CESD4	CESD5	CESD6	CESD7	CESD8	CESD9	CESD10	CESD11	CESD12	CESD13	CESD14	CESD15	CESD16	CESD17	CESD18	CESD19	CESD20
CESD1																				
CESD2	0.405																			
CESD3	0.54	0.428																		
CESD4	0.088	0.077	0.124																	
CESD5	0.388	0.301	0.37	0.074																
CESD6	0.605	0.392	0.586	0.123	0.456															
CESD7	0.447	0.349	0.45	0.136	0.477	0.538														
CESD8	0.228	0.194	0.263	0.406	0.219	0.27	0.278													
CESD9	0.424	0.337	0.478	0.199	0.409	0.507	0.508	0.348												
CESD10	0.439	0.353	0.464	0.124	0.347	0.514	0.441	0.234	0.466											
CESD11	0.354	0.375	0.375	0.087	0.282	0.383	0.343	0.186	0.337	0.399										
CESD12	0.341	0.269	0.38	0.277	0.244	0.387	0.322	0.474	0.372	0.305	0.298									
CESD13	0.243	0.226	0.258	0.063	0.181	0.252	0.228	0.12	0.231	0.224	0.226	0.213								
CESD14	0.433	0.333	0.495	0.108	0.337	0.514	0.398	0.235	0.457	0.464	0.372	0.359	0.336							
CESD15	0.364	0.289	0.427	0.096	0.304	0.414	0.373	0.214	0.42	0.396	0.318	0.312	0.267	0.504						

CESD16	0.344	0.282	0.377	0.279	0.262	0.388	0.331	0.47	0.373	0.312	0.291	0.648	0.204	0.373	0.349				
CESD17	0.47	0.345	0.483	0.119	0.319	0.519	0.392	0.216	0.434	0.5	0.366	0.316	0.237	0.466	0.395	0.332			
CESD18	0.536	0.371	0.555	0.129	0.367	0.616	0.469	0.253	0.496	0.529	0.393	0.374	0.27	0.531	0.451	0.379	0.704		
CESD19	0.422	0.328	0.463	0.139	0.361	0.479	0.429	0.251	0.503	0.451	0.339	0.33	0.271	0.527	0.592	0.355	0.486	0.539	
CESD20	0.453	0.371	0.454	0.118	0.524	0.516	0.558	0.28	0.499	0.436	0.383	0.345	0.263	0.44	0.402	0.351	0.42	0.495	0.482

Note: All correlations were statistically significant. ($p < 0.001$), N = 15,996.

Table S3. Pearson correlation coefficients among symptoms in late adolescence.

	CESD1	CESD2	CESD3	CESD4	CESD5	CESD6	CESD7	CESD8	CESD9	CESD10	CESD11	CESD12	CESD13	CESD14	CESD15	CESD16	CESD17	CESD18	CESD19	CESD20
CESD1																				
CESD2	0.381																			
CESD3	0.539	0.405																		
CESD4	0.076	0.083	0.118																	
CESD5	0.395	0.28	0.377	0.059																
CESD6	0.591	0.368	0.569	0.11	0.493															
CESD7	0.446	0.331	0.47	0.137	0.506	0.565														
CESD8	0.208	0.17	0.248	0.428	0.211	0.254	0.289													
CESD9	0.408	0.304	0.473	0.193	0.419	0.505	0.527	0.326												
CESD10	0.423	0.322	0.455	0.115	0.375	0.512	0.478	0.225	0.506											
CESD11	0.315	0.33	0.327	0.072	0.303	0.356	0.343	0.164	0.311	0.377										
CESD12	0.313	0.243	0.347	0.302	0.228	0.364	0.306	0.493	0.331	0.287	0.255									
CESD13	0.26	0.241	0.28	0.047	0.203	0.283	0.26	0.12	0.27	0.249	0.237	0.232								
CESD14	0.413	0.305	0.487	0.088	0.339	0.504	0.403	0.216	0.452	0.45	0.329	0.335	0.38							
CESD15	0.36	0.249	0.414	0.089	0.309	0.392	0.385	0.196	0.416	0.387	0.296	0.281	0.306	0.51						
CESD16	0.32	0.238	0.351	0.304	0.248	0.36	0.322	0.488	0.349	0.303	0.255	0.671	0.232	0.356	0.322					
CESD17	0.42	0.296	0.446	0.1	0.291	0.467	0.379	0.17	0.377	0.457	0.319	0.254	0.232	0.428	0.351	0.265				
CESD18	0.51	0.338	0.557	0.12	0.394	0.611	0.482	0.24	0.485	0.525	0.37	0.345	0.299	0.536	0.441	0.353	0.655			
CESD19	0.394	0.276	0.436	0.129	0.357	0.45	0.43	0.229	0.483	0.432	0.306	0.298	0.301	0.526	0.61	0.325	0.419	0.52		
CESD20	0.411	0.317	0.434	0.119	0.566	0.513	0.561	0.281	0.488	0.43	0.358	0.314	0.268	0.416	0.369	0.329	0.365	0.485	0.442	

Note: All correlations were statistically significant. ($p < 0.001$), N = 15,547.