

Supplementary Information

Supplementary Methods

S1. Sensitivity to the graphical LASSO penalty (α)

To assess whether the choice of the L1 penalty affected network sparsity and downstream summaries, we scanned $\alpha \in [0.01, 0.50]$ (step size as in the analysis script) and recorded, per phase, (i) the number of nonzero edges in the $|\rho|$ network, (ii) the minimum dominating set (MDS) size, and (iii) the Louvain community count K . Figure S2 indicates that $\alpha = 0.40$ lies in a stable regime where edge counts have largely plateaued and MDS size is consistently compact across phases.

S2. Geographic distribution by phase

Respondents were U.S. young adults (18–24 years). State-level information was missing for the Early phase, and partially missing for the First-wave phase (recorded as “Unknown”). For later phases, California and Texas were the most frequently reported states. Table S1 summarizes the top 10 reported states per phase.

S3. Pre-whitening diagnostic for lagged macro–symptom associations

For representative macro indices and MHQ items, we computed lagged Spearman correlations over positive lags $L = 0, \dots, 12$ weeks (macro leading symptoms). As a diagnostic for potential trend/autocorrelation effects, we additionally fit ARIMA models to each series and repeated the lag analysis using z-scored ARIMA residuals (ADF-guided differencing; $p, q \in \{0, 1, 2\}$ chosen by AIC). Pre-whitening generally attenuates correlations; results are descriptive and not causal.

Supplementary Results

Table S2: **Mapping between node IDs and MHQ item names.** IDs follow 0–46; conventional MHQ index equals ID+1.

ID	MHQ item name
0	Adaptability to Change
1	Self Worth & Confidence
2	Creativity & Problem Solving
3	Drive & Motivation
4	Stability & Calmness
5	Sleep Quality
6	Self Control & Impulsivity
7	Ability to Learn

ID	MHQ item name
8	Coordination
9	Relationships with Others
10	Emotional Resilience
11	Planning & Organisation
12	Physical Intimacy
13	Speech & Language
14	Memory
15	Social Interactions & Cooperation
16	Decision-making & Risk-taking
17	Curiosity, Interest & Enthusiasm
18	Energy Level
19	Emotional Control
20	Focus & Concentration
21	Appetite Regulation
22	Empathy
23	Sensory Sensitivity
24	Self-Image
25	Outlook & Optimism
26	Selective Attention
27	Restlessness & Hyperactivity
28	Fear & Anxiety
29	Susceptibility to Infections
30	Aggression Towards Others
31	Avoidance & Withdrawal
32	Unwanted, Strange or Obsessive Thoughts
33	Mood Swings
34	Sense of Being Detached from Reality
35	Nightmares
36	Addictions
37	Anger & Irritability
38	Suicidal Thoughts or Intentions
39	Experience of Pain
40	Guilt & Blame
41	Hallucinations
42	Traumatic Flashbacks
43	Repetitive or Compulsive Actions
44	Feelings of Sadness, Distress or Hopelessness
45	Physical Health Issues
46	Confusion or Slowed Thinking

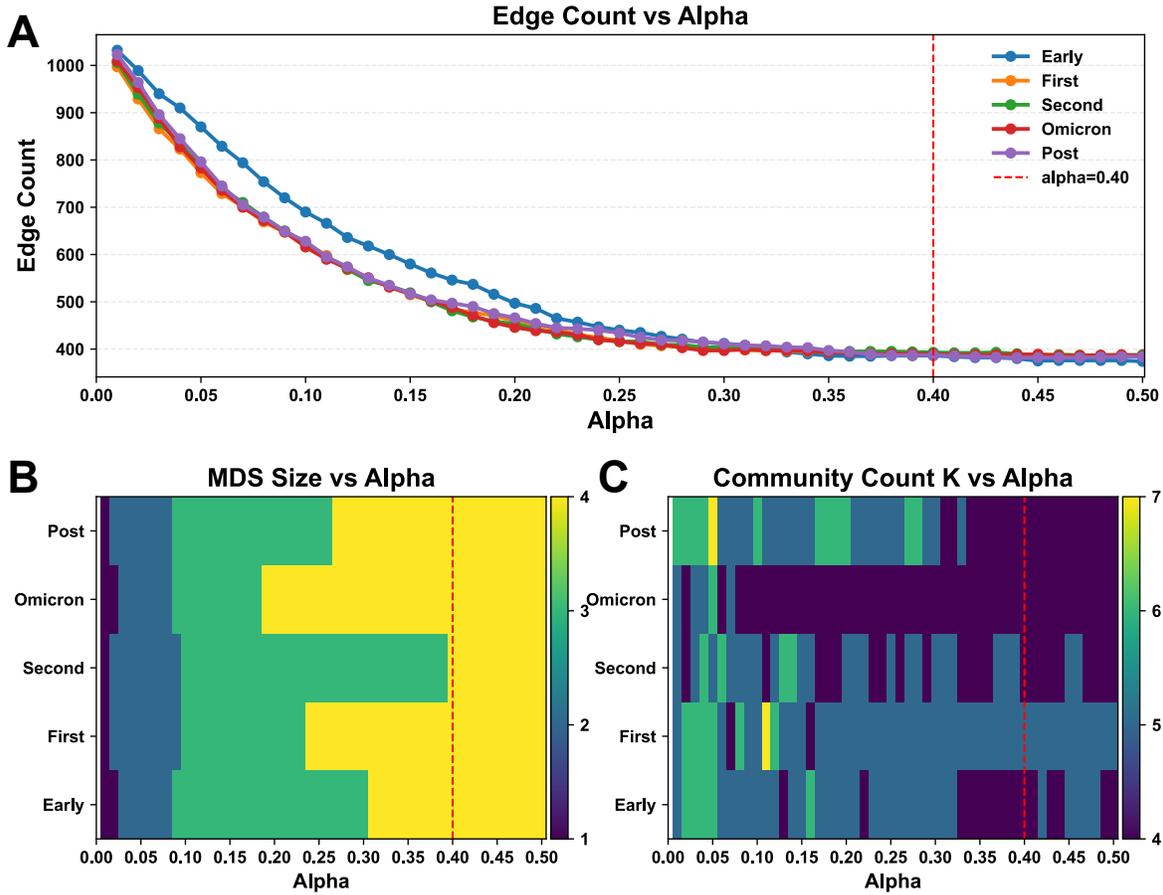


Figure S2: **Sensitivity analysis over the graphical LASSO penalty α .** (Top) Edge count vs. α across phases (red dashed line marks $\alpha = 0.40$). (Bottom) Heatmaps show how MDS size and Louvain community count K vary with α . Across phases, $\alpha = 0.40$ falls in a stable regime with compact MDS size and limited changes in K .

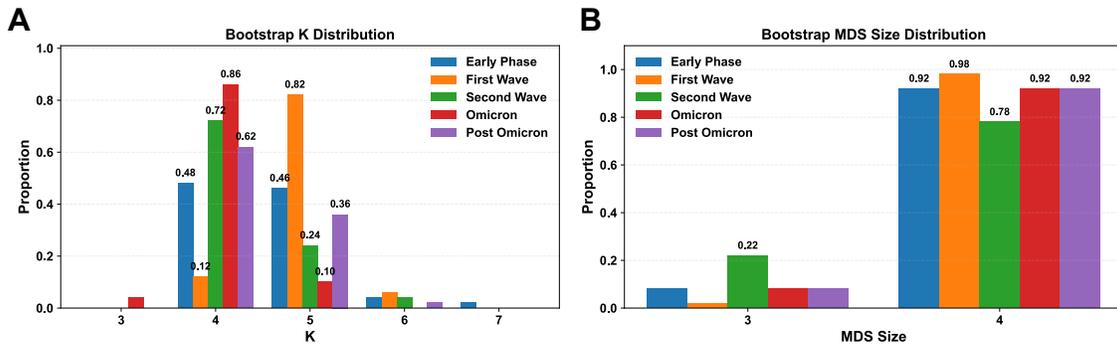


Figure S3: **Bootstrap distributions at $\alpha = 0.40$.** Equal-size bootstrapping summarizing the empirical distribution of community count K and MDS size at $\alpha = 0.40$ (panels A and B in the exported figure).

Table S1: **Geographic distribution (Top 10 states per phase)**. State information was unavailable in the Early phase and partially missing in the First-wave phase (recorded as “Unknown”). Percentages are within-phase proportions.

Left block				Right block			
Phase	State	N	Percent	Phase	State	N	Percent
Early Phase	Unknown	518	100.0	Omicron	California	626	15.6
First Wave	Unknown	1518	65.4	Omicron	Texas	344	8.6
First Wave	California	68	2.9	Omicron	New York	192	4.8
First Wave	Florida	64	2.8	Omicron	Florida	173	4.3
First Wave	Illinois	55	2.4	Omicron	Illinois	166	4.1
First Wave	Texas	54	2.3	Omicron	Pennsylvania	139	3.5
First Wave	New York	36	1.6	Omicron	Michigan	129	3.2
First Wave	Ohio	34	1.5	Omicron	Ohio	127	3.2
First Wave	Pennsylvania	32	1.4	Omicron	Georgia	118	2.9
First Wave	Arizona	27	1.2	Omicron	Minnesota	102	2.5
First Wave	Maryland	27	1.2	Post Omicron	California	467	18.0
Second Wave	California	604	12.8	Post Omicron	Texas	188	7.2
Second Wave	Texas	299	6.3	Post Omicron	New York	152	5.9
Second Wave	New York	247	5.2	Post Omicron	Florida	121	4.7
Second Wave	Florida	243	5.1	Post Omicron	Pennsylvania	100	3.8
Second Wave	Pennsylvania	186	3.9	Post Omicron	Ohio	89	3.4
Second Wave	Illinois	166	3.5	Post Omicron	Michigan	84	3.2
Second Wave	Ohio	162	3.4	Post Omicron	Illinois	83	3.2
Second Wave	Washington	161	3.4	Post Omicron	Washington	73	2.8
Second Wave	Virginia	161	3.4	Post Omicron	Virginia	72	2.8
Second Wave	Michigan	152	3.2				

Table S3: **Peak lagged associations before and after ARIMA pre-whitening**. Positive lags indicate macro indices leading MHQ symptoms ($L = 0, \dots, 12$).

Pair	Series	Peak lag (wk)	ρ	p	n_{weeks}
C7–Fear & Anxiety	raw	2	0.30	2.78×10^{-4}	139
C7–Fear & Anxiety	pre-whitened	0	0.12	0.172	141
C8–Emotional Resilience	raw	1	0.52	7.45×10^{-11}	140
C8–Emotional Resilience	pre-whitened	5	-0.20	0.0198	136

Table S7: **Module profile by phase and cohort (domain naming and purity)**. Modules were named by majority vote over the fixed node-to-domain mapping; purity is the fraction of nodes in the module belonging to the dominant domain.

Country	Phase	Module	Module name	Size	Purity	Dominant domain
US	Early	0	EMO	9	0.889	EMO
US	Early	1	STR	9	0.667	STR
US	Early	2	CSF	17	0.706	CSF
US	Early	3	STR	12	0.917	STR
US	First	0	EMO	9	0.889	EMO
US	First	1	STR	17	1.000	STR
US	First	2	SPF	6	1.000	SPF
US	First	3	CSF	12	1.000	CSF
US	First	4	SPF	3	1.000	SPF
US	Second	0	EMO	8	1.000	EMO
US	Second	1	Mixed	11	0.545	SPF

Country	Phase	Module	Module name	Size	Purity	Dominant domain
US	Second	2	CSF	11	0.909	CSF
US	Second	3	STR	17	1.000	STR
US	Omicron	0	EMO	7	1.000	EMO
US	Omicron	1	STR	18	1.000	STR
US	Omicron	2	CSF	13	0.923	CSF
US	Omicron	3	SPF	9	0.667	SPF
US	Post	0	EMO	6	1.000	EMO
US	Post	1	CSF	12	1.000	CSF
US	Post	2	SPF	9	0.667	SPF
US	Post	3	STR	20	0.900	STR
India	Early	0	EMO	5	1.000	EMO
India	Early	1	CSF	19	0.632	CSF
India	Early	2	SPF	3	1.000	SPF
India	Early	3	STR	20	0.900	STR
India	First	0	STR	20	0.900	STR
India	First	1	SPF	3	1.000	SPF
India	First	2	CSF	18	0.667	CSF
India	First	3	EMO	6	0.667	EMO
India	Second	0	CSF	14	0.857	CSF
India	Second	1	SPF	3	1.000	SPF
India	Second	2	SPF	10	0.600	SPF
India	Second	3	STR	20	0.900	STR
India	Omicron	0	STR	20	0.900	STR
India	Omicron	1	SPF	3	1.000	SPF
India	Omicron	2	CSF	13	0.923	CSF
India	Omicron	3	Mixed	11	0.545	SPF
India	Post	0	EMO	5	1.000	EMO
India	Post	1	SPF	9	0.667	SPF
India	Post	2	CSF	13	0.923	CSF
India	Post	3	STR	20	0.900	STR

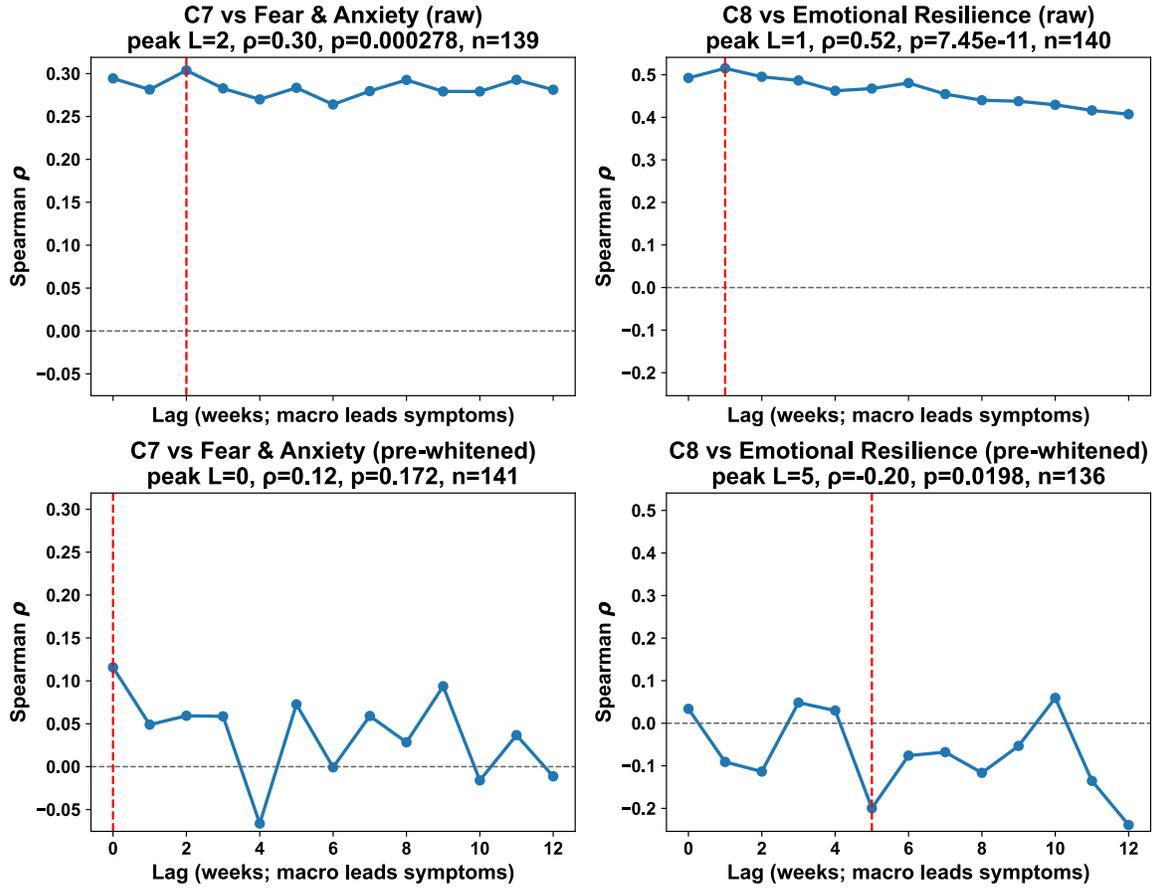


Figure S4: **Pre-whitening diagnostic (lags 0–12 weeks; macro leads symptoms)**. Lagged Spearman correlations for representative macro–item pairs before (raw) and after ARIMA pre-whitening (residuals). Red dashed lines indicate the lag with maximal $|\rho|$ within $L = 0, \dots, 12$. Pre-whitening attenuates correlations overall, consistent with partial trend/autocorrelation contributions.

Table S4: Demographic composition by phase and country (within-phase percentages).

Phase	Country	N	Female (%)	Studying (%)	High school (%)	Bachelor's (%)
Early-Phase	US	518	65.1	50.6	62.4	14.3
First-Wave	US	2321	57.9	50.2	64.5	11.6
Second-Wave	US	4721	53.3	53.5	58.1	12.2
Omicron	US	4023	63.3	42.4	58.0	10.7
Post-Omicron	US	2598	58.4	42.2	58.6	12.1
Early-Phase	India	345	71.6	86.1	44.4	41.2
First-Wave	India	5366	65.1	80.1	44.0	41.4
Second-Wave	India	8942	64.2	78.9	41.5	41.9
Omicron	India	8757	61.7	75.7	42.5	38.9
Post-Omicron	India	8216	62.2	84.5	53.1	30.2

Note. Sex was harmonized across survey versions using `Biological Sex` when available and `ARCHIVED: Gender` otherwise. Household income and several location/ethnicity fields exhibited phase-dependent missingness due to survey versioning (see Table S5).

Table S5: Field availability by phase and country (percent missing).

Phase	Country	N	Biological Sex	ARCHIVED: Gender	Gender Identity	Ethnicity	State	City	Income
Early-Phase	US	518	100.0	0.0	100.0	100.0	100.0	100.0	100.0
First-Wave	US	2321	100.0	0.9	100.0	65.4	65.4	100.0	100.0
Second-Wave	US	4721	100.0	0.0	100.0	0.0	0.0	100.0	0.5
Omicron	US	4023	0.0	100.0	85.3	0.0	0.0	80.2	0.0
Post-Omicron	US	2598	0.0	100.0	84.6	0.0	0.0	79.2	0.0
Early-Phase	India	345	100.0	0.0	100.0	100.0	100.0	100.0	100.0
First-Wave	India	5366	100.0	1.1	100.0	100.0	44.4	100.0	100.0
Second-Wave	India	8942	100.0	0.0	100.0	100.0	0.0	100.0	1.2
Omicron	India	8757	0.0	100.0	95.1	100.0	0.0	50.1	0.1
Post-Omicron	India	8216	0.0	100.0	93.7	100.0	0.0	50.3	0.0

Note. Several demographic fields were introduced or reformatted across GMP survey versions, leading to phase-dependent missingness. The harmonized sex variable used in Table S4 selects **Biological Sex** when available and otherwise uses **ARCHIVED: Gender**.

Table S6: **Cross-national phase-wise module alignment summary.** Mean/median/min/max Jaccard overlap between matched Louvain modules within each phase after Hungarian matching.

Phase	Mean	Median	Min	Max	K_{US}	K_{India}	Matched pairs
Early	0.520	0.540	0.200	0.800	4	4	4
First	0.720	0.758	0.364	1.000	5	4	4
Second	0.519	0.476	0.273	0.850	4	4	4
Omicron	0.654	0.642	0.333	1.000	4	4	4
Post	0.939	0.962	0.833	1.000	4	4	4

Table S8: **Exact control summary across phases and cohorts.** MDS size is the minimum dominating set cardinality on the unweighted graph support. n_{MDS} is the total number of distinct minimum-cardinality MDS solutions obtained by exact enumeration.

Country	Phase	MDS size	n_{MDS}	Runtime (s)	K	Edges
US	Early	4	135	0.02	4	386
US	First	4	423	0.02	5	390
US	Second	4	655	0.03	4	393
US	Omicron	4	252	0.02	4	389
US	Post	4	144	0.01	4	387
India	Early	4	27	0.01	4	357
India	First	4	861	0.03	4	418
India	Second	4	702	0.03	4	397
India	Omicron	3	5	0.00	4	405
India	Post	4	1115	0.04	4	409

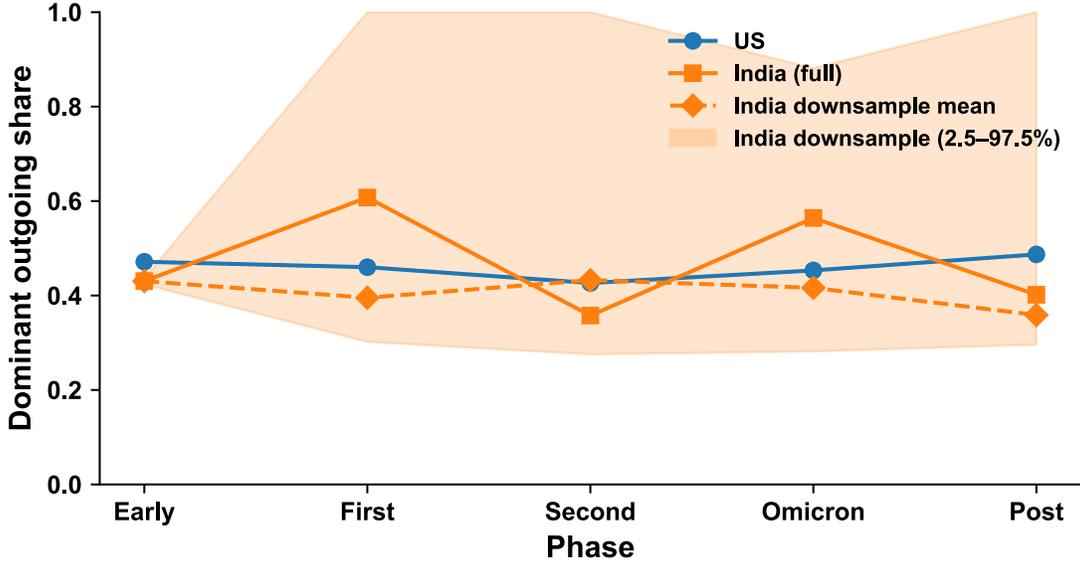


Figure S5: **Cross-national replication and sample-size sensitivity of domain-level control concentration.** For each phase, we computed each domain’s outgoing control mass from the 4×4 domain-level MCN and defined the *dominant-domain outgoing share* as the maximum domain outgoing mass divided by the total outgoing mass across domains. Solid lines show full-sample estimates for the U.S. and India cohorts. The dashed line (diamond markers) indicates the mean dominant-share value across phase-wise downsampling resamples in India, and the shaded band shows the 2.5th–97.5th percentile range. Downsampling matches India sample sizes to the corresponding U.S. phase size; networks, communities, and control summaries were re-estimated for each resample.

Table S9: **India downsample-to-U.S. sensitivity for MDS size.** For each phase, the India cohort was repeatedly downsampled without replacement to match the corresponding U.S. phase sample size (target n). The table reports the mean MDS size and the empirical CI across downsampling resamples.

Phase	Target n	Mean	CI low	CI high
Early	345	4.00	4.0	4.0
First	2321	3.96	3.0	4.0
Second	4721	3.99	4.0	4.0
Omicron	4023	3.93	3.0	4.0
Post	2598	3.94	3.0	4.0

Table S10: **Exact 3-node MDS examples in India Omicron.** Exact enumeration identified five distinct minimum-cardinality ($|D| = 3$) dominating sets in India Omicron; three examples are shown. Each set dominates all 47 nodes.

Driver-node set D (3 nodes)
Coordination; Mood Swings; Outlook & Optimism
Coordination; Nightmares; Outlook & Optimism
Coordination; Experience of Pain; Outlook & Optimism

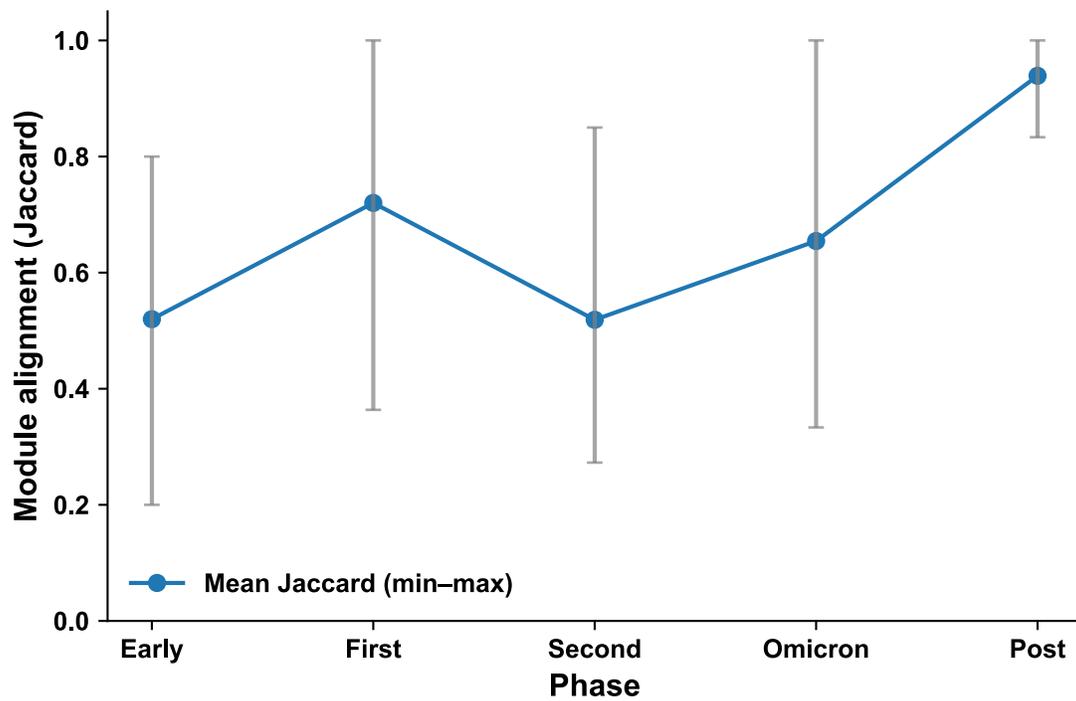


Figure S6: **Cross-national module alignment across pandemic phases.** Points indicate the mean Jaccard overlap of matched Louvain modules between the U.S. and India within each phase. Error bars indicate the min-max overlap across matched module pairs after Hungarian matching.