The Spread of Depressive Symptoms in a Large Social Network

SUPPLEMENTARY MATERIALS

Measuring Network Centrality

Eigenvector centrality[i]ii assumes that the centrality of a given individual is an increasing function of the centralities of all the individuals to whom he or she is connected. While this is an intuitive way to think about which subjects might be better connected, it yields a practical problem—how do we simultaneously estimate the centrality of all subjects in the network? Let a_{ij} equal 1 if subjects *i* and *j* have a social connection and 0 if they do not. Furthermore, let *x* be a vector of centrality scores so that each subject's centrality x_j is proportional to the sum of the centralities of the subjects to whom they are connected: $\lambda x_i = a_{1i}x_1 + a_{2i}x_2 + \cdots + a_{ni}x_n$. This yields *n* equations, which can be represented as $\lambda x = A^T x$. The vector of centralities *x* can now be computed since it is an eigenvector of the eigenvalue λ. Although there are *n* nonzero solutions to this set of equations, in symmetric matrices, the eigenvector corresponding to the principal eigenvalue is used because it maximizes the accuracy with which the associated eigenvector can reproduce the original social network.[iii] To be sure of reaching a solution, we symmetrized all asymmetric relationships in the observed network (i.e., we assumed all friendship ties were mutual).

Measures of Occupational Prestige

The Framingham dataset does not itself contain specific occupational information. However, we were able to construct a measure of occupational prestige by using occupation data obtained from tracking records used by the study administrators but not previously used for research, and also data obtained from public records in Framingham and adjoining towns (as part of New England town Censuses).

This data was then coded using the International Standard Classification of Occupations (ISCO-88). Occupations coded in this way can be easily recoded into various other scales using freely available software.[iv] Once occupations have been assigned ISCO-88 codes, the occupations can then be mapped to occupational prestige scores using a variety of extant methods. Here, occupational prestige is coded as a Treiman score, which places occupations in an ordered scale based on public perceptions of their prestige. The scale runs hierarchically from 13 to 78.[v]

When we add the variables to the social contagion models, as shown in Table S7, they do not yield a significant relationship between occupational prestige and depression. This is because occupational prestige correlates strongly with education (ρ=0.51), which appears to be a superior proxy for socioeconomic status and its influence on depression.

Table S1: Survey Waves and Sample Sizes of the Framingham Offspring Cohort (Network Egos)

Survey Wave/ Physical Exam	Time period	N alive	Number Alive and 18+	N examined	% of adults participating
Exam 1	1971-75	5124	4914	5,124	100.0
Exam 2	1979-82	5053	5037	3,863	76.7
Exam 3	1984-87	4974	4973	3,873	77.9
Exam 4	1987-90	4903	4903	4,019	82.0
Exam 5	1991-95	4793	4793	3,799	79.3
Exam 6	1996-98	4630	4630	3,532	76.3
Exam 7	1998-01	4486	4486	3,539	78.9

Table S2: Association of Alter Depression and Ego Depression

	Spouse	Sibling	Alter Type Immediate Neighbor	Neighbor within 25M	Co-worker
Alter Currently Depressed	0.41	-0.16	1.39	0.11	-0.67
	(0.28)	(0.21)	(0.72)	(0.29)	(0.95)
Alter Previously Depressed	0.69	0.13	0.13	0.44	0.25
	(0.24)	(0.16)	(0.97)	(0.31)	(0.63)
Ego Previously Depressed	1.89	1.72	3.15	1.82	-0.26
	(0.20)	(0.19)	(0.85)	(0.42)	(0.86)
Exam 7	0.36	0.14	1.83	0.23	0.41
	(0.17)	(0.17)	(0.93)	(0.33)	(0.61)
Ego's Age	-0.03	-0.03	0.00	-0.01	-0.06
	(0.01)	(0.01)	(0.04)	(0.02)	(0.03)
Ego Female	0.79	0.64	2.15	1.00	2.30
	(0.18)	(0.18)	(1.06)	(0.48)	(1.08)
Ego's Years of Education	-0.09	-0.12	0.02	-0.06	-0.01
	(0.04)	(0.04)	(0.17)	(0.09)	(0.14)
Constant	-0.75	0.03	-6.75	-1.77	-1.57
	(1.08)	(0.90)	(3.63)	(2.24)	(2.56)
Deviance	152	367	12	90	31
Null Deviance	172	404	17	104	32
N	2498	4981	186	965	665

We test the effects of other kinds of alters as shown in Table S2. Spouses do not significantly affect one another (though the p-value is low at 0.14), nor do siblings (p=0.46) or coworkers (p=0.48). However, next-door neighbors who are depressed increase ego's likelihood of depression by 338% (CI 1% to 1119%). It is interesting to note that this effect quickly becomes insignificant and drops close to 0 among neighbors who live within 25 meters on the same block (p=0.69). The neighbor relationships indicate the importance of physical proximity, so we tested the effect of distance on the association in friends' depression.

Coefficients and standard errors in parenthesis for logit regression of ego's depression status on covariates are shown. Observations for each model are restricted by type of relationship (*e.g.*, the leftmost model includes only observations in which the ego named the alter as a "spouse" in the previous and current period). Models were estimated using a general estimating equation with clustering on the ego and an independent working covariance structure. Models with an exchangeable correlation structure yielded poorer fit. Fit statistics show sum of squared deviance between predicted and observed values for the model and a null model with no covariates.

Table S3. Influence of Distance on Depression Association Between Friends

	Coef.	S.E.	*p*
Friend Currently Depressed * Log(Distance)	-0.480	0.169	0.005
Friend Currently Depressed	0.837	0.427	0.050
Log(Distance)	0.147	0.081	0.069
Friend Previously Depressed	0.682	0.484	0.159
Ego Previously Depressed	2.509	0.353	0.000
Exam 7	0.466	0.315	0.140
Ego's Age	-0.008	0.025	0.760
Female	0.598	0.441	0.176
Ego's Years of Education	-0.224	0.097	0.021
Constant	-0.651	2.310	0.778
Deviance	42		
Null Deviance	55		
N	749		

In Table S3 we show that the effect of one friend on another significantly decreases as a function of the logged distance between their households (p=0.005). These results and the strong influence of neighbors suggest that the spread of depression may depend both on frequent social contact and deep social connections.

Results for logistic regression of ego's current depression status on covariates are shown. The interaction term in the first row tests the hypothesis that geographic distance (in logged miles) decreases the influence of a friend's depression status on the ego's probability of being depressed. Models were estimated using a general estimating equation (GEE) with clustering on the ego and an independent working covariance structure. Models with an exchangeable correlation structure yielded poorer fit. Fit statistics show sum of squared deviance between predicted and observed values for the model and a null model with no covariates. The results show that geographically distant friends exert significantly less influence on each other than friends who live near one another.

Table S4. Prospective Influence of the Logarithm of Centrality on Depression

	Dependent Variable: Current CES-D Score		
	Coef	**S.E.**	***p***
Previous Network Centrality	**-0.007**	**0.003**	**0.036**
Previous Number of Friends	-0.218	0.101	0.031
Previous Number of Family	0.044	0.026	0.090
Previous CES-D Score	0.456	0.019	0.000
Age	1.133	0.170	0.000
Years of Education	0.023	0.008	0.005
Female	-0.177	0.038	0.000
Exam 7	1.096	0.159	0.000
Constant	-4.612	1.444	0.001
Deviance	243947		
Null Deviance	327588		
N	6113		

In table S4 we present a model of ego's CES-D score at current exam regressed on measures from the previous exam including the logarithm of ego's network centrality, number of friends, number of family, plus other covariates. Since the logarithm is undefined for 0 values, we added the minimum positive value to all values prior to taking the logarithm. The model was estimated using a general estimating equation (GEE) with clustering on the ego and an independent working covariance structure. Models with an exchangeable correlation structure yielded poorer fit. Fit statistics show sum of squared deviance between predicted and observed values for the model and a null model with no covariates. The results show that the relationship between network centrality and future depressive symptoms is robust to a logarithmic transformation of the centrality measure.

Table S5: Association of Ego and Alter Depression Remains Significant When Controlling for Changes in Total Number of Social Ties

	Alter Type			
	Friend	Mutual Friend	Female Friend	Next Door Neighbor
Alter Currently Depressed	0.79	1.40	0.97	1.51
	(0.37)	(0.62)	(0.40)	(0.70)
Alter Previously Depressed	0.69	2.22	0.81	0.00
	(0.42)	(0.63)	(0.46)	(1.07)
Ego Previously Depressed	2.32	2.40	2.25	3.21
	(0.31)	(0.76)	(0.33)	(0.96)
Exam 7	0.47	-0.79	0.68	1.92
	(0.27)	(0.62)	(0.31)	(1.06)
Ego's Age	-0.01	0.08	-0.02	0.00
	(0.02)	(0.05)	(0.03)	(0.04)
Ego Female	0.68	-0.38	0.47	2.66
	(0.39)	(0.59)	(0.68)	(1.46)
Ego's Years of Education	-0.23	-0.43	-0.24	0.02
	(0.09)	(0.21)	(0.11)	(0.18)
Change in Total Number of Social Ties From Previous Exam	0.03	-0.02	0.06	-0.10
	(0.03)	(0.05)	(0.03)	(0.09)
Constant	-0.47	-3.39	0.68	-7.45
	(2.08)	(4.29)	(2.56)	(4.19)
Deviance	51	11	37	12
Null Deviance	66	18	49	17
N	858	265	499	182

In table S5 we present a model testing whether the number of social ties impacts the significance of alter on ego effects. Coefficients and standard errors in parenthesis for linear logit regression of ego's depression status on covariates are shown. Observations for each model are restricted by type of relationship (*e.g.*, the leftmost model includes only observations in which the ego named the alter as a "friend" in the previous and current period). Models were estimated using a general estimating equation with clustering on the ego and an independent working covariance structure. Models with an exchangeable correlation structure yielded poorer fit. Fit statistics show sum of squared deviance between predicted and observed values for the model and a null model with no covariates. The results here show strong a strong relationship between ego and alter depression, even controlling for changes in the total number of social ties.

Table S6: Association of Ego and Alter Depression Remains Significant Among Subjects Who Survive to the End of the Study Period

	Alter Type			
	Friend	Mutual Friend	Female Friend	Next Door Neighbor
Alter Currently Depressed	0.78	1.43	0.92	1.39
	(0.36)	(0.61)	(0.38)	(0.72)
Alter Previously Depressed	0.68	2.23	0.77	0.13
	(0.42)	(0.63)	(0.44)	(0.97)
Ego Previously Depressed	2.33	2.35	2.24	3.15
	(0.31)	(0.72)	(0.33)	(0.85)
Exam 7	0.46	-0.75	0.67	1.83
	(0.27)	(0.64)	(0.32)	(0.93)
Ego's Age	0.00	0.08	-0.02	0.00
	(0.02)	(0.04)	(0.03)	(0.04)
Ego Female	0.62	-0.35	0.28	2.15
	(0.40)	(0.58)	(0.70)	(1.06)
Ego's Years of Education	-0.24	-0.42	-0.25	0.02
	(0.09)	(0.21)	(0.12)	(0.17)
Constant	-0.46	-3.25	0.81	-6.75
	(2.13)	(4.25)	(2.66)	(3.63)
Deviance	51	11	38	12
Null Deviance	66	18	49	17
N	851	264	497	186

In table 6 we consider the potential impact of egos dropping out of our analysis prior to Wave 7. Coefficients and standard errors in parenthesis for linear logit regression of ego's depression status on covariates are shown. Observations for each model are restricted by type of relationship (*e.g.*, the leftmost model includes only observations in which the ego named the alter as a "friend" in the previous and current period). Models were estimated using a general estimating equation with clustering on the ego and an independent working covariance structure. Models with an exchangeable correlation structure yielded poorer fit. Fit statistics show sum of squared deviance between predicted and observed values for the model and a null model with no covariates. The results here show strong a strong relationship between ego and alter depression, even after eliminating observations where the ego or alter died or dropped out of the study prior to exam 7.

Table S7: Association of Ego and Alter Depression Remains Significant When Controlling for Occupational Prestige

	Alter Type			
	Friend	Mutual Friend	Female Friend	Next Door Neighbor
Alter Currently Depressed	0.80	1.52	0.92	1.39
	(0.36)	(0.63)	(0.38)	(0.65)
Alter Previously Depressed	0.67	2.25	0.77	0.39
	(0.42)	(0.65)	(0.45)	(0.86)
Ego Previously Depressed	2.35	2.33	2.29	3.24
	(0.31)	(0.71)	(0.33)	(0.87)
Exam 7	0.51	-0.68	0.73	1.86
	(0.28)	(0.67)	(0.33)	(0.83)
Ego's Age	-0.03	0.06	-0.04	0.05
	(0.02)	(0.05)	(0.03)	(0.06)
Ego Female	0.71	-0.27	0.42	2.15
	(0.39)	(0.58)	(0.68)	(0.99)
Ego's Years of Education	-0.21	-0.41	-0.23	-0.03
	(0.09)	(0.21)	(0.12)	(0.19)
Treiman Occupational Prestige Score	-0.02	-0.01	-0.01	0.02
	(0.01)	(0.02)	(0.01)	(0.03)
Constant	1.09	-1.79	2.05	-9.88
	(2.21)	(4.39)	(2.62)	(3.63)
Deviance	51	11	38	12
Null Deviance	66	18	49	17
N	858	265	499	186

In table S7 we control for a potential environmental confounder, namely the socio economic status of ego and alter occupational prestige. Coefficients and standard errors in parenthesis for linear logit regression of ego's depression status on covariates are shown. Observations for each model are restricted by type of relationship (*e.g.*, the leftmost model includes only observations in which the ego named the alter as a "friend" in the previous and current period). Models were estimated using a general estimating equation with clustering on the ego and an independent working covariance structure. Models with an exchangeable correlation structure yielded poorer fit. Fit statistics show sum of squared deviance between predicted and observed values for the model and a null model with no covariates. The results here show a strong relationship between ego and alter depression, even after controlling for occupational prestige using Treiman scores (see description above).

Table S8: Association of Ego and Alter Depression Remains Significant When Controlling for Marital Status

	Alter Type			
	Friend	Mutual Friend	Female Friend	Next Door Neighbor
Alter Currently Depressed	0.81	1.42	0.98	1.39
	(0.36)	(0.63)	(0.39)	(0.69)
Alter Previously Depressed	0.72	2.23	0.84	0.10
	(0.42)	(0.63)	(0.44)	(1.03)
Ego Previously Depressed	2.31	2.35	2.22	3.28
	(0.31)	(0.71)	(0.32)	(0.95)
Exam 7	0.50	-0.76	0.72	1.78
	(0.28)	(0.65)	(0.32)	(0.99)
Ego's Age	-0.01	0.08	-0.02	-0.01
	(0.02)	(0.04)	(0.02)	(0.04)
Ego Female	0.66	-0.36	0.33	2.27
	(0.40)	(0.59)	(0.70)	(1.07)
Ego's Years of Education	-0.23	-0.42	-0.24	0.02
	(0.09)	(0.21)	(0.12)	(0.17)
Is Ego Married?	0.26	-0.04	0.38	-0.71
	(0.29)	(0.53)	(0.32)	(0.88)
Constant	-0.65	-3.23	0.42	-5.85
	(2.14)	(4.33)	(2.71)	(3.34)
Deviance	51	11	38	12
Null Deviance	66	18	49	17
N	858	265	499	186

In table S8 we control for another possible confounding variable, the marital status of the ego. Coefficients and standard errors in parenthesis for linear logit regression of ego's depression status on covariates are shown. Observations for each model are restricted by type of relationship (*e.g.*, the leftmost model includes only observations in which the ego named the alter as a "friend" in the previous and current period). Models were estimated using a general estimating equation with clustering on the ego and an independent working covariance structure. Models with an exchangeable correlation structure yielded poorer fit. Fit statistics show sum of squared deviance between predicted and observed values for the model and a null model with no covariates. The results here show a strong relationship between ego and alter depression, even after controlling for marital status.

References

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