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Substitution or Multiplication? How Personal Networks Modify the Association Between Perceived Neighbourhood Social Capital and Loneliness: A Cross-Sectional Analysis of 124,175 adults in England

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Abstract

Background

Loneliness is shaped by both personal relationships and the wider social environment, yet these resources are commonly modelled as independent or additive correlates. The resource substitution and multiplication framework predicts that the relevance of one resource depends on whether other resources are scarce or abundant. We examined whether friendship, intimate-partnership and kin resources modified the association between perceived neighbourhood social capital and loneliness among adults in England.

Methods

Cross-sectional secondary analysis of the INTERACT online survey, which recruited adults aged 16 years or older in England between 1 March and 31 July 2023 by non-probability convenience sampling. Of 135,725 source records, 124,175 formed the eligible cohort and 116,111 had complete data for fully adjusted models. Loneliness was measured with the three-item loneliness scale (UCLA-3; scores 3–9) and the Office for National Statistics Direct Measure of Loneliness (DMOL; scores 1–5). Perceived neighbourhood social capital was measured using a seven-item index (0–7). Multivariable ordered logistic regression for UCLA-3 and linear regression for DMOL, both with robust standard errors, tested multiplicative interactions between social capital and friend count, relative count, and married/cohabiting status in separate models.

Results

Higher perceived neighbourhood social capital was associated with lower loneliness on both measures (UCLA-3 coefficient − 0.185, 95% CI − 0.190 to − 0.179; DMOL coefficient − 0.084, 95% CI − 0.087 to − 0.081; both $p < 0.001$). The inverse association was stronger among respondents with fewer friends for UCLA-3 (interaction + 0.0033; $p < 0.001$), consistent with substitution; the corresponding DMOL interaction was directionally similar, smaller and statistically inconclusive (+ 0.0009; $p = 0.066$). It was stronger among married/cohabiting respondents for both UCLA-3 (interaction − 0.0371; $p < 0.001$) and DMOL (− 0.0260; $p < 0.001$), consistent with multiplication. Relative count did not modify the association (UCLA-3 P = 0.249; DMOL $p = 0.253$).

Conclusions

Different personal network resources conditioned the association between perceived neighbourhood social capital and loneliness in distinct ways: friendship showed partial evidence consistent with resource substitution, intimate partnership showed consistent evidence of resource multiplication, and

kin resources showed no evidence of interaction. Together, these findings provide an initial empirical illustration for the Social Resource Ecology of Loneliness, a conceptual model in which interpersonal and contextual social resources may substitute for, reinforce or operate relatively independently of one another. The model is proposed as a testable organising framework rather than a validated causal theory and requires longitudinal and multilevel evaluation.

Introduction

Loneliness is a subjective experience of social disconnection that arises when a person's relationships are perceived as insufficient in quantity, quality or meaning, reflecting a discrepancy between desired and achieved social relations (Perlman & Peplau, 1981). It is distinct from objective social isolation: people may have extensive networks yet feel lonely, or few contacts without feeling lonely. The World Health Organization estimates that approximately one in six people globally experiences loneliness, and longitudinal and meta-analytic evidence links deficient social connection with poorer mental and physical health and premature mortality (World Health Organization, 2025; Hawkley & Cacioppo, 2010; Holt-Lunstad et al., 2010, 2015; Valtorta et al., 2016).

Social connection is organised across interpersonal and contextual levels. Close personal ties can provide companionship, emotional support and practical assistance, whereas neighbourhood environments may offer trust, reciprocity, cohesion and opportunities for weak-tie interaction. We use perceived neighbourhood social capital to denote these locally perceived resources. This is an individual-level appraisal of the local social environment rather than an aggregated or administratively defined contextual measure and we retain the qualifier “perceived” throughout to signal this distinction. Prior studies have linked lower trust and neighbourhood belonging with greater loneliness, while broader evidence also demonstrates associations between social capital and health, and social-network research has shown that ties differ in their availability and functions (Nyqvist et al., 2016; Ehsan et al., 2019; Berkman et al., 2000). These bodies of evidence establish associations at each level, but do not by themselves explain whether the relevance of neighbourhood resources depends on the personal network resources people possess. The direction of any such conditional association also remains unresolved.

The resource substitution and multiplication framework provides a principled basis for examining this question (Ross & Mirowsky, 2006). Resource substitution occurs when one resource becomes more consequential because another is scarce; resource multiplication occurs when coexisting resources reinforce one another. Applied to loneliness, personal network resources and perceived neighbourhood social capital are distinct potential sources of social connection. A stronger inverse social capital-loneliness association among people with fewer personal network resources would be consistent with substitution, whereas a stronger association among those with more or stronger personal resources would be consistent with multiplication. This conditional-resource logic complements research distinguishing network structure from support function (Cohen & Wills, 1985; Seeman & Berkman, 1988). This conditional-resource logic is related to but distinct from the stress-buffering hypothesis (Cohen & Wills, 1985). Buffering concerns whether a social resource attenuates the effect of a stressor on health;

substitution and multiplication concern whether the relevance of one social resource depends on the availability of another. The present analysis therefore examines interdependence among social resources rather than moderation of a stressor.

Personal network resources are not homogeneous, so their type and function should shape which conditional pattern is plausible. Friendships are elective relational resources that may overlap with neighbourhood opportunities for companionship, belonging and interaction; neighbourhood social capital may therefore become more consequential when friendships are scarce. Marriage or cohabitation indexes an intimate partnership resource. A partner may facilitate engagement with neighbourhood opportunities through shared activities, overlapping networks or practical support, making multiplication plausible. Relatives constitute a distinct kin resource, but counts do not capture proximity, contact frequency or emotional closeness, so substitution is plausible but less certain. This resource-specific classification is consistent with social-network, convoy and network-typology perspectives that distinguish ties by closeness, stability and function rather than treating all ties as interchangeable (Seeman & Berkman, 1988; Antonucci et al., 2014; Litwin, 2001; Fiori et al., 2006).

These relationships can be integrated through what we term social resource ecology: the multilevel configuration of interpersonal and contextual social resources within which the relevance of any one resource depends partly on the availability and function of others. This perspective does not assume that resources are independent or uniformly additive; it allows substitution, multiplication and relative independence to coexist across resource types and levels. In this study, the term is introduced as an organising concept that connects social-ecological attention to interpersonal and community influences (McLeroy et al., 1988) with conditional-resource reasoning (Ross & Mirowsky, 2006), rather than as a previously validated theory.

Using the large volunteer-based INTERACT sample (El-Osta et al., 2026) and two non-equivalent loneliness measures, we tested four hypotheses: (H1) higher perceived neighbourhood social capital would be associated with lower loneliness on both measures; (H2) this inverse association would be stronger among respondents with fewer friends; (H3) it would be stronger among respondents who were married or cohabiting; and (H4) it would be stronger among respondents with fewer relatives. The analysis was designed to test heterogeneity of association and whether observed patterns were consistent with resource substitution or multiplication; it was not designed to establish causal substitution, multiplication or their underlying mechanisms.

The primary aim of this study was to determine whether friendship, kin and intimate-partnership resources modified the association between perceived neighbourhood social capital and loneliness, and whether the resulting patterns were consistent with resource substitution, resource multiplication or no detectable interaction. The secondary aim was to estimate the overall association between perceived neighbourhood social capital and loneliness across the UCLA-3 and DMOL measures and assess whether the findings were consistent across indirect and direct measures.

Methods

Study design and participants

We conducted a secondary cross-sectional analysis of the Measuring Loneliness in England (INTERACT) Study, an online observational survey of loneliness, social connection and neighbourhood social capital among people aged 16 years or older residing in England (El-Osta et al., 2026). The survey was administered using Qualtrics. Recruitment used NHS primary care and trust networks, voluntary and community-sector organisations, NIHR's Be Part of Research network, and digital and social-media outreach. Participation was voluntary; neither a probability sampling frame nor sampling quotas were used. The analytic cohort for this programme of work comprised responses collected between 1 March and 31 July 2023. The source cohort contained 135,725 respondents. After application of the study's analytic eligibility criteria, 124,175 respondents formed the eligible cohort; 11,550 source records were excluded. A further 8,064 respondents had incomplete outcome or covariate data, leaving 116,111 complete cases (93.5% of the eligible cohort) for the fully adjusted models (Fig. 1). Because individual inclusion probabilities were unknown, the analyses estimate conditional associations within the responding sample. No survey weighting, raking or post-stratification was applied.

Measures

Loneliness was assessed in two ways. The UCLA three-item loneliness scale (UCLA-3) asked how often respondents lacked companionship, felt left out and felt isolated. Items were scored from 1 to 3 and summed to a 3–9 score, with higher values indicating greater loneliness (Hughes et al., 2004). All seven possible summed scores were retained as ordered categories for ordered logistic regression. The Office for National Statistics (ONS) Direct Measure of Loneliness (DMOL) asked, '*How often do you feel lonely?*' Responses ranged from never (1) to often or always (5). The full 1–5 DMOL score was analysed as a continuous outcome to retain information across response levels and estimate adjusted mean-score differences. The outcomes were analysed separately because indirect and direct measures capture related but non-equivalent experiences of loneliness (Shiovitz-Ezra & Ayalon, 2012).

Perceived neighbourhood social capital was measured using seven items adapted from neighbourhood cohesion and collective-efficacy measures (Sampson et al., 1997; Lochner et al., 1999). Items assessed trust, reciprocity, cohesion, shared values, and willingness to help. For positively worded items, agree and strongly agree responses were scored 1, and disagree and strongly disagree responses were scored 0; negatively worded items were reverse scored. Items were summed to an index from 0 to 7, with higher scores indicating greater perceived neighbourhood social capital. The score was retained as a continuous explanatory variable, so coefficients represent the adjusted change in loneliness associated with a one-point increase.

Friendship and kin resources were measured as reported numbers of friends and relatives, each grouped as 0, 1, 2, 3–4, 5–8 and ≥ 9. Intimate partnership was derived from marital/relationship status: married

and partnered/cohabiting respondents were coded 1; single, divorced, widowed and other categories were coded 0. These measures index structural availability rather than relationship quality or support function. Full survey wording, scoring procedures and coding rules for the loneliness outcomes, perceived neighbourhood social capital, personal-network resources and covariates are provided in the Supplementary Methods **(Supplementary File 1).**

Covariates

Models adjusted for age; gender; ethnicity; educational attainment; employment status; disability; long-term health condition; pet ownership; having children; marital status; number of friends; and number of relatives. Categorical definitions and reference groups match Tables 2 and 3. Household size was summarised descriptively but was not included in the regression models.

Statistical analysis

UCLA-3 was designated the primary loneliness outcome and DMOL a secondary outcome capturing the directly labelled experience of loneliness; both were analysed for all hypotheses, and consistency across the two measures was considered when assessing the robustness of each result. Participant characteristics were summarised using means and standard deviations or frequencies and percentages. Analyses were conducted in Stata 15.1. The primary UCLA-3 model used multivariable ordered logistic regression with heteroskedasticity-robust standard errors. Coefficients represent changes in the log cumulative odds of greater loneliness; negative values indicate lower loneliness. Corresponding odds ratios were calculated for interpretability. The model is conditional on the proportional-odds specification. The DMOL model used multivariable linear regression with robust standard errors; coefficients represent adjusted mean differences in the 1–5 score. Model fit was summarised using pseudo-R^2 for UCLA-3 and R^2 and root mean squared error for DMOL.

Moderation was tested by adding one multiplicative interaction between continuous social capital and each personal network moderator in separate models for each outcome. Friend and relative categories were assigned scores of 0, 1, 2, 3.5, 6.5 and 9, corresponding to category midpoints where bounded and the lower bound for the open-ended ≥ 9 group. The trend-coded moderator replaced its categorical representation in the corresponding interaction model. In partnership models, the binary married/cohabiting variable replaced the six-category marital-status term. All other covariates remained as specified in the main models.

Because the main social-capital association was inverse, a positive social capital × network-size coefficient indicated that the inverse slope weakened as network size increased—a pattern consistent with resource substitution. A negative interaction indicated that the inverse slope strengthened as the moderator increased—a pattern consistent with resource multiplication. For the binary partnership moderator, a negative interaction indicated a stronger inverse association among married/cohabiting respondents. We report interaction direction, magnitude and two-sided P values; $P < 0.05$ was used as a

conventional reference threshold rather than as the sole basis for interpretation. Further details on model specification, interaction-term construction and complete-case criteria are provided in the Supplementary Methods **(Supplementary File 1).**

Missing data

The primary analyses used complete cases for both outcomes and all model covariates. Of 124,175 eligible respondents, 116,111 (93.5%) contributed to the fully adjusted models. No imputed estimates are reported in this manuscript. Variable-specific missingness and the number of respondents excluded from the fully adjusted complete-case analyses are reported in **Supplementary Table S1.**

Ethics and reporting

The INTERACT Study was registered on the NIHR Portfolio (CPMS 52230) and received favourable ethics and institutional review under references 21IC6950 and 305483. All participants provided informed electronic consent. Responses were pseudonymised and stored on secure Imperial College London servers. The study was reported with reference to Checklist for Reporting Results of Internet E-Surveys *(*CHERRIES) and this secondary analysis followed Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) principles.

Results

Participant characteristics

The eligible analytic cohort included 124,175 respondents, of whom 116,111 (93.5%) had complete data for both outcomes and all covariates. The characteristics of the eligible cohort and the complete-case analytic sample are compared in **Supplementary Table S2**. Mean UCLA-3 loneliness was 5.4 (SD 2.1; range 3–9), mean DMOL loneliness was 3.1 (SD 1.3; range 1–5), and mean perceived neighbourhood social capital was 4.3 (SD 2.2; range 0–7). Mean age was 56.5 years (SD 16.3). Respondents were predominantly female (61.3%), White (88.7%), and married or partnered/cohabiting (58.0%). Overall, 9.5% reported no friends and 5.9% no relatives, whereas 18.8% reported at least nine friends and 12.3% at least nine relatives (Table 1).

Table 1
Characteristics of the eligible analytic cohort

Variable	Category / statistic	N	Value
UCLA-3 score (3–9)	Mean (SD)	124,175	5.4 (2.1)
DMOL score (1–5)	Mean (SD)	124,175	3.1 (1.3)
Social capital (0–7)	Mean (SD)	119,226	4.3 (2.2)
Age	Mean (SD)	123,511	56.5 (16.3)
Gender	Female	76,123	61.3%
	Male	46,932	37.8%
	Other/prefer not to say	1,104	0.9%
Ethnicity	White	110,091	88.7%
	Asian/Asian British	5,881	4.7%
	Black/African/Caribbean	2,232	1.8%
	Mixed/Multiple	1,991	1.6%
	White and Black Caribbean	452	0.4%
	Other	2,781	2.2%
Education	Secondary school	29,516	23.8%
	A-level/college	36,602	29.5%
	Degree+	57,634	46.4%
Employment	Full-time	36,035	29.0%
	Part-time	13,981	11.3%
	Self-employed	7,718	6.2%
	Student	3,802	3.1%
	Unemployed	7,660	6.2%
	Retired	46,424	37.4%
	Unpaid carer	1,664	1.3%
	Volunteer	1,527	1.2%

Note: Percentages use the eligible cohort (N = 124,175) as the denominator and do not sum to 100% where items had missing responses; item-level completeness ranged from 96.0% (social capital) to 100% (both loneliness outcomes). Household composition is descriptive only and was not included in regression models. UCLA-3, three-item loneliness score; DMOL, Direct Measure of Loneliness; SD, standard deviation.

Variable	Category / statistic	N	Value
	Other	4,060	3.3%
Disability	No	95,152	76.6%
	Yes	25,151	20.3%
	Prefer not to say	3,564	2.9%
Long-term condition	No	58,916	47.5%
	Yes	62,022	50.0%
	Prefer not to say	2,998	2.4%
Marital status	Single	26,435	21.3%
	Married	60,139	48.4%
	Partnered	11,874	9.6%
	Divorced	12,691	10.2%
	Widowed	9,839	7.9%
	Other	2,961	2.4%
Household size	Lives alone	33,421	26.9%
	1	52,701	42.4%
	2–3	29,390	23.7%
	4–5	6,972	5.6%
	More than 5	1,485	1.2%
Pets	No	69,626	56.1%
	Yes	54,239	43.7%
Children	No	40,168	32.4%
	Yes	83,624	67.3%
Friends	0 (none)	11,823	9.5%
	1	13,715	11.0%
	2	18,956	15.3%

Note: Percentages use the eligible cohort (N = 124,175) as the denominator and do not sum to 100% where items had missing responses; item-level completeness ranged from 96.0% (social capital) to 100% (both loneliness outcomes). Household composition is descriptive only and was not included in regression models. UCLA-3, three-item loneliness score; DMOL, Direct Measure of Loneliness; SD, standard deviation.

Variable	Category / statistic	N	Value
	3–4	31,211	25.1%
	5–8	24,943	20.1%
	9 or more	23,324	18.8%
Relatives	0 (none)	7,262	5.9%
	1	12,069	9.7%
	2	20,780	16.7%
	3–4	39,403	31.7%
	5–8	29,159	23.5%
	9 or more	15,293	12.3%

Note: Percentages use the eligible cohort (N = 124,175) as the denominator and do not sum to 100% where items had missing responses; item-level completeness ranged from 96.0% (social capital) to 100% (both loneliness outcomes). Household composition is descriptive only and was not included in regression models. UCLA-3, three-item loneliness score; DMOL, Direct Measure of Loneliness; SD, standard deviation.

Main associations

In the fully adjusted ordered logistic model, each one-point increase in perceived neighbourhood social capital was associated with lower UCLA-3 loneliness (coefficient − 0.185, 95% CI − 0.190 to − 0.179; $p < 0.001$), equivalent to an odds ratio of approximately 0.83 for being in a higher loneliness category (Table 2). In the fully adjusted linear model, each one-point increase was associated with a 0.084-point lower DMOL score (coefficient − 0.084, 95% CI − 0.087 to − 0.081; $p < 0.001$; Table 3). Both models used robust standard errors and included 116,111 complete cases (Fig. 2). These findings supported H1.

Personal network coefficients followed graded patterns. Relative to reporting no friends, coefficients became progressively more negative across friend-count categories in both models. Higher relative-count categories were generally associated with lower loneliness. Married and partnered respondents reported lower loneliness than single respondents, whereas widowed respondents reported higher loneliness on both measures. These covariate associations are descriptive components of the adjusted models and are not interpreted causally.

Table 2
Fully adjusted main model for UCLA-3 ordered loneliness

Variable (N = 116,111)		Coefficient	Robust SE	p	95% CI
Social capital	Social capital (per point, 0–7)	-0.185	0.003	< 0.001	(-0.190, -0.179)
Age	Age (per year)	-0.030	0.001	< 0.001	(-0.031, -0.029)
Gender (Ref: Female)	Male	-0.226	0.012	< 0.001	(-0.249, -0.202)
	Other/prefer not to say	0.056	0.062	0.363	(-0.065, 0.178)
Education (Ref: Secondary school)	A-level/college	0.103	0.016	< 0.001	(0.072, 0.134)
	Degree	0.230	0.015	< 0.001	(0.201, 0.260)
Employment (Ref: Full-time)	Part-time	0.068	0.019	< 0.001	(0.031, 0.105)
	Self-employed	0.113	0.025	< 0.001	(0.064, 0.161)
	Student	0.072	0.034	0.034	(0.006, 0.138)
	Unemployed	0.536	0.027	< 0.001	(0.484, 0.588)
	Retired	0.006	0.019	0.759	(-0.031, 0.043)
	Unpaid carer	0.668	0.048	< 0.001	(0.574, 0.761)
	Volunteer	0.124	0.051	0.014	(0.025, 0.224)
	Other	0.580	0.035	< 0.001	(0.512, 0.648)
Ethnicity (Ref: White)	Asian/Asian British	0.143	0.028	< 0.001	(0.089, 0.197)
	Black/African/Caribbean	-0.094	0.043	0.028	(-0.177, -0.010)

Note: Ordered logistic regression with robust standard errors; N = 116,111; log pseudolikelihood −176,959.3; pseudo-R^2=0.172. Coefficients are on the ordered-logit scale; cut points are omitted. Reference categories are shown in the term labels.

Variable (N = 116,111)		Coefficient	Robust SE	p	95% CI
	Mixed/Multiple	-0.014	0.044	0.758	(-0.100, 0.073)
	White and Black Caribbean	0.091	0.086	0.285	(-0.076, 0.259)
	Other	-0.016	0.040	0.697	(-0.094, 0.063)
Disability (Ref: No)	Yes	0.525	0.016	< 0.001	(0.494, 0.556)
	Prefer not to say	0.392	0.035	< 0.001	(0.324, 0.459)
Condition (Ref: No)	Yes	0.445	0.012	< 0.001	(0.421, 0.469)
	Prefer not to say	0.423	0.038	< 0.001	(0.349, 0.497)
Pets (Ref: No)	Yes	0.039	0.012	0.001	(0.016, 0.062)
Children (Ref: No)	Yes	0.059	0.015	< 0.001	(0.030, 0.088)
Marital (Ref: Single)	Married	-0.941	0.018	< 0.001	(-0.976, -0.907)
	Partnered	-0.853	0.021	< 0.001	(-0.895, -0.812)
	Divorced	0.121	0.024	< 0.001	(0.075, 0.167)
	Widowed	0.502	0.026	< 0.001	(0.450, 0.554)
	Other	-0.014	0.039	0.714	(-0.092, 0.063)
Friends (Ref: 0)	1	-0.230	0.025	< 0.001	(-0.279, -0.180)
	2	-0.564	0.024	< 0.001	(-0.611, -0.517)
	3–4	-1.053	0.023	< 0.001	(-1.098, -1.008)

Note: Ordered logistic regression with robust standard errors; N = 116,111; log pseudolikelihood −176,959.3; pseudo-R^2=0.172. Coefficients are on the ordered-logit scale; cut points are omitted. Reference categories are shown in the term labels.

Variable (N = 116,111)		Coefficient	Robust SE	p	95% CI
	5–8	-1.605	0.025	< 0.001	(-1.653, -1.556)
	9 or more	-2.156	0.026	< 0.001	(-2.207, -2.104)
Relatives (Ref: 0)	1	0.016	0.031	0.597	(-0.044, 0.077)
	2	-0.165	0.029	< 0.001	(-0.221, -0.109)
	3–4	-0.509	0.028	< 0.001	(-0.563, -0.455)
	5–8	-0.898	0.029	< 0.001	(-0.955, -0.841)
	9 or more	-1.210	0.032	< 0.001	(-1.273, -1.146)

Note: Ordered logistic regression with robust standard errors; N = 116,111; log pseudolikelihood −176,959.3; pseudo-R^2=0.172. Coefficients are on the ordered-logit scale; cut points are omitted. Reference categories are shown in the term labels.

Table 3
Fully adjusted main model for DMOL continuous loneliness

Variable (N = 116,111)		Coefficient	Robust SE	p	95% CI
Social capital	Social capital (per point, 0–7)	-0.084	0.002	< 0.001	(-0.087, -0.081)
Age	Age (per year)	-0.016	0.0003	< 0.001	(-0.016, -0.015)
Gender (Ref: Female)	Male	-0.152	0.007	< 0.001	(-0.165, -0.139)
	Other/prefer not to say	-0.100	0.032	0.002	(-0.163, -0.036)
Education (Ref: Secondary school)	A-level/college	0.001	0.009	0.882	(-0.015, 0.018)
	Degree	0.024	0.008	0.003	(0.008, 0.040)
Employment (Ref: Full-time)	Part-time	0.039	0.010	< 0.001	(0.018, 0.059)
	Self-employed	0.042	0.014	0.002	(0.015, 0.069)
	Student	0.046	0.019	0.014	(0.009, 0.082)
	Unemployed	0.212	0.013	< 0.001	(0.186, 0.238)
	Retired	0.007	0.010	0.496	(-0.013, 0.027)
	Unpaid carer	0.246	0.025	< 0.001	(0.198, 0.294)
	Volunteer	0.046	0.027	0.089	(-0.007, 0.099)
	Other	0.189	0.018	< 0.001	(0.154, 0.224)
Ethnicity (Ref: White)	Asian/Asian British	0.139	0.015	< 0.001	(0.110, 0.168)
	Black/African/Caribbean	0.005	0.023	0.838	(-0.040, 0.049)

Note: Linear regression of the DMOL score (1–5) with robust standard errors; N = 116,111; R^2=0.359; root MSE = 1.012. The intercept is omitted. Reference categories are shown in the term labels.

Variable (N = 116,111)		Coefficient	Robust SE	p	95% CI
	Mixed/Multiple	-0.001	0.024	0.981	(-0.047, 0.046)
	White and Black Caribbean	0.015	0.049	0.759	(-0.080, 0.110)
	Other	0.040	0.021	0.061	(-0.002, 0.082)
Disability (Ref: No)	Yes	0.183	0.009	< 0.001	(0.166, 0.200)
	Prefer not to say	0.130	0.018	< 0.001	(0.095, 0.166)
Condition	Yes	0.207	0.007	< 0.001	(0.193, 0.220)
	Prefer not to say	0.221	0.021	< 0.001	(0.180, 0.261)
Pets (Ref: No)	Yes	0.003	0.006	0.644	(-0.009, 0.015)
Children (Ref: No)	Yes	0.083	0.008	< 0.001	(0.067, 0.098)
Marital (Ref: Single)	Married	-0.446	0.010	< 0.001	(-0.464, -0.427)
	Partnered	-0.403	0.012	< 0.001	(-0.426, -0.380)
	Divorced	0.037	0.012	0.003	(0.013, 0.062)
	Widowed	0.345	0.014	< 0.001	(0.317, 0.373)
	Other	0.012	0.021	0.577	(-0.029, 0.053)
Friends (Ref: 0)	1	-0.042	0.013	0.001	(-0.067, -0.016)
	2	-0.165	0.012	< 0.001	(-0.190, -0.141)
	3–4	-0.356	0.012	< 0.001	(-0.379, -0.332)

Note: Linear regression of the DMOL score (1–5) with robust standard errors; N = 116,111; R^2=0.359; root MSE = 1.012. The intercept is omitted. Reference categories are shown in the term labels.

Variable (N = 116,111)		Coefficient	Robust SE	p	95% CI
	5–8	-0.575	0.013	< 0.001	(-0.601, -0.550)
	9 or more	-0.804	0.014	< 0.001	(-0.831, -0.777)
Relatives (Ref: 0)	1	0.019	0.016	0.234	(-0.012, 0.051)
	2	-0.026	0.015	0.077	(-0.056, 0.003)
	3–4	-0.180	0.014	< 0.001	(-0.208, -0.152)
	5–8	-0.361	0.015	< 0.001	(-0.391, -0.331)
	9 or more	-0.524	0.017	< 0.001	(-0.557, -0.491)

Note: Linear regression of the DMOL score (1–5) with robust standard errors; N = 116,111; R^2=0.359; root MSE = 1.012. The intercept is omitted. Reference categories are shown in the term labels.

Moderation by personal network resources

The friend-count trend interaction was positive for UCLA-3 (+ 0.0033; p < 0.001), indicating that the inverse social capital–loneliness association was stronger among respondents with fewer friends and supporting H2 for the indirect measure. The DMOL interaction was in the same direction but smaller (+ 0.0009; p = 0.066); H2 was therefore only partially supported across outcomes. Relative count did not modify the association for UCLA-3 (+ 0.0012; p = 0.249) or DMOL (+ 0.0006; p = 0.253), providing no support for H4.

The married/cohabiting interaction was negative for both UCLA-3 (− 0.0371; p < 0.001) and DMOL (− 0.0260; p < 0.001). Thus, the inverse association between perceived neighbourhood social capital and loneliness was stronger among respondents with an intimate partnership resource, supporting H3 and a pattern consistent with resource multiplication (Table 4; Fig. 3). Exact interaction coefficients, robust standard errors, 95% confidence intervals and model-specific sample sizes for all six moderation models are reported in **Supplementary Table S3.**

Table 4
Moderation of the social capital–loneliness association by personal network resources

Network	Outcome	Interaction p value	Interaction coefficient	Direction
Friends	UCLA-3	< 0.001	+ 0.0033	Substitution
Friends	DMOL	0.066	+ 0.0009	Directionally similar; inconclusive
Relatives	UCLA-3	0.249	+ 0.0012	No evidence
Relatives	DMOL	0.253	+ 0.0006	No evidence
Married/cohabiting	UCLA-3	< 0.001	-0.0371	Multiplication
Married/cohabiting	DMOL	< 0.001	-0.0260	Multiplication

Note: Friend and relative trend scores were 0, 1, 2, 3.5, 6.5 and 9; married/cohabiting was binary. Positive interactions indicate that the inverse social-capital slope is stronger at lower moderator values (substitution); negative interactions indicate that it is stronger at higher moderator values (multiplication). Each interaction was estimated in a separate fully adjusted model, with the moderator entered in the form used for its interaction.

Discussion

Principal findings

Higher perceived neighbourhood social capital was associated with lower loneliness on both UCLA-3 and DMOL, but the strength of this association differed according to the personal network resource considered. Friendship showed partial evidence consistent with resource substitution: the inverse association was stronger among respondents with fewer friends for UCLA-3, while the DMOL interaction was directionally concordant but weaker. Marriage or cohabitation showed a pattern consistent with resource multiplication across both measures. Relative count did not modify the association, despite higher relative counts being independently associated with lower loneliness. H1 and H3 were supported, H2 was partially supported, and H4 was not supported.

Viewed together, partial substitution, multiplication and no detectable interaction provide an initial empirical illustration of social resource ecology, the multilevel configuration of interpersonal and contextual social resources. The concept is not offered as a separate tested theory. It organises heterogeneous resource relationships across levels while remaining grounded in the resource substitution and multiplication framework (Ross & Mirowsky, 2006) and compatible with social-network, convoy and ecological perspectives (Berkman et al., 2000; Antonucci et al., 2014; McLeroy et al., 1988). In this sample, the relevance of neighbourhood social capital varied with the type and configuration of personal resources rather than following a single compensatory or reinforcing pattern.

Friendship and resource substitution

The friendship result is consistent with substitution because relational and neighbourhood resources may partly overlap in function. Friendships and cohesive neighbourhood environments are structurally different, but both can provide companionship, recognition, belonging and opportunities for interaction (Cohen & Wills, 1985; Seeman & Berkman, 1988). When friendship resources are scarce, neighbourhood trust and reciprocity may therefore become relatively more consequential. This interpretation is compatible with prior evidence linking trust and neighbourhood belonging with loneliness (Nyqvist et al., 2016). It does not imply that contextual resources can replace close friendship, nor does the cross-sectional interaction identify a compensatory mechanism.

The difference between the two outcomes requires restraint. UCLA-3 assesses experiences such as lacking companionship, exclusion and isolation without requiring respondents to label themselves as lonely, whereas DMOL uses a direct loneliness label. Direct and indirect measures can identify different prevalence patterns and correlates (Shiovitz-Ezra & Ayalon, 2012). The weaker DMOL interaction may therefore reflect measurement differences, chance or a smaller effect on the directly labelled experience. Because the interaction did not converge across outcomes at the conventional reference threshold, friendship substitution should be described as partial and outcome-dependent until replicated.

Intimate partnership and resource multiplication

The partnership result is consistent with resource multiplication because an intimate tie may facilitate access to or use of contextual resources. A spouse or cohabiting partner may enable neighbourhood engagement through shared activity, overlapping networks or practical support for participation, thereby strengthening the social capital-loneliness association (Seeman & Berkman, 1988; Antonucci et al., 2014). This pattern was consistent across UCLA-3 and DMOL and contradicts a simple deficit model in which contextual resources must matter most to those with fewer personal ties. However, being married or cohabiting status is an imperfect proxy for relationship quality, support, conflict or duration, and it may also reflect residential selection and unmeasured socioeconomic circumstances. The result identifies heterogeneity of association, not a causal mechanism.

Kin resources and non-interaction

The absence of moderation by relative count marks a boundary of the substitution prediction. Higher relative counts were independently associated with lower loneliness, yet they did not change the social capital-loneliness association. A resource may therefore be relevant to loneliness without conditioning another resource. Counts describe structural availability but not proximity, contact frequency, reciprocity, conflict or emotional closeness, which may be especially important for kin. More detailed measures could reveal functional forms of kin support that interact with neighbourhood social capital even though total relative count does not. The present finding should therefore be interpreted as no evidence of interaction for this measure, not evidence that kin resources are unimportant.

Implications

To integrate these findings, we propose the social resource ecology of loneliness framework (Fig. 4). We define social resource ecology as the configuration of interpersonal and contextual resources surrounding an individual. Within this configuration, the relevance of one resource may depend on the availability, quality and function of others. The framework draws on social-ecological approaches that locate influences across multiple levels and on resource substitution and multiplication reasoning (McLeroy et al., 1988; Ross & Mirowsky, 2006). Its distinctive focus is therefore not simply the presence of resources at different levels, but the relationships among them. It is proposed here as a testable organising framework rather than an established or validated theory. The Social Resource Ecology of Loneliness framework makes three central propositions. First, personal ties and neighbourhood social capital represent distinct but potentially connected domains of social resources. Friendship, intimate partnership and kin relationships may provide companionship, emotional support, practical assistance or social integration, whereas neighbourhood social capital may provide trust, reciprocity, belonging and opportunities for interaction. Second, these resources are not necessarily interchangeable or uniformly additive. One resource may compensate when another is scarce, strengthen the association of another resource, or operate with little detectable interdependence. Third, these relationships are likely to be resource-specific and dynamic. They may vary according to relationship quality, support function, negative interaction, life stage and changes such as partnership transitions, friendship loss or relocation. This framing is compatible with social-network and convoy perspectives that regard social ties as functionally differentiated and embedded within wider social contexts (Berkman et al., 2000; Antonucci et al., 2014).

The present findings provide an initial empirical illustration of these propositions. For UCLA-3 loneliness, the inverse association with perceived neighbourhood social capital became weaker as friend count increased. This pattern is consistent with partial resource substitution, whereby neighbourhood resources may be more relevant when friendship resources are scarce. The corresponding DMOL interaction was directionally similar but not statistically conclusive, indicating that the substitution pattern may depend on how loneliness is measured. Marriage or cohabitation showed a different configuration. Its interaction with neighbourhood social capital was consistent with resource multiplication for both outcomes, suggesting that intimate partnership and neighbourhood resources may reinforce rather than replace one another. Relative count showed no detectable effect modification for either outcome. This result does not establish that kin resources are functionally independent, because the number of relatives cannot capture relationship quality, support exchange or negative interaction.

These contrasting patterns illustrate why a social resource ecology cannot be reduced to a single compensatory or reinforcing process. Different personal resources may occupy different positions within the wider configuration of social connection. The same neighbourhood resource may therefore have different relevance across friendship, partnership and kin configurations. Conversely, the apparent value of a personal relationship may depend on the contextual resources surrounding it. This perspective moves beyond estimating the average association of each resource in isolation and directs attention towards the configuration within which social resources are experienced.

The framework also generates a research agenda that can be evaluated more directly than was possible in this cross-sectional analysis. Prospective studies should measure personal and neighbourhood resources before changes in loneliness and should assess relationship quality, support functions and negative exchanges alongside structural availability. Repeated measurements could examine how resource configurations change following partnership transitions, bereavement, friendship loss, relocation or changes in neighbourhood conditions. Multilevel studies could further distinguish individual perceptions from shared neighbourhood characteristics. Formal evaluations should pre-specify substitution and multiplication hypotheses and assess whether the resulting patterns replicate across populations, settings and loneliness measures.

Practically, the framework cautions against designing loneliness interventions around a single average resource association. Initiatives that strengthen neighbourhood trust, belonging or opportunities for interaction may have different consequences across personal network configurations. However, the present findings do not justify targeting particular groups or assuming that changing one resource will causally alter another. Instead, they support developing and evaluating interventions that assess both personal and contextual resources. The current results should therefore be understood as an initial empirical illustration of the proposed framework, rather than as evidence that its causal pathways have been validated.

Strengths and limitations

Strengths include the large complete-case sample, a theory-led comparison of three personal network resources, robust standard errors, and use of both indirect and direct loneliness measures. The convergence of the partnership interaction across outcomes and the explicit separation of friendship, partnership and kin resources provide a more discriminating test than an undifferentiated network-size measure.

Five limitations should be considered. The principal limitation is the cross-sectional, self-reported design, which precludes temporal ordering and is vulnerable to reverse causation, common-source bias and appraisal effects. Second, despite being one of the largest studies on loneliness, because INTERACT is a volunteer-based non-probability sample, its size improves precision but cannot remove selection bias or support population-representative inference. Third, friend and relative counts and relationship status capture structural availability rather than tie quality, contact frequency, support functions or negative interactions. This measurement boundary may be particularly important for kin resources.

Fourth, complete-case estimates may be biased if missingness depends on unobserved values after conditioning on model covariates. Fifth, interpretation depends on several model specifications: trend coding imposes monotonicity and uses the lower bound of the open-ended ≥ 9 category, ordered-logit estimates depend on the proportional-odds specification, and treating the five-category DMOL score as continuous assumes equal-score spacing. Sensitivity analyses using alternative link functions, categorical moderator interactions and approaches to missing data would strengthen future replication. In a sample of this size, small coefficients can be estimated precisely; statistical evidence should

therefore be distinguished from practical importance. The terms substitution and multiplication describe patterns consistent with theory and do not establish that one resource causally compensates for or amplifies another.

Conclusion

Perceived neighbourhood social capital was inversely associated with loneliness, but its relevance differed according to the configuration of personal network resources. Friendship showed partial, outcome-dependent evidence consistent with resource substitution; marriage or cohabitation showed consistent evidence of resource multiplication; and relative count did not modify the association. These contrasting patterns suggest that social resources should not be understood as uniformly additive or interchangeable.

Building on these findings, we introduce the Social Resource Ecology of Loneliness, a conceptual model in which loneliness is understood in relation to the configuration and interplay of social resources operating across interpersonal and contextual levels. Within this ecology, one resource may compensate for the scarcity of another, amplify the relevance of another, or operate relatively independently, with the nature of these relationships depending on the type, function and configuration of the resources concerned. The coexistence of substitution, multiplication and non-interaction observed in this study provides an initial empirical basis for this model and suggests that the relationship between social connection and loneliness may be inherently configurational rather than simply additive.

The Social Resource Ecology of Loneliness is proposed here as a testable organising model rather than a validated causal theory. Longitudinal, multilevel and intervention studies using richer measures of relationship quality, function and change are now needed to determine whether these resource configurations prospectively shape loneliness, how they evolve across the life course, and whether modifying one component of the social resource ecology changes the relevance of others.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki. The INTERACT Study was registered on the NIHR Portfolio (CPMS #52230) and was approved by the Imperial College London Research Ethics Committee (#21IC6950) and the NHS Research Ethics Committee (#305483). All participants received study information and provided informed electronic consent.

Consent to participate

All participants received study information and provided informed electronic consent prior to participation in the study.

Consent for publication

Not applicable.

Availability of data and materials

Individual-level data are not publicly available because participant consent and research governance conditions restrict open sharing. A de-identified dataset and accompanying documentation may be made available by the corresponding author on reasonable request, subject to institutional approval and applicable data-protection requirements.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

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Use of artificial intelligence tools

Generative artificial intelligence tools were used for language editing, structural revision and formatting after the statistical results had been produced. The authors reviewed and take responsibility for all scientific interpretations and final wording. Artificial intelligence was not used to conduct the statistical analyses or generate study results.

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Patient and public involvement

Patients and members of the public were not involved in the design, conduct, reporting or dissemination plans of this analysis.

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References

1. Antonucci TC, Ajrouch KJ, Birditt KS. The convoy model: explaining social relations from a multidisciplinary perspective. Gerontologist. 2014;54(1):82–92. doi:10.1093/geront/gnt118.
2. Berkman LF, Glass T, Brissette I, Seeman TE. From social integration to health: Durkheim in the new millennium. Soc Sci Med. 2000;51(6):843–857. doi:10.1016/S0277-9536(00)00065-4.
3. Cohen S, Wills TA. Stress, social support, and the buffering hypothesis. Psychol Bull. 1985;98(2):310–357. doi:10.1037/0033-2909.98.2.310.
4. Ehsan A, Klaas HS, Bastianen A, Spini D. Social capital and health: a systematic review of systematic reviews. SSM Popul Health. 2019;8:100425. doi:10.1016/j.ssmph.2019.100425.
5. El-Osta, A., Alaa, A., Al-Ammouri, M. *et al.* Measuring loneliness at a national scale: The measuring loneliness in England (INTERACT) study's approach and initial findings. *BMC Glob. Public Health* **4**, 69 (2026). https://doi.org/10.1186/s44263-026-00296-5
6. Fiori KL, Antonucci TC, Cortina KS. Social network typologies and mental health among older adults. J Gerontol B Psychol Sci Soc Sci. 2006;61(1):P25–P32. doi:10.1093/geronb/61.1.P25.
7. Hawkley LC, Cacioppo JT. Loneliness matters: a theoretical and empirical review of consequences and mechanisms. Ann Behav Med. 2010;40(2):218–227. doi:10.1007/s12160-010-9210-8.
8. Holt-Lunstad J, Smith TB, Layton JB. Social relationships and mortality risk: a meta-analytic review. PLoS Med. 2010;7(7):e1000316. doi:10.1371/journal.pmed.1000316.
9. Holt-Lunstad J, Smith TB, Baker M, Harris T, Stephenson D. Loneliness and social isolation as risk factors for mortality: a meta-analytic review. Perspect Psychol Sci. 2015;10(2):227–237. doi:10.1177/1745691614568352.
10. Hughes ME, Waite LJ, Hawkley LC, Cacioppo JT. A short scale for measuring loneliness in large surveys: results from two population-based studies. Res Aging. 2004;26(6):655–672. doi:10.1177/0164027504268574.
11. Litwin H. Social network type and morale in old age. Gerontologist. 2001;41(4):516–524. doi:10.1093/geront/41.4.516.
12. Lochner K, Kawachi I, Kennedy BP. Social capital: a guide to its measurement. Health Place. 1999;5(4):259–270. doi:10.1016/S1353-8292(99)00016-7.
13. McLeroy KR, Bibeau D, Steckler A, Glanz K. An ecological perspective on health promotion programs. Health Educ Q. 1988;15(4):351–377. doi:10.1177/109019818801500401.
14. Nyqvist F, Victor CR, Forsman AK, Cattan M. The association between social capital and loneliness in different age groups: a population-based study in Western Finland. BMC Public Health. 2016;16:542. doi:10.1186/s12889-016-3248-x.
15. Ross CE, Mirowsky J. Sex differences in the effect of education on depression: resource multiplication or resource substitution? Soc Sci Med. 2006;63(5):1400–1413. doi:10.1016/j.socscimed.2006.03.013.

16. Sampson RJ, Raudenbush SW, Earls F. Neighborhoods and violent crime: a multilevel study of collective efficacy. Science. 1997;277(5328):918–924. doi:10.1126/science.277.5328.918.
17. Seeman TE, Berkman LF. Structural characteristics of social networks and their relationship with social support in the elderly: who provides support. Soc Sci Med. 1988;26(7):737–749. doi:10.1016/0277-9536(88)90065-2.
18. Shiovitz-Ezra S, Ayalon L. Use of direct versus indirect approaches to measure loneliness in later life. Res Aging. 2012;34(5):572–591. doi:10.1177/0164027511423258.
19. Valtorta NK, Kanaan M, Gilbody S, Ronzi S, Hanratty B. Loneliness and social isolation as risk factors for coronary heart disease and stroke: systematic review and meta-analysis of longitudinal observational studies. Heart. 2016;102(13):1009–1016. doi:10.1136/heartjnl-2015-308790.
20. World Health Organization. From loneliness to social connection: charting a path to healthier societies. Report of the WHO Commission on Social Connection. Geneva: World Health Organization; 2025. ISBN 978-92-4-011236-0.

Figures

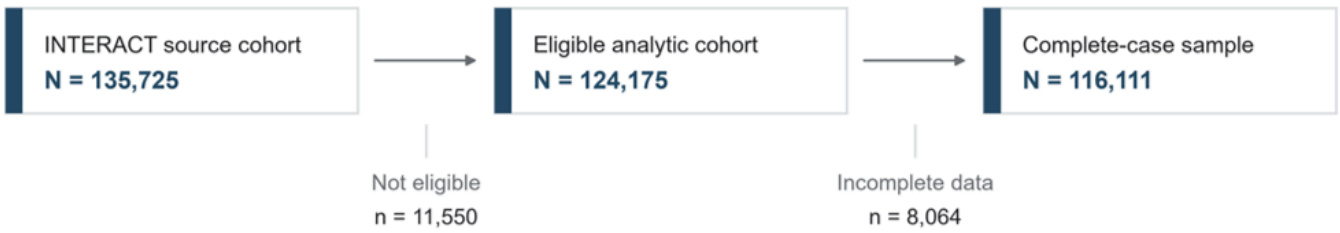


Figure 1

Analytic sample flow. The source cohort included 135,725 respondents; 124,175 met the analytic eligibility criteria, and 116,111 had complete outcome and covariate data for the fully adjusted models.

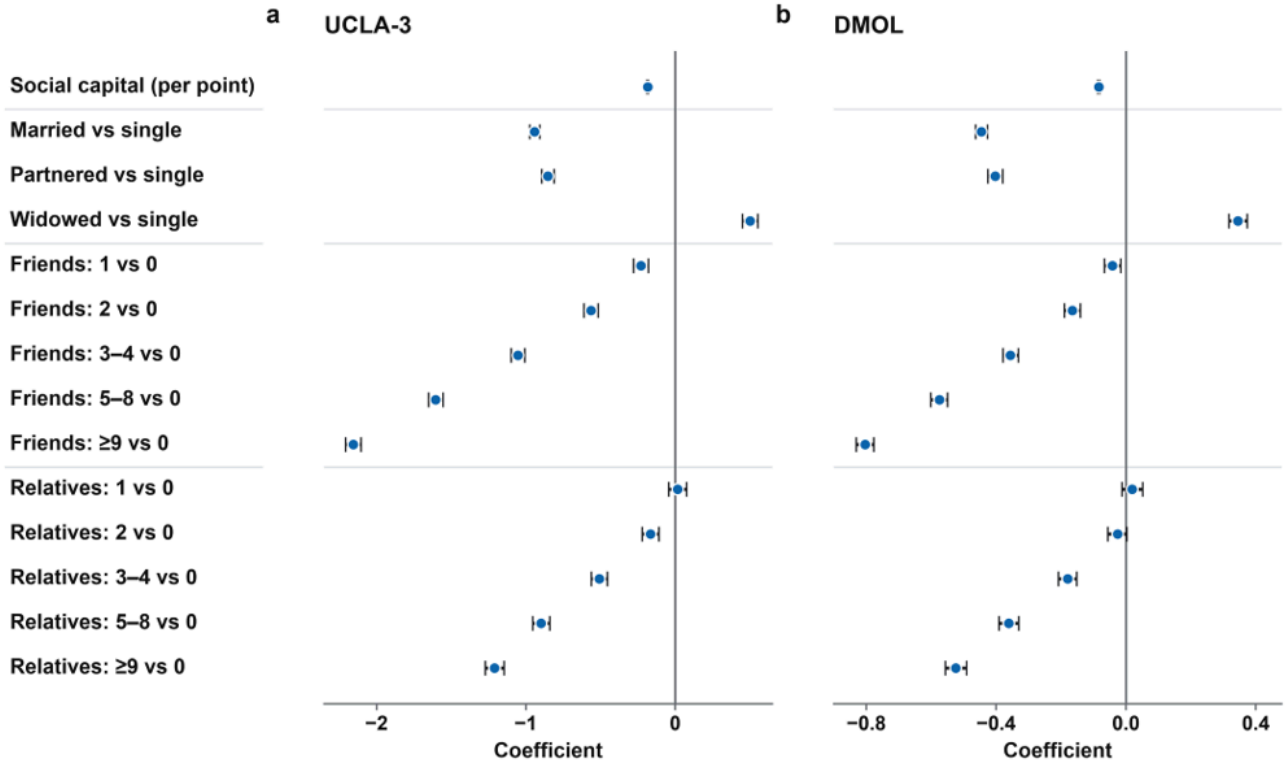


Figure 2

Adjusted associations with loneliness. Points and horizontal lines show coefficients and 95% confidence intervals from the fully adjusted UCLA-3 ordered-logit and DMOL linear models. Negative values indicate lower loneliness. The panels use different coefficient scales; exact estimates are reported in Tables 2 and 3. Models include the covariates listed in Methods; N=116,111.

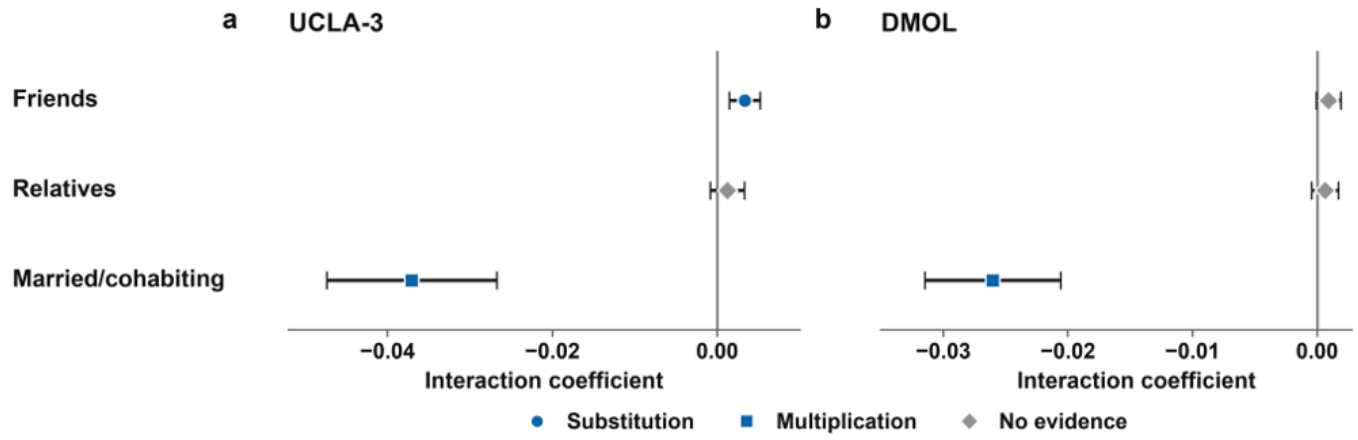


Figure 3

Modification by personal networks. Points and horizontal lines show interaction coefficients and 95% confidence intervals from separate fully adjusted models. Blue circles indicate substitution, blue squares indicate multiplication, and grey diamonds indicate no evidence at two-sided P<0.05. Positive coefficients indicate a weakening inverse association as network count increases; negative coefficients indicate a stronger inverse association at higher moderator values or among married/cohabiting respondents. The panels use different coefficient scales; N=116,111.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryFile1Methods.docx
- SupplementaryTablesS1S4.docx