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Temporal associations between dietary intake and emotional symptoms in older Chinese adults: a cross-lagged panel network study of the CLHLS, 2008–2014

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Abstract

Background

Dietary intake and emotional symptoms are associated in later life, but the direction of their longitudinal associations may vary. We examined food-intake frequency and four emotional symptoms across two successive observation windows in older Chinese adults.

Methods

This longitudinal cohort study used the 2008, 2011 and 2014 waves of the Chinese Longitudinal Healthy Longevity Survey. Cross-lagged panel networks included 12 food-intake items and four emotional-symptom items. Regularized regressions were fitted for 2008–2011 (N = 6,490) and 2011–2014 (N = 3,968). Paired bootstrap comparisons used 3,796 participants with complete data across all three waves, with false discovery rate correction across 256 paths. We examined network stability, age strata, missing data, complete-case weighting, age/sex adjustment, alternative model specifications and exclusion of the unhappiness item.

Results

In 2008–2011, more frequent fruit, nut and meat intake was associated with lower subsequent loneliness or uselessness. In 2011–2014, uselessness was associated with less frequent subsequent nut intake (β=−0.051, 95% confidence interval − 0.092 to − 0.025), and uselessness and loneliness had more outgoing connections within the emotional network. Unadjusted paired comparisons suggested changes in nuts→uselessness (Δβ = 0.051), uselessness→nuts (Δβ=−0.059) and loneliness→anxiety (Δβ = 0.056). These cross-lagged differences remained exploratory after correction (q = 0.099–0.228). Eight autoregressive differences survived correction at q < 0.05. The later-window pattern had the same direction in both age strata. Six of 480 age-stratified path-by-window comparisons were nominally significant (approximate P < 0.05), all six in 2008–2011; none survived false discovery rate (FDR) correction (smallest q = 0.83). Core cross-domain path directions were consistent under multiple imputation, inverse probability weighting and exclusion of the unhappiness item.

Conclusions

Diet–emotion associations showed possible changes across observation windows, alongside stronger autoregressive persistence. Cross-lagged differences were exploratory after multiple-testing correction. Independent samples and designs that distinguish within-person change from between-person differences are needed to test whether these patterns reflect stages of ageing and have implications for intervention.

Trial registration

Clinical trial number: not applicable.

Background

Anxiety and depressive symptoms are common in older Chinese adults and are associated with functional decline, lower quality of life and higher mortality risk [1]. Dietary behaviour is a modifiable lifestyle factor and a central topic in nutritional psychiatry [2, 3].

Cross-sectional studies consistently associate healthier diets, including higher fruit, vegetable, nut and fish intake, with fewer depressive symptoms [3, 4, 5, 6, 7]. Longitudinal findings point in both directions. Higher healthy-diet scores predict lower subsequent depression risk [4], while depressive symptoms can precede poorer diet quality and more emotional eating [8]. Most longitudinal studies have focused on middle-aged or young-old adults and have treated the direction of this association as stable. Later life spans substantial changes in function, appetite, social roles and access to food, so the dominant temporal pathway may change across observation windows. Dietary behaviour may precede emotional symptoms when function and routines remain relatively preserved, whereas emotional symptoms may precede changes in intake as functional reserve declines.

A dynamic account requires a framework that estimates bidirectional temporal associations across multiple variables. CLPN analysis uses LASSO-regularized regressions to predict each time-2 node from all time-1 nodes, yielding a sparse directed network of autoregressive and cross-lagged paths [9]. The approach has been used in psychopathology [9, 10] and health-behaviour research. It accommodates the 16-node system studied here, which includes 12 food items and four emotional items.

Using the 2008, 2011 and 2014 CLHLS waves, we constructed a 16-node CLPN to address three objectives: first, to characterize diet–emotion temporal associations separately in the 2008–2011 and 2011–2014 windows; second, to estimate cross-window coefficient changes using paired bootstrap comparisons in the three-wave common sample; and third, to assess robustness through network stability, age-stratified (< 80 versus ≥ 80 years), age×window interaction and sensitivity analyses. Sensitivity analyses considered age/sex adjustment, multiple imputation, inverse probability weighting, cross-validation-based LASSO selection and rank transformation. We hypothesized a shift from predominantly food-to-emotion associations towards a pattern with more emotion-to-food associations. CLPN estimates temporal associations rather than causal effects [11].

Methods

Data source and study population

We used publicly available data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS [12, 13]), conducted by the Center for Healthy Aging and Development Studies at Peking University. The

survey covers 23 provinces, autonomous regions and municipalities. From 2008, Hainan and Chengmai County were added, and about half of counties or cities were selected in the other 22 provincial units. We analysed the 2008/2009, 2011/2012 and 2014 waves. Eligible participants were aged 60 years or older at the 2008 wave (observed range 61–111 years; mean 80.4 ± 10.3 years; 51.6% aged ≥ 80 years) and survived to the next wave in the relevant window. The report follows the STROBE cohort checklist (Additional file 1).

We defined two consecutive observation windows. In Window 1 (2008→2011), the 16,954 respondents in 2008/2009 included 5,642 deaths and 2,894 losses to follow-up by 2011, leaving 8,418 survivors. Of these, 6,490 had valid data for all 16 nodes at both waves (77.1% of survivors). Window 2 (2011→2014) began with the 8,418 survivors in 2011: 2,589 died, 584 were lost to follow-up and 5,245 survived to 2014 (2,589 + 584+5,245 = 8,418). Of the survivors, 3,968 had complete data for all 16 nodes at both waves (75.7%). The 2014 dataset contained 591 records flagged as lost to follow-up, but seven had already been recorded as deceased in 2011 and were excluded from the decomposition of the 2011 survivor cohort. The three-wave common complete-case sample comprised 3,796 participants and was used for paired cross-window comparisons. Figure 1 summarizes the analytical workflow.

We assessed selective attrition by classifying 2008 respondents according to their 2011 status (died, lost to follow-up, alive but incomplete, or alive and complete) and comparing baseline characteristics (Table 2). Multiple imputation and inverse probability weighting addressed missingness and attrition in sensitivity analyses.

Measures

Emotional symptoms

Four items with consistent wording across all three waves were selected from the CLHLS emotional and subjective well-being scale: anxiety/tension (b23, “Do you often feel fearful or anxious?”), loneliness (b24, “Do you often feel lonely?”), uselessness (b26, “Do you feel that you are becoming more useless as you age?”) and unhappiness (b27, “Do you feel as happy as when you were younger?”). Items b23, b24 and b26 used 5-point response scales (1 = always, 2 = often, 3 = sometimes, 4 = seldom, 5 = never) and were reverse-coded as 6 − raw score so that higher values indicated more severe symptoms. Item b27 used identical wording and ordered response categories across waves (1 = always happy to 5 = never happy), was already aligned with symptom severity and was retained in its original direction. All four nodes therefore ranged from 1 to 5. They are single-item screening indicators and do not constitute clinical diagnoses.

Dietary intake frequency

We selected 12 food-frequency items: fruit (d31), vegetables (d32), meat (d4meat2), fish (d4fish2), eggs (d4egg2), bean products (d4bean2), pickled vegetables (d4veg2), sugar (d4suga2), tea (d4tea2), garlic (d4garl2), dairy products (d4milk1) and nuts (d4nut1). Each item used a 5-point scale (1 = almost every day, 2 = often, 3 = occasionally, 4 = seldom, 5 = never) and was reverse-coded as 6 − raw score, giving higher values for more frequent intake. Codes 8, 9 and invalid values were treated as missing. All 16 network nodes ranged from 1 to 5; Tables 1 and 2 report these analysis scores.

Statistical analysis

Descriptive statistics and contemporaneous networks

We summarized the baseline characteristics and age composition of each analysis sample descriptively. The three-wave common sample was nested within both window-specific samples; therefore, no independent-group significance tests were performed for Table 1. Comparisons among the mutually exclusive 2011 follow-up groups used one-way analysis of variance for continuous variables and chi-square tests for binary variables (Table 2). To describe cross-sectional association structure, we estimated contemporaneous partial-correlation networks separately for complete respondents in 2008, 2011 and 2014 (N = 7,574, 4,726 and 4,274). GraphicalLassoCV selected the precision-matrix regularization parameter by cross-validation; edges with |partial correlation| ≤ 0.05 were omitted.

Cross-lagged panel network estimation

We standardized the 1–5 analysis scores within each wave. Standardization parameters were estimated on the sample under analysis: window-specific complete cases for the main networks, the three-wave common sample for paired comparisons, and each age stratum for age-stratified networks. For each time-2 node j = 1,…,16, we fitted a LASSO regression with all 16 time-1 nodes as predictors: $z(j,T2)=\beta_0+\Sigma\beta ij\cdot z(i,T1)+\varepsilon j$. This produced a 16×16 coefficient matrix B, where diagonal entries represented autoregressive paths and off-diagonal entries represented cross-lagged paths. These coefficients summarize between-person lagged structure across the cohort rather than within-person change. The penalty λ was selected for each outcome using the Bayesian information criterion (BIC; sklearn LassoLarsIC). BIC favoured a sparse network in a model with 16 predictors per outcome and 256 candidate paths, whereas cross-validation was used in sensitivity analyses to assess path reproducibility. Because the items were ordinal, we treated the 5-point scores as standardized continuous variables in the primary analysis and evaluated this approximation with a rank-based normal-score transformation. We assessed uncertainty with 500 within-window non-parametric bootstrap resamples of complete cases (each resample re-selecting the LASSO-BIC penalty on the resampled cases, with window standardization parameters estimated once and carried into the resamples) and displayed paths whose 95% bootstrap CIs excluded zero. Out-expected influence (out-EI) was defined as the signed sum of all significant off-diagonal outgoing coefficients, including paths within and across the food and emotional domains. Autoregressive coefficients were excluded, and coefficients were not

converted to absolute values. In-expected influence was the corresponding signed sum of significant incoming off-diagonal coefficients. Complete significant edge lists for recomputing both measures are provided in Tables S1 and S2 (Additional files 2 and 3).

Network stability

We used case-dropping bootstrap to calculate the correlation stability (CS) coefficient [14]. After randomly dropping 5%–75% of cases, with 50 replicates at each 5% increment, we re-estimated the CLPN and correlated its coefficient vector with the original vector. The 5th percentile of these correlations defined the stability curve. The CS coefficient was the largest drop proportion at which this percentile remained ≥ 0.70; CS ≥ 0.25 is acceptable and ≥ 0.50 is good [14].

Cross-window difference testing

We compared the two windows in the three-wave common complete-case sample (N = 3,796). For each path, $\Delta\beta = \beta(2011 \rightarrow 2014) - \beta(2008 \rightarrow 2011)$. We used 500 paired bootstrap resamples of the same individuals in both windows to derive 95% CIs. Each resample re-ran the complete-case pipeline on the resampled individuals, including wave-specific re-standardization and LASSO-BIC penalty re-selection; coefficients shrunk to zero were retained as zeros when differencing. Percentile CIs used the 2.5th and 97.5th bootstrap quantiles. Approximate P values assumed a normal sampling distribution, with SE estimated from each percentile CI as (upper−lower)/(2×1.96) and $z = \Delta\beta/SE$, so 500 resamples give these P values limited tail resolution. A CI excluding zero indicated a nominal, unadjusted difference. Approximate two-sided P values derived from the bootstrap 95% CIs were adjusted across all 256 paths using the Benjamini–Hochberg false discovery rate (FDR) procedure [15]; $q < 0.05$ defined significance after correction. The common sample held participant composition constant across the paired comparison.

Age-stratified analysis

To assess age-related heterogeneity, we stratified complete cases by baseline age (< 80 versus ≥ 80 years) and re-estimated the CLPN within each stratum using within-stratum standardization, LASSO-BIC selection and 500 bootstraps. We estimated between-stratum differences for each path with bootstrap 95% CIs. Age 80 was close to the sample median and is a conventional threshold for the oldest-old. Approximate two-sided P values were derived from the bootstrap CIs using the same normal-approximation formula as in the paired analysis and Benjamini–Hochberg FDR correction was applied across 480 path-by-window between-stratum comparisons. Nominal and FDR-adjusted results are reported separately. In the common sample, age×window interactions assessed whether cross-window coefficient changes differed between the two age strata.

Sensitivity analyses

We conducted six sensitivity analyses. (1) Multiple imputation addressed item-level missingness in each survivor set (N = 8,418 and N = 5,245) using five imputations with predictive mean matching, five iterations and baseline age and sex as auxiliary variables (R package mice; [16]). We averaged coefficients across imputed datasets and pooled the 2.5th and 97.5th percentiles from 100 bootstraps per imputation. (2) Inverse probability weighting estimated the probability of complete-case status from baseline age, sex and the 16 time-1 nodes; weights $w = 1/\hat{p}$ were truncated at the 99th percentile [17], and weighted LASSO-BIC models used 200 bootstraps. (3) For Window 2 only, covariate adjustment regressed each time-1 and time-2 node on standardized baseline age and sex before CLPN estimation. This secondary analysis specifically addressed the older age distribution and changed composition of the later window and was not repeated post hoc in Window 1. (4) Ten-fold cross-validation with 50 candidate λ values replaced BIC for network selection. (5) Nodes were rank-transformed before standardization and CLPN estimation. (6) To assess the decrease in mean unhappiness at the 2011 baseline, complete-case networks were re-estimated after removing b27 at both time points while retaining the original samples and 500 bootstrap resamples. Table 5 and the corrected Tables S4/S5 use the same final coefficient matrices and bootstrap draws.

Software and reproducibility

Primary analyses used Python 3.10 (scikit-learn 1.7: LassoLarsIC, LassoCV and GraphicalLassoCV). Multiple imputation and inverse probability weighting used R 4.4 (mice and glmnet), and network figures used ggplot2, igraph and patchwork. We independently re-estimated the complete-case CLPNs in R and Python and compared coefficient matrices. Random seeds were fixed. Main model estimates and sensitivity results are reported in Tables 3–5. Statistical tests were two-sided with $\alpha = 0.05$.

Use of artificial intelligence

OpenAI Codex assisted with language editing, journal-specific formatting, incorporation of author-supplied revisions, checks of consistency between the text and tables, and execution of the item-exclusion sensitivity analysis. It was not used to generate participant data or to re-estimate the primary statistical models. The authors are responsible for the scientific content and its verification.

Results

Sample characteristics and selective attrition

Complete-case analysis yielded three overlapping samples: Window 1 (2008–2011, N = 6,490), Window 2 (2011–2014, N = 3,968) and the three-wave common sample (N = 3,796). Age distributions were similar at the respective window baselines: mean age was 80.4 ± 10.3 years in 2008 for Window 1 and 80.5 ± 9.2 years in 2011 for Window 2. The common sample was younger at its 2008 baseline (77.1 ± 9.0 years), indicating that participants who survived and completed all 16 items at three waves tended to form a younger survivor subgroup (Table 1).

Table 1
Baseline characteristics and network-node scores by analysis sample.

Characteristic	Window 1 sample (2008 baseline; N = 6,490)	Window 2 sample (2011 baseline; N = 3,968)	Three-wave common sample (2008 baseline; N = 3,796)
Sample size, n	6,490	3,968	3,796
Age, mean (SD), years	80.4 (10.3)	80.5 (9.2)	77.1 (9.0)
65–79 / 80–89 / 90+, %	46.4/30.3/21.3	51.7/30.4/17.8	59.4/27.9/10.2
Male, %	48.2	49.5	49.7
Education, mean (SD), years	2.7 (3.7)	2.9 (3.7)	2.9 (3.7)
Living with spouse, %	46.7	48.2	54.6
Urban residence at wave baseline, %	38.7	53.0	37.1
Self-rated health, mean (SD)	2.5 (0.9)	2.6 (0.9)	2.4 (0.9)
Anxiety/tension	1.9 (1.0)	1.9 (0.9)	1.9 (0.9)
Loneliness	1.9 (1.0)	1.9 (1.0)	1.9 (1.0)
Uselessness	2.7 (1.2)	2.7 (1.2)	2.6 (1.2)
Unhappiness	3.2 (1.1)	2.4 (1.3)	3.1 (1.1)
Fruit	3.3 (1.0)	3.3 (1.0)	3.4 (0.9)
Vegetables	4.6 (0.7)	4.5 (0.7)	4.6 (0.7)
Meat	3.7 (1.3)	3.8 (1.2)	3.7 (1.3)
Fish	2.9 (1.3)	3.0 (1.3)	2.9 (1.3)
Eggs	3.8 (1.3)	3.7 (1.3)	3.7 (1.3)
Bean products	3.3 (1.3)	3.3 (1.2)	3.3 (1.3)
Pickled vegetables	2.8 (1.6)	2.6 (1.6)	2.9 (1.6)

Note. Data are descriptive and shown as mean (SD) or %. Emotional-symptom and food-intake items are analysis scores (1–5); higher scores indicate more severe symptoms or more frequent intake, respectively. Self-rated health ranges from 1 (very good) to 5 (very poor). Residence was recorded at each wave baseline and coded as city, town or rural; urban includes city and town. The three columns overlap because the three-wave common sample is nested within both window-specific samples, and residential percentages are not paired estimates of neighbourhood change. Between-column significance tests were therefore not performed. The displayed age categories omit participants younger than 65 years, so their percentages need not sum to 100%.

Characteristic	Window 1 sample (2008 baseline; N = 6,490)	Window 2 sample (2011 baseline; N = 3,968)	Three-wave common sample (2008 baseline; N = 3,796)
Sugar	2.6 (1.5)	2.5 (1.5)	2.6 (1.5)
Tea	2.7 (1.9)	2.5 (1.8)	2.8 (1.9)
Garlic	3.0 (1.5)	3.0 (1.6)	3.1 (1.5)
Dairy products	2.3 (1.6)	2.4 (1.6)	2.2 (1.5)
Nuts	1.9 (1.2)	1.9 (1.2)	2.0 (1.2)

Note. Data are descriptive and shown as mean (SD) or %. Emotional-symptom and food-intake items are analysis scores (1–5); higher scores indicate more severe symptoms or more frequent intake, respectively. Self-rated health ranges from 1 (very good) to 5 (very poor). Residence was recorded at each wave baseline and coded as city, town or rural; urban includes city and town. The three columns overlap because the three-wave common sample is nested within both window-specific samples, and residential percentages are not paired estimates of neighbourhood change. Between-column significance tests were therefore not performed. The displayed age categories omit participants younger than 65 years, so their percentages need not sum to 100%.

The three-wave common sample included a higher proportion of participants living with a spouse (54.6%, compared with 46.7% in Window 1 and 48.2% in Window 2) and had slightly better self-rated health (2.4 ± 0.9, compared with 2.5 ± 0.9 and 2.6 ± 0.9, respectively). These descriptive differences are consistent with selective completion of three-wave follow-up.

Table 1 presents all 16 nodes on their 1–5 analysis scales. Most mean emotional-symptom and food-intake scores were close across samples; unhappiness was lower at the Window 2 baseline (2.4 ± 1.3) than at the Window 1 and common-sample baselines (3.2 ± 1.1 and 3.1 ± 1.1). The b27 wording and ordered response categories were consistent across waves, so the shift was not produced by a change in coding. It could reflect period-specific reporting, sample composition or both; we therefore re-estimated the networks after excluding b27. These overlapping samples were summarized descriptively, without independent-group significance tests.

Attrition was selective (Fig. 2; Table 2). Compared with complete cases (80.4 ± 10.3 years), participants who died were older (93.6 ± 8.8 years), as were those lost to follow-up (86.1 ± 13.9 years) and those alive with incomplete data (90.1 ± 10.1 years; between-group $P < 0.001$). Complete cases had more education (2.7 versus 1.3 years), were more often married or partnered (46.7% versus 16.0%), reported better self-rated health (2.48 versus 2.68; lower is better), had milder emotional symptoms and, compared with participants who died, reported more frequent intake of nine foods: fruit, vegetables, meat, fish, bean products, pickled vegetables, tea, garlic and nuts. The deceased group reported slightly higher intake of eggs, sugar and dairy. The same pattern occurred in Window 2. IPW sensitivity analyses assessed the influence of selective complete-case inclusion.

Table 2
Selective attrition by 2011 follow-up status.

2008 baseline characteristic	Died (n = 5,642)	Lost (n = 2,894)	Alive, incomplete (n = 1,928)	Alive, complete (n = 6,490)	P
Age, years	93.58 ± 8.78	86.13 ± 13.87	90.06 ± 10.08	80.36 ± 10.32	< 0.001
Male, %	38.8	43.1	35.5	48.2	< 0.001
Education, years	1.33 ± 2.81	2.59 ± 3.87	1.29 ± 2.70	2.70 ± 3.73	< 0.001
Living with spouse, %	16.0	30.2	22.9	46.7	< 0.001
Urban residence, %	33.6	53.7	36.3	38.7	< 0.001
Self-rated health (1–5)	2.68 ± 0.94	2.58 ± 0.91	2.57 ± 0.91	2.48 ± 0.92	< 0.001
Anxiety/tension	2.08 ± 1.00	2.10 ± 1.04	2.01 ± 0.97	1.91 ± 0.95	< 0.001
Loneliness	2.23 ± 1.05	2.16 ± 1.07	2.11 ± 1.06	1.92 ± 0.99	< 0.001
Uselessness	3.01 ± 1.17	2.77 ± 1.18	2.95 ± 1.19	2.65 ± 1.17	< 0.001
Unhappiness	3.39 ± 1.12	3.36 ± 1.11	3.28 ± 1.14	3.15 ± 1.09	< 0.001
Fruit	3.15 ± 0.96	3.44 ± 1.00	3.19 ± 0.97	3.31 ± 0.96	< 0.001
Vegetables	4.37 ± 0.86	4.47 ± 0.76	4.44 ± 0.77	4.56 ± 0.70	< 0.001
Meat	3.59 ± 1.31	3.62 ± 1.29	3.59 ± 1.31	3.67 ± 1.26	0.007
Fish	2.69 ± 1.32	3.06 ± 1.28	2.72 ± 1.34	2.88 ± 1.28	< 0.001
Eggs	3.78 ± 1.28	3.83 ± 1.22	3.72 ± 1.31	3.75 ± 1.27	0.011
Bean products	3.25 ± 1.29	3.38 ± 1.25	3.21 ± 1.31	3.33 ± 1.28	< 0.001
Pickled vegetables	2.35 ± 1.55	2.57 ± 1.59	2.52 ± 1.59	2.78 ± 1.60	< 0.001

Note. Data are mean ± SD for continuous variables and % for binary variables. P values compare the four mutually exclusive follow-up groups using one-way analysis of variance for continuous variables and chi-square tests for binary variables. Node scores are the 1–5 analysis scores described under Measures; higher scores indicate more severe symptoms or more frequent intake.

2008 baseline characteristic	Died (n = 5,642)	Lost (n = 2,894)	Alive, incomplete (n = 1,928)	Alive, complete (n = 6,490)	P
Sugar	2.81 ± 1.55	2.58 ± 1.49	2.71 ± 1.53	2.60 ± 1.47	< 0.001
Tea	2.27 ± 1.73	2.59 ± 1.80	2.30 ± 1.75	2.73 ± 1.85	< 0.001
Garlic	2.65 ± 1.50	2.88 ± 1.53	2.70 ± 1.47	3.01 ± 1.50	< 0.001
Dairy products	2.30 ± 1.60	2.65 ± 1.69	2.25 ± 1.57	2.26 ± 1.57	< 0.001
Nuts	1.47 ± 0.92	1.80 ± 1.16	1.58 ± 1.03	1.86 ± 1.17	< 0.001

Note. Data are mean ± SD for continuous variables and % for binary variables. P values compare the four mutually exclusive follow-up groups using one-way analysis of variance for continuous variables and chi-square tests for binary variables. Node scores are the 1–5 analysis scores described under Measures; higher scores indicate more severe symptoms or more frequent intake.

At the 2011 time point, mean age was 80.5 years in the Window 2 complete-case sample and 83.4 years in the Window 1 complete-case sample. These samples shared the three-wave common participants and were not tested as independent groups. Cross-window comparisons used paired bootstrap resampling in the common sample, while within-window age stratification and age×window interactions assessed the influence of age composition.

Contemporaneous network structure

The contemporaneous partial-correlation networks were broadly similar across the 2008, 2011 and 2014 waves (Fig. 3; complete respondents N = 7,574, 4,726 and 4,274). The four emotional nodes formed a connected positive cluster, as did the food nodes. Cross-cluster edges were mainly weak and negative, with recurring negative associations between fruit, vegetables and dairy and emotional symptoms, consistent with milder symptoms among participants reporting more frequent intake.

Window 1 (2008–2011): food-to-emotion pathways

The Window 1 CLPN was dominated by food-to-emotion associations (Fig. 4A; Table 3). Higher fruit, nut and meat intake was associated with lower loneliness and uselessness three years later. For example, fruit→loneliness was β=−0.053 (95% CI − 0.073 to − 0.024) and nuts→uselessness was β=−0.053 (95% CI − 0.085 to − 0.031). Most significant cross-domain paths ran from food to emotion. The only reverse path, uselessness→tea, was small (β=−0.027). Within the emotional domain, anxiety/tension→unhappiness and uselessness→unhappiness were significant. All significant cross-lagged paths are listed in Additional file 2 (Table S1).

Table 3
Main cross-lagged paths in the two windows.

Path	2008–2011 β (95% CI)	2011–2014 β (95% CI)
Fruit → Loneliness	−0.053 (− 0.073, − 0.024)	—
Fruit → Uselessness	−0.030 (− 0.061, − 0.007)	—
Nuts → Loneliness	−0.054 (− 0.072, − 0.026)	—
Nuts → Uselessness	−0.053 (− 0.085, − 0.031)	—
Meat → Uselessness	−0.039 (− 0.071, − 0.017)	—
Uselessness → Tea	−0.027 (− 0.055, − 0.006)	—
Anxiety/tension → Unhappiness	0.041 (0.013, 0.071)	—
Uselessness → Unhappiness	0.034 (0.007, 0.059)	—
Eggs → Loneliness	—	−0.046 (− 0.080, − 0.019)
Eggs → Unhappiness	—	−0.055 (− 0.084, − 0.022)
Uselessness → Nuts	—	−0.051 (− 0.092, − 0.025)
Uselessness → Loneliness	—	0.057 (0.023, 0.095)
Uselessness → Anxiety/tension	—	0.041 (0.006, 0.076)
Uselessness → Unhappiness	—	0.072 (0.038, 0.105)
Loneliness → Anxiety/tension	—	0.053 (0.015, 0.092)
Loneliness → Unhappiness	—	0.062 (0.025, 0.095)

Note. Estimates are from complete-case LASSO-BIC models with 500 bootstrap resamples. A dash indicates that the path did not have a bootstrap 95% CI excluding zero in that window. These within-window intervals are unadjusted; cross-window differences and their FDR interpretation are reported separately in Table 4 and the text.

Using this definition, food nodes had the largest out-EI values: dairy 0.264, fruit 0.217, eggs 0.123 and tea 0.097. The largest emotional out-EI was 0.041 for anxiety/tension. Dietary behaviour therefore accounted for most outgoing temporal prediction in Window 1, while emotional symptoms were mainly outcomes.

Window 2 (2011–2014): emotional connections and an emotion-to-food path

The Window 2 CLPN showed a different descriptive pattern (Fig. 4B; Table 3). Fewer food-to-emotion paths were retained; eggs were inversely associated with subsequent loneliness (β=−0.046, 95% CI − 0.080 to − 0.019) and unhappiness (β=−0.055, 95% CI − 0.084 to − 0.022). Uselessness was associated

with less frequent subsequent nut intake (β=−0.051, 95% CI − 0.092 to − 0.025). More paths connected emotional symptoms, including uselessness→loneliness, anxiety/tension and unhappiness, and loneliness→anxiety/tension and unhappiness. These paths connect baseline to follow-up symptoms and do not establish a sequential mediation process. All significant cross-lagged paths are listed in Additional file 3 (Table S2).

Centrality also shifted. Using the same signed-sum definition, the five largest out-EI values were dairy 0.143, uselessness 0.118, eggs 0.116, loneliness 0.114 and fruit 0.056. The eggs value combined its two negative food-to-emotion coefficients with positive food-to-food outgoing coefficients; each contributing edge is listed in Table S2. Uselessness and loneliness ranked second and fourth, compared with a maximum emotional out-EI of 0.041 in Window 1. Emotional nodes therefore contributed more outgoing temporal prediction in Window 2, while dietary behaviour became more strongly predicted.

Cross-window difference tests: exploratory evidence

Paired bootstrap comparisons in the common sample (N = 3,796) identified four nominal differences relevant to the study question (Fig. 5; Table 4). The nuts→uselessness estimate changed from β=−0.051 in Window 1 to 0.000 in Window 2 (Δβ = 0.051, 95% CI 0.002–0.085). In the opposite direction, uselessness→nuts changed from β=−0.007 to − 0.066 (Δβ=−0.059, 95% CI − 0.088 to − 0.004). Loneliness→anxiety/tension increased (Δβ = 0.056, 95% CI 0.011–0.091), and eggs→unhappiness was more negative in Window 2 (Δβ=−0.052, 95% CI − 0.081 to − 0.007). Other nominal cross-lagged differences involved food-to-food associations. The complete list of all 22 nominal differences is provided in Additional file 7 (Table S6). These estimates identify candidate changes whose statistical strength must be interpreted after FDR correction.

Benjamini–Hochberg correction across all 256 paths used approximate two-sided P values derived from the bootstrap 95% CIs [15]. Of 22 paths with nominal CIs excluding zero, only eight remained significant at $q < 0.05$, all autoregressive. No cross-lagged difference survived correction: $q = 0.228$ for nuts→uselessness and $q = 0.099$ for uselessness→nuts, loneliness→anxiety and eggs→unhappiness. Individual cross-lagged differences therefore remain exploratory. The systematic increase in autoregressive coefficients provided the evidence that survived FDR correction; consistency across model implementations and sensitivity analyses supports further testing of the candidate cross-lagged patterns.

Table 4
Paired bootstrap tests of cross-window differences.

Path	Window 1 β	Window 2 β	Δβ (95% CI)	Significant
Nuts → Uselessness	−0.051	0.000	0.051 (0.002, 0.085)	Yes
Uselessness → Nuts	−0.007	−0.066	−0.059 (− 0.088, − 0.004)	Yes
Loneliness → Anxiety/tension	0.000	0.056	0.056 (0.011, 0.091)	Yes
Eggs → Unhappiness	0.000	−0.052	−0.052 (− 0.081, − 0.007)	Yes
Fruit → Fish	0.066	0.016	−0.050 (− 0.097, − 0.006)	Yes
Fruit → Bean products	0.080	0.022	−0.058 (− 0.100, − 0.003)	Yes
Pickled vegetables → Nuts	0.000	0.056	0.056 (0.001, 0.082)	Yes
Fruit → Loneliness	−0.030	0.000	0.030 (− 0.014, 0.060)	No
Fruit → Uselessness	−0.022	0.000	0.022 (− 0.033, 0.053)	No
Nuts → Loneliness	−0.032	−0.019	0.013 (− 0.041, 0.047)	No
Meat → Uselessness	−0.023	0.000	0.023 (− 0.022, 0.056)	No
Eggs → Loneliness	−0.016	−0.051	−0.034 (− 0.080, 0.008)	No
Uselessness → Tea	−0.016	0.000	0.016 (0.000, 0.050)	No

Note. Paired bootstrap resampling used the three-wave common sample (N = 3,796) with 500 resamples. Δβ = β(2011–2014)−β(2008–2011). “Significant” denotes a nominal 95% CI for Δβ excluding zero and is shown for descriptive comparison. Approximate two-sided P values were derived from the bootstrap CIs and corrected across all 256 paths using the Benjamini–Hochberg procedure; q is the adjusted P value. No cross-lagged difference survived FDR correction at q < 0.05; all eight FDR-significant differences were autoregressive. Differences were calculated before rounding the displayed coefficients. An interval lower bound displayed as 0.000 touches zero and is classified as not significant.

Network stability

Both CLPNs remained above the 0.70 stability threshold throughout the tested 5%–75% case-drop range (Fig. 6). At 75% case removal, the 5th percentile correlation was 0.939 in Window 1 and 0.958 in Window

2 [14]. The CS coefficient therefore reached 0.75 in both windows, the maximum tested proportion. This supports stability of the overall coefficient vectors within the tested range, rather than proving stability of every individual edge.

Age-stratified analysis

Age-stratified CLPNs showed that Window 1 food-to-emotion paths were strongest in participants aged ≥ 80 years (Fig. 7; Additional file 4). Six of the 480 comparisons were nominally significant (approximate two-sided P < 0.05), all in Window 1. Meat→uselessness was significant only in this group (β=−0.076, 95% CI − 0.108 to − 0.031; <80 β = 0.000), with a between-stratum difference of 0.076 (95% CI 0.008–0.105; nominal P = 0.0021). The other five nominal differences were pickled vegetables→fruit (Δβ=−0.057, 95% CI − 0.102 to − 0.026), fish→vegetables (Δβ = 0.071, 0.000–0.102), uselessness→unhappiness (Δβ = 0.054, 0.020–0.104), unhappiness→loneliness (Δβ = 0.046, 0.000–0.087) and fruit→nuts (Δβ = 0.054, 0.003–0.104); for fish→vegetables and unhappiness→loneliness, the displayed interval bounds touch zero, and their nominal status follows the approximate P values (0.0061 and 0.0367). Fruit→loneliness was also significant only in the ≥ 80 group (β=−0.040 versus − 0.016), although the between-stratum difference was not significant. All 480 comparisons are listed in Additional file 4 (Table S3).

After Benjamini–Hochberg correction across all 480 comparisons, none of the six nominal differences survived FDR correction; the smallest q value was 0.83. The Window 2 pattern appeared in both age strata. Eggs→loneliness was significant in the < 80 group (β=−0.062, 95% CI − 0.112 to − 0.022), uselessness→nuts was negative in both groups (β=−0.030 and − 0.047), and the emotional associations included uselessness→loneliness and loneliness→anxiety/tension across the strata. In Window 2, no between-stratum comparison was nominally significant; even for eggs→loneliness, the between-stratum difference was − 0.062 (95% CI − 0.105 to 0.000, with the displayed upper bound touching zero).

In the common sample, age×window interactions for the four focal cross-lagged paths were all non-significant: nuts→uselessness 0.028 (95% CI − 0.055 to 0.069), uselessness→nuts − 0.041 (− 0.086 to 0.048), loneliness→anxiety − 0.040 (− 0.114 to 0.046) and eggs→unhappiness − 0.048 (− 0.099 to 0.013). The only nominally significant interaction among 256 paths involved nut autoregressive inertia (− 0.122, 95% CI − 0.253 to − 0.041), which increased more in the older stratum. No age-related differences were detected for the four focal cross-lagged changes; these tests do not establish equivalence between age groups.

Sensitivity analyses

Multiple imputation preserved the direction and nominal significance of the six core cross-domain paths in Window 1 and all three in Window 2, with absolute coefficient differences from complete-case estimates ≤ 0.016 (Table 5; Additional files 5 and 6). After IPW, fruit→uselessness in Window 1 remained negative (β=−0.033), but its 95% CI reached zero (− 0.058 to 0.000). Excluding b27 left the six Window 1 paths and the two Window 2 paths not involving unhappiness in the same direction with bootstrap 95%

CIs excluding zero; estimates ranged from − 0.027 to − 0.056 in Window 1 and were − 0.046 for eggs→loneliness and − 0.051 for uselessness→nuts in Window 2. Independent R and Python re-estimation produced highly concordant coefficient matrices, with maximum element-wise differences of 0.007 and 0.011 and correlations ≥ 0.9997.

After adjustment for baseline age and sex in Window 2, the conditional CLPN retained all three core cross-domain paths (Table 5; Additional file 12): uselessness→nuts (β=−0.059, 95% CI − 0.085 to − 0.010), eggs→loneliness (β=−0.036, 95% CI − 0.078 to − 0.013) and eggs→unhappiness (β=−0.054, 95% CI − 0.083 to − 0.018). Emotional paths also remained, including uselessness→loneliness (β = 0.046), uselessness→unhappiness (β = 0.069), loneliness→anxiety/tension (β = 0.058) and loneliness→unhappiness (β = 0.058). The adjusted network contained 13 nominally significant cross-lagged paths in total. Uselessness→anxiety/tension was no longer significant (β = 0.045, 95% CI including zero). Absolute changes in the three core cross-domain coefficients were all ≤ 0.010.

Table 5
Sensitivity analyses for core emotion–food paths.

Path	CC β (95% CI)	Multiple imputation β (95% CI)	IPW β (95% CI)	Age/sex-adjusted β (95% CI)
Fruit → Loneliness	−0.053 (− 0.073, − 0.024)	−0.048 (− 0.069, − 0.023)	−0.051 (− 0.073, − 0.023)	—
Nuts → Loneliness	−0.054 (− 0.072, − 0.026)	−0.048 (− 0.069, − 0.024)	−0.050 (− 0.074, − 0.024)	—
Fruit → Uselessness	−0.030 (− 0.061, − 0.007)	−0.035 (− 0.057, − 0.010)	−0.033 (− 0.058, 0.000)	—
Meat → Uselessness	−0.039 (− 0.071, − 0.017)	−0.054 (− 0.080, − 0.031)	−0.054 (− 0.084, − 0.026)	—
Nuts → Uselessness	−0.053 (− 0.085, − 0.031)	−0.055 (− 0.078, − 0.028)	−0.055 (− 0.080, − 0.026)	—
Uselessness → Tea	−0.027 (− 0.055, − 0.006)	−0.037 (− 0.060, − 0.012)	−0.030 (− 0.055, − 0.012)	—
Eggs → Loneliness	−0.046 (− 0.080, − 0.019)	−0.046 (− 0.069, − 0.009)	−0.048 (− 0.079, − 0.008)	−0.036 (− 0.078, − 0.013)
Eggs → Unhappiness	−0.055 (− 0.084, − 0.022)	−0.039 (− 0.065, − 0.009)	−0.050 (− 0.089, − 0.020)	−0.054 (− 0.083, − 0.018)
Uselessness → Nuts	−0.051 (− 0.092, − 0.025)	−0.057 (− 0.082, − 0.021)	−0.052 (− 0.090, − 0.029)	−0.059 (− 0.085, − 0.010)

Note. Values are β (95% CI) from each stated model. CC, complete case; MI, multiple imputation; IPW, inverse probability weighting. The first six paths refer to 2008–2011 and the final three to 2011–2014. MI and IPW point estimates come from their respective coefficient matrices and are paired with the corresponding 95% bootstrap intervals. Age/sex-adjusted analyses were performed only for 2011–2014. A dash indicates that the analysis was not performed.

Replacing BIC with 10-fold cross-validation produced denser networks (16 versus 6 cross-domain significant paths in Window 1; 13 versus 3 in Window 2), while reproducing every BIC-identified cross-domain path with 100% directional concordance. Rank-based normal-score transformation yielded five and four cross-domain paths in Windows 1 and 2, respectively, again with 100% directional concordance. For example, eggs→loneliness was β=−0.066 and uselessness→nuts was β=−0.044 after transformation. The selection criterion changed network density more than path direction. Additional files 10–12 provide the model-comparison and network plots for these analyses. Cross-lagged

coefficients were interpreted as predictive parameters, with effect sizes considered in the context of current guidance [11, 18, 19].

Autoregressive paths and symptom persistence

Food autoregressive coefficients were higher than emotional coefficients in both windows (food 0.073–0.329 versus emotion 0.026–0.093 in Window 1; food 0.169–0.441 versus emotion 0.072–0.176 in Window 2), indicating greater temporal stability of dietary behaviour. All autoregressive point estimates increased across windows. For emotional items, coefficients changed from 0.069 to 0.109 for anxiety/tension, 0.093 to 0.176 for loneliness, 0.069 to 0.167 for uselessness and 0.026 to 0.072 for unhappiness; the Window 1 unhappiness interval included zero, whereas the Window 2 interval excluded zero. Eight autoregressive differences survived FDR correction in the paired common-sample analysis (Additional files 8 and 9). These results indicate greater symptom persistence in the later window, without implying that every autoregressive change survived correction.

Discussion

Using three CLHLS waves and a 16-node CLPN, we identified candidate changes in the temporal organization of diet–emotion associations. Individual cross-lagged differences remained exploratory after FDR correction, whereas eight autoregressive increases survived correction. Several findings support further investigation. Most Window 1 cross-domain associations ran from food to emotion, with emotional out-EI values ≤ 0.041. In Window 2, a uselessness→nuts path appeared and uselessness and loneliness had out-EI values of 0.118 and 0.114. Unadjusted paired comparisons highlighted four focal cross-lagged changes, including a change in the predominant direction of the reciprocal nuts–uselessness association. The Window 2 pattern had the same direction in both age strata, and no age×window interactions were detected for the four focal cross-lagged paths. Coefficient-vector stability and sensitivity analyses using multiple imputation, IPW, age/sex adjustment, cross-validation and rank transformation supported consistency of core path directions. Together, these results motivate confirmatory testing in independent samples.

The Window 1 associations of fruit, nuts and meat intake with subsequent loneliness and uselessness align with the inverse association between healthy dietary indices and depression risk reported by previous meta-analyses [4, 5, 6, 7]. The Window 2 uselessness→nut path is consistent with prospective evidence that depressive symptoms can alter later eating behaviour [8]. Together, these observations suggest a temporal framework in which associations in either direction may be relevant. Whether their relative prominence changes across later life requires confirmation, given the exploratory cross-window differences.

CLPN estimates temporal associations, and CLPM-type models do not separate between-person from within-person effects [11]. The Window 1 food-to-emotion pattern may reflect several linked processes. Fruit, nuts and vegetables mark overall diet quality and intake of n-3 fatty acids, B vitamins and

antioxidants, which are related to neurotransmitter synthesis, inflammatory tone and brain health [20]. Dietary intake also covaries with loneliness, social isolation, social support, social frailty, physical function and purchasing resources in community-dwelling Chinese older adults [21]. Food frequency may therefore capture both nutritional exposure and the functional and social resources that sustain it. Broader evidence links loneliness and social isolation with adverse health and mortality outcomes in older adults [22, 23, 24, 25]. The stronger meat→uselessness association among participants aged ≥ 80 years is consistent with a closer link between food access and functional reserve in this group.

The Window 2 emotion-to-diet pattern is compatible with reduced appetite, motivation and functional capacity in later life. The negative uselessness→nuts association is consistent with prospective links between depressive symptoms and eating behaviour [8]. Connections from uselessness and loneliness to later emotional symptoms may reflect shared processes involving physical losses, changing social roles and bereavement. These paths do not demonstrate a sequential uselessness→loneliness→anxiety/unhappiness mechanism. Mean ages at the respective window baselines were similar (80.4 and 80.5 years), partly because survival and complete-case inclusion changed sample composition. The paired common-sample analysis followed the same individuals across both windows, but it cannot separate ageing from period effects, including changes in socioeconomic and nutritional environments between 2008–2011 and 2011–2014.

These findings suggest questions for public health research on nutrition and mental health in later life. Dietary interventions have been investigated as approaches to supporting mental health [7, 26, 27, 28, 29], while loneliness, uselessness and subthreshold depressive symptoms also warrant attention [30]. The observed associations motivate testing whether combined nutritional and psychosocial approaches are useful at different stages of later life. They do not establish stage-specific treatment effects or validate nut or egg intake as screening markers. Methodologically, paired comparisons in a common sample allow proposed changes in temporal associations to be tested while holding participant composition constant.

Strengths include the three-wave population-based sample, simultaneous modelling of bidirectional temporal associations across 16 nodes, paired bootstrap testing in a common sample, age-stratified and interaction analyses, sensitivity analyses for missingness and model specification, and reproducibility checks across R and Python.

The study has seven principal limitations. First, emotional symptoms were measured with single-item 5-point screening indicators, and dietary intake was measured by frequency rather than portion size or nutrient composition; dose–response relationships therefore could not be estimated. Second, complete cases represented 75%–77% of survivors, and attrition was associated with age, health and symptom burden. IPW preserved the core directions but cannot remove bias from unobserved determinants of missingness [17]. Third, covariate adjustment included age and sex but not chronic disease, cognition, medication use or socioeconomic status, leaving scope for residual confounding. Fourth, the b27 response distribution changed between waves despite consistent wording and ordered categories.

Exclusion of b27 preserved the core pathways, but period-specific reporting or differential sample composition cannot be fully excluded. Fifth, CLPN estimates between-person lagged structure. With three waves and 16 nodes, an RI-CLPN would require 16 random intercepts together with constrained within-person dynamics and is not reliably identified in this regularized network, so within-person effects cannot be inferred. Sixth, the 2018 CLHLS wave used a different emotional-item battery and could not extend the present network. Finally, none of the cross-window cross-lagged differences survived FDR correction across 256 paths. The candidate cross-lagged changes are therefore hypothesis-generating; eight autoregressive differences survived the reported correction. In addition, cross-window contrasts cannot isolate true temporal change from residual sample-composition differences or from variation in LASSO-BIC model selection; although penalty re-selection within each bootstrap resample propagates selection uncertainty into the CIs, the two windows differ in BIC-selected sparsity. The normal-approximation P values derived from 500-resample percentile CIs provide approximate rather than exact error rates, and confirmatory work could use alternative constructions such as BCa intervals with larger resample counts.

Conclusions

Across the 2008–2014 CLHLS waves, diet–emotion associations showed signs of change across observation windows. The 2008–2011 window was characterized mainly by inverse associations between food intake and subsequent emotional symptoms. In 2011–2014, fewer food-to-emotion paths were retained, more connections appeared among emotional symptoms, autoregressive persistence increased, and uselessness was associated with less frequent subsequent nut intake. Unadjusted paired comparisons suggested a change in the predominant direction of the nuts–uselessness association, but cross-lagged differences remained exploratory after FDR correction; eight autoregressive differences survived correction. Age-stratified estimates were directionally consistent for the focal later-window paths, no between-stratum difference survived FDR correction, and exclusion of the unhappiness item preserved the core pathways. These findings motivate further study of temporal variation in diet–emotion associations. Independent samples and designs that distinguish within-person changes from between-person differences are needed before drawing mechanistic or stage-specific intervention conclusions.

Abbreviations

BIC, Bayesian information criterion; CC, complete case; CI, confidence interval; CLHLS, Chinese Longitudinal Healthy Longevity Survey; CLPM, cross-lagged panel model; CLPN, cross-lagged panel network; CS, correlation stability; FDR, false discovery rate; IPW, inverse probability weighting; LASSO, least absolute shrinkage and selection operator; MI, multiple imputation; out-EI, out-expected influence; SD, standard deviation; SE, standard error.

Declarations

Ethics approval and consent to participate

CLHLS was approved by the Biomedical Ethics Committee of Peking University (IRB00001052-13074); written informed consent was obtained from all participants or their proxies. The present study used de-identified publicly available data.

Trial registration

Clinical trial number: not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The study used publicly available CLHLS datasets from Peking University, accessible at https://opendata.pku.edu.cn/. A persistent catalogue record for the 1998–2018 dataset is available at https://doi.org/10.3886/ICPSR38899 [13].

Code availability

The Python and R code for network estimation, bootstrap inference, sensitivity analyses and figure generation is available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors’ contributions

Xiaohui Wen: Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft. Haibin Lu and Mei Wang: Conceptualisation, Data curation, Formal analysis,

Writing – original draft. Shugong Zheng: Conceptualisation, Methodology, Supervision, Validation, Writing – review and editing. All authors read and approved the final manuscript.

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Figures

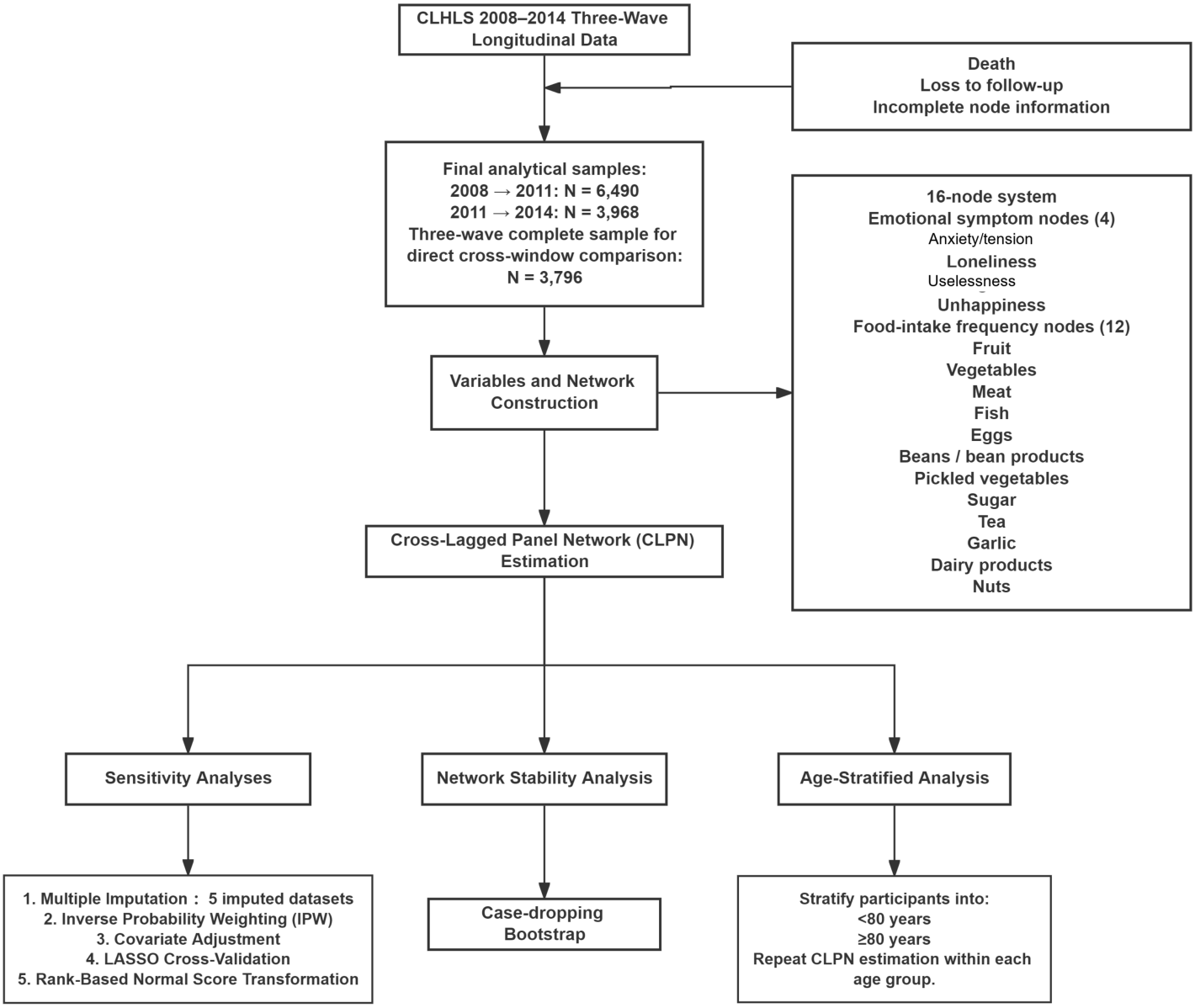


Figure 1

Analytical workflow. The diagram summarizes the three-wave data, window-specific complete-case samples, 16-node system, cross-lagged panel network estimation and robustness analyses. Beans/bean products in the diagram denotes the bean-products node used in the analysis.

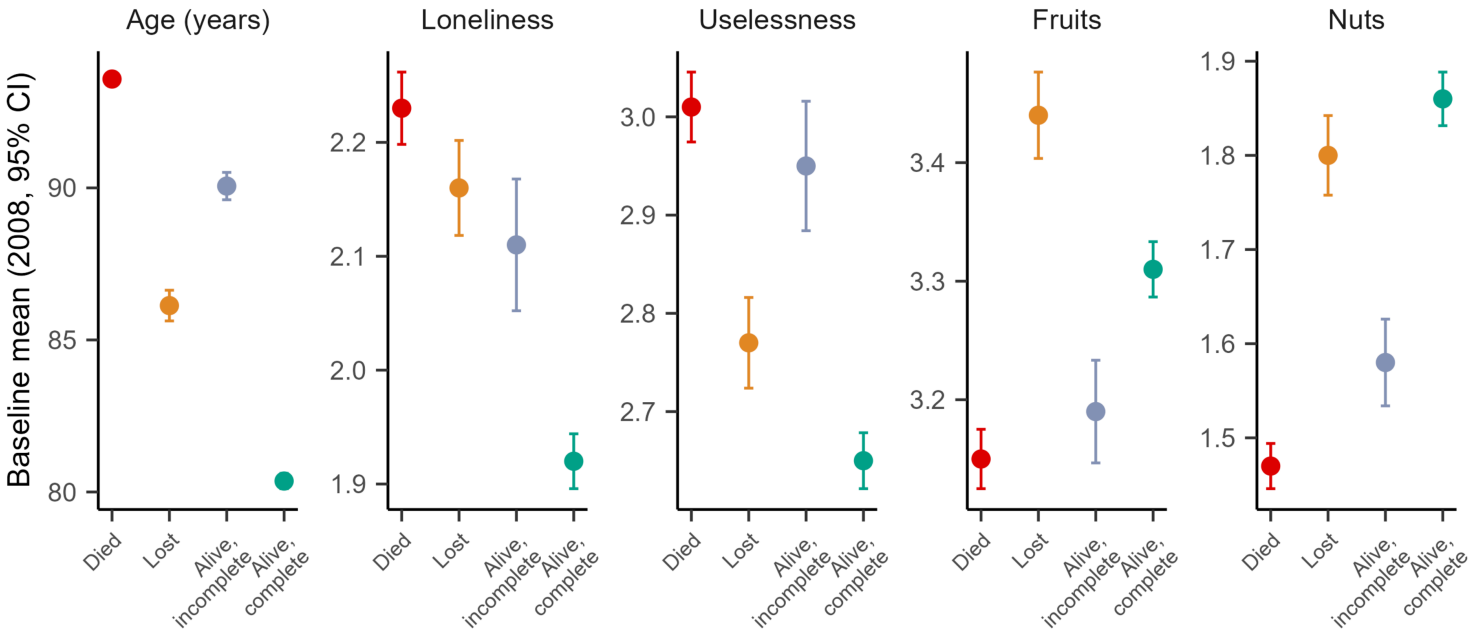


Figure 2

Selective attrition by follow-up status. Baseline means and 95% CIs in the 2008 cohort are shown by 2011 status: died, lost to follow-up, alive but incomplete, or alive and complete. Panels display a prespecified representative subset (age, loneliness, uselessness, fruit and nuts); all baseline variables are reported in Table 2. Age is measured in years; emotional-symptom and food-intake panels use 1–5 analysis scores, with higher scores indicating more severe symptoms or more frequent intake. Error bars are mean ± 1.96 SE. Deceased participants were oldest and had the highest loneliness and uselessness scores; complete cases were youngest and had the lowest symptom scores, indicating under-representation of older and more symptomatic participants in complete-case analyses.

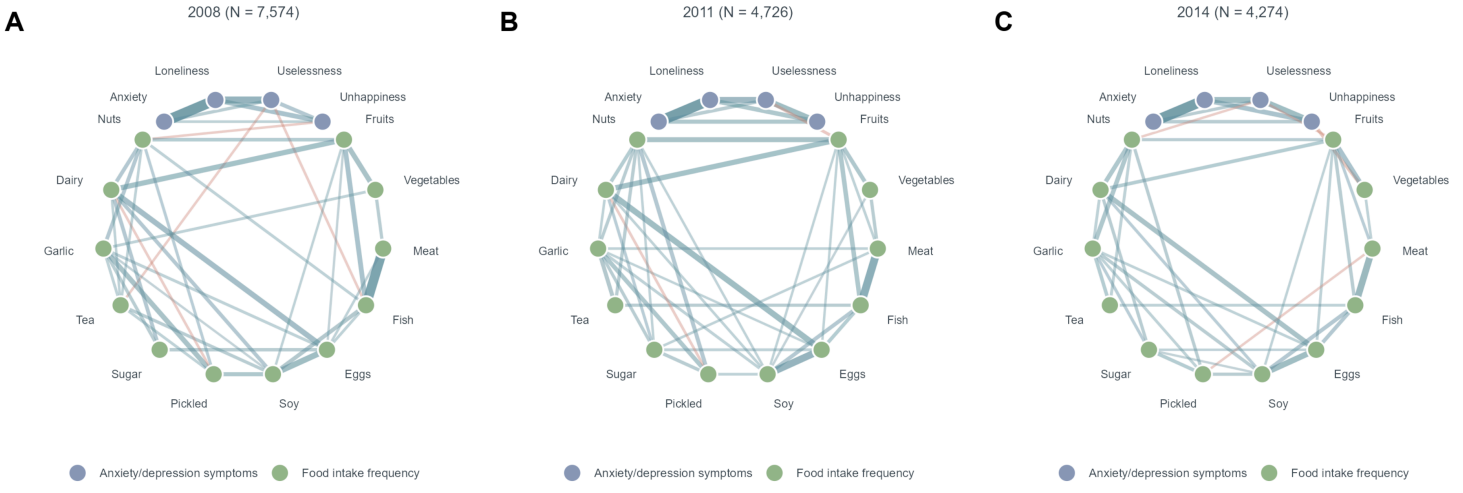


Figure 3

Contemporaneous partial-correlation networks. Panels show 2008 (A, N=7,574), 2011 (B, N=4,726) and 2014 (C, N=4,274). Blue nodes indicate emotional symptoms and green nodes food-intake frequency. Green and red edges indicate positive and negative partial correlations, respectively; edge width represents |partial correlation|. Only edges with |partial correlation|>0.05 are shown. For compact plotting, Anxiety denotes anxiety/tension, Fruits denotes fruit, Pickled denotes pickled vegetables, and Soy denotes bean products. Emotional and dietary clusters are visible in all three waves, with mainly weak negative associations between clusters.



Figure 4

Cross-lagged panel networks in two observation windows. Panels show 2008→2011 (A, N=6,490) and 2011→2014 (B, N=3,968). Left and right columns show time-1 and time-2 nodes. Green and red solid edges indicate positive and negative cross-lagged paths; dashed edges indicate autoregressive paths. Edge width represents |β|. Only paths with bootstrap 95% CIs excluding zero are shown. For compact plotting, Anxiety denotes anxiety/tension, Fruits denotes fruit, Pickled denotes pickled vegetables, and Soy denotes bean products. Window 1 has predominantly food-to-emotion cross-domain paths, whereas Window 2 contains more connections among emotional symptoms and a uselessness→nuts path.

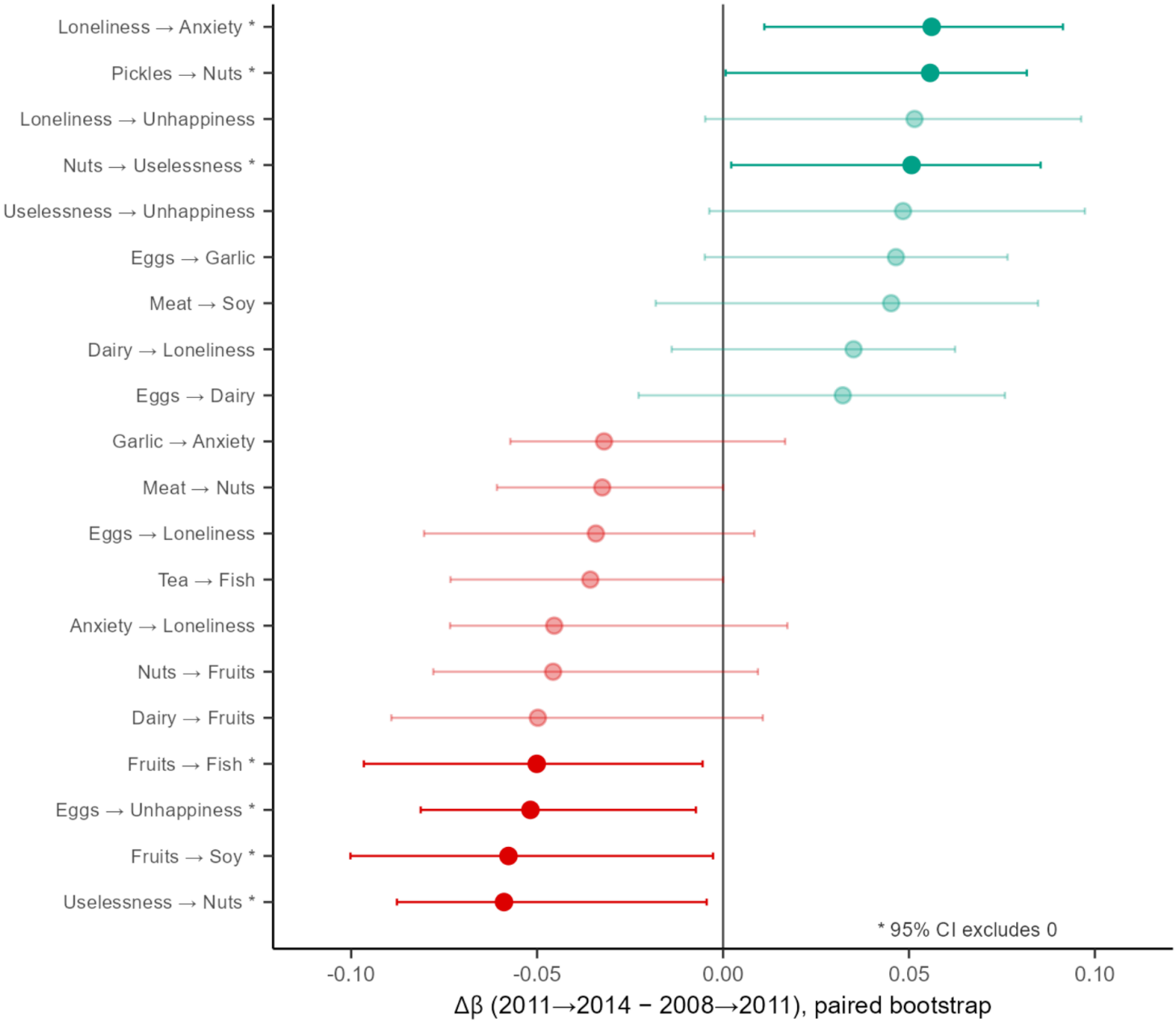


Figure 5

Cross-window differences in path coefficients. The forest plot shows the 20 cross-lagged paths with the largest |Δβ|, estimated from 500 paired bootstrap resamples in the three-wave common complete-case sample (N=3,796). Δβ=β(2011–2014)−β(2008–2011). Opaque points and intervals indicate unadjusted 95% CIs excluding zero; translucent estimates have CIs including zero. Red indicates a more negative Window 2 coefficient and green a more positive coefficient. No cross-lagged difference survived FDR correction across 256 paths at q<0.05.

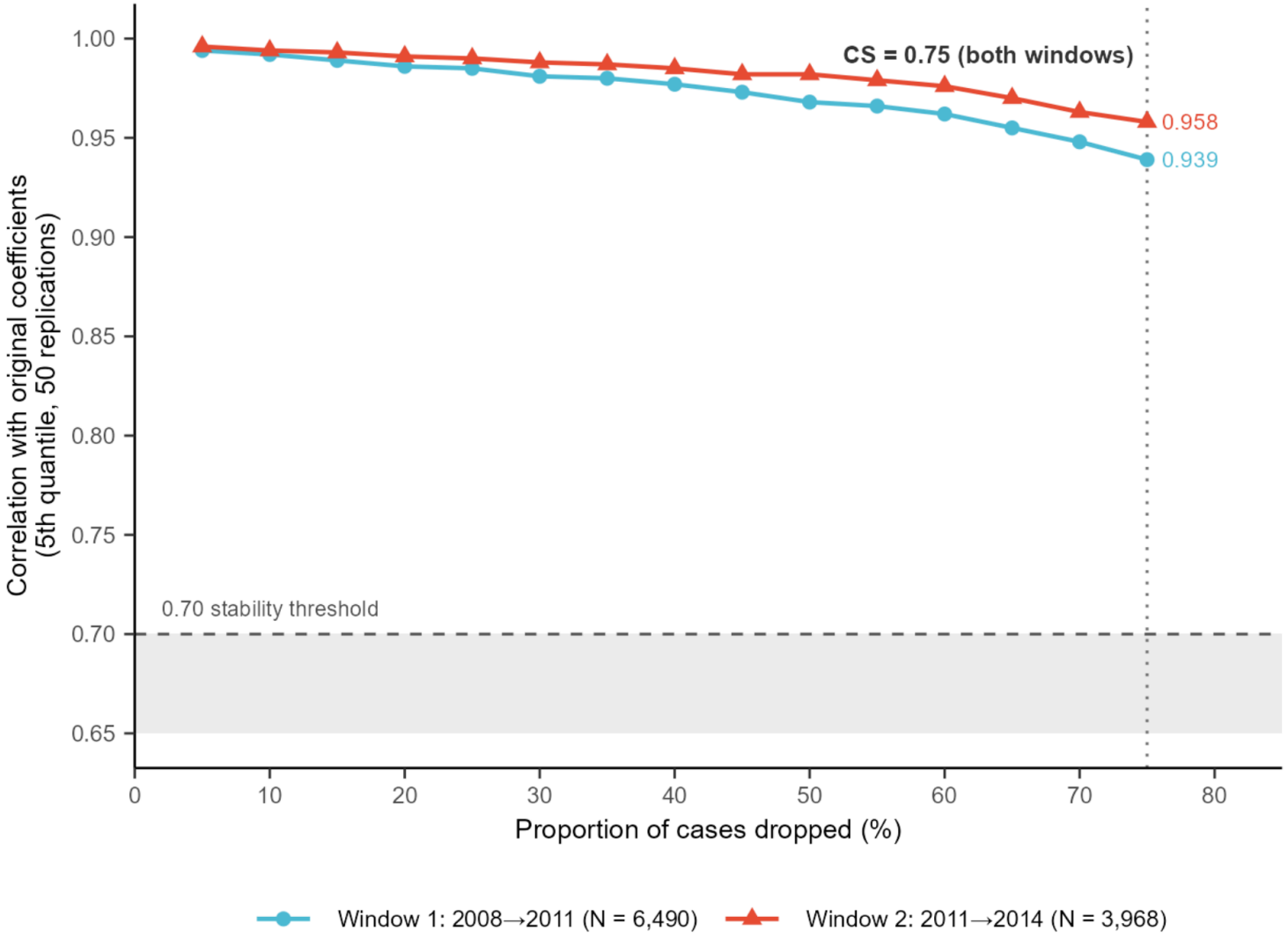


Figure 6

Network stability from case-dropping bootstrap. Curves show the 5th percentile of Pearson correlations between re-estimated and original CLPN coefficient vectors after dropping 5%–75% of cases, with 50 replicates at each 5% increment. The horizontal dashed line marks the 0.70 stability threshold, the grey region lies below this threshold, and the vertical dotted line marks the maximum tested drop proportion of 75%. Correlations declined from 0.994 to 0.939 in Window 1 and from 0.996 to 0.958 in Window 2. The CS coefficient reached 0.75 in both windows, the largest proportion tested.

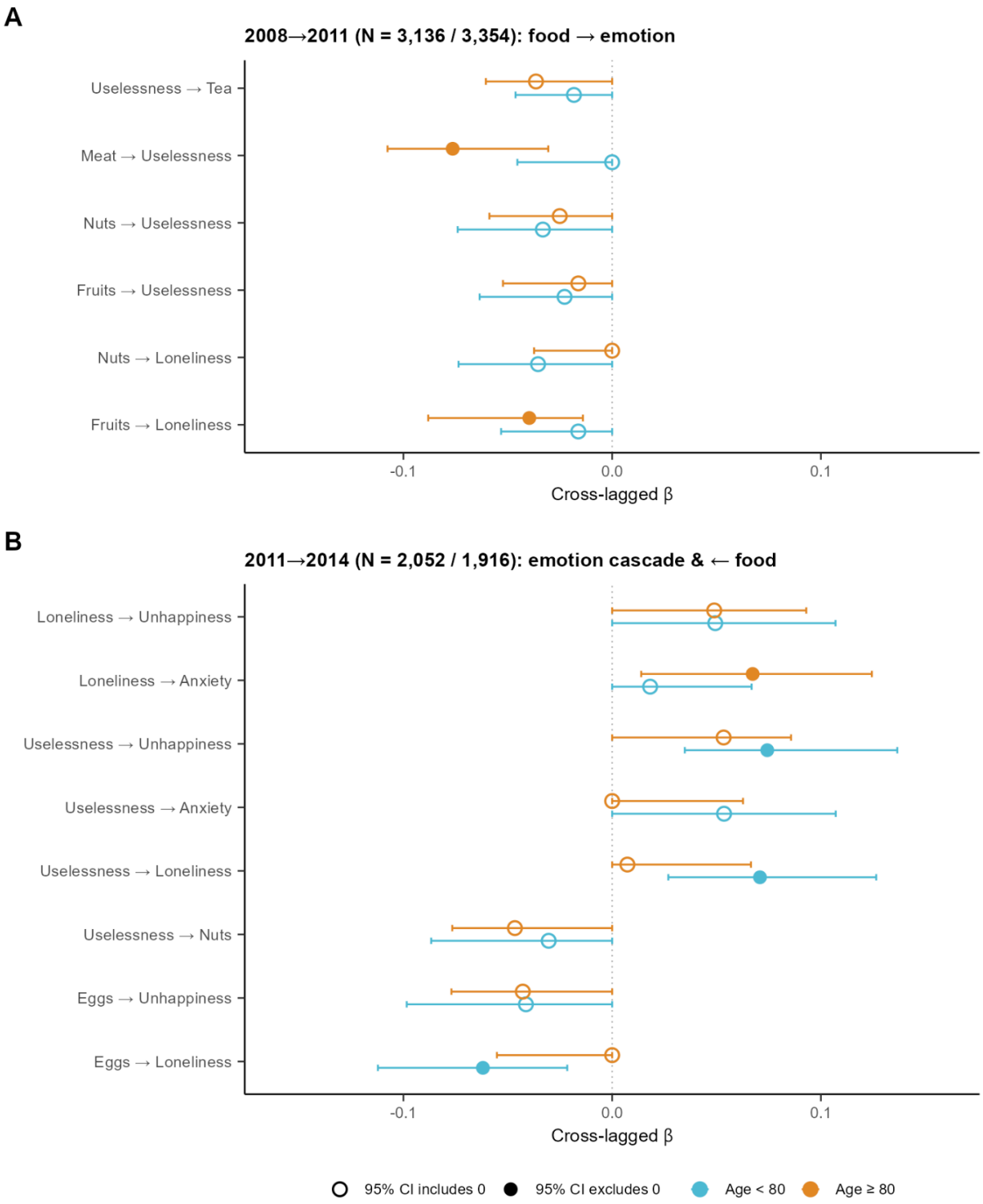


Figure 7

Age-stratified estimates for core paths. Panel A shows the six focal Window 1 cross-domain paths, including the reverse uselessness→tea path (<80 years, N=3,136; ≥80 years, N=3,354). Panel B shows the focal Window 2 cross-domain and emotion-to-emotion paths (<80 years, N=2,052; ≥80 years, N=1,916). Points represent standardized β and horizontal bars bootstrap 95% CIs; filled points have CIs excluding zero and open points have CIs including zero. Window 1 food-to-emotion associations were

more prominent in the ≥80-year stratum. The meat→uselessness difference between strata was nominally significant, but no age-stratified difference survived FDR correction across 480 path-by-window comparisons. The Window 2 pattern had the same direction in both strata.

Supplementary Files

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

- AdditionalFilesV2Aligned20261023.zip
- Additionalfiles.docx