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Transitions in Leisure-Time Exercise Participation and Subsequent Changes in Energy Intake and Protein Density in Chinese Adults: A Three-Assessment Longitudinal Study Using China Health and Nutrition Survey Data

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Abstract

Background/Objectives: Evidence on subsequent dietary changes associated with leisure-time exercise participation patterns remains limited. We examined these associations among Chinese adults. **Methods:** We used two China Health and Nutrition Survey sequences (T0–T1–T2): 2004–2006–2009 and 2006–2009–2011. Linear regression examined associations between reported T0–T1 participation patterns and T1-to-T2 changes in energy intake and protein density (co-primary outcomes) and absolute protein intake, adjusting for T0 and T1 dietary levels and covariates and accounting for repeated observations and community clustering. Holm correction was applied within comparison families. **Results:** The analysis included 6279 adults contributing 10,016 observations. Compared with reporting no leisure-time exercise at either assessment, reporting exercise only at T1 or at both assessments was associated with adjusted between-group differences in protein density change of 1.30 (95% confidence interval [CI], 0.59 to 2.00) and 2.09 (95% CI, 0.70 to 3.48) g/1000 kcal, respectively (Holm-adjusted $p = 0.002$ and 0.017). Corresponding adjusted differences in absolute protein intake change were 0.66 (95% CI, −1.53 to 2.84) and 4.28 (95% CI, 1.20 to 7.36) g/day (Holm-adjusted $p = 1.000$ and 0.020); statistical support for the latter varied across sensitivity analyses. The energy omnibus test was significant (Holm-adjusted $p = 0.044$), but individual energy contrasts were not significant after correction. Direct comparisons between these participation groups were not significant for any of the three outcomes after correction. **Conclusions:** Compared with nonparticipation at both assessments, reported participation only at T1 or at both assessments was associated with modestly greater subsequent protein density changes. Interpretation should consider both protein density and absolute protein intake.

Keywords: leisure-time exercise; dietary energy intake; dietary protein; protein density; longitudinal study; China Health and Nutrition Survey

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1. Introduction

Physical activity and diet are associated with long-term weight change and health outcomes [1–3] and are central components of lifestyle interventions [4]. Exercise-related changes in energy expenditure and appetite may influence food intake [5]. Behavioral links may involve shared goals and self-regulation. In a one-year weight-management trial, autonomous exercise motivation was associated with better eating self-regulation [6].

Repeated assessments of exercise participation and diet can describe how these behaviors are linked over time.

Total energy intake and relative nutrient composition provide complementary information about dietary change. Protein intake is related to the muscle protein synthesis response after resistance exercise [7]. In the Health, Aging, and Body Composition (Health ABC) Study, higher protein intake among adults aged 70–79 years was associated with less lean mass loss over three years [8]. Controlled feeding research has also linked the proportion of energy from protein to ad libitum energy intake [9]. Total energy intake describes the amount of dietary energy consumed, whereas protein density describes protein intake per unit of energy [10,11]. Because protein density depends on both protein and energy intake, examining absolute protein intake alongside density helps distinguish changes in the amount consumed from changes in relative intake.

Among adults in the China Health and Nutrition Survey (CHNS), the energy share from carbohydrate declined and that from fat increased between 1991 and 2015, while protein's share rose slightly from 12.6% to 13.1% [12]. Among CHNS participants aged ≥60 years in 2018, median protein intake was 62.8 g/day in men and 53.9 g/day in women; intake was lower at ages ≥70 than at 60–69 years [13].

Exercise interventions have reported mixed changes in energy intake, macronutrient intake, and food choices [5,14–20]. Observational studies have also examined physical activity and dietary change over longer periods. In the 1958 British birth cohort, increased leisure-time activity was associated with improved diet quality between ages 33 and 42 [21]. The Young Finns Study related activity trajectories to fruit and vegetable consumption from childhood to adulthood [22]. A Japanese cohort found no clear association between concurrent changes in physical activity and diet quality [23]. Shorter-term studies have examined physical activity in relation to next-day energy intake [24] and eating behaviors at three-month intervals [25]. Evidence remains limited on whether leisure-time exercise participation patterns defined by two assessments are associated with changes in energy intake and protein density over the following 2–3 years, accounting for dietary intake at both earlier assessments.

We used repeated assessments from CHNS [26–29] to examine associations between reported leisure-time exercise participation patterns and subsequent dietary changes in Chinese adults. We constructed two three-assessment sequences, 2004–2006–2009 and 2006–2009–2011. Participation patterns were defined using reports from the first two assessments. Changes in total energy intake and protein density between the second and third assessments were the co-primary outcomes. The analysis adjusted for dietary levels at T0 and T1 and for other covariates. We also examined changes in absolute protein intake to aid interpretation of the protein density findings.

2. Materials and Methods

2.1. Study Design and Participants

We conducted a longitudinal analysis of CHNS data. CHNS uses multistage cluster random sampling to collect individual, household, and community information on health, nutrition, and socioeconomic conditions. Its design has been described previously [28,29]. The original survey was approved by the institutional review boards of the University of North Carolina at Chapel Hill and the National Institute for Nutrition and Food Safety, Chinese Center for Disease Control and Prevention. Participants provided written informed consent [29].

Data from the 2004, 2006, 2009, and 2011 surveys were organized into two three-assessment sequences: 2004–2006–2009 and 2006–2009–2011. The first, second, and third assessments within each sequence were designated T0, T1, and T2, respectively. The

exposure was the pattern of leisure-time exercise participation reported at T0 and T1; outcomes were dietary changes from T1 to T2. The 2–3-year intervals reflect the timing of the selected survey waves. Each observation linked three assessments for one participant. Depending on data availability, participants contributed one or two observations.

Candidate samples comprised participants aged ≥18 years in 2004 or 2006. Eligible observations required survey records and ages of 18–100 years at all three assessments, with classifiable exercise participation at T0 and T1. At each assessment, mean daily energy intake had to be 500–5000 kcal. Protein, fat, and carbohydrate intakes had to be valid positive values, with each contributing >0% and <100% of total energy. Observations with documented pregnancy at any assessment were excluded; those with unknown pregnancy status were retained. Participant identities had to match across assessments. Interview dates had to correspond to survey years and increase chronologically, with actual intervals differing from nominal intervals by no more than 1 year. Age could not decrease between consecutive assessments, and age increments could differ from nominal intervals by no more than 2 years. The main analysis included observations with complete required T0 covariates (Figure 1).

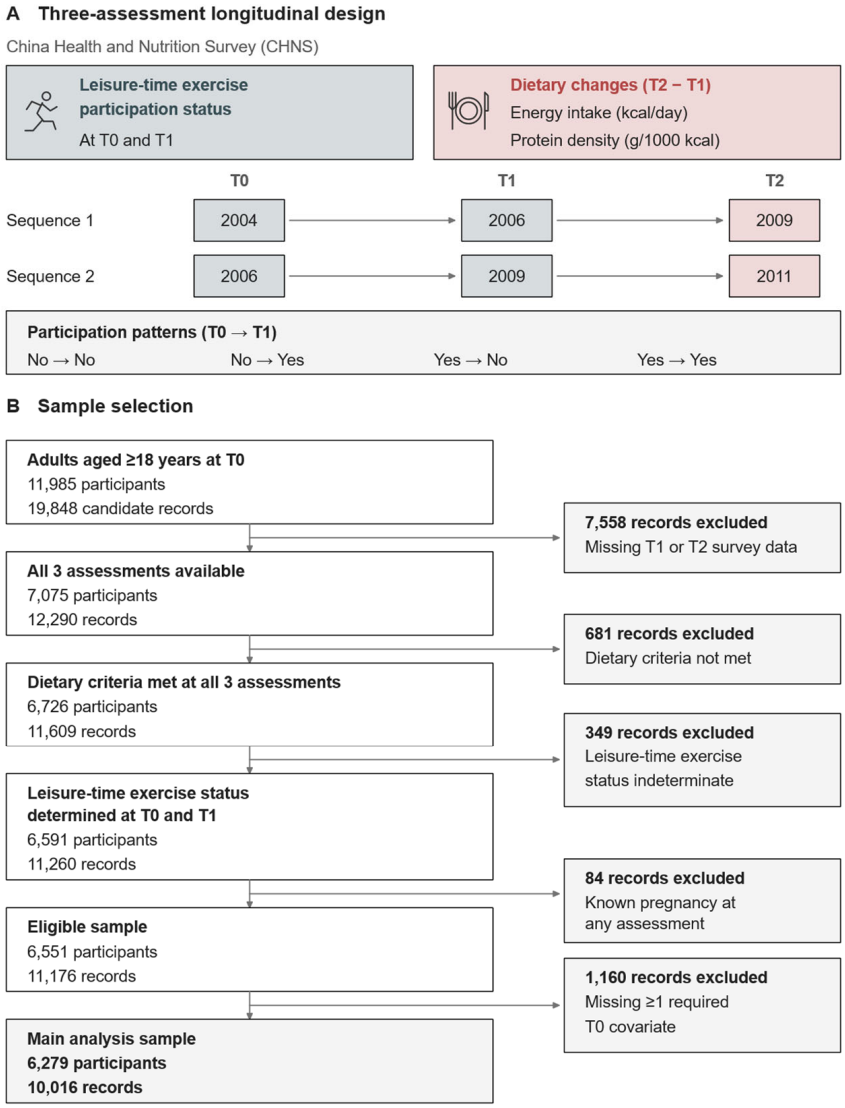


Figure 1. Three-assessment study design and sample selection. (**A**) The 2004–2006–2009 and 2006–2009–2011 survey sequences. T0, T1, and T2 denote the first, second, and third assessments

within each sequence, respectively. Leisure-time exercise participation patterns were classified from T0 to T1, and dietary changes were assessed from T1 to T2. No and Yes denote nonparticipation and participation in the listed leisure-time exercises at each assessment. The timeline is schematic and not to scale. (**B**) Sample selection. "Participants" denotes unique individuals at each stage; "records" denotes three-assessment observations. Exclusions were applied sequentially at the observation level. Each participant could contribute up to two observations. The two survey sequences share some participants and assessment years.

2.2. Assessment of Leisure-Time Exercise and Dietary Intake

Leisure-time exercise participation was coded as a binary indicator using six questionnaire categories: martial arts; gymnastics, dancing, or acrobatics; track and field, running, or swimming; soccer, basketball, or tennis; badminton or volleyball; and other activities, such as table tennis or tai chi. A "Yes" response to any category indicated participation. A "No" response to every category, with no valid positive exercise duration reported for those items, indicated nonparticipation. Other response patterns were classified as indeterminate. We used this binary definition to compare changes in participation status across assessments. Reported duration was used for consistency checks. Frequency, intensity, and duration were not modeled as exposure measures. T0 and T1 responses defined four groups: nonparticipation at both assessments, transition from nonparticipation to participation, transition from participation to nonparticipation, and participation at both assessments. Observations meeting the other eligibility criteria were included regardless of exercise participation status at T2.

At each survey, CHNS collected dietary data using 24 h recalls on three consecutive days alongside household food-weighing records [27,30]. We used the released three-day averages of daily energy and protein intake. Protein density was calculated as daily protein intake (g) divided by daily energy intake (kcal), multiplied by 1000, and expressed as g/1000 kcal.

The co-primary outcomes were changes in total energy intake and protein density from T1 to T2. Protein density was selected to characterize protein intake relative to total energy intake. Change in absolute protein intake was an auxiliary outcome used to interpret density findings in terms of changes in the daily amount of protein consumed. All changes were calculated as T2 minus T1 and were not annualized.

2.3. Statistical Analysis

Descriptive statistics are presented at the observation level, except for sex-specific age summaries, which use each participant's T0 age from their first sequence included in the main analysis. Continuous variables are presented as means (standard deviations [SDs]) or medians (25th and 75th percentiles), and categorical variables as counts (percentages). Exercise categories are summarized separately at T0 and T1 among observations reporting participation, using item-specific valid Yes/No responses as denominators. Multiple categories can be reported.

Multivariable linear regression estimated associations between leisure-time exercise participation patterns, modeled as a four-category variable, and each dietary outcome, defined as change from T1 to T2. Models included the corresponding dietary measure at T0 and T1 to estimate subsequent between-group differences conditional on these earlier dietary levels. Additional T0 covariates included body mass index (BMI) and self-reported hypertension, diabetes, myocardial infarction, and stroke. Other T0 covariates were age and age squared, sex, residential location, province, education, marital status, annual per capita household income, smoking, alcohol use, and occupation. Models also adjusted for survey period and the T1-to-T2 follow-up interval. Intervals were estimated from household interview dates. The difference between the actual interval and its nominal

duration of 3 or 2 years entered the model as a linear term. Annual per capita household income, expressed in constant 2015 prices, was transformed using the inverse hyperbolic sine, asinh(income/10,000), retaining zero and negative values [31]. Covariate definitions and processing are described in Supplementary Methods S1.

Communities linked by the same participant across the three assessments and survey sequences were combined into connected clusters. For the main analysis, this yielded 214 clusters, with repeated observations from each participant and records from the same household in the same year assigned to one cluster. Observations with missing community identifiers were not linked on the basis of that missingness. We used a heteroskedasticity-consistent type 1 (HC1) cluster-robust covariance estimator with the cluster-count correction G/(G−1), where G denotes the number of clusters. Between-group differences were standardized to the covariate distribution of the full main analysis sample. For the main analysis, 95% confidence intervals (CIs) and two-sided p values were based on a t distribution with 213 degrees of freedom. Four-group omnibus tests and interactions with survey period used Wald F tests with 3 and 213 degrees of freedom [32].

Four contrasts are reported for each outcome in the main analysis. The first three contrasts were transition to participation versus nonparticipation at both assessments; participation at both assessments versus nonparticipation at both assessments; and transition to nonparticipation versus participation at both assessments. The fourth contrast compared transition to participation with participation at both assessments (No→Yes versus Yes→Yes). For the main analysis, Holm correction was applied separately to three families: the first three contrasts for each of the two co-primary outcomes (six tests); the first three absolute-protein contrasts (three tests); and the No→Yes versus Yes→Yes contrasts across the three outcomes (three tests) [33]. The two four-group omnibus tests formed a separate Holm family. Interactions between participation pattern and survey period were added to assess period differences and derive period-specific estimates. Changes in absolute protein intake were analyzed using the same model framework. Correction families for period-specific and sensitivity analyses are specified in the supplementary table notes. Test families were corrected separately without a gatekeeping sequence. Contrasts were tested two-sided, with Holm-adjusted $p < 0.05$ considered statistically significant. CIs were not adjusted for multiple comparisons.

The main analysis used observations with complete required T0 covariates. An inverse probability weighting (IPW) analysis assessed the potential influence of selection due to missing covariates among otherwise eligible observations. Logistic regression estimated the probability of covariate completeness using demographic characteristics, exercise participation pattern, survey period, dietary measures at all three assessments, and actual survey intervals. Complete observations were weighted by the inverse of this probability [34,35]. Analyses of all three outcomes were repeated using untruncated weights and weights truncated at the 99th percentile. Standard errors for weighted estimates were obtained by cluster bootstrap [36]. A further sensitivity analysis excluded observations identified in the CHNS release as having imputed income. Details of the probability model, weighting, and resampling are provided in Supplementary Methods S2. For the IPW and income-restriction analyses of absolute protein intake, four contrasts, including No→Yes versus Yes→Yes, were Holm-corrected within each analysis.

An additional sensitivity analysis restricted the main sample to observations with complete T1 BMI and self-reported hypertension, diabetes, myocardial infarction, and stroke. The main-analysis model was refitted in this common sample (model A), and T1 BMI and disease status were then added while retaining all main-analysis covariates (model B). Both models used the same observations and connected community clusters. Within

each model, the Holm correction families were the same as in the main analysis. Details are provided in Supplementary Methods S3 and Table S6.

Analyses were conducted in R version 4.5.2, using sandwich version 3.1-3 for cluster-robust variance estimation [37]. Survey sampling weights were not used. The sensitivity models with and without T1 BMI and disease status were fitted in Python version 3.12.14.

3. Results

3.1. Participant Characteristics and Dietary Intake

Of 11,176 otherwise eligible observations from 6551 adults, 1160 (10.4%) were excluded because of missing T0 covariates. The main analysis included 6279 adults contributing 10,016 observations: 3737 participants contributed two observations and 2542 contributed one (Figure 1). At T0 of their first included sequence, mean (SD) age was 48.67 (13.65) years in men (n = 2946) and 49.27 (13.29) years in women (n = 3333). The 2004–2006–2009 and 2006–2009–2011 sequences contributed 4856 and 5160 observations, respectively. Mean (SD) T0-to-T1 and T1-to-T2 intervals were 1.97 (0.09) and 3.01 (0.08) years in the first sequence, and 3.01 (0.08) and 1.97 (0.08) years in the second. Covariate missingness and characteristics of observations with complete and incomplete covariates are shown in Table S1.

The four participation groups comprised 8602 observations (85.9%) with nonparticipation at both assessments, 549 (5.5%) with transition to participation, 555 (5.5%) with transition to nonparticipation, and 310 (3.1%) with participation at both assessments.

Mean T0 age ranged from 49.1 to 50.6 years across groups. Compared with nonparticipation at both assessments, the other three groups had higher proportions living in cities, towns, or county seats (49.0–55.5% versus 22.3%), higher median annual per capita household income, and higher T0 protein density (Tables 1 and 2).

Table 1. Baseline characteristics by leisure-time exercise participation pattern.

Characteristic	Nonparticipation at Both Assessments n = 8602	Transition to Participation n = 549	Transition to Nonparticipation n = 555	Participation at Both Assessments n = 310
Age, years	49.94 (12.99)	49.10 (13.71)	50.56 (14.93)	49.76 (15.61)
Female, *n* (%)	4770 (55.5)	263 (47.9)	237 (42.7)	135 (43.5)
BMI, kg/m^2	23.16 (3.36)	23.83 (3.16)	23.90 (3.30)	24.24 (3.52)
City, town, or county seat, *n* (%)	1919 (22.3)	269 (49.0)	305 (55.0)	172 (55.5)
Married, *n* (%)	7686 (89.4)	480 (87.4)	485 (87.4)	262 (84.5)
Annual per capita household income, yuan	5425 [2742, 9865]	9837 [5000, 16,285]	9887 [5344, 15,781]	13,461 [7865, 21,967]
Education, *n* (%)				
Primary school or less	4473 (52.0)	123 (22.4)	150 (27.0)	48 (15.5)
Secondary or vocational school	3937 (45.8)	368 (67.0)	347 (62.5)	205 (66.1)
College or higher	192 (2.2)	58 (10.6)	58 (10.5)	57 (18.4)
Smoking, *n* (%)				
Never	5899 (68.6)	364 (66.3)	357 (64.3)	223 (71.9)
Former	287 (3.3)	20 (3.6)	33 (5.9)	28 (9.0)
Current	2416 (28.1)	165 (30.1)	165 (29.7)	59 (19.0)
Alcohol use, *n* (%)	2722 (31.6)	189 (34.4)	235 (42.3)	146 (47.1)

Table 1. *Cont.*

Characteristic	Nonparticipation at Both Assessments *n* = 8602	Transition to Participation *n* = 549	Transition to Nonparticipation *n* = 555	Participation at Both Assessments *n* = 310
Occupation, *n* (%)				
Not working	3206 (37.3)	259 (47.2)	300 (54.1)	159 (51.3)
Farming	3261 (37.9)	53 (9.7)	32 (5.8)	1 (0.3)
Manual, driving, or military/police work	814 (9.5)	61 (11.1)	59 (10.6)	30 (9.7)
Professional, managerial, or related work	617 (7.2)	120 (21.9)	120 (21.6)	108 (34.8)
Other, including service work	704 (8.2)	56 (10.2)	44 (7.9)	12 (3.9)
Self-reported hypertension, *n* (%)	784 (9.1)	59 (10.7)	91 (16.4)	36 (11.6)
Self-reported diabetes, *n* (%)	108 (1.3)	11 (2.0)	13 (2.3)	6 (1.9)
Self-reported myocardial infarction, *n* (%)	34 (0.4)	0 (0.0)	4 (0.7)	0 (0.0)
Self-reported stroke, *n* (%)	78 (0.9)	7 (1.3)	5 (0.9)	0 (0.0)

Values are means (standard deviations [SDs]), medians [25th percentile, 75th percentile], or counts (percentages). *n* denotes three-assessment observations; baseline is the first assessment (T0) in each sequence. Income is expressed in constant 2015 yuan. Percentages use the number of observations in each group as the denominator. No values are missing for the variables shown. BMI, body mass index.

Table 2. Dietary intake at three assessments and unadjusted subsequent changes.

Measure and Assessment	Nonparticipation at Both Assessments *n* = 8602	Transition to Participation *n* = 549	Transition to Nonparticipation *n* = 555	Participation at Both Assessments *n* = 310
Total energy intake (kcal/day)				
T0	2215.58 (666.94)	2131.91 (612.12)	2180.17 (626.12)	2233.74 (638.84)
T1	2178.43 (669.50)	2121.26 (625.49)	2089.60 (619.93)	2161.61 (645.57)
T2	2080.92 (674.89)	1996.20 (598.72)	2075.36 (628.19)	2071.22 (650.56)
T2−T1	−97.51 (784.75)	−125.06 (731.24)	−14.24 (758.29)	−90.40 (797.64)
Protein density (g/1000 kcal)				
T0	29.94 (6.41)	32.78 (7.98)	32.01 (7.11)	33.94 (7.56)
T1	30.29 (6.58)	32.52 (7.57)	33.04 (7.60)	34.27 (8.01)
T2	31.17 (7.16)	34.10 (8.40)	34.25 (8.08)	35.71 (8.28)
T2−T1	0.88 (8.60)	1.58 (9.79)	1.21 (10.08)	1.44 (9.63)
Absolute protein intake (g/day)				
T0	65.85 (23.32)	69.94 (29.43)	69.10 (22.98)	75.06 (25.66)
T1	65.38 (23.23)	68.45 (24.12)	68.26 (23.59)	73.65 (26.75)
T2	64.00 (23.37)	67.60 (25.59)	70.36 (25.28)	72.89 (24.97)
T2−T1	−1.39 (28.09)	−0.85 (27.86)	2.10 (31.10)	−0.76 (30.82)

Values are means (standard deviations [SDs]), with equal weight assigned to each observation. All dietary measures are complete. *n* denotes three-assessment observations. T0, T1, and T2 are the first, second, and third assessments in each sequence. Changes are T2−T1 and are not annualized.

Dietary intake at each assessment and unadjusted changes are presented in Table 2. Mean total energy intake declined in all four groups from T1 to T2, by 14.24–125.06 kcal/day. Mean protein density increased by 0.88–1.58 g/1000 kcal.

Among observations reporting exercise participation, other activities, such as table tennis or tai chi, were the most commonly reported category (40.6% at T0 and 42.1% at T1), followed by track and field, running, or swimming (33.7% and 28.6%, respectively; Table S5).

3.2. Leisure-Time Exercise Participation Transitions and Subsequent Dietary Changes

The adjusted four-group omnibus test for total energy intake change was significant ($F\ [3,213] = 2.740$; Holm-adjusted $p = 0.044$). Transition to participation, compared with nonparticipation at both assessments, was associated with an adjusted difference in change of −67.62 kcal/day (95% CI, −123.08 to −12.17; Holm-adjusted $p = 0.068$). None of the first three energy contrasts was statistically significant after correction (Figure 2).

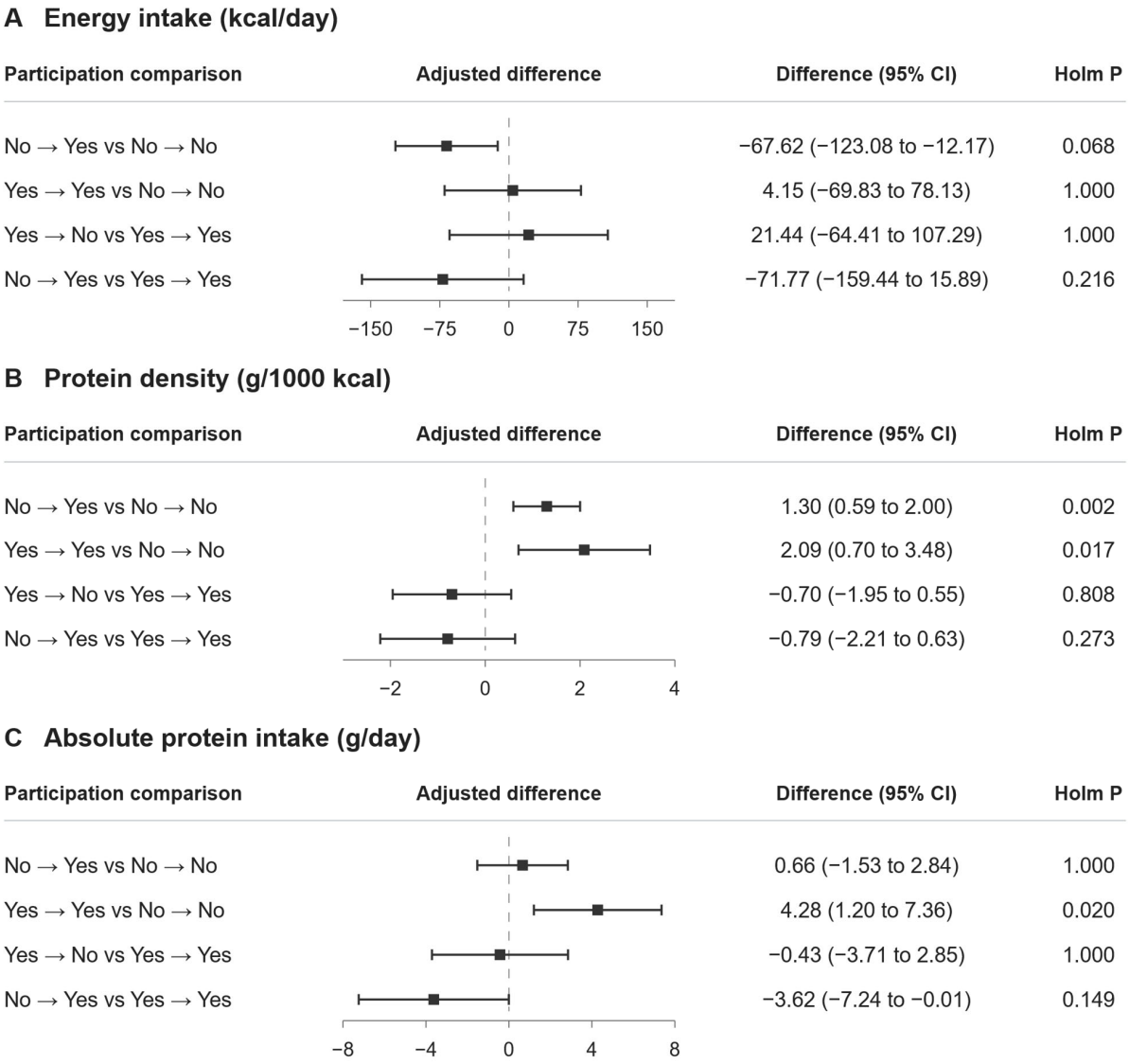


Figure 2. Adjusted associations of leisure-time exercise participation patterns with subsequent dietary changes. Panels (**A**–**C**) show adjusted between-group differences in changes in total energy intake, protein density, and absolute protein intake, respectively. T0, T1, and T2 denote the three successive assessments within each sequence. No and Yes indicate self-reported nonparticipation and participation in leisure-time exercise; arrows denote T0-to-T1 patterns. Points represent adjusted differences in T2−T1 change, calculated as the first group minus the reference group. Horizontal lines indicate cluster-robust 95% confidence intervals (CIs), and dashed lines indicate zero difference. Analyses included 6279 participants and 10,016 observations. Holm correction was applied separately to the first three contrasts in panels **A** and **B** combined (six tests), the first three contrasts in panel **C** (three tests), and the No→Yes versus Yes→Yes contrasts across all three panels (three tests). *p* values are Holm-adjusted; CIs are unadjusted for multiplicity. Changes are not annualized.

The omnibus test for protein density change was also significant ($F[3,213] = 6.823$; Holm-adjusted $p < 0.001$). Compared with nonparticipation at both assessments, adjusted differences were 1.30 g/1000 kcal (95% CI, 0.59 to 2.00) for transition to participation and 2.09 g/1000 kcal (95% CI, 0.70 to 3.48) for participation at both assessments. Corresponding Holm-adjusted p values were 0.002 and 0.017. Transition to nonparticipation versus participation at both assessments was associated with an adjusted difference in change of −0.70 g/1000 kcal (95% CI, −1.95 to 0.55; Holm-adjusted $p = 0.808$; Figure 2).

Compared with nonparticipation at both assessments, adjusted differences in absolute protein intake change were 0.66 g/day (95% CI, −1.53 to 2.84) for transition to participation and 4.28 g/day (95% CI, 1.20 to 7.36) for participation at both assessments. Corresponding Holm-adjusted p values were 1.000 and 0.020 (Figure 2).

For No→Yes versus Yes→Yes, adjusted differences were −71.77 kcal/day (95% CI, −159.44 to 15.89) for energy intake, −0.79 g/1000 kcal (95% CI, −2.21 to 0.63) for protein density, and −3.62 g/day (95% CI, −7.24 to −0.01) for absolute protein intake. Holm-adjusted p values were 0.216, 0.273, and 0.149, respectively (Figure 2).

3.3. Associations by Survey Period

Interactions between exercise participation pattern and survey period were not significant for energy intake or protein density (Holm-adjusted $p = 0.138$ and 0.656, respectively). Period-specific estimates are shown in Table S2.

3.4. Sensitivity Analyses

IPW with untruncated weights produced protein density estimates close to those from the main analysis. Compared with nonparticipation at both assessments, adjusted differences were 1.31 g/1000 kcal (95% CI, 0.63 to 1.98) for transition to participation and 2.06 g/1000 kcal (95% CI, 0.72 to 3.39) for participation at both assessments (Figure 3; Table S3). Estimates were similar after truncating weights at the 99th percentile (Table S3).

After excluding observations with income identified as imputed in the CHNS release, both protein density estimates were positive and statistically significant after Holm correction. None of the energy contrasts were significant after correction in either weighted analysis or the income sensitivity analysis (Figure 3; Table S3). Weight diagnostics are reported in the notes to Table S3.

For absolute protein intake, the Yes→Yes versus No→No difference was 4.18 g/day (95% CI, 1.12 to 7.23; Holm-adjusted $p = 0.030$) with both untruncated and truncated IPW. After excluding observations with imputed income, the difference was 3.37 g/day (95% CI, 0.46 to 6.27; $p = 0.093$). The No→Yes versus Yes→Yes contrast was not significant after Holm correction in any of these analyses (Table S4).

The analysis with complete T1 BMI and disease status included 9574 observations from 5954 participants in 213 connected community clusters. Estimates from the main-analysis model refitted in this sample and the model additionally adjusted for T1 covariates were similar (Table S6). In the latter model, protein density differences versus No→No were 1.26 g/1000 kcal (95% CI, 0.55 to 1.98; Holm-adjusted $p = 0.004$) for No→Yes and 2.05 g/1000 kcal (95% CI, 0.65 to 3.46; $p = 0.022$) for Yes→Yes. The absolute-protein difference for Yes→Yes versus No→No was 4.13 g/day (95% CI, 1.05 to 7.20; $p = 0.026$). Energy contrasts and No→Yes versus Yes→Yes contrasts were not significant after Holm correction in either model.

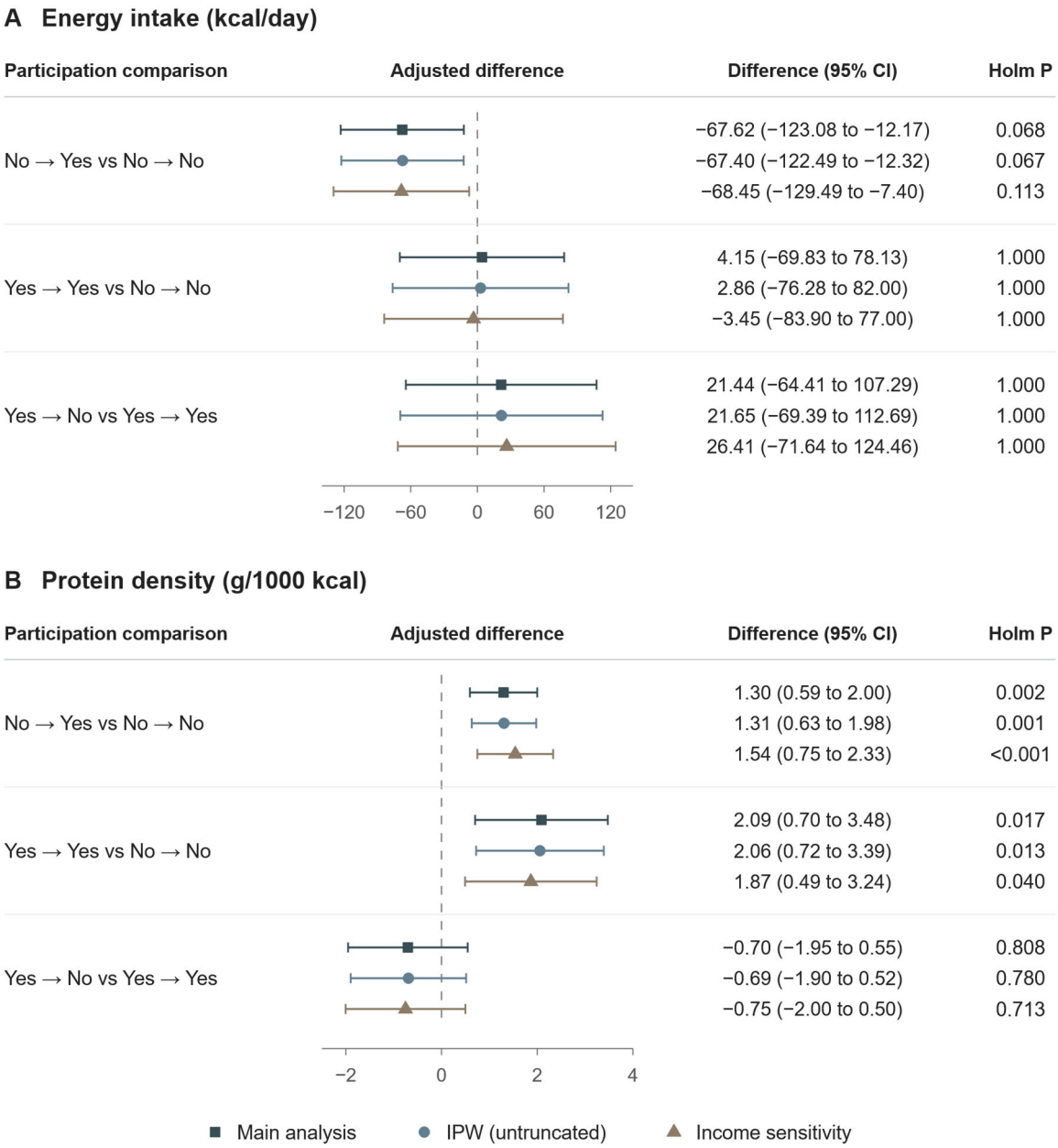


Figure 3. Comparison of the main associations across sensitivity analyses. Panels (**A**,**B**) show adjusted between-group differences in changes in total energy intake and protein density. No and Yes denote nonparticipation and participation in the listed leisure-time exercises; arrows indicate T0-to-T1 patterns. T0, T1, and T2 denote the first, second, and third assessments within each sequence, respectively. Within each contrast, estimates are shown from top to bottom for the main analysis (squares), untruncated inverse probability weighting (IPW; circles), and the income sensitivity analysis (triangles). Points represent T2−T1 change in the first group minus that in the reference group, after adjustment; horizontal lines are 95% confidence intervals (CIs). Dashed lines indicate zero difference. Main and weighted analyses included 6279 participants and 10,016 observations. The income sensitivity analysis included 5168 participants and 7221 observations after excluding observations with imputed income. All analyses used the same covariates and 214 connected community clusters. Main and income analyses used heteroskedasticity-consistent type 1 (HC1) covariance estimates; weighted standard errors used 999 valid cluster bootstrap replicates. All inference used t(213). Six contrasts were Holm-corrected within each analysis. *p* values are Holm-adjusted; CIs are unadjusted for multiplicity. Changes are not annualized. Full results, including weights truncated at the 99th percentile, are in Table S3.

4. Discussion

This three-assessment CHNS analysis examined associations between leisure-time exercise participation patterns reported at T0 and T1 and dietary changes from T1 to T2. After adjustment for dietary levels at T0 and T1, transition to participation and participation at both assessments were associated with greater subsequent protein density changes than nonparticipation at both assessments. None of the energy contrasts were statistically significant after multiple-comparison correction. Participation at both assessments was also associated with a greater adjusted change in absolute protein intake than nonparticipation at both assessments. The difference in protein density change between transition to nonparticipation and participation at both assessments remained uncertain.

Dietary responses in physical activity intervention studies have varied. Studies of middle-aged and older adults and sedentary women found no clear association between increased activity and dietary improvement [14,15]. In young adults, an aerobic training study linked exercise dose to changes in some dietary patterns [18]. In Resist Diabetes, adults with prediabetes reported lower energy intake after resistance training, without a significant change in absolute protein intake [19]. These studies differed in their populations, exercise programs, and dietary outcomes. A Japanese observational study found no clear association between concurrent changes in accelerometer-measured activity and diet quality [23]. The Fenland study examined concurrent changes in physical activity and diet quality and their associations with adiposity [3]. Our binary participation indicator captured varied activities. The most commonly reported categories were other activities (e.g., table tennis or tai chi) and track and field, running, or swimming (Table S5).

Expressed as the percentage of energy from protein (4 kcal/g), the adjusted between-group differences in change were approximately 0.52 and 0.84 percentage points. These estimates compare transition to participation and participation at both assessments, respectively, with nonparticipation at both assessments. The density association for transition to participation was not accompanied by a clear difference in absolute protein intake change. Participation at both assessments showed greater adjusted changes in both measures. The direct No→Yes versus Yes→Yes contrasts provided no clear evidence of differences in any of the three outcomes after Holm correction. Unadjusted mean absolute protein intake declined slightly in the Yes→Yes group; the positive adjusted estimate represents its change relative to the reference group. Protein density depends on both protein and energy intake [10]. The three outcomes describe changes in amount and relative composition, but their separately fitted models do not quantify each component's contribution to the density difference. The density differences were modest; their nutritional relevance depends on initial intake, individual requirements, and food sources. Health outcomes were not evaluated, so the clinical importance of these differences remains uncertain.

The omnibus test for energy intake change indicated between-group differences, although none of the energy contrasts was statistically significant after Holm correction. The Examination of Mechanisms of Exercise-Induced Weight Compensation (E-MECHANIC) trial estimated increased energy intake in exercise groups during 24 weeks of supervised exercise using doubly labeled water and other measurements [5]. The Midwest Exercise Trial 2 (MET-2) found no clear between-group difference in absolute energy intake change during 10 months of supervised exercise [17]. Our study related exercise participation reports at T0 and T1 to dietary changes from T1 to T2. The 2–3-year intervals reflect the survey schedule. Our exposure definition and dietary measurements differed from those used in these trials. Adjustment for T1 intake makes the estimates conditional on intake at that assessment [38]. Dietary changes from T0 to T1 were not analyzed as outcomes. Evaluating exercise-related energy compensation would require concurrent measurement of exercise energy expenditure and intake.

Earlier CHNS analyses documented declining occupational activity, lower cereal consumption, and higher animal-source food consumption from 1991 to 2011, closely related to urbanization [26,27]. In our sample, the three groups reporting exercise at least once differed from the No→No group in urban residence, income, education, and occupation. Their protein density was also higher at earlier assessments. Shared health or weight-management goals may encourage changes in both exercise and food choices. Studies have linked exercise motivation and habit strength with eating regulation and dietary behavior [6,39]. These behavioral links could contribute to dietary changes during follow-up, alongside changes in health, daily routines, and food access.

Protein sources are relevant to nutritional interpretation. US prospective cohorts reported different associations of animal and plant protein with all-cause and cardiovascular mortality [40] and lower all-cause and cardiovascular mortality with higher plant protein intake [41]. Our estimates describe total protein density; animal and plant contributions were not quantified in this sample. Source-specific intake data would help interpret these differences alongside overall diet and individual requirements. More frequent assessments of exercise participation, diet, and health would help distinguish dietary changes during participation transitions from those occurring afterward.

Strengths include repeated exercise and dietary measurements within participants, adjustment for earlier intake, and accounting for repeated observations and community clustering. The two main protein density estimates were similar across sensitivity analyses, including additional adjustment for T1 BMI and disease status in the common sample (Tables S3 and S6). Period-specific estimates for these contrasts were positive, but not all were significant after correction; evidence for consistency across periods remains limited. The Yes→Yes versus No→No absolute-protein estimate remained positive across sensitivity analyses, with varying statistical support.

Several limitations warrant consideration. Exercise was self-reported at T0 and T1; initiation or cessation dates, continuity, and dose between surveys were unknown. The onset of dietary changes was also unknown, and participation changes after T1 were outside the exposure definition. The binary indicator combined activities with different physical demands and did not capture occupational, household, or transport activity. Variation in frequency, intensity, and duration within groups may obscure type- or dose-specific associations. Three-day dietary assessments may not represent habitual intake, and recall-based energy and protein estimates are subject to measurement error [42]. Ingredient quantities for some mixed foods were missing, and some food composition and quantity records required further validation for source-specific estimation.

Subsequent health and weight changes, retirement, medical advice, and motivations to modify diet or manage weight may influence both exercise participation and food choices. Baseline adjustment does not fully address these processes, which could partly account for the observed associations. Additional adjustment for T1 BMI and disease status conditions the estimates on measurements that may themselves reflect earlier behavioral changes. The direction and magnitude of residual confounding remain uncertain. Requiring three consecutive assessments and complete covariates may introduce selection bias [43]. IPW addressed selection due to missing covariates among eligible three-assessment observations, subject to the probability model and missingness assumptions [35], but not selection from earlier missed assessments. The small Yes→Yes group limited precision, and these 2004–2011 data have limited generalizability to the current national adult population. Earlier analyses informed the research question and were not covered by the reported multiplicity adjustments. Independent studies are needed to assess these findings.

5. Conclusions

Among Chinese adults, reporting leisure-time exercise participation at T1 after nonparticipation at T0, or at both assessments, was associated with modestly greater T1-to-T2 protein density changes than reporting nonparticipation at both assessments. Participation at both assessments was also associated with a greater adjusted change in absolute protein intake, with varying statistical support across sensitivity analyses. Protein density and absolute protein intake should be considered together when interpreting associations between exercise participation and subsequent dietary changes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/nu18223787/s1, Supplementary Methods S1: Variable definitions and processing; Supplementary Methods S2: Inverse probability weighting for missing covariates; Supplementary Methods S3: Additional adjustment for T1 BMI and disease status; Table S1: Covariate missingness and characteristics of observations with complete and incomplete covariates; Table S2: Period-specific associations and interaction tests; Table S3: Sensitivity analyses; Table S4: Sensitivity analyses of absolute protein intake change; Table S5: Reported leisure-time exercise categories at T0 and T1; Table S6: Sensitivity analyses with additional adjustment for T1 BMI and disease status. Supplementary References [44,45].

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Informed Consent Statement: Written informed consent was obtained from participants in the original CHNS [29].

Data Availability Statement: This study used publicly available data from the China Health and Nutrition Survey (CHNS). Source data and documentation are available through the CHNS website at https://chns.cpc.unc.edu/ (accessed on 11 November 2026). Access and use are subject to the data provider's requirements.

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