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Temporal Changes in Associations of Sleep Duration, Dietary Energy Intake, and Physical Activity with Obesity among U.S. Adults: NHANES 2005–2018

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Abstract. Obesity remains one of the major public health issues in the United States, but the factors that influence obesity are not static, and the strength of the relationship between modifiable behavioral factors and obesity may change over time. This study analyzed the temporal variation in the association between sleep duration, dietary energy intake, and physical activity with obesity among U.S. adults from 2005-2006 to 2017-2018 by examining data from seven consecutive National Health and Nutrition Examination Survey. The main analysis involved 38,185 adults aged 20 and over who completed the evaluation at the mobile survey center; due to the inability to access relevant activity data during the 2005-2006 period, the physical activity analysis was based on the data of 33,412 participants. This study applied weighted logistic regression analysis, multiple imputation, interaction models, period-specific estimates for each survey cycle, and error discovery rate correction methods. The results show that within a single survey cycle, longer sleep duration is negatively correlated with obesity. Research conclusions on the correlation between sleep duration and survey cycle indicate that this protective association gradually weakens over time. Compared to other variables, there is no significant linear relationship between dietary energy intake and obesity, and no significant time trend exists. The findings indicate that the association between sleep duration and obesity varies across different NHANES survey cycles, whereas the association related to dietary energy intake and physical activity is relatively stable.

Keywords: Obesity, Sleep duration, Dietary energy intake, Physical activity, NHANES

1. Introduction

Obesity has emerged as a major public health concern in the United States, with prevalence increasing substantially since the beginning of the 21st century [1]. Numerous behavioral, demographic, and socioeconomic factors are associated with obesity, but whether the strength of these associations has changed over time remains unclear. Identifying factors with stable or changing associations across different survey periods may provide useful evidence for obesity prevention and control.

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Previous studies have extensively examined factors associated with obesity, including sleep duration, but findings regarding the magnitude and shape of these associations have varied across study periods and populations. A large-scale analysis of National Health and Nutrition Examination Survey (NHANES) data from 2005–2020 reported an inverse dose-response association between sleep duration and obesity, with evidence of a saturation range between approximately 6.5 and 9 hours [2]. A more recent NHANES analysis among adults aged 45 years and older found that sleep duration was inversely associated with body mass index, waist circumference, and waist-to-height ratio, although the magnitude differed across population subgroups [3]. Another analysis of NHANES 2007–2018 reported an inverse association between sleep duration and obesity and identified a nonlinear dose-response pattern [4]. In contrast, an analysis of NHANES 2015–2020 found that short sleep was not significantly associated with obesity in the overall adult sample, although an association was observed among women [5]. Recent NHANES studies also indicate that physical-activity associations can vary by activity domain [6], while diet quality and nutrient intake have changed over time and differ across bodyweight groups [7]. These findings support the need to evaluate whether obesity-related behavioral associations remain stable across repeated national survey cycles.

Earlier research often summarized the association between sleep and obesity as a relatively stable pattern, whereas later NHANES analyses have reported weaker, nonlinear, subgroup-specific, or non-significant associations. It remains unclear whether these differences across NHANES survey periods reflect genuine temporal changes in the strength of association or differences in study populations and analytic specifications.

This study therefore combined seven comparable NHANES cycles from 2005–2006 through 2017–2018 to examine temporal modification of the associations between sleep duration, dietary energy intake, physical activity, and obesity. Each two-year survey cycle was analyzed to estimate exposure–obesity associations, and the combined dataset was used to test exposure-by-cycle interactions. Cycle-specific odds ratios and 95% confidence intervals were summarized graphically to show changes over time. The primary objective was to distinguish associations that remained comparatively stable from those that weakened or strengthened across survey periods.

2. Methods

2.1. Data source

This study used data from the National Health and Nutrition Examination Survey (NHANES), a nationally representative cross-sectional survey conducted by the National Center for Health Statistics, part of the Centers for Disease Control and Prevention. Seven consecutive two-year cycles from 2005–2006 through 2017–2018 were combined. NHANES uses a complex, multistage, stratified, cluster probability sampling design to represent the non-institutionalized civilian population of the United States [8]. The NHANES protocol was approved by the National Center for Health Statistics Ethics Review Board, and all participants provided written informed consent. Only publicly available, de-identified secondary data were used.

The analysis included adults aged 20 years or older who completed a physical examination at a mobile examination center. Of 39,749 eligible adults, 1,564 participants without a completed examination were excluded, leaving 38,185 participants in the main analytic sample. Because comparable physical-activity data were unavailable for 2005–2006, analyses of physical activity were restricted to 2007–2008 through 2017–2018 and included 33,412 participants. Sleep duration and dietary energy intake were analyzed across all seven cycles.

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2.2. Variable definitions

Obesity was evaluated using measured body mass index (BMI). The primary binary obesity outcome was defined as BMI ≥30 kg/m². BMI was also categorized as underweight (<18.5 kg/m²), normal weight (18.5–24.9 kg/m²), overweight (25.0–29.9 kg/m²), and obese (≥30 kg/m²), with normal weight as the reference category in category-specific models.

The exposure variables were sleep duration, dietary energy intake, and physical activity. Sleep duration was based on self-reported typical nightly sleep duration from the NHANES questionnaire, using SLD010H for 2005–2014 and SLD012 for 2015–2018. Dietary energy intake was derived from total energy intake on the first day of the 24-hour dietary recall (DR1TKCAL). Physical activity was derived from the Physical Activity Questionnaire and expressed as metabolic equivalent task minutes per week (MET-min/week), weighting vigorous activity by 8 METs and moderate activity by 4 METs across five activity domains. Because effect sizes for energy intake and physical activity are very small on their original one-unit scales, estimates were summarized per 100 kcal and per 1,000 MET-min/week, respectively.

2.3. Statistical methods

All analyses accounted for the complex NHANES sampling design. Survey-weighted logistic regression was the primary modeling approach, supplemented by multiple imputation for item non-response, cycle-specific estimation, exposure-by-cycle interaction testing, and false-discovery-rate correction for multiple comparisons.

2.3.1. Complex sampling design and weighted estimation

For the pooled seven-cycle dataset, each participant's two-year mobile examination center weight was divided by seven to obtain the combined-cycle weight, consistent with NHANES guidance for combining survey cycles [8]. Primary sampling units and strata were made unique across cycles, and the nesting structure was retained. Variance estimation used first-order Taylor linearization. Weighted rates and means were calculated using survey-design methods.

2.3.2. Missing data handling and multiple imputation

Missing values were handled using multiple imputation by chained equations (MICE). Predictive mean matching was used for continuous variables, and linear discriminant analysis was used for multicategory variables. Thirty imputed datasets were generated with a maximum of 10 iterations. Obesity outcomes based on measured BMI were not imputed. Model estimates and variances were combined across imputed datasets using Rubin's rules. Multiple imputation has been used in recent NHANES analyses to retain participants with incomplete covariate data and to evaluate sensitivity to complete-case analysis [9].

2.3.3. Primary analysis

Survey-weighted logistic regression models estimated associations between each exposure and obesity. Odds ratios (ORs) and 95% confidence intervals (CIs) were obtained from weighted generalized linear models. For BMI categories, separate binary models compared underweight, overweight, and obese categories with normal weight. Covariates included age, sex, race and ethnicity, education level, smoking status, and family income-to-poverty ratio.

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2.3.4. Time trend testing

Temporal modification was assessed in two complementary ways. First, survey cycle was modeled as a continuous variable and an interaction term between each exposure and cycle was included to test a monotonic temporal trend. Second, survey cycle was treated as a categorical variable and cycle-specific ORs were estimated for visual comparison across periods. This strategy is consistent with repeated NHANES analyses of obesity trends [10].

2.3.5. Multiple comparison correction

To control the false-positive rate arising from repeated tests across three exposures and multiple obesity outcomes, p-values were adjusted using the Benjamini–Hochberg false discovery rate procedure [11]. Adjusted values are reported as q-values. Statistical significance was evaluated using a two-sided threshold of 0.05, and interpretation emphasized patterns that remained supported after multiplicity correction rather than isolated nominal p-values.

3. Results

3.1. Missing data patterns

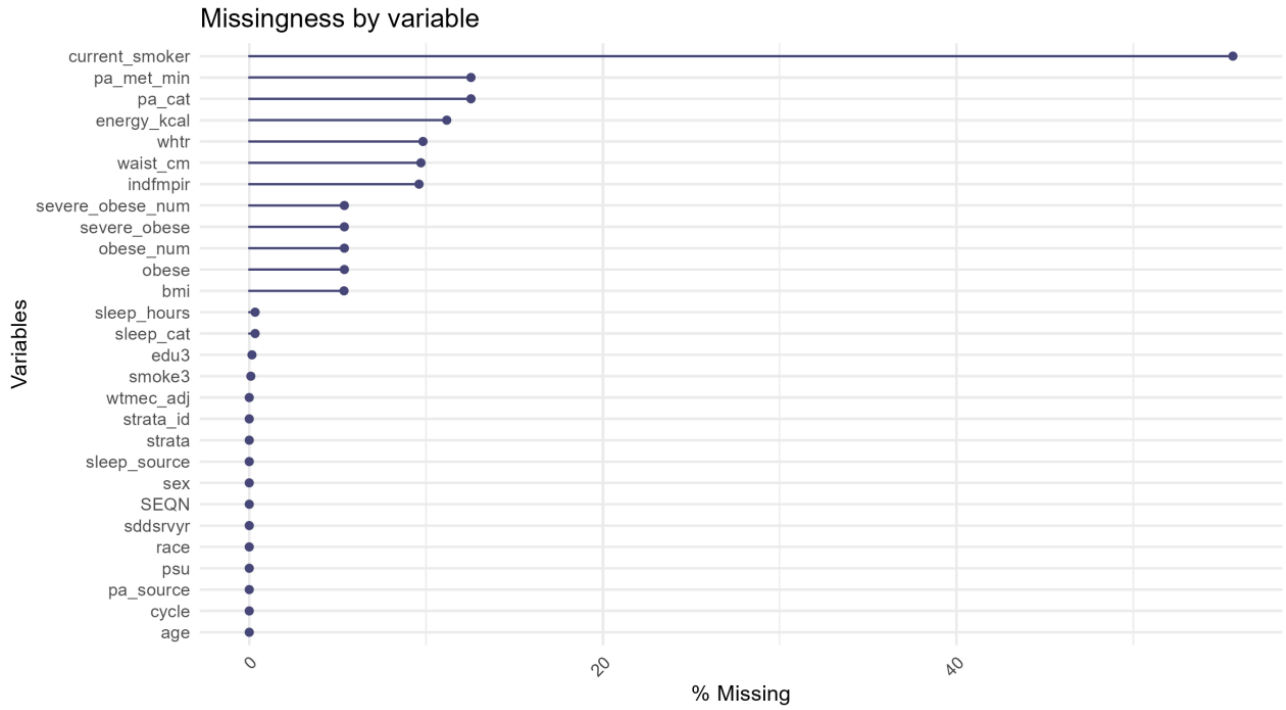


Figure 1. Missingness by variable (picture credit: original)

Missingness differed substantially across variables. Structural missingness was concentrated in current smoking status and physical activity. The original current_smoker item was missing for approximately 55.6% of participants because of questionnaire skip logic and was replaced by the three-level smoke3 variable, which had only 0.09% missingness. Physical activity was unavailable for the entire 2005–2006 cycle, producing 12.5% missingness in the pooled dataset; this structural gap was handled by restricting physical-activity analyses to later cycles rather than imputing the

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unavailable period. Item non-response was most notable for dietary energy intake, waist-related measures, family income-to-poverty ratio, and BMI-related outcomes. Figure 1 summarizes the overall missingness pattern by variable.

Missingness also varied across survey cycles. Family income-to-poverty ratio and dietary energy intake showed higher non-response in later cycles, whereas missingness for BMI, obesity, and severe obesity remained low and comparatively stable. The analysis of cycle-specific missingness was restricted to examination participants and excluded variables with structural missingness by design. Figure 2 shows these temporal patterns. The combination of variable-specific and cycle-specific missingness supported the use of multiple imputation for item non-response while treating structurally unavailable physical-activity data separately.

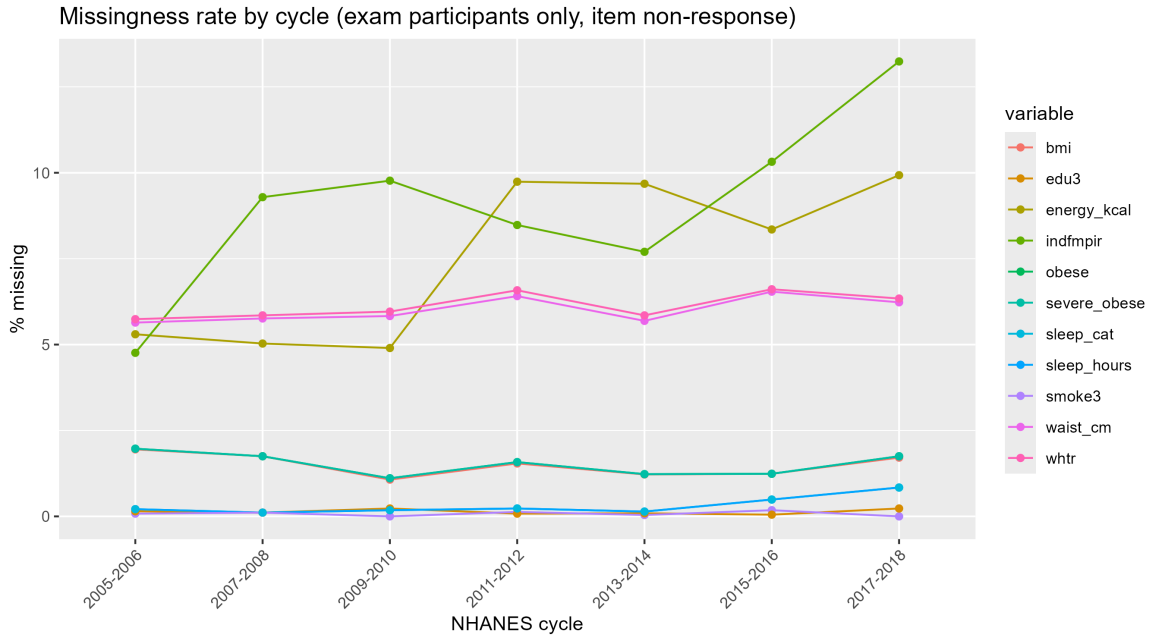


Figure 2. Missingness rate by NHANES cycle (picture credit: original)

3.2. Primary association analysis

After adjustment for age, sex, race and ethnicity, education, smoking status, and family income-to-poverty ratio, the three behavioral exposures showed different association patterns with obesity. Longer sleep duration was inversely associated with obesity within individual cycles; each additional hour of sleep was associated with approximately 9%–13% lower odds of obesity in several cycle-specific models. The association was concentrated in overweight and obesity outcomes, while the underweight outcome remained close to the null.

Dietary energy intake, summarized per 100 kcal, showed no clear linear association with the obesity outcomes. Physical activity, summarized per 1,000 MET-min/week, showed a weak inverse association with obesity, but the magnitude was small. These results suggest that sleep duration had the strongest and most consistent cycle-specific association among the three exposures, whereas dietary energy intake and physical activity showed smaller or less consistent associations.

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3.3. Temporal trend analysis

Temporal trend testing indicated that the association between sleep duration and obesity weakened across survey cycles. The sleep-duration × cycle interaction was positively associated with binary obesity (OR 1.015, 95% CI 1.006–1.023, q = 0.003), overweight (OR 1.016, 95% CI 1.006–1.025, q = 0.010), and the obese BMI category (OR 1.023, 95% CI 1.012–1.034, q < 0.001). The interaction for underweight was not significant (OR 0.991, 95% CI 0.959–1.024, q = 0.718). In contrast, interaction terms for dietary energy intake and physical activity were not statistically significant after false-discovery-rate correction. Table 1 summarizes the exposure-by-cycle interaction estimates.

Table 1. Temporal interaction estimates for exposure–outcome associations

Exposure	Outcome	Interaction OR	95% CI	p-value	q-value
Sleep duration	Binary obesity	1.015	1.006–1.023	<0.001	0.003
Sleep duration	BMI: underweight	0.991	0.959–1.024	0.577	0.718
Sleep duration	BMI: overweight	1.016	1.006–1.025	0.002	0.010
Sleep duration	BMI: obese	1.023	1.012–1.034	<0.001	<0.001
Energy intake	Binary obesity	1.001	0.999–1.002	0.253	0.484
Energy intake	BMI: underweight	1.001	0.997–1.006	0.499	0.665
Energy intake	BMI: overweight	0.999	0.997–1.001	0.313	0.533
Energy intake	BMI: obese	1.000	0.999–1.002	0.673	0.815
Physical activity	Binary obesity	1.000	0.998–1.003	0.944	0.965
Physical activity	BMI: underweight	0.999	0.988–1.011	0.931	0.962
Physical activity	BMI: overweight	0.998	0.995–1.002	0.288	0.517
Physical activity	BMI: obese	0.999	0.996–1.002	0.439	0.653

Note: ORs represent exposure × survey-cycle interaction terms. Energy intake is scaled per 100 kcal and physical activity per 1,000 MET-min/week. Data from: NHANES 2005–2018; calculations by the author.

Cycle-specific estimates provide a similar visual pattern. For the binary obesity outcome, the sleep-duration OR was approximately 0.90 in 2005–2006 and 2007–2008, then moved toward the null in later cycles, reaching approximately 0.98 in 2015–2016 and 0.97 in 2017–2018. Figure 3 shows the cycle-specific estimates for sleep duration across obesity outcomes. By comparison, the physical-activity estimates remained very close to the null across cycles, with no clear monotonic pattern; these estimates are shown in Figure 4. Together, the interaction tests and cycle-specific plots indicate temporal attenuation of the sleep–obesity association but comparatively stable associations for dietary energy intake and physical activity.

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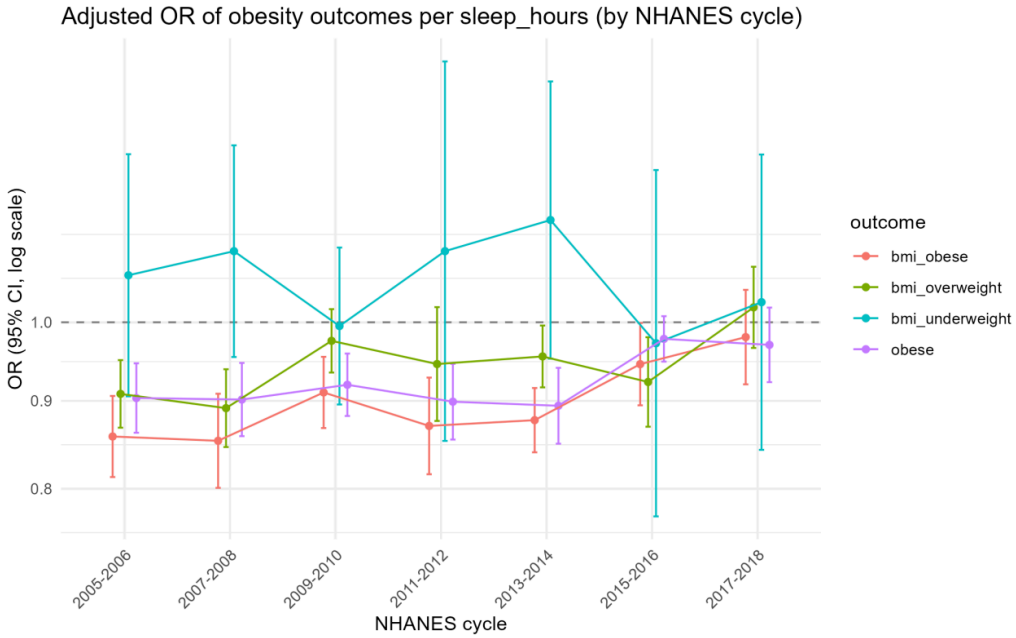


Figure 3. Cycle-specific obesity associations with sleep duration (picture credit: original)

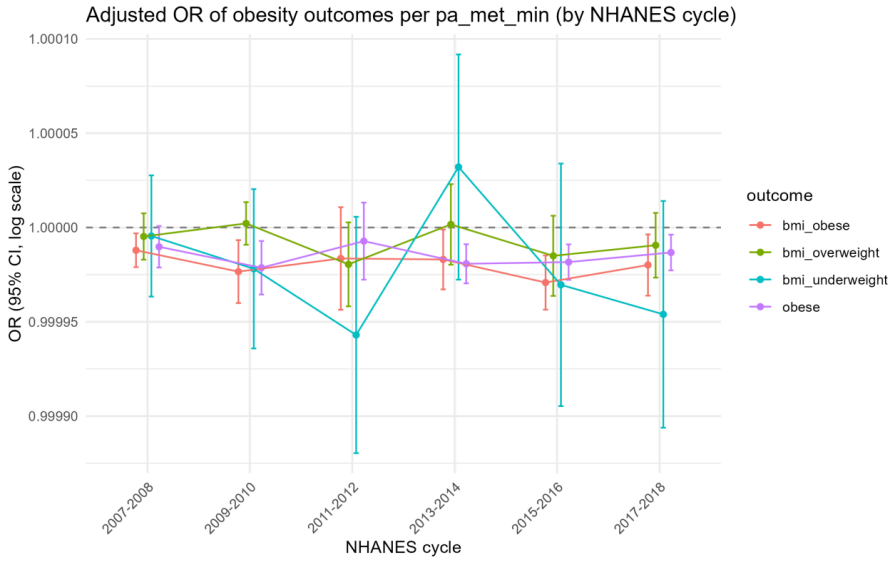


Figure 4. Cycle-specific obesity associations with physical activity B (picture credit: original)

4. Conclusion

This study examined temporal changes in the associations of sleep duration, dietary energy intake, and physical activity with obesity across seven NHANES cycles from 2005–2006 through 2017–2018. Using survey-weighted analyses and multiple imputation, the results indicate that sleep duration had the clearest temporal pattern. Longer sleep duration was generally associated with lower odds of obesity within individual cycles, but the interaction between sleep duration and survey cycle was positive, indicating that this inverse association weakened over time. The cycle-specific estimates similarly moved toward the null in later survey periods, and the association was no longer statistically significant in the final cycles. This pattern was more evident for overweight and obesity

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outcomes than for underweight, suggesting that the temporal attenuation was concentrated in higher-BMI outcomes.

In contrast, dietary energy intake showed no clear linear association with obesity in the primary analyses, and the interaction with survey cycle did not indicate a meaningful temporal change. Physical activity showed a weak inverse association with obesity, but the magnitude was small and remained comparatively stable across the available survey periods. Together, these findings suggest that temporal changes were not uniform across modifiable behavioral factors and that sleep duration may warrant particular attention when evaluating changing obesity-related associations in repeated national surveys.

Several limitations should be considered when interpreting these findings. NHANES is cross-sectional within each survey cycle, so the analyses identify associations rather than temporal or causal effects at the individual level. Sleep duration, dietary intake, and physical activity rely partly on self-reported information and may be affected by measurement error or reporting bias. Physical-activity data were not comparable for 2005–2006, resulting in a shorter analytic period for that exposure. Missingness also varied across variables and survey cycles, although multiple imputation was used for item non-response. Future research should extend the analysis to later NHANES cycles, examine whether the observed attenuation in the sleep–obesity association persists, and evaluate potential heterogeneity by age, sex, race and ethnicity, and socioeconomic characteristics. Longitudinal or repeated-measures data would be particularly valuable for clarifying the direction and mechanisms of these associations.

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