

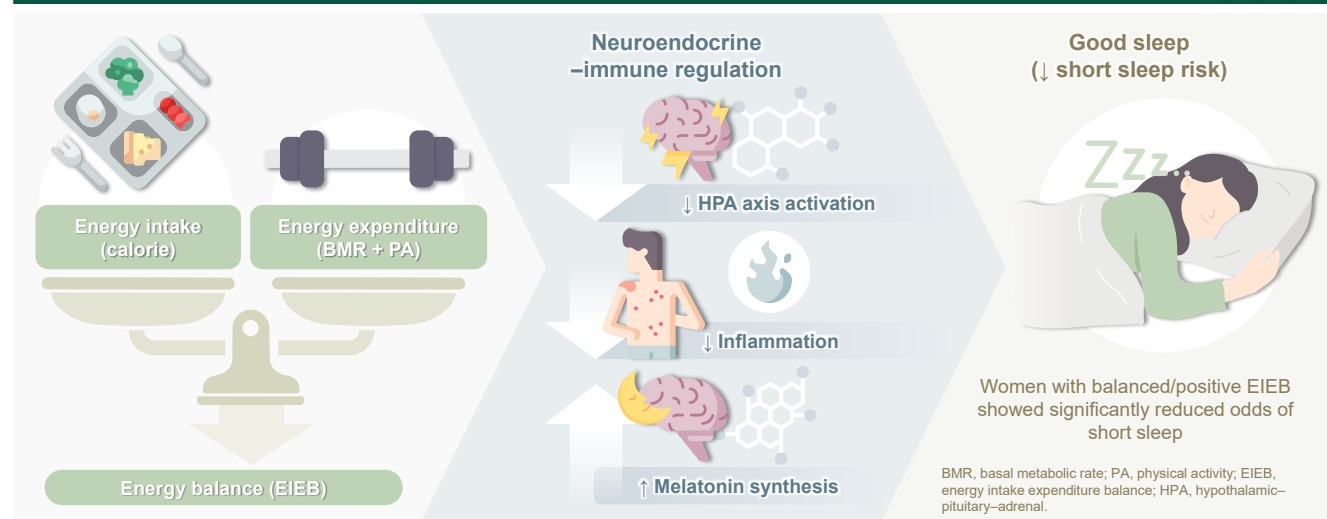
# Effect of energy intake expenditure balance on sleep duration: a cross-sectional study concerning the 2019, 2020, and 2022 Korea National Health and Nutrition Examination Surveys

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## Conclusion

A balanced or positive EIEB is associated with longer sleep duration in female participants, particularly in the middle quartiles, suggesting that better energy balance reduces the likelihood of short sleep.

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**ABSTRACT**

**Background:** Diet and physical activity influence sleep duration; however, the association between energy intake expenditure balance (EIEB) and sleep duration has not been fully investigated. This study examined the relationship between EIEB and sleep duration among Korean adults.

**Methods:** This cross-sectional study included 13,164 adults aged  $\geq 19$  years (5,707 males and 7,457 females) from the 2019, 2020, and 2022 Korea National Health and Nutrition Examination Surveys. EIEB was defined as the difference between daily energy intake and energy expenditure. Energy intake was assessed using a 24-hour dietary recall, and energy expenditure was calculated by summing basal metabolic rate and physical activity. Participants were categorized into sex-specific EIEB quartiles (Q1–Q4). Logistic regression analyses were performed to evaluate the association between EIEB quartiles and short sleep duration ( $\leq 6$  hours), adjusting for socioeconomic status, body mass index, lifestyle factors, and comorbidities.

**Results:** Among women, those in the Q2 EIEB group ( $-260.45$  to  $90.81$  kcal) had a significantly lower risk of short sleep (odds ratio [OR], 0.71; 95% confidence interval [CI], 0.60–0.84). Reduced odds were also observed in Q3 (OR, 0.75; 95% CI, 0.63–0.91) and Q4 (OR, 0.76; 95% CI, 0.62–0.94), with a significant trend across quartiles ( $P$  for trend=0.03). No significant associations were observed among men.

**Conclusion:** A balanced EIEB was inversely associated with short sleep duration in women but not in men, suggesting that sex-specific strategies for energy balance may be needed to support adequate sleep.

**Keywords:** Energy Intake; Energy Expenditure; Sleep Duration; Exercise; Balance

## Introduction

Sleep is fundamental to human health and affects development, immune response, and disease prevention. Sleep deprivation is associated with chronic conditions such as type 2 diabetes, hypertension (HTN), and metabolic syndrome, which collectively increase the risk of heart disease, stroke, and diabetes [1,2]. Insufficient sleep is increasingly common; for example, a survey in Britain found that 58% of respondents experienced sleep problems, with 18% reporting inadequate sleep on most nights [3]. Lifestyle interventions, such as proper sleep hygiene and regular physical activity (PA), are crucial for managing and preventing sleep problems [1]. Regular PA has been shown to improve sleep quality across age groups, reduce the need for sleep medication, and regulate circadian rhythms, thereby alleviating sleep problems [2,4]. Diet also plays a vital role in sleep regulation; for example, high-fat intake at dinner may disrupt circadian rhythms and contribute to shorter sleep duration [5]. While the effects of diet and activity on sleep duration have been studied independently, the relationship between their balance—termed the energy intake expenditure balance (EIEB)—and sleep remains underexplored. Emerging evidence from metabolic research suggests that EIEB plays a regulatory role in physiological recovery, including sleep recovery. Research on Ramadan fasting, a form of intermittent fasting, indicates that energy balance can affect sleep-related outcomes even in the absence of major changes in total energy expenditure [6]. Moreover, sex-based differences have been observed in responses to altered energy balances, including variations in weight regulation, metabolic adaptation, and hormonal responses between male and female participants [6]. Building on this evidence, we investigated the influence of EIEB on sleep duration.

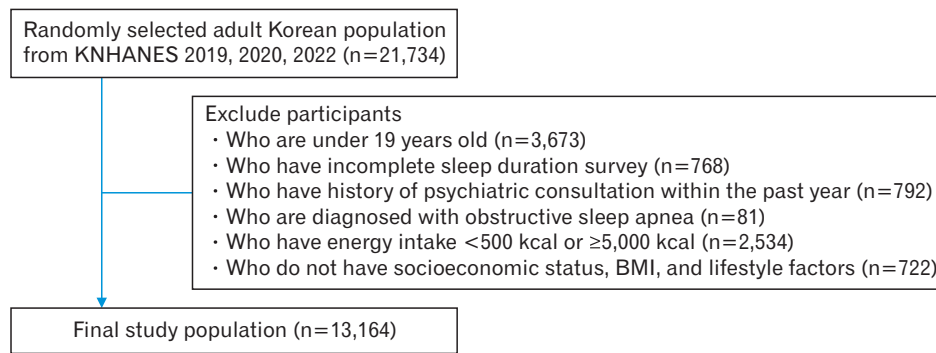
## Methods

### Study participants

Data for this study were obtained from the Korea National Health and Nutrition Examination Survey (KNHANES) conducted in 2019, 2020, and 2022; the KNHANES is a cross-sectional survey of the Korean population, conducted by the Korea Disease Control and Prevention Agency using a complex multistage probability-sampling model [7]. These three survey years were selected because sleep duration was assessed using the same questionnaire that collected data on average sleep duration; in contrast, the 2021 questionnaire collected data on sleep timing (bedtime). Additionally, the Global Physical Activity Questionnaire (GPAQ) was administered in these same years. From a total of 21,734 participants, we excluded individuals based on the following criteria: incomplete sleep questionnaires ( $n=768$ ), a history of psychiatric consultation within the past year ( $n=792$ ), daily energy intake either exceeding 5,000 kcal or falling below 500 kcal ( $n=2,534$ ), a diagnosis of obstructive sleep apnea ( $n=81$ ), and missing data on socioeconomic status (education, marital status, income, living status), body mass index (BMI; height and weight), and lifestyle factors (smoking and alcohol consumption). Consequently, a total of 13,164 participants aged 19 years and older were included in our study (Figure 1). This study used publicly available data; therefore, institutional review board approval was not required.

### Energy intake evaluation

Energy intake data were derived from the KNHANES dataset, which used a 24-hour recall method to estimate daily energy intake.



**Figure 1.** Study population flow chart. KNHANES, Korea National Health and Nutrition Examination Survey; BMI, body mass index.

## Energy expenditure evaluation

The KNHANES utilized the GPAQ to evaluate participants' daily energy expenditure by recording the weekly frequency and daily duration of vigorous and moderate-intensity PA. According to the GPAQ, vigorous PA refers to exercises that significantly raise breathing or heart rate and last for over 10 minutes, whereas moderate-intensity PA involves a slight increase in breathing or heart rate for the same duration. Additionally, the KNHANES included a questionnaire on the weekly frequency and daily duration of walking. PA calories were calculated using the metabolic equivalent of task (MET), assigning 8.0, 4.0, and 3.3 METs for vigorous-intensity PA, moderate-intensity PA, and walking, respectively; the following equation was used:  $1 \text{ kcal} = 3.5 \times \text{MET} \times \text{weight} / 200$  [8,9]. Daily energy expenditure was determined by combining a participant's PA level with the basal metabolic rate that was calculated using the Harris-Benedict equation [9]. Furthermore, EIEB was calculated by subtracting energy expenditure from energy intake. The participants were categorized into four groups based on EIEB (kcal) for both male and female participants: female: 1st quartile (Q1:  $E < -260.45$  kcal); 2nd quartile (Q2:  $-260.45 \text{ kcal} \leq E < 90.81$  kcal), 3rd quartile (Q3:  $90.81 \text{ kcal} \leq E < 498.46$  kcal), and 4th quartile (Q4:  $E \geq 498.46$  kcal); male: 1st quartile (Q1:  $E < -245.0$  kcal), 2nd quartile (Q2:  $-245.0 \text{ kcal} \leq E < 230.5$  kcal), 3rd quartile (Q3:  $230.5 \text{ kcal} \leq E < 753.84$  kcal), and 4th quartile (Q4:  $E \geq 753.84$  kcal).

## Assessment of sleep duration and quality

Sleep duration was assessed using self-reported data from the KNHANES sleep questionnaire, which included two items: (1) average sleep duration on weekdays (or workdays), and (2) average sleep duration on weekends (or non-workdays, or the night before a non-workday). In accordance with the definition of "short sleep" ( $\leq 6$  hours) provided by the International Classification of Sleep Disorders, weekday sleep duration was divided into two categories:  $\leq 6$  hours and  $> 6$  hours. Weekend catch-up sleep (WCUS) was calculated by subtracting average weekday sleep duration from average weekend sleep duration, using the following formula:  $\text{WCUS} = \text{average weekend sleep duration} - \text{average weekday}$

sleep duration [1]. Concerning sleep quality, the STOP-BANG (Snoring, Tiredness, Observed apnea, high blood Pressure, Body mass index, Age, Neck circumference, and Gender) questionnaire was used to evaluate tiredness.

## Confounding variables

Confounding variables included WCUS, socioeconomic status, BMI, lifestyle factors, and underlying diseases. WCUS values were divided into four categories:  $\leq 0$  hours, 0–1 hour, 1–2 hours, and  $\geq 2$  hours [1]. Non-catch-up sleep was defined as WCUS  $\leq 0$  hours [10]. Socioeconomic status factors included educational level, marital status, income level, and living arrangement. Educational level was classified into three categories: less than high school, high school graduate, and above high school [9]. Marital status was classified as "married" or "unmarried." Income level was grouped into three categories: low (0%–25%), middle (25%–75%), and high (75%–100%). Living arrangement was categorized as "living alone" or "living with others." Lifestyle factors included smoking and alcohol consumption. Smoking status was classified into three groups: never smoked, former smoker, and current smoker. Alcohol consumption was categorized into two groups: non-high-risk and high-risk. High-risk drinking was defined based on the following criterion of the World Health Organization (WHO): consumption of more than 60 g and 40 g of pure alcohol by male and female participants, respectively [11]. Underlying diseases were identified based on whether participants were taking medications for diabetes mellitus (DM), dyslipidemia (DL), or HTN.

Diet quality was evaluated using the mean adequacy ratio, which represents the average nutrient adequacy ratios (NARs) for proteins, vitamin A, thiamine, riboflavin, niacin, vitamin C, calcium, phosphorus, and iron. The NAR for each nutrient was calculated as the ratio of daily intake to recommended intake as specified in the 2020 Dietary Reference Intakes for Koreans [12,13].

## Statistical analysis

The characteristics of the study participants, stratified by sex

and sleep duration, were expressed as mean±standard error or number (%). The means of continuous variables were compared using a t-test, while categorical variables were compared using a

chi-square test. Logistic regression analysis was conducted to assess the odds ratios (ORs) for short sleep duration across the sex-specific quartile groups based on EIEB, with the first quartile

**Table 1.** Basal characteristics of study participants according to average weekday (or workday) sleep duration and sex

Characteristic	Female (n=7,457)			Male (n=5,707)		
	Sleep ≤6 h	Sleep >6 h	P-value	Sleep ≤6 h	Sleep >6 h	P-value
No. of patients	1,377	6,080		927	4,780	
Age (y)	59.1±15.9	50.9±16.3	<0.001	55.8±16.5	51.4±17.2	<0.001
Body mass index (kg/m <sup>2</sup> )	23.5±3.5	23.3±3.7	0.051	24.8±3.6	24.6±3.4	0.013
Education			<0.001			<0.001
Less than high school	676 (49.1)	1,641 (27.0)		308 (33.2)	955 (20.0)	
High school graduate	384 (27.9)	1,987 (32.7)		297 (32.0)	1,737 (36.3)	
Beyond high school	317 (23.0)	2,452 (40.3)		322 (34.7)	2,088 (43.7)	
Marital status			<0.001			<0.001
Married	1,256 (91.2)	5,116 (84.1)		766 (82.6)	3,691 (77.2)	
Unmarried	121 (8.8)	964 (15.9)		161 (17.4)	1,089 (22.8)	
Income percentage			<0.001			<0.001
Low (0%–25%)	424 (30.8)	1,025 (16.9)		209 (22.5)	757 (15.8)	
Middle (25%–75%)	670 (48.7)	3,213 (52.8)		470 (50.7)	2,477 (51.8)	
High (75%–100%)	283 (20.6)	1,842 (30.3)		248 (26.8)	1,546 (32.3)	
Living alone			<0.001			0.015
Yes	310 (22.5)	766 (12.6)		145 (15.6)	606 (12.7)	
No	1,067 (77.5)	5,314 (87.4)		782 (84.4)	4,174 (87.3)	
Smoking status			0.049			0.229
Never	1,209 (87.8)	5,399 (88.8)		211 (22.8)	1,205 (25.2)	
Former	87 (6.3)	415 (6.8)		421 (45.4)	2,150 (45.0)	
Current	81 (5.9)	266 (4.4)		295 (31.8)	1,425 (29.8)	
Alcohol drinking			0.667			0.033
High-risk drinking	43 (3.1)	206 (3.4)		735 (79.3)	3,931 (82.2)	
Non-high-risk drinking	1,334 (96.9)	5,874 (96.6)		192 (20.7)	849 (17.8)	
Diet						
Energy intake (kcal/d)	2,290.5±845.9	2,252.5±835.3	<0.001	1,715.7±653.0	1,674.1±707.8	0.293
Protein intake (g/d)	81.3±39.0	78.7±42.3	<0.001	60.5±29.3	58.2±31.4	0.009
Fat intake (g/d)	48.5±34.7	47.3±34.2	<0.001	37.3±26.9	36.5±28.7	0.0001
Carbohydrate intake (g/d)	340.6±122.9	328.8±123.1	<0.001	276.1±108.0	265.8±113.4	0.199
Diet quality	1.196±0.521	1.148±0.526	<0.001	1.063±0.500	1.010±0.506	0.0499
WCUS			0.693			<0.001
Sleep less than workday	18 (1.3)	180 (3.0)		8 (0.9)	116 (2.4)	
Sleeps the same (≤0 h)	960 (69.7)	3,802 (62.5)		571 (61.6)	3,000 (62.8)	
Short WCUS (>0 h, ≤1 h)	124 (9.0)	897 (14.8)		78 (8.4)	656 (13.7)	
Medium WCUS (>1 h, ≤2 h)	110 (8.0)	767 (12.6)		103 (11.1)	662 (13.8)	
Long WCUS (>2 h)	165 (12.0)	434 (7.1)		167 (18.0)	346 (7.2)	
Tiredness <sup>a)</sup>	1,179 <sup>a)</sup>	4,390 <sup>a)</sup>	<0.001	751 <sup>a)</sup>	3,351 <sup>a)</sup>	<0.001
Yes	484 (41.1)	1,334 (30.4)		259 (34.5)	861 (25.7)	
No	695 (58.9)	3,056 (69.6)		492 (65.5)	2,490 (74.3)	
Basal metabolic rate (kcal/d)	1,289.2±194.2	1,345.5±185.8	<0.001	1,545.9±248.8	1,586.8±238.7	<0.001
Physical activity (kcal/d)	159.9±259.2	163.8±216.5	0.561	270.8±381.6	260.2±331.8	0.384
EIEB (kcal/d)	16.7±630.4	83.8±650.3	<0.001	284.2±861.1	283.9±845.5	0.993
Premedical history						
On HTN medication	467 (33.9)	1,236 (20.3)	<0.001	287 (31.0)	1,176 (24.6)	<0.001
On DM medication	182 (13.2)	480 (7.9)	<0.001	134 (14.5)	532 (11.1)	0.004
On DL medication	361 (26.2)	1,058 (17.4)	<0.001	166 (17.9)	697 (14.6)	0.01

Values are presented as number, mean±standard error, or the number (%) unless otherwise stated. P-values were calculated using t-test for continuous variables and chi-square test for categorical variables.

WCUS, weekend catch-up sleep; EIEB, energy intake expenditure balance; HTN, hypertension; DM, diabetes mellitus; DL, dyslipidemia.

<sup>a)</sup>STOP-BANG (Snoring, Tiredness, Observed apnea, high blood Pressure, Body mass index, Age, Neck circumference, and Gender) questionnaire, age ≥40 only.

group (Q1) serving as the reference group. Four models were developed to account for potential confounding variables: Model 1 used a logistic regression analysis without any adjustments; Model 2 involved a multivariate logistic regression analysis adjusted for age and WCUS; Model 3 included diet quality adjustments to those in Model 2. Model 4 included further adjustments for BMI, educational level, marital status, income level, living status, smoking, alcohol consumption, and medication history for DM, DL, and HTN, in addition to all variables adjusted in Model 3. A trend analysis was also performed for these models.

Moreover, a subgroup analysis was conducted to categorize our participants based on age group, WCUS, BMI, diet quality, PA, and occupational activeness. The participants were divided into two groups for each variable. For age, diet quality, and PA, median values were used to separate the participants into two groups. A BMI of 25 kg/m<sup>2</sup> was used to distinguish between the obese and non-obese groups, in accordance with WHO and Asia-Pacific guidelines [14]. Regarding WCUS, participants were classified into two groups: WCUS (no), for those with WCUS ≤0 hours, and WCUS (yes), for those with WCUS >0 hours. Occupations were categorized as “sedentary” and “active,” with sedentary occupations including housewives, office workers, and laborers engaged in simple tasks [15]. The quartiles of EIEB were utilized, and the ORs were calculated after adjusting for age, BMI, educational level, marital status, income level, living status, smoking habits, alcohol consumption, and medication history for DM, DL, and HTN.

Our subgroup analyses also involved multivariate logistic regression. In all statistical analyses, two-sided P-values less than 0.05 were considered statistically significant. These analyses were conducted using Stata ver. 16.0 (Stata Corp.).

## Results

### Basal characteristics of study participants

Table 1 summarizes the basal characteristics of study participants stratified by sex and average sleep duration per day on weekdays. Participants were categorized into two groups—those sleeping ≤6 hours and those sleeping >6 hours—comprising both female (n=7,457) and male participants (n=5,707). Our analysis of their basal characteristics included demographic data, lifestyle factors, dietary intake, sleep quality, and medical history.

Overall, 18.5% of female (n=1,377) and 16.2% of male (n=927) reported sleeping ≤6 hours. Short sleepers were older, less educated, unmarried, and more likely to have low-income levels. Male participants who slept ≤6 hours had a slightly higher BMI (24.8 kg/m<sup>2</sup>) than those who slept longer (24.6 kg/m<sup>2</sup>, P=0.013). No significant differences in smoking status were observed among male participants (P=0.229), whereas high-risk drinking was more prevalent among male participants who slept ≤6 hours.

**Table 2.** Odds ratios and 95% confidence intervals for short sleep duration according to energy intake expenditure balance

Variable	Energy intake expenditure balance (kcal/d)									
	Female				Male					
	1st quartile (<-260.45)	2nd quartile (-260.45 to 90.81)	3rd quartile (90.81 to 498.46)	4th quartile (>498.46)	P for trend	1st quartile (<-245.0)	2nd quartile (-245.0 to 230.5)	3rd quartile (230.5 to 753.8)	4th quartile (>753.84)	P for trend
No. of patients	1,864	1,864	1,865	1,864		1,427	1,427	1,427	1,426	
No. of sleep ≤6 h	410	334	337	296		231	232	232	232	
Model 1	1 (Ref)	0.77 (0.66-0.91)*	0.78 (0.67-0.92)*	0.67 (0.57-0.79)*	<0.001	1 (Ref)	1.01 (0.82-1.23)	1.01 (0.82-1.23)	1.01 (0.82-1.23)	0.955
Model 2	1 (Ref)	0.68 (0.58-0.81)*	0.67 (0.57-0.79)*	0.64 (0.54-0.77)*	<0.001	1 (Ref)	0.89 (0.73-1.10)	0.89 (0.72-1.09)	0.94 (0.77-1.16)	0.575
Model 3	1 (Ref)	0.70 (0.59-0.83)*	0.74 (0.61-0.88)*	0.75 (0.61-0.92)*	0.015	1 (Ref)	0.90 (0.73-1.11)	0.90 (0.73-1.12)	0.97 (0.77-1.23)	0.827
Model 4	1 (Ref)	0.71 (0.60-0.84)*	0.75 (0.63-0.91)*	0.76 (0.62-0.94)*	0.028	1 (Ref)	0.92 (0.75-1.14)	0.93 (0.74-1.16)	0.96 (0.75-1.22)	0.75

Values are presented as odds ratios (95% confidence interval) unless otherwise stated. Statistical differences were tested using logistic regression analysis using following 4 models: Model 1, not adjusted; Model 2, adjusted for age and weekend catch-up sleep; Model 3, adjusted with diet quality in addition to model 2; Model 4, adjusted with body mass index, educational level, marital status, income level, living status, smoking and alcohol consumption, diabetes mellitus, dyslipidemia, and hypertension medication in addition to Model 3. Ref, reference.

\*P<0.05 (Statistical significance).

Diet quality scores were significantly lower among short sleepers. Among male participants, short sleepers reported longer WCUS ( $P < 0.001$ ). Short sleepers were also more likely to report feelings of tiredness, indicating poorer sleep quality. No statistically significant differences in PA levels were observed between short and longer sleepers of either sex, suggesting a limited impact of PA on sleep duration in our sample. However, short sleepers were more likely to be taking medications for HTN, DM, and DL.

### Association between EIEB and sleep duration

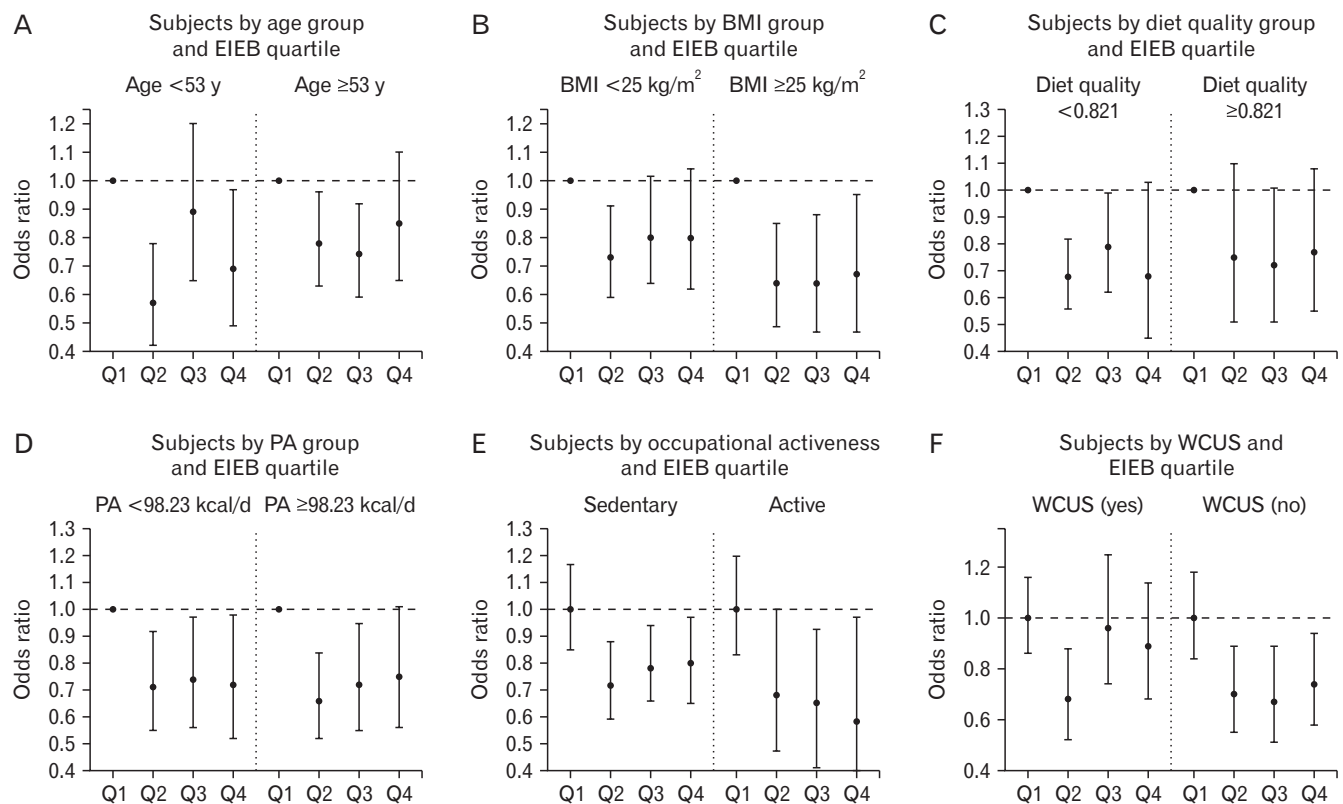
We explored the relationship between EIEB and the likelihood of short sleep duration ( $\leq 6$  hours) among both male and female participants, categorizing them into quartiles comprising a wide range of EIEB values (from lowest to highest). Table 2 outlines this relationship.

After adjusting for age and WCUS in Model 2, followed by an additional adjustment for diet quality in Model 3 and further controlling for social factors and comorbid conditions—including DM, HTN, and DL in Model 4—the association between EIEB and short sleep duration among female participants remained statistically significant across all quartiles, although it was slightly

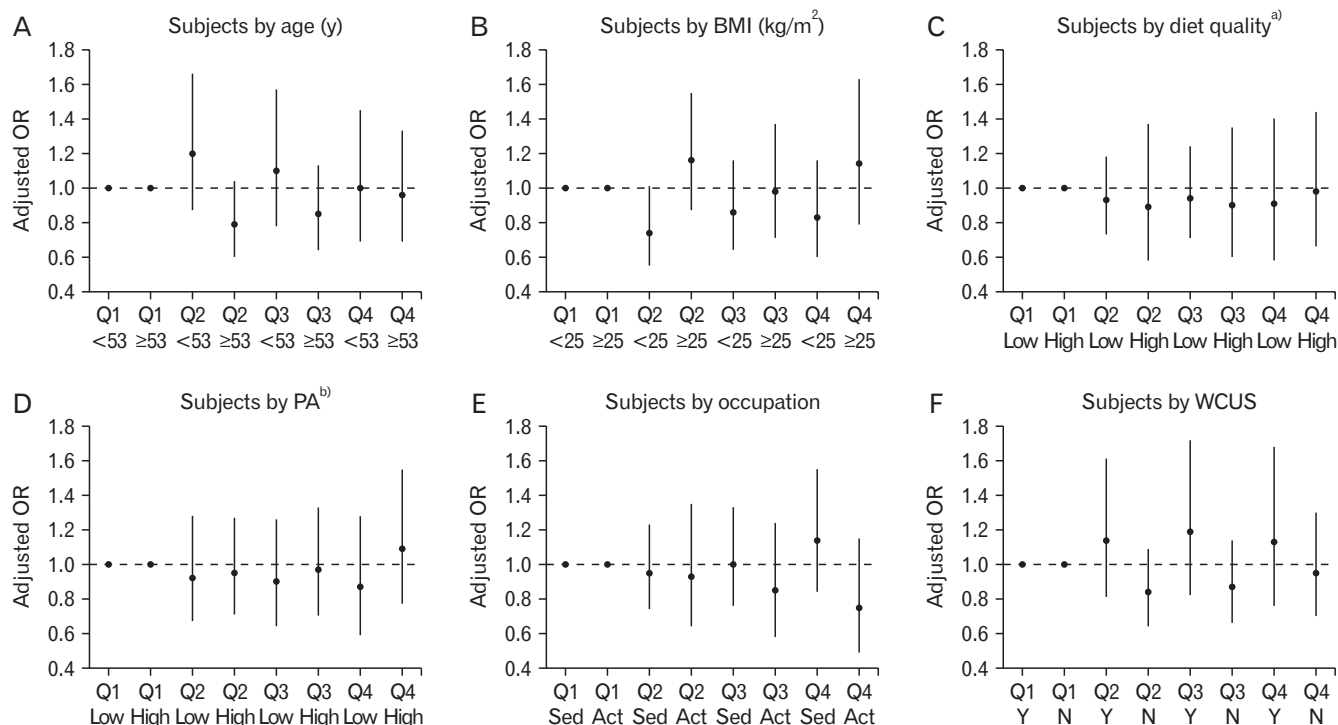
weakened. Even in the fully adjusted Model 4, higher EIEB was significantly associated with lower odds of short sleep. Compared with the first quartile (reference), the adjusted ORs for short sleep were 0.71 (95% confidence interval [CI], 0.60–0.84), 0.75 (95% CI, 0.63–0.91), and 0.76 (95% CI, 0.62–0.94) in Q2, Q3, and Q4, respectively. In contrast, no significant association was observed between the EIEB quartiles and sleep duration among male participants. In Model 4, the adjusted ORs for short sleep in Q2, Q3, and Q4 were 0.92 (95% CI, 0.75–1.14), 0.93 (95% CI, 0.74–1.16), and 0.96 (95% CI, 0.75–1.22), respectively.

### Subgroup analysis

Subgroup analyses were conducted to evaluate the association between EIEB and short sleep duration across age, BMI, diet quality, PA, occupational activeness, and WCUS (Figures 2, 3). Participants were divided into two subgroups for each of the following variables: age ( $< 53$  years vs.  $\geq 53$  years), BMI ( $< 25$  kg/m<sup>2</sup> vs.  $\geq 25$  kg/m<sup>2</sup>), diet quality (below vs. above the median score), PA (below median kcal/d vs. above the median kcal/d), occupational activeness (sedentary vs. active), and WCUS (WCUS [no]:  $\leq 0$  hours; WCUS [yes]:  $> 0$  hours).



**Figure 2.** Subgroup analysis of odds ratios for short sleep among women based on energy intake expenditure balance (EIEB) quartiles. Quartiles are displayed on the x-axis (first [ $< -260.45$  kcal], second [ $-260.45$  to  $90.81$  kcal], third [ $90.81$  to  $498.46$  kcal], and fourth [ $> 498.46$  kcal] quartiles). Adjustments were made for age, body mass index (BMI), diet quality, physical activity (PA), occupation, and weekend catch-up sleep (WCUS). Statistically significant differences between subgroups, with 95% confidence intervals ( $P$ -value for interaction  $< 0.05$ ). (A) Subjects by age group and EIEB quartile. (B) Subjects by BMI group and EIEB quartile. (C) Subjects by diet quality group and EIEB quartile. (D) Subjects by PA group and EIEB quartile. (E) Subjects by occupational activeness and EIEB quartile. (F) Subjects by WCUS and EIEB quartile.



**Figure 3.** Subgroup analysis of odd ratios (ORs) for short sleep based on energy intake expenditure balance (EIEB) quartile in males. Quartiles are shown on the x-axis, 1st quartile (Q1:  $E < -245.0$  kcal), 2nd quartile (Q2:  $-245.0 \text{ kcal} \leq E < 230.5$  kcal), 3rd quartile (Q3:  $230.5 \text{ kcal} \leq E < 753.84$  kcal), and 4th quartile (Q4:  $E \geq 753.84$  kcal). No statistical significance was observed in males. Adjustments were made for age (A), body mass index (BMI) (B), diet quality (C), physical activity (PA) (D), occupation (E), and weekend catch-up sleep (WCUS) (F). Sed, sedentary; Act, active; Y, yes; N, no. <sup>a)</sup>Low indicates diet quality  $< 0.821$ ; high indicates diet quality  $\geq 0.821$ . <sup>b)</sup>Low indicates physical activity  $< 98.23$  kcal/d; high indicates physical activity  $\geq 98.23$  kcal/d.

Regardless of age groups and PA statuses, higher EIEB quartiles were associated with reduced odds of short sleep. In the second and third quartiles, female participants with lower diet quality showed reduced odds of short sleep. However, no significant association was observed among female participants with a higher diet quality.

In higher-EIEB quartiles, both sedentary and active female participants demonstrated lower odds of short sleep; across all quartiles, active female participants showed a significant prominent effect of EIEB on reduced ORs regarding short sleep ( $P=0.044$ ). Female participants who did not engage in WCUS showed significantly reduced odds of short sleep across higher-EIEB quartiles (significant trend,  $P=0.015$ ), whereas no significant trend was observed among female participants in the increasing-EIEB quartile who engaged in WCUS. Concerning male participants, no significant relationship was observed between the EIEB quartile groups and short sleep duration across most subgroups (Figure 3, Supplements 1, 2).

## Discussion

A key finding of our study is the significant inverse relationship between energy EIEB and the odds of short sleep duration ( $\leq 6$  hours) among female participants (but not among male par-

ticipants). Research has suggested that dietary quality is closely associated with sleep health. Our study extends this literature by demonstrating that a more favorable EIEB is associated with a reduced likelihood of short sleep duration, particularly among female participants. This finding aligns with those of previous studies that have focused on diet quality. For example, Castro-Diehl et al. [16] reported that greater adherence to the Mediterranean diet was associated with adequate sleep duration and fewer insomnia symptoms in a multiethnic US cohort. Similarly, Zuraikat et al. [17] in 2020 reported that higher adherence to a Mediterranean dietary pattern predicted better sleep quality and efficiency in female participants over a 1-year follow-up period.

However, research has primarily focused on overall dietary adherence or quality, without considering the actual energy balance between intake and expenditure. To the best of our knowledge, no prior research has directly investigated the association between EIEB and sleep duration using nationally representative data. By incorporating both dietary intake and estimated energy expenditure, we provide a novel perspective that integrates energy balance into the sleep-diet relationship. These findings may offer additional insights into the underlying biological mechanisms and sex-specific metabolic responses that influence sleep regulation. The observed association between positive EIEB and lower odds of short sleep duration, particularly among female participants, may reflect underlying neuroendocrine-immune interac-

tions. Straub et al. [18] highlighted that immune activation, especially during nighttime sleep, requires approximately 400 kcal/d to sustain antigen-specific lymphocyte proliferation, antibody production, and cytokine regulation. Therefore, adequate energy availability may support nighttime repair and anti-inflammatory activity, enhancing sleep continuity and quality.

Sex differences in neuroendocrine regulation may further explain why the association between EIEB and sleep duration is stronger among female participants than among male participants. Female participants exhibit greater sensitivity to metabolic and hormonal fluctuations involving cortisol, leptin, and estrogen—key regulators of both energy storage and circadian immune function [18]. Under conditions of negative energy balance, these systems may become dysregulated, resulting in more pronounced inflammatory signaling, impaired sleep, and emotional stress among female participants than among male participants. Moreover, the stress–inflammation–sleep cycle plays a central role in this interplay. Energy deprivation activates the hypothalamic–pituitary–adrenal axis and the sympathetic nervous system, leading to increased production of cortisol and proinflammatory cytokines (e.g., Interleukin 6, tumor necrosis factor- $\alpha$ ), both of which are known to disrupt sleep architecture [18].

Our subgroup analyses were generally consistent with our overall findings, with certain groups showing more prominent linear trends. BMI significantly influenced the linear relationship between EIEB and short sleep duration among female participants. Female participants with higher BMI consistently benefited from a positive energy balance across all quartiles, suggesting that those with higher BMI may require higher energy intake to achieve better sleep duration, potentially reflecting greater energy needs. Among female participants in active occupations, maintaining a positive energy balance was particularly important for reducing short sleep periods, emphasizing the need for tailored dietary and lifestyle interventions based on energy demands. Our data highlight the importance of dietary quality as a critical factor regarding sleep health. Shorter sleep duration is often associated with higher carbohydrate intake and lower fat (especially polyunsaturated fatty acids or PUFA) intake [19]. Poor diet can negatively affect sleep, while inadequate sleep can lead to poor dietary choices, creating a cycle of negative health outcomes. In our study, among female participants in higher-EIEB quartiles, those reporting a poor diet quality showed reduced odds of short sleep, although this association did not reach statistical significance. This finding indicates that a proper EIEB does not necessarily improve sleep when diet quality is suboptimal, highlighting the need for a balanced energy intake and good diet quality. Research has demonstrated that a higher diet quality is positively associated with sleep health, likely through improved metabolic efficiency and vascular function [20]. Our stratified analysis extends this evidence by showing that EIEB was significantly associated with short sleep only in individuals with lower diet quality (Supplement 2). This finding suggests that diet quality may play a primary

role in sleep regulation, possibly by facilitating efficient circulation and energy utilization. When diet quality is poor, adequate energy intake may compensate for suboptimal nutrient composition, supporting sleep through improved energy availability. In contrast, when diet quality is high, the influence of EIEB on sleep appears to be attenuated, suggesting that diet composition—particularly nutrient density and balance—plays a significant role in supporting healthy sleep. Collectively, these findings highlight the importance of sleep-related interventions targeting both macronutrient balance and diet quality, particularly for individuals with poor dietary habits.

For female participants who did not engage in WCUS, maintaining a positive energy balance was strongly associated with lower odds of short sleep duration, suggesting that a consistent energy balance supports adequate sleep without the need for compensatory sleep. However, the relationship between positive EIEB and sleep was less clear among female participants who engaged in WCUS. The reliance on catch-up sleep may contribute to irregular sleep patterns and result in irregular energy intake or unhealthy and high processed-food intake, leading to sleep disturbances among female participants [21]. Male participants' sleep may be more influenced by external stressors, such as work demands and unhealthy behaviors, that potentially overshadow the effects of EIEB [22]. Recent meta-analyses have highlighted the role of dietary patterns, particularly the consumption of ultra-processed foods (UPFs), in sleep disturbances including insomnia [23]. A systematic review by Pourmotabbed et al. [24] in 2024 reported that a higher UPF intake was significantly associated with increased odds of insomnia, particularly among adolescents and female participants. These findings align with mechanistic insights suggesting that UPFs may disrupt sleep via glycemic instability, altered gut microbiota, reduced intake of sleep-supporting nutrients such as tryptophan, and exposure to endocrine-disrupting chemicals [25]. Classification via the Nova system and specific snack food consumption were deemed stronger predictors of sleep disruption than generalized Western diets, underscoring the importance of considering both food processing levels and dietary contexts in sleep research [24].

The strengths of our study include the use of data from the KNHANES—a large, nationally representative survey that enabled a comprehensive analysis of the association between EIEB and sleep. However, the cross-sectional design limited our ability to establish causation; moreover, our sleep assessment relied on self-reported data and may not have accurately reflected actual sleep durations. Furthermore, dietary intake was estimated using a single 24-hour recall that may not have captured habitual dietary patterns. Future research should explore the causal relationships between EIEB and sleep using longitudinal data, examining how interventions targeting EIEB can specifically improve sleep in different populations.

In our study, a positive EIEB was associated with reduced odds of short sleep duration among female participants—particularly

female participants with low diet quality—but not among male participants. These sex-specific findings may reflect underlying differences in neuroendocrine-immune regulation that requires substantial energy to support repair and anti-inflammatory processes; insufficient energy availability may disrupt this balance, especially in female participants with heightened metabolic and hormonal sensitivity. Given the differential effects of diet quality, future research should explore the interactions among diet quality, calorie intake, EIEB, PA, and sleep health.

## Article Information

### Conflict of interest

No potential conflict of interest relevant to this article was reported.

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### Data availability

Data of this research are available from the corresponding author upon reasonable request.

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Conceptualization: MS. Methodology: MS, HJK. Software: MS, HJK. Validation: MS, MP. Formal analysis: MS. Investigation: MS. Data curation: MS. Project administration: MS. Visualization: MS. Supervision: MP. Writing—original draft: MS. Writing—review & editing: MS. Final approval of the manuscript: all authors.

### Supplementary materials

Supplementary materials can be found via <https://doi.org/10.4082/kjfm.24.0228>. Supplement 1. Subgroup analysis—stratification according to age, WCUS, BMI, diet quality, PA, and occupational activeness (male). Supplement 2. Subgroup analysis—stratification according to age, WCUS, BMI, diet quality, PA, and occupational activeness (female).

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