# Commuting time, residential floor area, and their associations with insomnia and daytime sleepiness among residents of the Tokyo metropolitan area: a cross-sectional study

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# Commuting time, residential floor area, and their associations with insomnia and daytime sleepiness among residents of the Tokyo metropolitan area: a cross-sectional study

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A B S T R A C T

*Introduction:* While urban residences offer advantages in commuting time, they are associated with a less favorable living environment than sub-urban residences. Understanding how housing location and size influence insomnia symptoms and daytime sleepiness can inform housing selection and supply strategies. This study examined whether commuting time and residential floor area predict insomnia and daytime sleepiness, whether these associations are attenuated by demographic/socioeconomic factors, and how commuting time and residential floor area are interrelated.
*Methods:* In September 2024, we conducted an online survey involving 2000 employed individuals, aged 40–59 years, commuting to Tokyo workplaces, selected by stratified random sampling. Commuting time was calculated using a route search system based on home and workplace postal codes and commute modes. Insomnia and daytime sleepiness were assessed using the Athens Insomnia Scale (AIS) and Epworth Sleepiness Scale (ESS). Associations among sleep outcomes, commuting time, and demographic/socioeconomic factors were analyzed using bivariate logistic and multivariate linear regression with propensity score matching.
*Results:* We analyzed 1757 valid responses. Even after adjusting for covariates, longer commuting times predicted insomnia and daytime sleepiness, whereas small residential floor area predicted insomnia. Shorter commutes improved sleep, suggesting a trade-off between commuting time and floor area. For a 95 $m^2$ home, a 53-min commute was associated with exceeding the AIS insomnia cutoff.
*Conclusion:* Reducing commuting time and optimizing housing location and size trade-offs may help mitigate commuter insomnia.

## 1. Introduction

Long commute times have been shown to negatively affect sleep. A study using the American Time Use Survey found that the average daily commuting time was 62 min (31 min one-way), with a median of 55 min, and that 10.1 % of workers commuted for more than 120 min per day (Christian, 2012). Basner et al. reported that commuting time is the second-largest waking activity traded for sleep after working hours and that short-duration sleepers engaged in more travel than normal-duration sleepers (Basner et al., 2007, 2014). Furthermore, Petrov reported that individuals with moderate commuting times exhibit greater variability in sleep duration and lower day-to-day sleep stability than those with short commuting times (Petrov et al., 2018) According to the 2021 OECD report, Japan has the shortest average sleep duration among developed countries, at 7 h and 22 min. Additionally, the 2020 NHK National Time Use Survey in Japan found that individuals in their 40s and 50s had the shortest weekday sleep durations across all age groups, averaging <7 h per night (men: 40s, 6 h 58 m; 50s, 6 h 54 m; women: 40s, 6 h 53 m; 50s, 6 h 36 m). Similarly, this age group also had longer weekday commuting times (round trip) compared to the other age groups (men: 40s, 88 min; 50s, 89 min; women: 40s, 79 min; 50s, 68 min).Poor sleep results in increased risks of morbidity and mortality (Crowley, 2011). Long commuting distances and durations have

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been reported to lead to physical inactivity, overweight, and sleep disorders (Raza et al., 2021); hypertension (Walsleben et al., 1999); chronic stress and fatigue (Kageyama et al., 1997); negative health outcomes (Hansson et al., 2011); self-reported musculoskeletal pain, pseudo-neurological symptoms, and gastrointestinal disorders (Urhonen et al., 2016); low life satisfaction and obesity (Sha et al., 2019a); and reduced subjective well-being and overall health (Costal et al., 1988; Lorenz, 2018; Sha et al., 2019b; Tao et al., 2023). Ryu et al. also reported that long commutes of at least 120 min per day (60 min one way) and working hours of 52 h or 41–52 h per week were associated with a higher risk of insomnia symptoms (Ryu et al., 2024; Ryu et al., 2024). As shown above, long commuting times reduce sleep duration and increase the risk of health issues such as hypertension, stress, fatigue, and obesity, as well as mortality. In that case, would living closer to the workplace in central urban areas be more advantageous for sleep health?

However conversely, some studies have found that residing in housing near workplaces in urban areas is associated with poor sleep outcomes due to unfavorable living environments. Several international studies have highlighted how housing location is related to sleep quality in various respects. Lin et al. showed that participants with higher daytime personal noise exposure had poorer nighttime sleep quality, particularly a lower proportion of slow-wave sleep and reduced sleep efficiency (Lin et al., 2018; Lin et al., 2018). Similarly, Hunter et al. provided evidence that environmental factors, such as aircraft, road, and railway noise pollution, air pollution from ozone and particulate matter (PM10), and, to some extent, ambient light, disrupted residents' sleep onset, sleep maintenance, and restful awakening. In contrast, neighborhood characteristics, such as green spaces, walkability, safety, built environment quality, and social factors (e.g., order in the neighborhood and trust in neighbors) significantly influenced sleep outcomes (Hunter and Hayden, 2018; Hunter and Hayden, 2018). Liu et al. reported a positive association between the adverse effects of noise pollution, light pollution, secondhand smoke, air pollution exposure, and various sleep problems (Liu et al., 2021). Similarly, Adjaye-Gbewonyo et al. reported that the presence of relaxing spaces and pedestrian accessibility was associated with improved sleep health, while unsafe walking conditions were linked to poorer sleep health (Adjaye-Gbewonyo et al., 2023) Bottino et al. suggested that living in more urbanized environments may be associated with reduced infant sleep duration (Bottino et al., 2012). Hill et al. observed that neighborhood disturbances were related to lower sleep quality and increased psychological distress, and that the positive association between neighborhood disorder and psychological distress was partially mediated and amplified by reduced sleep quality (Hill et al., 2009). Additionally, Johnson et al. reported that higher perceived neighborhood safety was associated with 18.4 % lower odds of daytime sleepiness (Johnson et al., 2015). Similarly, DeSantis et al. reported an association between perceived safety, neighborhood satisfaction, and sleep (DeSantis et al., 2016) Jang et al. reported that people accept long commutes for the benefit of a high-quality neighborhood (Jang and Ko, 2019). According to a survey by Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), first-time homebuyers are predominantly in their 30s across all housing types, and it is common for them to remain in the same residence for the rest of their lives (Annual Housing Market Trends Survey Report, 2023; Infrastructure, Transport, and Tourism (MLIT) Ministry of Land, 2024) These data indicate that the housing choices made by commuters in this age group may have a lasting impact on their sleep quality.

As described above, urban environmental disturbances—such as noise, air pollution, light pollution, and a lack of trust in the community—have been shown to contribute to reduced sleep health, including symptoms of insomnia and daytime sleepiness. In other words, both long commuting times associated with suburban living and environmental stressors associated with urban living are linked to poorer sleep health. In other words, while urban living offers shorter commuting times, suburban residences with superior environmental quality may provide sleep-related advantages. Although various factors determine the residential environment, studies have reported that residents living in cramped housing or those dissatisfied with their living environment tend to have shorter sleep durations (Gabet et al., 2024; Johnson et al., 2021), whereas those living in low-density areas or low-rise housing tend to sleep longer. As such, household crowding is associated with reduced sleep duration, indicating that the size of a dwelling is one of the key indicators representing the quality of the residential environment. The effects of external environmental disturbances such as noise and light pollution on residents can be either mitigated or exacerbated by the size of the dwelling and the number of rooms. Moreover, due to the balance of housing supply and demand, it is well known that dwellings in urban areas tend to be more expensive, smaller, and higher in density, whereas those in suburban areas tend to be more affordable, larger, and lower in density. (Infrastructure, Transport, and Tourism (MLIT) Ministry of Land, 2024).

Considering the residential conditions of commuters, sleep is not a simple monotonic function of commuting time. Research that reevaluates existing evidence suggesting that shorter commuting times are inherently beneficial for sleep while simultaneously considering both housing location and size is lacking. The studies reviewed above provide only partial insights, leaving a gap in the evidence needed to address both individual and societal needs for sleep-friendly housing selection and supply.

## 2. The present study

This study investigated the relationship among commuting time, residential floor area—assumed to reflect overall living environment quality, including disturbances from cohabitants and external sources during sleep—and sleep outcomes, specifically insomnia and daytime sleepiness, among middle-aged (40–50 years) employed individuals commuting to workplaces in Tokyo, Japan. Using survey data from a large-scale panel, we analyzed responses related to sleep, housing conditions, and demographic and socioeconomic factors to identify the trade-off between housing location and size. Our objectives were to determine which demographic and socioeconomic characteristics predict sleep outcomes, whether housing location and size independently predict sleep outcomes, and whether any observed associations are attenuated by demographic or socioeconomic factors. This objective consists of the following three sub-objectives.

### 2.1. Objective 1

To examine the associations between the presence of insomnia and excessive daytime sleepiness and categories of sleep duration, commute time, residential floor area, and other sociodemographic characteristics using separate bivariate logistic regression models with unadjusted odds ratios.

### 2.2. Objective 2

To explore the potential causal relationships between the presence of insomnia and excessive daytime sleepiness and commute time and residential floor area, by applying bivariate logistic regression models with confounding factors controlled through propensity score matching.

### 2.3. Objective 3

To evaluate the contributions of commute time and residential floor area to AIS and ESS scores using nested multivariate linear regression models.

## 3. Methods

### 3.1. Study design and data collection

We conducted a cross-sectional study using survey data from Rakuten Insight, Inc., to examine the data of employed adults aged 40–59 years residing in the Tokyo metropolitan area and commuting to workplaces in Tokyo at least 5 days per week. Rakuten Insight, Inc. is an internet research service company that operates the largest consumer panels in Japan, linked with purchasing, web search, and location data accumulated by the Rakuten Group. Participants were selected via stratified random sampling from the Rakuten Insight panel of over 2.2 million members, including 1000 residents from Tokyo and 1000 from the surrounding metropolitan area. A total of 2000 participants completed the online survey in September 2024. Because commuting modes are assumed to influence factors such as physical activity and stress levels, which may in turn affect sleep health, this study limited the analysis to participants who commute by walking or public transportation. Only individuals with complete data for all the analytical variables were included.

In Objective 1, unadjusted odds ratios were calculated for insomnia (AIS $\geq$6) and excessive daytime sleepiness (ESS $\geq$10) across categories of sleep duration, commute time, gross floor area (GFA) of home, age, sex, marital status, education, and family income. The AIS was designed according to the diagnostic criteria for insomnia in the International Classification of Diseases (ICD-10). For Objective 2, propensity score matching (PSM) was conducted to reduce confounding when assessing the associations between the outcome variables and two key exposures: commuting time and residential floor area.

To do so, two separate sets of PSM analyses were performed:

(1) For evaluating the effect of commuting time, participants were divided into two groups based on commuting time: over 50 min vs. 50 min or less, based on the average weekday commuting time in the Tokyo metropolitan area (NHK, 2020). These groups were matched on the following covariates: residential floor area, age, sex, marital status, education level, and household income.
(2) For evaluating the effect of residential floor area, participants were grouped as having less than 95 $m^2$ vs. 95 $m^2$ or more, based on the MLIT's urban residential floor area standard for a four-person household (Ministry of Land, 2011). These groups were matched on commuting time, age, sex, marital status, education level, and household income.

After matching, bivariate logistic regression models were used to estimate unadjusted odds ratios for two binary outcome variables: insomnia (AIS $\geq$6) and excessive daytime sleepiness (ESS $\geq$10). As part of Objective 1, we first estimated unadjusted odds ratios to examine the crude associations between sleep outcomes and individual predictors. In Objective 2, we applied propensity score matching (PSM) to reduce potential confounding and re-estimated the associations using the matched samples. For Objective 3, nested multivariate linear regression models were used to examine the relationships among commuting time, residential floor area, and AIS and ESS scores. Participation in this survey was voluntary, and informed consent was obtained from all participants prior to data collection by Rakuten Insight, Inc. Since the survey was conducted anonymously, no personally identifiable information was collected. This study was approved by the Research Ethics Committee of the Faculty of Human Life and Science, Osaka Metropolitan University (Approval No. 2024–44 on September 18, 2024).

### 3.2. Procedures

The home and workplace postal codes of participants commuting by walking or public transportation were converted to latitude and longitude using the "Block-Level Location Reference Information" dataset from the MLIT (Infrastructure, Transport and Tourism (MLIT) Ministry of Land, 2024). The shortest one-way commuting time, assuming arrival at the workplace at 9:00 a.m., was calculated using a route search service API and Geographic Information System. The participants also responded to the eight-item AIS and the eight-item ESS using a four-point scale. Additionally, participants provided information on residential floor area as well as

demographic and socioeconomic characteristics.

## 4. Measures

We assumed the outcome, predictors, and covariates according to the measured values.

### 4.1. Outcomes

The AIS and ESS scores were used as outcome variables. Insomnia symptoms were assessed using the AIS, a validated 8-item questionnaire rated on a 0–3 scale. In this sample, the AIS showed excellent internal consistency (Cronbach's $\alpha = 0.91$).

Daytime sleepiness was measured using the ESS, a widely used 8-item questionnaire rated on a 0–3 scale. In this sample, the ESS showed high internal consistency (Cronbach's $\alpha = 0.89$).

Cutoff values were set at AIS $\geq$6 for insomnia and ESS $\geq$10 for excessive daytime sleepiness.

### 4.2. Predictors

Commute time and residential floor area were treated as predictor variables.

### 4.3. Covariates

Factors presumed to confound the associations between commuting time or residential floor area and the AIS or ESS scores were adjusted for in the statistical analysis. The presumed confounders included age (40s and 50s), sex (male and female), marital status (single, married), highest educational attainment (Junior High School, High School, Vocational School, Junior/Technical College, University, Graduate School, Other), and household income categories (<¥3,000,000; ¥3,000,000–5,000,000; ¥5,000,000–7,000,000; ¥7,000,000–10,000,000; and >¥10, 000, 000). Age was collected as a continuous variable (in years). As noted earlier, weekday sleep duration is shortest among individuals in their 40s and 50s across all age groups (2020 NHK National Time Use Survey in Japan), and there is a general trend of declining sleep health with increasing age. Moreover, the proportion of employed individuals decreases significantly among those aged 60 and older. For these reasons, the analysis focused on participants in their 40s and 50s.

### 4.4. Statistical analysis

An a priori power analysis was conducted using G × Power 3.1. Assuming a significance level of $\alpha = 0.05$, statistical power of 0.90, and a medium effect size ($f^2 = 0.15$) with seven predictors, the minimum required sample size for linear regression was estimated to be 130. The sample size in this study exceeded this threshold. Furthermore, the assumptions of normality and homoscedasticity required for linear regression were considered. The skewness and kurtosis values for the dependent variables did not exceed ±1 (AIS: skewness = 0.79, kurtosis = 0.33; ESS: skewness = 0.70, kurtosis = 0.46), suggesting approximate normality of residuals. In addition to evaluating skewness and kurtosis values, visual inspections using Q-Q plots were performed (Fig SM1 and SM2. in Supplementary materials). These plots did not reveal significant deviations from normality or homoscedasticity, supporting the assumptions of linear regression (Hair et al., 2010). For Objective 1, descriptive analysis was used to determine the prevalence of suspected insomnia (AIS $\geq$6) and excessive daytime sleepiness (ESS $\geq$10) and to describe the unadjusted odds ratio of other variables. Separate bivariate logistic regression models were constructed to determine which demographic and socioeconomic factors predicted insomnia and daytime sleepiness. For Objective 2, propensity score matching (PSM) was conducted to control for confounding when estimating the association between commuting time or residential floor area and sleep-related outcomes (AIS and ESS). Two separate sets of bivariate logistic regression models were applied after matching to evaluate the unadjusted associations. The binary outcome variables were insomnia (AIS $\geq$6) and excessive daytime sleepiness (ESS $\geq$10).

The treatment variables were:

Commuting time >50 min (treatment group) vs. $\leq$ 50 min (control group), based on the average weekday commuting time in the Tokyo metropolitan area (NHK, 2020), and.

Residential floor area <95 $m^2$ (treatment group) vs. $\geq$ 95 $m^2$ (control group), based on the MLIT's urban housing standard for a four-person household (Ministry of Land, 2011).

The covariates used to calculate the propensity scores included the alternate treatment variable (either commuting time or floor area), as well as age, sex, marital status, educational attainment, and household income category. Categorical covariates were converted into dummy variables using a fully disjunctive (one-hot encoded) format, with a reference category defined for each (e.g., "married" for marital status, "male" for sex). After matching, these covariates were not included in the logistic regression models, as balance was achieved during the matching process. For Objective 3, two sets of nested multivariate linear regression models were used to assess the contributions of commuting time and residential floor area to AIS and ESS scores. In the nested models, Model 1 examined the bivariate correlation between commuting time and AIS/ESS. Model 2 incorporated residential floor area. Model 3 further adjusted for demographic and socioeconomic covariates (age, sex, marital status, educational attainment, and household income category). Finally, multiple linear regression analyses were conducted to examine how commuting time and residential floor area contributed to the variation in continuous AIS and ESS scores. All analyses were conducted using JMP Pro, Version 18.0.2 (SAS Institute Inc., Cary, NC, 1989–2025).

## 5. Results

The final valid sample consisted of 1757 participants commuting by walking or public transportation, after excluding extreme responses (Fig. 1). In the analysis for Objective 1, suspected insomnia (AIS ≥6) was reported by 911 participants, while excessive daytime sleepiness (ESS ≥10) was reported by 499 participants (Table 1). Sleep duration of 7–9 h was significantly associated with lower odds of both AIS and ESS (AIS: unadjusted OR 0.13, 95 % confidence interval [CI], 0.088–0.18, $p < 0.0001$; ESS: 0.19, 0.13–0.27; $p < 0.0001$). Participants in their 50s had significantly lower odds of AIS and ESS than those in their 40s (AIS: 0.80, 0.66–0.97, $p = 0.020$; ESS: 0.75, 0.61–0.92, $p = 0.0072$). Higher household income was associated with lower odds of AIS and ESS, though not at a statistically significant level (>¥10, 000, 000 – AIS: 0.70, 0.47–1.04, $p = 0.080$; ESS: 0.69, 0.45–1.06, $p = 0.092$). Longer commuting time was associated with higher odds of AIS and ESS, with commutes exceeding 100 min leading to a statistically significant increase (AIS: 1.61, 1.03–2.50, $p = 0.033$; ESS: 1.70, 1.07–2.70, $p = 0.025$). Larger residential floor area was associated with lower odds of AIS, and floor areas exceeding 115 $m^2$ were significantly protective (AIS: 0.66, 0.45–0.95, $p = 0.027$).

In the analysis for Objective 2, To enhance comparability and reduce confounding, participants were matched using propensity score matching before each bivariate logistic regression analysis. For each treatment variable (commuting time or residential floor area), logistic models were estimated using matched samples: first, controlling only for the alternate treatment variable, and second, controlling additionally for sociodemographic covariates (age, sex, marital status, education, and household income). Full matching numbers and variable combinations are provided in the Supplementary materials (Fig SM3-SM6), and the results of each logistic regression model (PSM 1–4) are summarized in Table 2. (Table 2). When the commuting time was the treatment variable, 1382 participants were matched on residential floor area (Supplementary Material Figs. 1 and 2) and 1352 participants were matched on residential floor area, age, sex, marital status, education, and household income (Supplementary Material Figs. 3 and 4). When the

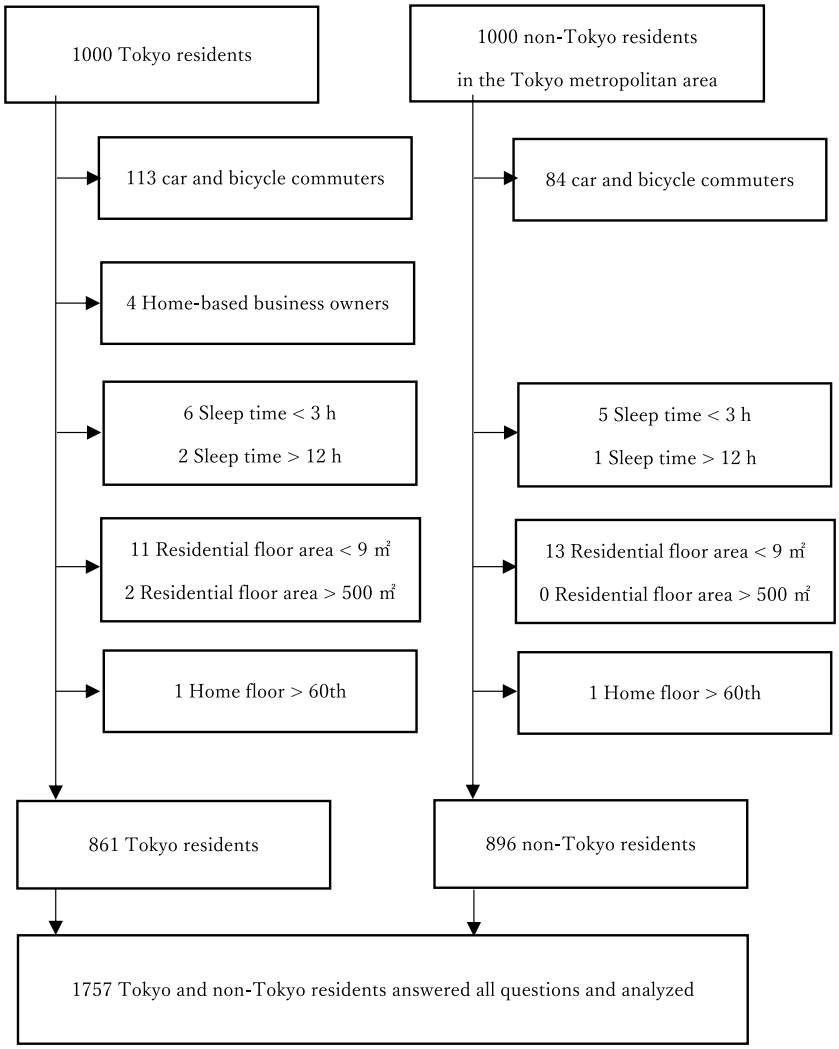
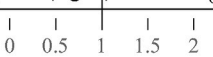
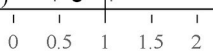



**Fig. 1.** Consort diagram of participants included in the analysis.

**Table 1**
Separate bivariate logistic regression models showing the associations between demographic/socioeconomic factors and (1) insomnia (AIS ≥6) and (2) excessive daytime sleepiness (ESS ≥10). Unadjusted odds ratios (ORs) with 95 % confidence intervals (CIs) are presented for each category. The reference group for each variable is indicated as "1 (reference)". Black dots represent point estimates of ORs, and horizontal lines indicate 95 % CIs. ORs greater than 1 indicate a higher odds of the outcome (AIS ≥6 or ESS ≥10), whereas ORs less than 1 indicate lower odds relative to the reference category.

| | (1) AIS ≥ 6<br>n = 911/1757 (51.85%) | | (2) ESS ≥ 10<br>n = 499/1757 (28.40%) | |
|---|---|---|---|---|
| | Unadjusted odds ratio (95% confidence interval) | p value | Unadjusted odds ratio (95% confidence interval) | p value |
| **AIS** | | | | |
| <6 | - | | 1(reference) | |
| >6 | - | | 4.25(3.37–5.37) | <0.0001 |
| **ESS** | | | | |
| <10 | 1(reference) | | - | |
| >10 | 4.25(3.37–5.37) | <0.0001 | - | |
| **Sleep duration** | | | | |
| <5 h | 1(reference) | | 1(reference) | |
| 5 h – 7 h | 0.32(0.23–0.45) | <0.0001 | 0.46(0.35–0.62 | <0.0001 |
| 7 h – 9 h | 0.13(0.088–0.18) | <0.0001 | 0.19(0.13–0.27) | <0.0001 |
| >9 h | 0.32(0.10–1.01) | 0.052 | 0.50(0.15–1.65) | 0.25 |
| **Commute time (mins)** | | | | |
| <20 mins | 1(reference) | | 1(reference) | |
| 20 mins–40 mins | 1.19(0.84–1.68) | 0.33 | 0.86(0.57–1.30) | 0.47 |
| 40 mins–60 mins | 1.22(0.92–1.61) | 0.16 | 1.24(0.90–1.70) | 0.19 |
| 60 mins–8 0mins | 1.17(0.89–1.54) | 0.27 | 1.36(1.00–1.86) | 0.05 |
| 80 mins–100 mins | 1.25(0.92–1.72) | 0.16 | 1.44(1.02–2.04) | 0.04 |
| >100 mins | 1.61(1.04–2.50) | 0.033 | 1.70(1.07–2.70) | 0.025 |
| **Residential floor area (sqm)** | | | | |
| <35sqm | 1(reference) | | 1(reference) | |
| 35 sqm–55 sqm | 0.98(0.71–1.33) | 0.88 | 0.95(0.67–1.34) | 0.77 |
| 55 sqm–75 sqm | 0.86(0.65–1.14) | 0.30 | 0.97(0.72–1.32) | 0.87 |
| 75 sqm–95 sqm | 0.89(0.65–1.21) | 0.46 | 0.90(0.64–1.27) | 0.56 |
| 95 sqm–115 sqm | 0.73(0.52–1.02) | 0.07 | 0.80(0.55–1.18) | 0.27 |
| >115 sqm | 0.66(0.45–0.95) | 0.03 | 1.07(0.72–1.60) | 0.73 |
| **Age** | | | | |
| 40s | 1(reference) | | 1(reference) | |
| 50s | 0.80(0.66–0.97) | 0.020 | 0.75(0.61–0.92) | 0.0072 |
| **Sex** | | | | |
| Male (n=1407) | 1(reference) | | 1(reference) | |
| Female (n=353) | 1.14(0.90–1.44) | 0.28 | 0.94(0.72–1.22) | 0.63 |
| **Marital status** | | | | |
| Married | 1(reference) | | 1(reference) | |
| Single | 1.13(0.93–1.37) | 0.21 | 1.14(0.92–1.40) | 0.23 |
| **Education** | | | | |
| Junior High School | 1(reference) | | 1(reference) | |
| High School | 1.19(0.36–3.99) | 0.78 | 1.32(0.34–5.09) | 0.69 |
| Vocational School | 1.23(0.37–4.14) | 0.74 | 0.87(0.22–3.40) | 0.85 |
| Junior/Technical College | 2.02(0.57–7.12) | 0.27 | 1.02(0.25–4.14) | 0.98 |
| University | 1.31(0.40–4.34) | 0.65 | 1.04(0.27–3.95) | 0.95 |
| Graduate school | 1.01(0.29–3.53) | 0.98 | 1.14(0.28–4.57) | 0.86 |
| Other | 1.92(0.38–9.80) | 0.43 | 0.48(0.065–3.61) | 0.48 |
| **Family income/year** | | | | |
| <¥3,000,000 | 1(reference) | | 1(reference) | |
| ¥3,000,000 - ¥5,000,000 | 0.96(0.64–1.46) | 0.86 | 1.09(0.70–1.71) | 0.69 |
| ¥5,000,000 - ¥7,000,000 | 0.85(0.56–1.28) | 0.44 | 0.96(0.61–1.49) | 0.85 |
| ¥7,000,000 -¥10,000,000 | 0.79(0.53–1.18) | 0.25 | 0.98(0.64–1.52) | 0.94 |
| >¥10,000,000 | 0.70(0.47–1.04) | 0.080 | 0.69(0.45–1.06) | 0.092 |




Note: Adjusted $R^2$ and area under the ROC curve (AUC) are shown in Supplementary materials (Table SM1.)

**Table 2**
Bivariable logistic regression model using propensity score matching, with commuting time >50 min and residential floor area <95 sqm as the treatment variables, AIS ≥6 and ESS ≥10 as the response variables, and demographic and socioeconomic factors as the covariates.

| Propensity Score Matching (PSM) | Before PSM No matching | | PSM1 Matched on Residential floor area | | PSM2 Matched on Residential floor area, Age, Sex, Marital status, Education and Family income | |
|---|---|---|---|---|---|---|
| n of Treatment group (Commute time >50 min) | 976 | | 691 | | 676 | |
| n of Control group (Commute time ≤50 min) | 781 | | 691 | | 676 | |
| Standardized mean difference (SMD) | 0.39 | | 0.0011 | | 0.0035 | |
| **Bivariable logistic regression model** | | | | | | |
| AIS ≥6 | OR (95 %CI) | p value | OR (95 %CI) | p value | OR (95 %CI) | p value |
| Commute time >50 min | 1.26 (1.04–1.52) | 0.017 | 1.38 (1.12–1.71) | 0.0026 | 1.35 (1.09–1.67) | 0.0065 |
| ESS ≥10 | | | | | | |
| Commute time >50 min | 1.34 (1.09–1.66) | 0.0061 | 1.32 (1.05–1.68) | 0.02 | 1.22 (0.96–1.56) | 0.099 |

| **Propensity Score Matching (PSM)** | Before PSM No matching | | PSM3 Matched on Commute time | | PSM4 Matched on Commute time, Age, Sex, Marital status, Education and Family income | |
|---|---|---|---|---|---|---|
| n of Treatment group (Residential floor area <95 sqm) | 1381 | | 374 | | 371 | |
| n of Control group (Residential floor area ≥95 sqm) | 376 | | 374 | | 371 | |
| Standardized mean difference (SMD) | 0.39 | | 0.00051 | | 0.00081 | |
| **Bivariable logistic regression model** | | | | | | |
| AIS ≥6 | OR (95 %CI) | p value | OR (95 %CI) | p value | OR (95 %CI) | p value |
| Residential floor area <95 sqm | 1.33 (1.06–1.67) | 0.015 | 1.34 (1.00–1.78) | 0.048 | 1.44 (1.08–1.93) | 0.013 |
| ESS ≥10 | | | | | | |
| Residential floor area <95 sqm | 1.05 (0.81–1.35) | 0.72 | 1.05 (0.77–1.45) | 0.74 | 1.01 (0.74–1.40) | 0.93 |

Note: Matching method: Nearest neighbor (1:1), Caliper = 0.2 SD, No replacement.
Adjusted $R^2$, area under the ROC curve (AUC) and Akaike's information criterion (AIC) are shown in Supplementary materials (Table SM2.).

**Table 3**
Nested multivariate linear regression models testing commute time and residential floor area independently predicted AIS (n = 1757).

| | Model1 | **p value** | Model2 | **p value** | Model3 | **p value** |
|---|---|---|---|---|---|---|
| | **Coefficient (95 % confidence interval)** | | **Coefficient** | | **Coefficient** | |
| **Intercept** | **5.76** | < **0.0001** | **6.50** | < **0.0001** | **7.96** | < **0.0001** |
| **Commute time (mins)** | 0.0085 (0.0017–0.015) | 0.014 | 0.011 (0.0045–0.018) | 0.0011 | 0.012 (0.0051–0.019) | 0.0007 |
| **Residential floor area (sqm)** | | | −0.013 (-0.019–0.0072) | <0.0001 | −0.0088 (-0.015–0.0025) | 0.0062 |
| **Age** | | | | | | |
| 40s | | | | | 0 | |
| 50s | | | | | −0.45 (-0.92–0.02) | 0.061 |
| **Sex** | | | | | | |
| Male (n = 1407) | | | | | 0 | |
| Female (n = 353) | | | | | −0.20 (-0.83–0.43) | 0.53 |
| **Marital status** | | | | | | |
| Married | | | | | 0 | |
| Single | | | | | 0.23 (-0.31–0.77) | 0.40 |
| **Education** | | | | | | |
| Junior High School | | | | | 0 | |
| High School | | | | | −1.10 (-3.96–1.76) | 0.45 |
| Vocational School | | | | | −0.37 (-3.24–2.51) | 0.80 |
| Junior/Technical College | | | | | 0.93 (-2.06–3.93) | 0.54 |
| University | | | | | −0.63 (-3.46–2.20) | 0.66 |
| Graduate school | | | | | −1.03 (-3.98–1.93) | 0.50 |
| Other | | | | | −0.04 (-3.86–3.78) | 0.98 |
| **Family income/year** | | | | | | |
| <\3,000,000 | | | | | 0 | |
| \3,000,000-\5,000,000 | | | | | −0.45 (-1.43–0.53) | 0.37 |
| \5,000,000-\7,000,000 | | | | | −1.11 (-2.10–0.12) | 0.028 |
| \7,000,000-\10,000,000 | | | | | −1.08 (-2.08–0.08) | 0.035 |
| >\10,000,000 | | | | | −1.28 (-2.30–0.27) | 0.013 |

Note: AIS: Athens Insomnia Scale.
Adjusted $R^2$ = 0.0028 (Model1), 0.013 (Model2), 0.035 (Model3), $\Delta R^2$ = 0.010 (Model 2 – Model 1), 0.022 (Model 3 – Model 2).
AIC = 10497.62 (Model1), 10480.35 (Model2), 10475.41 (Model3).

**Table 4**
Nested multivariate linear regression models testing commute time and residential floor area independently predicted ESS (n = 1757).

| | Model1 | p value | Model2 | p value | Model3 | p value |
|---|---|---|---|---|---|---|
| | **Coefficient** | | **Coefficient** | | **Coefficient** | |
| **Intercept** | **6.65** | **< 0.0001** | **6.91** | **< 0.0001** | **6.42** | **0.0001** |
| **Commute time (mins)** | 0.016 (0.0087–0.023) | <0.0001 | 0.017 (0.0096–0.024) | <0.0001 | 0.016 (0.0089–0.024) | <0.0001 |
| **Residential floor area (sqm)** | | | −0.0047 (-0.011–0.0016) | 0.14 | −0.0012 (-0.008–0.0057) | 0.74 |
| **Age** | | | | | | |
| 40s | | | | | 0 | |
| 50s | | | | | −0.62 (-1.13–0.12) | 0.016 |
| **Sex** | | | | | | |
| Male (n = 1407) | | | | | 0 | |
| Female (n = 353) | | | | | −0.54 (-1.21–0.14) | 0.12 |
| **Marital status** | | | | | | |
| Married | | | | | 0 | |
| Single | | | | | 0.12 (-0.47–0.70) | 0.70 |
| **Education** | | | | | | |
| Junior High School | | | | | 0 | |
| High School | | | | | 2.22 (-0.87–5.31) | 0.16 |
| Vocational School | | | | | 1.18 (-1.92–4.28) | 0.46 |
| Junior/Technical College | | | | | 1.97 (-1.26–5.20) | 0.23 |
| University | | | | | 1.33 (-1.72–4.38) | 0.39 |
| Graduate school | | | | | 1.93 (-1.26–5.12) | 0.24 |
| Other | | | | | −0.43 (-4.55–3.69) | 0.84 |
| **Family income/year** | | | | | | |
| <\3,000,000 | | | | | 0 | |
| \3,000,000-\5,000,000 | | | | | −0.53 (-1.59–0.53) | 0.32 |
| \5,000,000-\7,000,000 | | | | | −0.60 (-1.67–0.46) | 0.27 |
| \7,000,000-\10,000,000 | | | | | −0.87 (-1.95–0.22) | 0.12 |
| >\10,000,000 | | | | | −1.14 (-2.24–0.04) | 0.041 |

Note: ESS: Epworth Sleepiness Scale.
Adjusted $R^2$ = 0.010 (Model1), 0.012 (Model2), 0.031 (Model3), $\Delta R^2$ = 0.002 (Model 2 – Model 1), 0.019 (Model 3 – Model 2).
AIC = 10741.57 (Model1), 10741.43 (Model2), 10742.92 (Model3).

residential floor area was the treatment variable, 748 participants were matched on commuting time (Supplementary Material Figs. 5 and 6), and 742 participants were matched on commuting time, age, sex, marital status, education, and household income (Supplementary Material Figs. 7 and 8). Bivariate logistic regression analyses revealed that participants with commuting times >50 min had higher odds of high AIS and ESS scores (Model 3: AIS OR, 1.35, 1.09–1.67, p = 0.0065; ESS OR, 1.22, 0.96–1.56, p = 0.099). Additionally, participants with residential floor area <95 $m^2$ had higher odds of high AIS scores (Model 5: 1.44, 1.08–1.92, p = 0.013). As a result of matching on covariates, the odds ratios for AIS ≥6 were higher in the group with commute times over 50 min and in the group with residential floor area below 95 sqm, compared to the unadjusted estimates.

In the analysis for Objective 3, we examined whether commuting time and residential floor area independently predicted AIS and ESS scores and whether these associations were attenuated by demographic and socioeconomic factors (Table 4). Fully adjusted models demonstrated that longer commuting times and smaller residential floor areas were significant independent predictors of higher AIS scores (commuting time: 95 % CI, 0.0051–0.019, p = 0.0007; residential floor area: 0.015 to −0.0025, p = 0.0062). Similarly, a longer commuting time independently predicted higher ESS scores (95 % CI, 0.0090–0.024, p < 0.0001). The effects of commuting time and residential floor area persisted, even after adjusting for demographic and socioeconomic confounders. In addition, to examine whether the effect of commuting time on sleep outcomes was moderated by residential floor area, an interaction term between commuting time and residential floor area (centered) was included in the regression models. The interaction term was not statistically significant in either model (AIS: p = 0.45; ESS: p = 0.78), indicating no significant moderating effect. Using the Model 3 regression equation, we explored a theoretical trade-off between commuting time and residential floor area in relation to insomnia risk. Specifically, by setting the predicted AIS score to the cutoff value of 6, and solving the equation for different commuting times and floor areas, we identified combinations that would yield similar outcome levels. For instance, for a married male in his 40s with a university degree, household income of ¥5–7 million, and a home size of 95 $m^2$, an estimated commuting time of approximately 52.2 min would correspond to reaching the AIS cutoff. This reflects a model-based, mathematical equivalence rather than a direct empirical interaction. (AIS = 6.2118 + 0.01204 × commuting time − 0.00884 × residential floor area). The intercept and covariate terms used in the prediction (6.2118) were derived by combining the baseline constant and the coefficients for university education and income (both coded as 1), as shown in Table 3. While the estimated commuting time of 52.2 min corresponds to the AIS cutoff score of 6, the 95 % prediction interval for individual AIS scores was wide (approximately [–3.4, 15.4]) due to the large residual variance in the model.

## 6. Discussion

Commuting time was a significant predictor of insomnia symptoms and excessive daytime sleepiness, whereas a trade-off

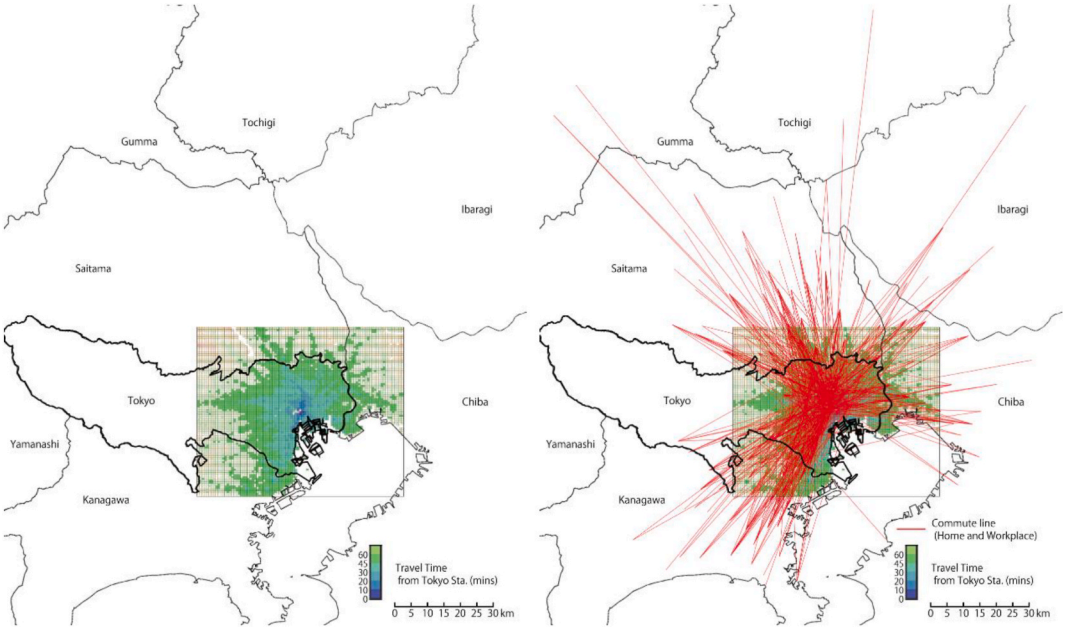



**Fig. 2.** Area based on travel time from Tokyo Station and Commute line of home and workplace
Based on "RESAS (Regional Economic Analysis System) - Population Mesh -" https://resas.go.jp/traveltime-mesh/#/map/13/13101/2/5/533946113/a/8/10.831159468211348/35.70168615321769/139.8 330909698959/13101055001009/0, created by the authors.

relationship was observed between commuting time and residential floor area in predicting insomnia symptoms. These effects remained significant even after adjusting for the presumed demographic and socioeconomic confounders.

Sleep duration of 7–9 h had the lowest odds ratios for both insomnia symptoms and daytime sleepiness. In contrast, sleep exceeding 9 h showed odds ratios comparable to or higher than those of 5–7 h. This finding aligns with The National Sleep Foundation's guideline and many previous studies recommending 7–9 h of sleep for adults (Allen et al., 2016; Hirshkowitz et al., 2015; Pelayo, 2017; Allen et al., 2016; Hirshkowitz et al., 2015; Pelayo, 2017).

Higher household income was an independent predictor of lower odds of insomnia and daytime sleepiness. Similarly, bivariate logistic regression analysis after propensity score matching showed that individuals with commuting times exceeding the Tokyo metropolitan average of 50 min had higher odds of AIS and ESS prevalence, while those with residential floor areas below the urban-induced standard of 95 $m^2$ had higher odds of AIS prevalence (Table 2, Supplementary Material Fig. 1–8). These findings suggest that independently, shorter-than-average commuting times and residential floor areas exceeding the standard may predict lower risks of insomnia symptoms and daytime sleepiness. In line with previous findings on sex difference, namely that long commuting times have a greater adverse impact on women's mental health (Künn-Nelen, 2016; Roberts et al., 2011; Shen et al., 2021; Künn-Nelen, 2016; Roberts et al., 2011; Shen et al., 2021), the odds ratio for insomnia was higher among women in this study (unadjusted OR, 1.14, 95 % CI, 0.90–1.44); however, the difference was not statistically significant.

According to the AIS score prediction model, for an average married male in his 40s with a university degree and a household income of ¥5–7 million, a residential floor area of 95 $m^2$ corresponded to reaching the AIS cutoff at a commuting time of 52.2 min. This finding corresponds to the typical situation in the metropolitan area, where a standard two- or three-story wooden house is located approximately 25 km from the city center (Fig. 2). However, as noted above, the wide 95 % prediction interval for the AIS score highlights the limitations of using the model for individual-level predictions. The results should therefore be interpreted as indicative of general trends rather than as precise thresholds. Given that the average commuting time in the Tokyo metropolitan area is 100 min per day (SD 66 min/day, mean one-way 50 min), according to the NHK National Time Use Survey (2020), this relationship aligns with actual housing choices. This finding reinforces previous evidence that commuting times exceeding 60 min are associated with increased sympathetic nervous system activity, poor self-rated health, and lower life satisfaction (Hansson et al., 2011; Hori et al., 2020; Ingenfeld et al., 2019; Sha et al., 2019a; Urhonen et al., 2016). Additionally, our findings suggest that a larger residential floor area mitigates the adverse effects of long commuting times on sleep, further supporting the existing evidence that commuters maximize their utility based on life satisfaction and matches between home and workplace when selecting their residence and workplace (Jang and Ko, 2019; Levine, 1998; Morris and Zhou, 2018) However, it should be noted that no statistically significant association was found between excessive daytime sleepiness and residential floor area. These findings are limited to the relationship between commuting time, residential floor area, and insomnia, and further research is needed to explore the association between daytime sleepiness and residential floor area.

However, considering that the proportion of commuters with commuting times exceeding 60 min is lower in the United States (8.9 % in 2023 (United States Census Bureau, 2023) and the United Kingdom (12 % in 2023 (National Travel Survey statistics, 2023) than in

Japan's Tokyo metropolitan area (31.6 % in 2008 (Ministry of Internal Affairs and Communications, 2019), applying findings from Western studies to the Japanese context may lead to an overestimation.

Morris et al. reported that loNational Travel Survey statistics, 2023nger commutes are associated with higher wages for workers and with suburban areas, as opposed to principal city living and higher homeownership rates (Morris and Zhou, 2018) Similarly, Tokyo metropolitan commuters tend to sacrifice commuting time to obtain higher wages associated with high-value jobs in the city center; however, when this trade-off surpasses a threshold, sleep outcomes deteriorate. By integrating previous independent findings that shorter commuting times benefit sleep and that poorer residential environments impair sleep (Billings et al., 2020; DeSantis et al., 2016; Hunter and Hayden, 2018; Johnson et al., 2015; Lin et al., 2018; Liu et al., 2021), our study provides insights into housing selection and policy. Similarly, Morris et al. suggested that the lack of an association between commuting time and life satisfaction may be due to the net benefits and costs of commuting being nearly equal regardless of commute duration, or because the burden and benefits of commuting are not strong enough to significantly impact broad constructs like life satisfaction. They also proposed that individuals may be making rational decisions to maximize utility when choosing their residence and workplace. The complementary relationship between commuting time and residential environment in relation to sleep observed in this study may be explained by those concept of utility maximization.

This study has both strengths and limitations. Given the challenges of conducting randomized controlled trials in this field, propensity score matching and adjustments for presumed confounders have strengthened the evidence. The use of well-validated, easy-to-administer sleep-related scales such as the AIS and ESS as well as data collection linked to highly reliable personal information through a survey company's diverse online services improved the credibility of the findings. However, self-reported data have some inherent limitations. A longitudinal study could have provided stronger evidence if sufficient sample sizes were obtained to track residential environment changes and sleep quality before and after relocation; however, a cross-sectional design was the next best alternative. Additionally, residual confounding may exist beyond the presumed demographic and socioeconomic factors such as diet, physical activity, work style, and family composition. The type of work, position, and work style may also be confounding factors. Although the regression models explained only a limited proportion of the variance, and the effect sizes of the associations were relatively small, the observed relationships offer meaningful insights into the potential influence of commuting time and residential floor area on sleep health indicators. These findings should be interpreted with caution, especially in terms of their practical implications.

## 7. Conclusion

Even after adjusting for covariates, longer commuting time predicted insomnia and daytime sleepiness, while smaller residential floor area predicted insomnia. These findings reinforce evidence that shorter commutes improve sleep and suggest a trade-off between commuting time and floor area. For a 95 $m^2$ home, a 53-min commute was associated with exceeding the AIS insomnia cutoff. Reducing not only commuting time but also optimizing housing location and size trade-offs may help mitigate commuter insomnia.

## CRediT authorship contribution statement

**Daisuke Matsushita:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Xiao Xiong:** Writing – review & editing, Formal analysis, Data curation. **Xiaorui Wang:** Writing – review & editing, Software, Formal analysis, Data curation.

## Data sharing

Deidentified individual participant data, along with a data dictionary defining each field in the dataset, will be made available to others upon request. The following additional documents will also be available: study protocol, statistical analysis plan, and informed consent form. These data will be accessible from the date of publication and for a period of five years thereafter. The dataset and related materials can be requested from the corresponding author at matsushita@omu.ac.jp. Access to the data will be granted only to qualified researchers conducting scientifically valid analyses, and will require submission of a research proposal, approval by an independent review panel, and signing of a data access agreement. The data will be shared without investigator support and in accordance with ethical and legal regulations.

## Role of funding source

The sponsors had no role in the design of the study; collection, analysis, and interpretation of the data; or writing of the report. The corresponding author has full access to the data and is responsible for the decision to submit it for publication.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2025.102156.

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