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ORIGINAL ARTICLE

Association Between Combustible Tobacco Cigarette Smoking, Liquid Electronic Cigarette Use and Inadequate Sleep Duration Among Adults in South Korea: KNHANES 2016–2020

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Objective: Nicotine use is associated with inadequate sleep. However, there is limited research on the relationship between smoking and inadequate sleep duration in the Korean population. This study assessed the effect of combustible tobacco cigarette use, liquid electronic cigarette use, and dual use on inadequate sleep duration. **Methods:** This study included 32,005 Korean adults in the final analysis, using data from the Korean National Health and Nutrition Examination Survey (2016–2020). Smoking patterns were classified into four groups: non-users, exclusive combustible cigarette users, exclusive liquid e-cigarette users, and dual users. Inadequate sleep duration was defined as less than 7 hours of sleep per day, according to the National Sleep Foundation's age-specific recommendations. Logistic regression analysis was performed to evaluate the incidence of inadequate sleep, according to smoking patterns. **Results:** After adjusting for covariates, logistic regression analysis showed that both exclusive combustible cigarette users and dual users had significantly higher odds of inadequate sleep duration compared to non-users (adjusted odds ratio [AOR]=1.11, 95% confidence interval [CI]: 1.02–1.20; p=0.010 and AOR=1.25, 95% CI: 1.01–1.55; p=0.043, respectively). Although the trend between exclusive e-cigarette use and inadequate sleep was consistent, it was not statistically significant (AOR=1.34, 95% CI: 0.90–1.99; p=0.153). **Conclusion:** Smoking only combustible tobacco cigarettes, as well as the dual use of e-cigarettes and combustible cigarettes, is linked to inadequate sleep duration among Korean adults. Encouraging smoking cessation, particularly for dual users and combustible cigarette smokers, can help improve sleep health.

Keywords: Combustible cigarette smoking; Electronic cigarettes; Sleep duration; Inadequate sleep; Nicotine

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INTRODUCTION

Smoking cigarettes is widely recognized as a significant risk factor for various chronic conditions, including cancer, cardiovascular disease, and respiratory illnesses [1]. Nevertheless, cigarette smoking is still one of the major issues in public health. In 2021, the Korea Disease Control and Prevention Agency reported that 21.5% of the population smokes either daily or occasionally. Among these, 35.7% were men and 6.7% were women [2].

Recently, electronic cigarettes (e-cigarettes) have become widely used as an alternative to conventional cigarettes. E-cigarettes are battery-powered devices consisting of an atomizer and a cartridge, which produce vapor rather than smoke. The liquid in e-cigarettes ("e-liquid") is a mixture of propylene glycol and glycerin and varying concentrations of nicotine and flavor additives [3]. However, there is limited empirical evidence showing that e-cigarettes are less harmful than tobacco cigarettes. Despite the absence of long-term studies, e-cigarettes are frequently viewed as

less harmful, which has contributed to their increasing popularity [4]. This raises concerns that e-cigarettes may become more accessible to adults, increasing their vulnerability to nicotine addiction and leading to dual use alongside conventional cigarettes [5].

Smoking, whether through combustible tobacco cigarettes or e-cigarettes, poses well-documented risks to respiratory, cardiovascular, and immunological health and also significantly impacts sleep [6-8]. Sleep duration, the total hours of sleep within a day, is vital for overall health and well-being [9]. The National Sleep Foundation advises that adults should aim for 7–9 hours of sleep, while older adults should get 7–8 hours [10]. However, studies indicate a decline in sleep duration, with more than 2 out of 10 adults getting less than 6 hours of sleep in recent decades [11]. This inadequate sleep is a significant public health concern linked to increased risks of various physical and mental health issues, including diabetes, obesity, cardiovascular disease, and depression [12,13].

Nicotine, an addictive substance in both traditional and e-cigarettes, disrupts sleep by affecting the central nervous system and altering neurotransmitters that regulate the sleep-wake cycle [14]. Research shows that smokers, including e-cigarette users, generally experience shorter sleep durations compared to non-smokers, underscoring the broader health risks associated with nicotine use beyond its impact on chronic diseases [15,16]. In addition to its neurobiological effects, nicotine use may also impair sleep through behavioral mechanisms. Nighttime nicotine withdrawal has been associated with reduced sleep quality, as well as prolonged or frequent nocturnal awakenings [17,18]. Furthermore, other studies have reported that smoking within 4 hours before bedtime is associated with disrupted sleep continuity and decreased overall sleep efficiency, in the context of nighttime substance use [19].

However, there is limited understanding of the relationships between smoking and sleep duration among adults in Korea, especially regarding the effects of tobacco cigarette smoking and e-cigarette use on sleep patterns. To address this gap, our study aims to investigate the impact of tobacco cigarette smoking and e-cigarette use on sleep duration, using representative data from the Korean population to analyze and compare these effects.

METHODS

Participants and procedures

This cross-sectional study utilized data from the 2016 to 2020 Korean National Health and Nutrition Examination Survey (KNHANES), conducted by the Korea Centers for Disease Control and Prevention (KCDC). The KNHANES is a national survey that utilizes a stratified, multi-stage sampling design. Since 1998, this cross-sectional, nationwide survey has been conducted annually to gather data on the dietary intake, prevalence of chronic diseases, and health behaviors of the Korean population.

This study analyzed data from 39,738 Korean adults aged 19 years and older. After excluding 7,521 participants with missing sleep duration data and 212 with missing smoking data, a total of 32,005 adults were included in the final analysis (Figure 1). Informed consent was obtained from all participants during the survey by KCDC. This study adhered to the principles of the Declaration of Helsinki and was approved by the Institutional Review Board of Severance Hospital (IRB No. 4-2024-0934).

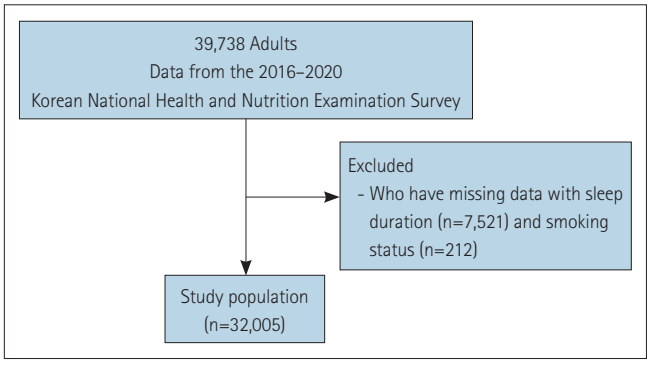

Figure 1. Study population selection process.

Current liquid e-cigarette use and combustible tobacco cigarette smoking

In the "Liquid E-Cigarettes" and "Tobacco Use" survey, participants were asked two separate questions about their current use of liquid e-cigarettes and whether they smoke combustible tobacco cigarettes. "Tobacco Use" survey has response options including "every day," "some days," "have smoked but currently not," and "not at all." And the "Liquid E-Cigarettes" survey has "Yes" and "not at all." We analyzed the responses from both surveys and organized them into four distinct groups based on usage patterns: 1) non-users, who reported neither using liquid e-cigarettes nor smoking combustible tobacco cigarettes; 2) exclusive liquid e-cigarette users, who confirmed using e-cigarettes but reported no use of combustible cigarettes; 3) exclusive combustible cigarette smokers, who reported smoking combustible cigarettes either "every day" or "some days" while not using e-cigarettes; and 4) dual product users, who reported smoking combustible cigarettes either "every day" or "some days" and also using liquid e-cigarettes.

Inadequate sleep duration

In the "Inadequate Sleep" survey, participants were asked about their average daily sleep duration. Using the National Sleep Foundation's age-specific recommendations for adults, we categorized sleep duration into two groups: inadequate sleep (<7 hours per day) and adequate sleep (≥7 hours per day) [10].

Covariates

Anthropometric variables, such as height and body weight, were obtained by trained medical staff using a standardized procedure. Body mass index (BMI) was calculated by dividing the weight in kilograms by the square of the height in meters. Sociodemographically, covariates that we included in this study were age, sex, body mass index, household income level (lowest, medium-lowest percentile, medium-highest percentile, highest), and education level (≤elementary school graduate, middle school, high school, and ≥college graduate). Alcohol consumption and

current physical activity were also included as potentially important factors that can influence sleep among adults [20]. Alcohol consumption was measured into two categories ("yes" and "never") based on whether they had ever drunk alcohol. Physical activity was also assessed into two categories: "yes" for participating in moderate or intensive physical activity, and "no" if neither type of activity was performed.

Statistical analysis

The data are presented as mean±standard error (SE) or as a percentage (SE). Sampling weights were applied to account for the complexity of the sampling process. For continuous variables, group characteristics were compared using analysis of variance (ANOVA), while Pearson's chi-square test was utilized for categorical variables. Multiple logistic regression analysis was conducted to evaluate the incidence of inadequate sleep according to smoking pattern, with odds ratios (ORs) and 95% confidence intervals (CIs) calculated. Both unadjusted and adjusted models were reported, with the adjusted model controlling for age, sex, household income, BMI, alcohol consumption, and physical activity. The analyses were carried out using R statistical software (version 4.3.0; R Foundation for Statistical Computing, http://www.R-project.org). Statistical significance was set at $p<0.05$, with all tests being two-sided.

RESULTS

Table 1 shows the clinical characteristics of the participants according to the patterns of current e-cigarette and combustible cigarette use. Among the 32,005 Korean adults included in this study, 49.9% were male, with an overall mean age of 44.9 years. Regarding smoking habits, 0.45% were exclusive e-cigarette users (n=133), 14.9% were exclusive combustible cigarette smokers (n=4,763), and 1.44% were dual product users (n=461). The average BMI was 23.8 kg/m^2. Approximately 68% had a household income at or below the medium-highest percentile, and 38.7% had completed education at the college level or above. Additionally, 54% of subjects reported current alcohol use, and 46.2% engaged in physical activity. Among non-users, e-cigarette users, and combustible cigarette users, there were statistically significant differences in age, sex, BMI, household income, education level, current alcohol use, and physical activity (all $p<0.01$) (Table 1). Participants with higher household income and education levels (college or above) were more likely to be exclusive liquid e-cigarette users (40.9% and 61.5%, respectively) or dual product users (36.9% and 46%, respectively). On average, participants reported 7.1 hours of sleep, with 38.7% experiencing inadequate sleep. The mean sleep duration was 7.93 hours in the adequate sleep group and 5.87 hours in the inadequate sleep group.

Figure 2 illustrates the clinical characteristics of participants according to cigarette use patterns in the adequate and inadequate sleep duration groups. The clinical characteristics of participants in the inadequate sleep group were largely consistent with those observed in the adequate sleep group and the overall population. In terms of age, both non-smokers and exclusive combustible cigarette smokers were older than exclusive e-cigarette users and dual

Table 1. Characteristics of Korean adults overall and based on patterns of current e-cigarette and combustible cigarette use

	Patterns of current e-cigarette and combustible cigarette use					
	Overall	Non-user	Exclusive e-cigarette user	Exclusive combustible cigarette smoker	Dual product user	p
Unweighted number	32,005	26,648	133	4,763	461	-
Age (yr)	44.9±18.2	45.2±19.0	37.0±11.2	44.3±14.4	35.3±11.4	<0.001
Sex (%, SE)						<0.001
Male	49.9 (0.3)	41.1 (0.3)	88.2 (3.9)	85.8 (0.6)	84.6 (2)	
Female	50.1 (0.3)	58.9 (0.3)	11.8 (2.5)	14.2 (0.5)	15.4 (1.7)	
Body mass index (kg/m^2)	23.8±3.8	23.7±3.8	25.2±3.7	24.3±3.7	25.0±4.0	<0.001
Household income (%, SE)						<0.001
Lowest	15 (0.4)	15.2 (0.4)	8.8 (1.8)	14.7 (0.7)	8.6 (1.3)	
Medium-lowest percentile	23.8 (0.5)	23.7 (0.5)	18.2 (3.3)	24.5 (0.8)	22.4 (2)	
Medium-highest percentile	29.2 (0.5)	28.7 (0.5)	32.1 (4.3)	31.2 (0.9)	32.1 (2.5)	
Highest	32 (0.7)	32.4 (0.7)	40.9 (4.6)	29.6 (0.9)	36.9 (2.6)	
Education level (%, SE)						<0.001
Elementary school or less	16.1 (0.3)	18.1 (0.4)	1.3 (0.5)	8.7 (0.5)	1.1 (0.3)	
Middle school	11.5 (0.2)	12.2 (0.3)	4.5 (1.3)	9.1 (0.4)	3.9 (0.9)	
High school	33.7 (0.4)	31.1 (0.5)	32.8 (4.1)	44.2 (0.9)	49 (2.9)	
College or higher	38.7 (0.6)	38.5 (0.6)	61.5 (4.4)	38.1 (0.9)	46 (2.9)	
Alcohol consumption (%, SE)	54 (0.4)	47.9 (0.4)	76.1 (4.7)	78.6 (0.7)	84.5 (2.1)	<0.001
Physical activity (%, SE)	46.2 (0.4)	46.2 (0.5)	52.4 (4.5)	45.2 (0.9)	54 (2.7)	0.006

Data are presented as mean±standard error for continuous variables unless otherwise indicated. e-cigarettes, electronic cigarettes; SE, standard error

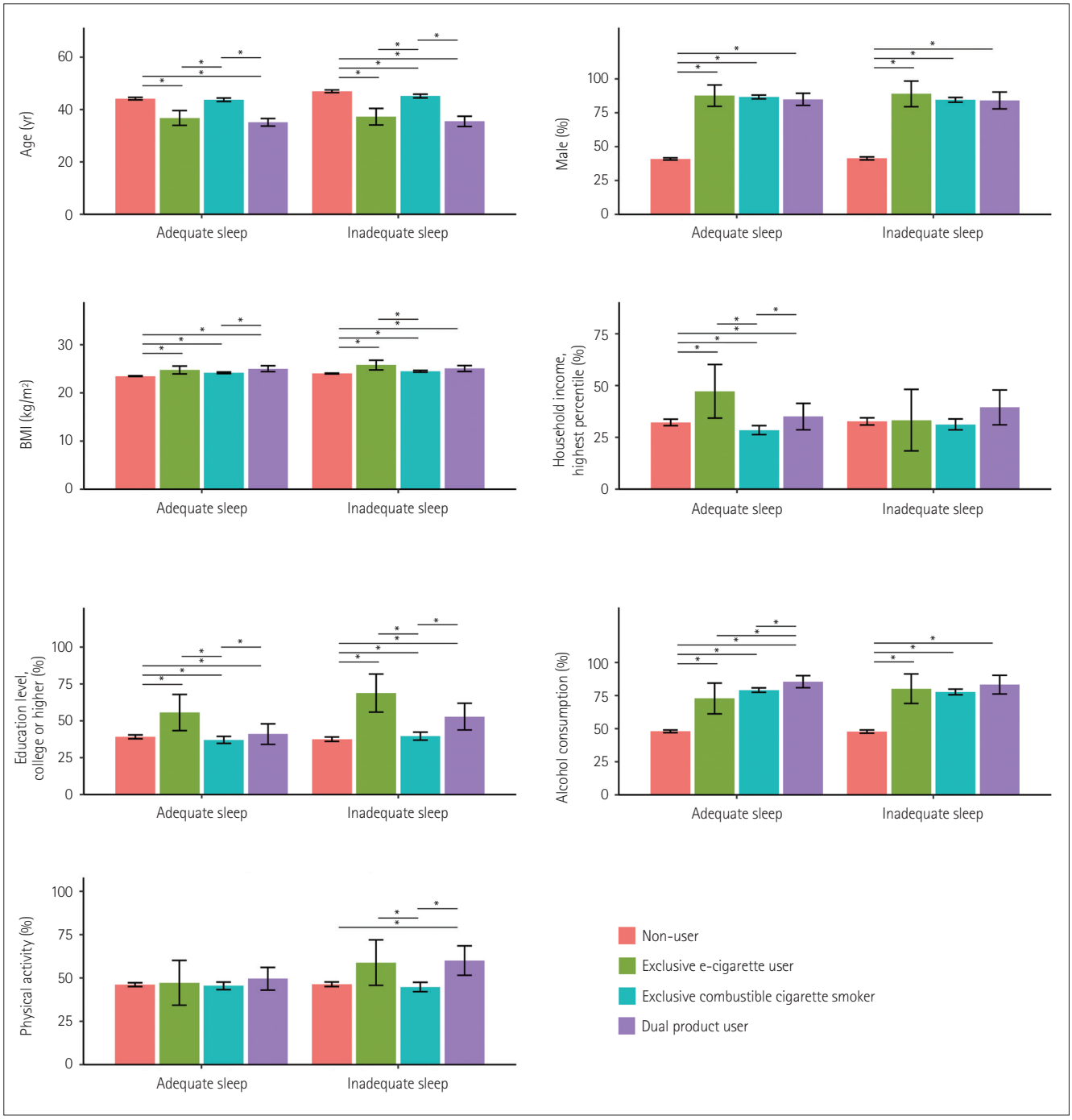

Figure 2. Clinical characteristics of participants by cigarette use patterns in adequate and inadequate sleep groups. p-value was assessed by utilizing Pearson's chi-square test. *statistically significant correlation. BMI, body mass index.

users, regardless of sleep duration. The proportions of males and current alcohol users were significantly higher among all smoking groups compared to non-users. The proportion of participants with higher education levels (college or above) was higher in the exclusive e-cigarette user and dual user groups compared to the other groups. In the inadequate sleep group, no statistically significant differences were found in household income distribution across smoking patterns. However, within this group, the proportion of individuals engaging in physical activity was higher among exclusive e-cigarette users and dual users.

Figure 3 illustrates the percentage of individuals experiencing inadequate sleep duration among different groups of smokers. The results show that 44.4% of exclusive e-cigarette users, 40.4% of exclusive combustible cigarette smokers, and 42.0% of dual product users reported inadequate sleep. Among these groups, only the difference between non-users and exclusive combustible cigarette smokers was statistically significant. Moreover, the difference among these groups in overall was statistically significant (p-value for overall test=0.033).

Table 2 presents the associations between different patterns of

e-cigarette and combustible cigarette use and inadequate sleep duration among Korean adults. The unadjusted logistic regression results show that exclusive combustible cigarette smokers had 1.09 times higher odds (95% CI: 1.02−1.18; p=0.014) of reporting inadequate sleep compared to non-users. After adjusting for covariates, the adjusted logistic regression results indicated that both exclusive combustible cigarette smokers (adjusted OR [AOR]= 1.11, 95% CI: 1.02−1.20; p=0.010) and dual users of e-cigarettes and combustible cigarettes (AOR=1.25, 95% CI: 1.01−1.55; p= 0.043) were at significantly higher odds of reporting inadequate sleep compared to non-users. Although exclusive e-cigarette users also showed higher odds (AOR=1.34, 95% CI: 0.90−1.99), the result was not statistically significant (p=0.153).

DISCUSSION

In this study, we found that exclusive combustible cigarette smoking and dual use of e-cigarettes and combustible cigarettes were consistently associated with inadequate sleep duration of less than 7 hours per day among Korean adults, while exclusive e-cigarette use was not. These findings underscore the distinct impact of different smoking behaviors on sleep duration.

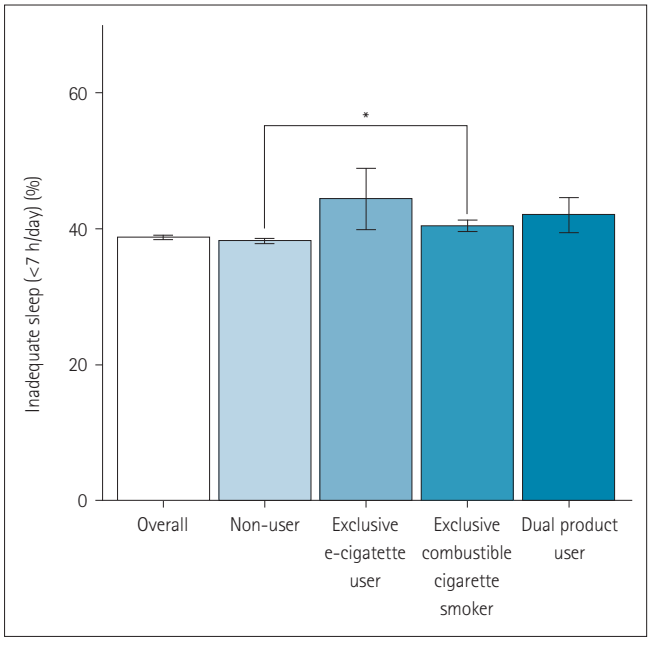

Figure 3. The percentage of individuals experiencing inadequate sleep duration among different groups of smokers. p-value was assessed by utilizing Pearson's chi-square test. *statistically significant correlation.

Nicotine is well known for its role in sleep disturbances. It stimulates nicotine-acetylcholine receptors in the hypothalamus and reticular formation, leading to the release of neurotransmitters such as acetylcholine, dopamine, serotonin, and gamma-aminobutyric acid, which influence the sleep-wake cycle [21]. Additionally, nicotine can inhibit sleep-promoting neurons, further disrupting the cycle [22].

Our findings are consistent with previous research indicating that the use of combustible cigarettes is associated with shorter sleep duration [23]. For instance, a study conducted on the German population found that smokers were more likely to experience inadequate sleep compared to non-smokers. Moreover, the study reported that greater nicotine dependence and a higher number of cigarettes smoked per day were linked to shorter sleep duration. This effect was especially noticeable when comparing smokers with high dependence to those with lower dependence [24].

In our study, dual users had significantly higher odds of experiencing inadequate sleep duration compared to exclusive combustible cigarette smokers, even after adjusting for covariates. This is consistent with prior research showing that dual users tend to have greater nicotine dependence than exclusive smokers, which aligns with findings that higher nicotine dependence is associated with shorter sleep duration [24,25].

Our findings are largely consistent with previous research demonstrating sociodemographic differences across tobacco product user groups. Prior studies have shown that exclusive e-cigarette users and dual users were generally younger and more likely to have attained higher education levels than exclusive combustible cigarette smokers or non-smokers [26,27]. This demographic trend may reflect the marketing appeal and perceived modernity of e-cigarettes among younger and more highly educated populations. Additionally, all tobacco user groups showed higher proportions of males and current alcohol users compared to non-users, reinforcing the well-established co-occurrence of tobacco and alcohol use as a behavioral risk pattern [28,29].

Interestingly, although exclusive e-cigarette users and dual users in the adequate sleep group had a higher proportion of indi-

Table 2. Associations of patterns of current e-cigarette and combustible cigarette use with inadequate sleep duration among Korean adults (n=39,738)

Current e-cigarette and cigarette use	Inadequate sleep (<7 h/day)				
	Inadequate sleep	Unadjusted logistic regression		Adjusted logistic regression*	
	n (%)†	OR (95% CI)	p	AOR (95% CI)	p
Non-user (n=26,648)	10,097 (37.9)	1 (Ref)	Ref	1 (Ref)	Ref
Exclusive e-cigarette user (n=133)	58 (43.6)	1.29 (0.87−1.92)	0.209	1.34 (0.90−1.99)	0.153
Exclusive combustible cigarette smoker (n=4,763)	1,920 (40.3)	1.09 (1.02−1.18)	0.014	1.11 (1.02−1.20)	0.010‡
Dual product user (n=461)	184 (39.9)	1.17 (0.94−1.45)	0.149	1.25 (1.01−1.55)	0.043‡

*logistic regression adjusting for participants' age, sex, body mass index, household income, education level, alcohol consumption, physical activity; †n refers to unweighted count and % refers to weighted row percentage; ‡statistical significance. E-cigarettes, electronic cigarettes; OR, odds ratio; Cl, confidence interval; AOR, adjusted odds ratio; Ref, reference

viduals with greater household income, no statistically significant differences in household income were found across smoking categories in the inadequate sleep group. While previous research has suggested that lower socioeconomic status may influence smoking behavior through mechanisms such as sleep disturbances and psychological stress [30], direct associations among socioeconomic status, smoking behavior, and inadequate sleep have rarely been reported. This may suggest that, in the context of sleep insufficiency, factors beyond income level or smoking status—such as behavioral or psychosocial determinants—could play a more prominent role. Although few studies have directly examined the relationship between tobacco use patterns and physical activity levels, previous research has shown that individuals with higher educational attainment tend to engage in higher levels of physical activity, particularly during leisure time [31,32]. In our study, the relatively higher proportion of highly educated individuals among exclusive e-cigarette users and dual users within the inadequate sleep group, compared to those in the adequate sleep group, may suggest that these individuals are more inclined to engage in health-related behaviors and may be more likely to maintain higher levels of physical activity. However, this also raises the possibility that they may underestimate the potential harms associated with e-cigarette use [25,33]. Further research is needed to clarify the relationship between smoking behavior, physical activity levels, and inadequate sleep.

In this study, although the trend between exclusive e-cigarette use and inadequate sleep was consistent with that observed among combustible cigarette users and dual users, the association was not statistically significant. This may be due to the small proportion of e-cigarette users in our sample, variable nicotine levels in e-cigarettes, and their lower nicotine content per puff compared to combustible cigarettes [3,34]. Additionally, not accounting for smokeless tobacco use, which has been linked to inadequate sleep, may have influenced our findings [35]. Lower nicotine dependence and intake among e-cigarette users compared to cigarette smokers could also explain the lack of difference between e-cigarette users and non-users [36]. Further research with larger samples, consistent nicotine measurements, and consideration of other tobacco use is needed to better understand the impact of e-cigarette use on sleep duration.

This study has several limitations. The cross-sectional design restricts our ability to determine causal or longitudinal relationships. Additionally, the reliance on self-reported data could introduce recall or social desirability biases. In addition, the survey did not collect detailed information on the frequency of e-cigarette and combustible cigarette use or smokeless tobacco use, which could affect the findings. We also did not assess excess sleep duration, which might be relevant for certain populations [37]. Future research should aim to gather more comprehensive data on smoking patterns and consider other covariates, such as psychosocial factors, to better understand the trajectories and health impacts of e-cigarette and cigarette use among adults [38]. Despite its limitations, this study is the first in Korea to explore and identify differences in how cigarette smoking and e-cigarette use affect sleep duration.

In conclusion, our study showed that exclusive combustible tobacco cigarette smoking and dual use of e-cigarettes and combustible cigarettes were consistently associated with inadequate sleep duration among Korean adults, while exclusive e-cigarette use was not. These findings highlight the distinct effects of different smoking behaviors on sleep duration. Clinically, healthcare providers should consider the type of smoking behavior when addressing sleep-related issues in patients. Understanding these differences can help tailor interventions more effectively, emphasizing the importance of smoking cessation, particularly for dual users and combustible cigarette smokers, to improve sleep health and overall well-being. Considering the limitation of the small proportion of exclusive e-cigarette users, future studies should incorporate targeted recruitment strategies to increase the representation of this group. This approach would enable more robust and representative analyses, ultimately enhancing the generalizability of the study findings.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Availability of Data and Material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Author Contributions

Conceptualization: Gisoo Kang, Yu-Jin Kwon, Ji-Won Lee, Ehn-Young Kim. Data curation: Yaeji Lee. Formal analysis: Yaeji Lee. Investigation: Gisoo Kang, Yaeji Lee, Yu-Jin Kwon. Methodology: Yu-Jin Kwon, Ji-Won Lee, Ehn-Young Kim. Project administration: Yu-Jin Kwon, Ehn-Young Kim. Supervision: Ji-Won Lee, Ehn-Young Kim. Validation: alll authors. Visualization: Yaeji Lee. Writing—original draft: Gisoo Kang, Ehn-Young Kim. Writing—review & editing: all authors.

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