Title

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Journal

Journal of Clinical Sleep Medicine, 17(11)

ISSN

1550-9389

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Publication Date

2021-11-01

DOI

10.5664/jcsm.9414

Peer reviewed

https://doi.org/10.5664/jcsm.9414

JCSM | Journal of Clinical Sleep Medicine

SCIENTIFIC INVESTIGATIONS

Assessing the potential impact of age and inhalant use on sleep in adolescents

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Study Objectives: Targeted marketing has caused a recent surge in teen electronic cigarette usage. In all-age surveys, we isolated adolescent data (13–20 years) to assess age alongside electronic cigarettes, traditional tobacco, and dual usage of both with sleep quality and cough. Based on existing adult literature, we hypothesized an association between dual usage and increased sleep latency.

Methods: Participants were recruited to complete surveys via social media sites. We performed 3 surveys: Survey 1 (n = 347) in 2018, Survey 2 (n = 1198) in 2019, Survey 3 (n = 554) in 2020. Surveys 1 and 2 had 3 sections: UCSD Inhalant Use Survey, Pittsburgh Sleep Quality Index, and Leicester Cough Questionnaire. Survey 3 did not include the Leicester Cough Questionnaire, instead the Hospital Anxiety and Depression Scale and Patient Health Questionnaire were used. The adolescent data were isolated (n = 609).

Results: Adolescents reported longer sleep duration with increasing age by one-way analysis of variance. By Tukey's multiple comparisons test, females slept more at ages 19 and 20 years than at age 14 years ($P < .01$). Female dual users slept more than nonsmokers, ($P = .01$; mean difference 43.8 minutes; confidence interval = 0.11 to 1.36). We observed an association between dual use and sleep latency vs nonsmokers ($P = .0008$; mean difference 6.27 minutes; confidence interval = 1.40 to 11.13). We saw no correlation between inhalant use and cough.

Conclusions: In females, we observed a peak in sleep hours at age 19 years. College-aged females may wake later than younger adolescent females. The data also raised concern for sleep disruption and nicotine-induced wakefulness. Further data are required to guide public health strategies.

Keywords: vaping, electronic cigarettes, tobacco, dual use, sleep latency

Citation: Malhotra CK, Gunge D, Advani I, Boddu S, Nilaad S, Crotty Alexander LE. Assessing the potential impact of age and inhalant use on sleep in adolescents. *J Clin Sleep Med*. 2021;17(11):2233–2239.

BRIEF SUMMARY

Current Knowledge/Study Rationale: Adolescents already face shorter sleep duration than the recommended 9 hours per night due to multiple factors, and short sleep duration has been associated with increased body weight, risk of myocardial infarction, anxiety, depression, and poor quality of life. With rising nicotine containing electronic cigarette use in adolescents, it is likely that vaping may further worsen sleep duration and quality due to the activating and sleep-disturbing effects of nicotine.

Study Impact: This work demonstrates that females in particular have more healthy sleep durations once they reach college age. Also, dual use of electronic cigarettes and conventional tobacco impacts sleep latency, lengthening the amount of time it takes for adolescents to fall asleep.

INTRODUCTION

Many people consider diet, exercise, and sleep to be the 3 pillars of health.[1–3] These are particularly important in teenagers, because behaviors acquired at this stage may impact their health as adults.[4] Electronic cigarette (e-cigarette) use, commonly known as vaping, has been surging in adolescents in recent years and could impact each of these 3 pillars: 1) Nicotine drives appetite suppression and the majority of e-cigarettes contain nicotine[5]; 2) Vaping can cause shortness of breath, and therefore impact exercise; and 3) In adults, vaping has been associated with increased sleep latency.[6] Conventional tobacco use continues to be a problem, but the combination of e-cigarettes and tobacco (dual use) is not a well-studied area.

E-Cigarette companies such as JUUL and Puff Bar have marketed aggressively, targeting adolescents with fruity, minty, enticing flavors. They market them as a safer alternative to conventional smoking; of note, few teenagers fully understand the risks of nicotine addiction and health effects caused by vaping known to date, including asthma, bronchitis, lung injury, and cardiovascular disease.[7,8] This aggressive, targeted marketing, coupled with easy accessibility to the product, including front door delivery, has led to increased acceptance of e-cigarettes and rising levels of adolescents who vape or combine the use of e-cigarettes and conventional tobacco.[9] However, the impact of this trend on the 3 pillars of health is unknown.

Due to factors such as stress and electronic devices, adolescents tend already to face shorter sleep duration or worse quality than the recommended 9 hours per night.[10–12] Short sleep duration has been associated with increased body weight, risk of myocardial infarction, anxiety, depression, and poor quality of

life.[13–17] Sleep issues are rarely prioritized in today's 24/7 society, despite the health benefits of adequate quantity and quality sleep. Of note, men and women have differences in inclination to use inhalants. Also, according to the existing literature, anxiety and depression are more prevalent in females than males.[18–21] Therefore, it is important to break down all data by gender to view any separate gender health implications. Little research has been done to assess not only sleep quality or duration across the spectrum of adolescence, but also the changes when combined with inhalant usage. The bulk of the prior literature is focused on adults, leaving little information about the specific effects on teenagers.

We sought to test the hypothesis that dual usage of e-cigarettes and conventional tobacco is associated with poor sleep quality in adolescents. Both inhalants have been associated with cough.[6,22] We undertook these studies to determine if use of both e-cigarettes and conventional tobacco, dual use, had additive effects on cough. We also hypothesized an association between dual usage and increased anxiety and depression based on the correlation between shorter sleep duration and these mental health effects.

METHODS

Participants were recruited to complete online surveys via random posting on multiple days and at different times across social media sites such as Facebook, Craigslist, Reddit, and Twitter. We performed 3 surveys: Survey 1 (n = 347) was conducted in 2018, Survey 2 (n = 1198) in 2019, and Survey 3 during late March 2020 (n = 554). Participants were incentivized via a $250 Amazon gift card lottery. Surveys 1 and 2 were broken up into 3 sections: past and current inhalant use, the Pittsburgh Sleep Quality Index (PSQI; range 0–21, with lower scores representing better sleep quality), and the Leicester Cough Questionnaire (range 3–21, with higher scores representing less cough severity/prevalence and better quality of life). Because the Leicester Cough Questionnaire did not yield significant findings in Surveys 1 and 2, it was not included in subsequent surveys. Survey 3 instead included the Hospital Anxiety and Depression Scale and Patient Health Questionnaire to assess questions related to inhalant impact on mental health. The data were broken down by age group, specifically analyzing adolescents, ages 13–20 years, as well as by inhalant usage: e-cigarettes, conventional tobacco, dual users, and nonsmokers/nonvapers. For ages 13–20 years after removing outliers, Survey 1 received 71 responses; survey 2 received 475 responses, and Survey 3 received 63. Sleep-related assessments were conducted using all 3 surveys (n = 609; **Table 1**). An online software was utilized to map the IP addresses of all respondents' ages 13–20 years (**Figure 1**).

RESULTS

From **Figure 1**, we see a global map of the respondents to our survey. Although we had good global representation, the majority of the respondents are from affluent countries, ie, from North America and Europe. From **Table 1**, the majority of our participants were non-Hispanic, with substantial representation of Caucasian and east Asian people.

Inhalant use impacts sleep latency

We observed a significant association between inhalant use and sleep latency ($P < .001$), with dual use correlating with a longer sleep latency than nonsmokers (mean difference = 6.27 minutes; confidence interval = 1.40 to 11.13 minutes) (**Figure 2A**). When broken down by gender, this finding was significant in male dual users only (**Figure 2B**). We saw no correlation between inhalant use and anxiety or depression nor between inhalant use and cough severity/prevalence.

Sleep latency differences between genders

Adolescents reported an increase in sleep duration with increasing age by 1-way analysis of variance ($P = .009$). When broken down by gender, females got significantly more sleep at ages 19 and 20 years than at age 14 years, by Tukey's multiple comparisons test ($P < .01$; **Figure 3A**). However, males had no change in sleep duration with increasing age (**Figure 3B**). There was no significant correlation between inhalant use and sleep duration. When broken down by gender, female dual users got significantly more sleep than female nonsmokers, ($P = .01$; mean difference = 0.73 hours; confidence interval = 0.11 to 1.36 hours) (**Figure 3C**), whereas there was no difference in males (**Figure 3D**).

Adolescent age impacts sleep and wake times

Older adolescents (aged 18–20 years) reported a significantly later wake time of 9:10 AM relative to the earlier wake time of 6:41 AM reported by younger adolescents (age 13–17; **Figure 4A**). While older adolescents reported a later falling to sleep time of 12:56 AM, relative to 11:23 PM reported by younger adolescents (**Figure 4B**), this difference of 1 hour and 33 minutes was significantly less than the wake time difference of 2 hours and 29 minutes between younger and older adolescents.

Inhalant use impacts wake time

Inhalant use was found to impact wake times, with dual users reporting a later wake time of 9:06 AM relative to both nonsmokers (7:22 AM) and e-cigarette users (7:53 AM; **Figure 4C**). Time at sleep onset was not impacted by inhalant use (**Figure 4D**).

DISCUSSION

Adolescents are an understudied population in the world of sleep medicine. Because they have been a target population for e-cigarette and tobacco companies, more is known about their ever increasing use of nicotine delivery devices. Marijuana use, both smoked and vaped, is climbing in this demographic, but again this has been understudied.[23] Our findings contribute to the existing literature in a number of ways. First, we observed that, particularly in adolescent males, dual usage of conventional tobacco and e-cigarettes is associated with increased sleep latency. This finding fits with the known effects of nicotine, of

Table 1—Demographics of survey responders between ages 13–20 yrs.

	Total (n = 609)	Survey 1 (n = 71)	Survey 2 (n = 475)	Survey 3 (n = 63)
Inhalant Group				
Nonsmoker	424 (69.62%)	43 (60.5%)	342 (72.00%)	39 (61.90%)
Conventional	11 (1.81%)	5 (7.04%)	6 (1.26%)	0 (0%)
Electronic cigarette	86 (14.12%)	14 (19.72%)	61 (12.84%)	11 (17.46%)
Dual	88 (14.45%)	9 (12.68)	66 (14.45%)	13 (20.63%)
Total	609 (100%)	71 (100%)	475 (100%)	63 (100%)
Gender				
Female	347 (56.98%)	38 (53.52%)	269 (56.98%)	40 (63.49%)
Male	254 (41.71%)	33 (46.48%)	202 (41.71%)	19 (30.16%)
Nonbinary	6 (0.99%)	0 (0%)	2 (0.42%)	4 (6.35%)
Missing	2 (0.33%)	0 (0%)	2 (0.42%)	0 (0%)
Total	609 (100%)	71 (100%)	475 (100%)	63 (100%)
Race				
Caucasian	263 (43.19%)	24 (33.80%)	219 (46.11%)	20 (31.75%)
East Asian	186 (30.54%)	18 (25.35%)	149 (31.37%)	19 (30.16%)
South Asian	25 (4.11%)	4 (5.63%)	19 (4.00%)	2 (3.17%)
Hispanic	30 (4.93%)	15 (21.13%)	9 (1.89%)	6 (9.53%)
Black	11 (1.81%)	4 (5.63%)	5 (1.05%)	2 (3.17%)
Pacific Islander	10 (1.22%)	1 1.41%)	4 (0.84%)	5 (7.94%)
Middle Eastern	3 (0.49%)	0 (0%)	3 (0.63%)	0 (0%)
Mixed	61 (10.02%)	2 (2.82%)	51 (10.74%)	8 (12.70%)
Missing	20 (3.28%)	3 (4.23%)	16 (3.37%)	1 (1.59%)
Total	609 (100%)	71 (100%)	475 (100%)	63 (100%)
Ethnicity				
Hispanic	31 (5.09%)	16 (22.54%)	9 (1.89%)	6 (9.52%)
Non-Hispanic	561 (92.12%)	55 (77.46%)	450 (94.74%)	57 (90.47%)
Missing	17 (2.79%)	0 (0%)	16 (3.37%)	0 (0%)
Total	609 (100%)	71 (100%)	475 (100%)	63 (100%)
Age				
Mean (range)	17.14 (13–20)	18.97 (16–20)	16.57 (13–20)	19.35 (17–20)

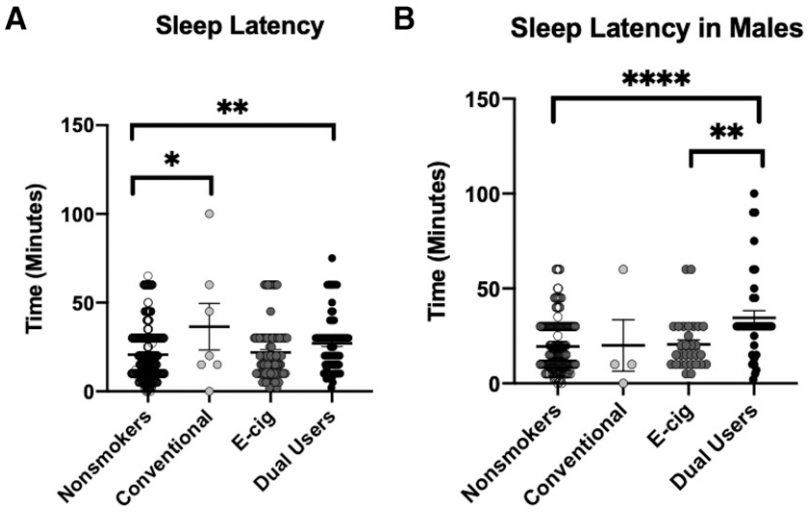
Figure 1—Locations of the 609 adolescent survey responders by IP address.

Responses were collected from 19 countries across 6 continents.

which dual users have a higher intake, such that dual users are more likely to experience greater symptoms and side effects specific to nicotine compared to other users. While the effects of dual use on the developing brain remain unknown, we hypothesize that the effects may be similar to those of nicotine alone but amplified due to the higher nicotine intake by dual users of conventional tobacco and e-cigarettes. Overall, it is well described that the use of addictive substances during years in which brain development is ongoing leads to altered susceptibility and response to all addictive substances as an adult. Further data on the impact of vaping nicotine, vaping marijuana, and dual use of either or both with conventional tobacco is desperately needed.

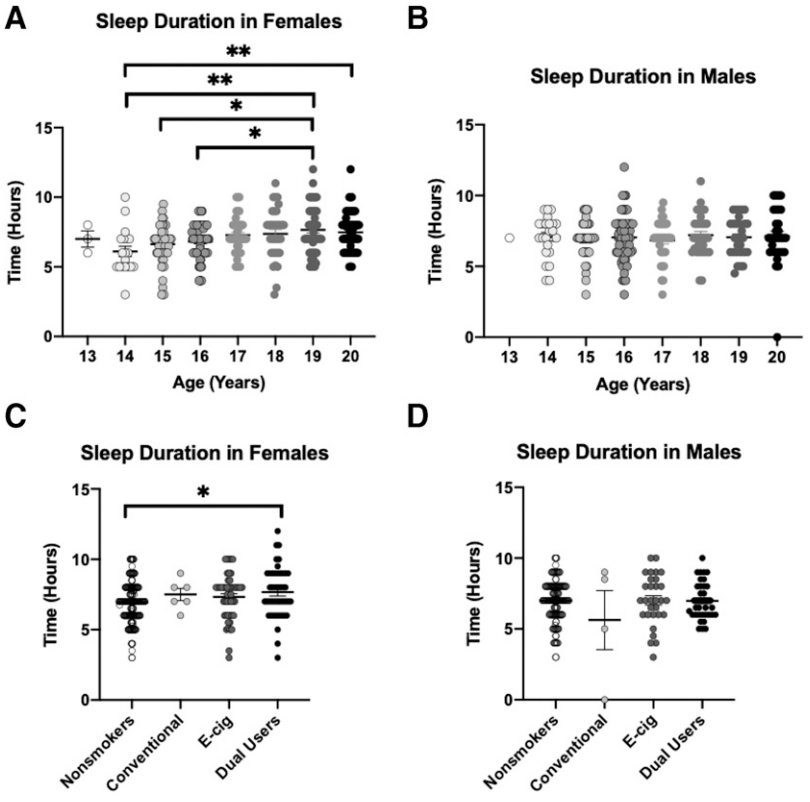
Females reported significantly more sleep at age 19 and 20 years than at age 14 years, a finding that suggests that females get more sleep during their college years relative to during high school. With males, sleep duration remained constant throughout adolescence. Thus, the lower duration of sleep seen in females aged 14–16 years may be routed in gender-specific differences present during high school. We found that females aged

Figure 2—Gender and usage impacts sleep latency.



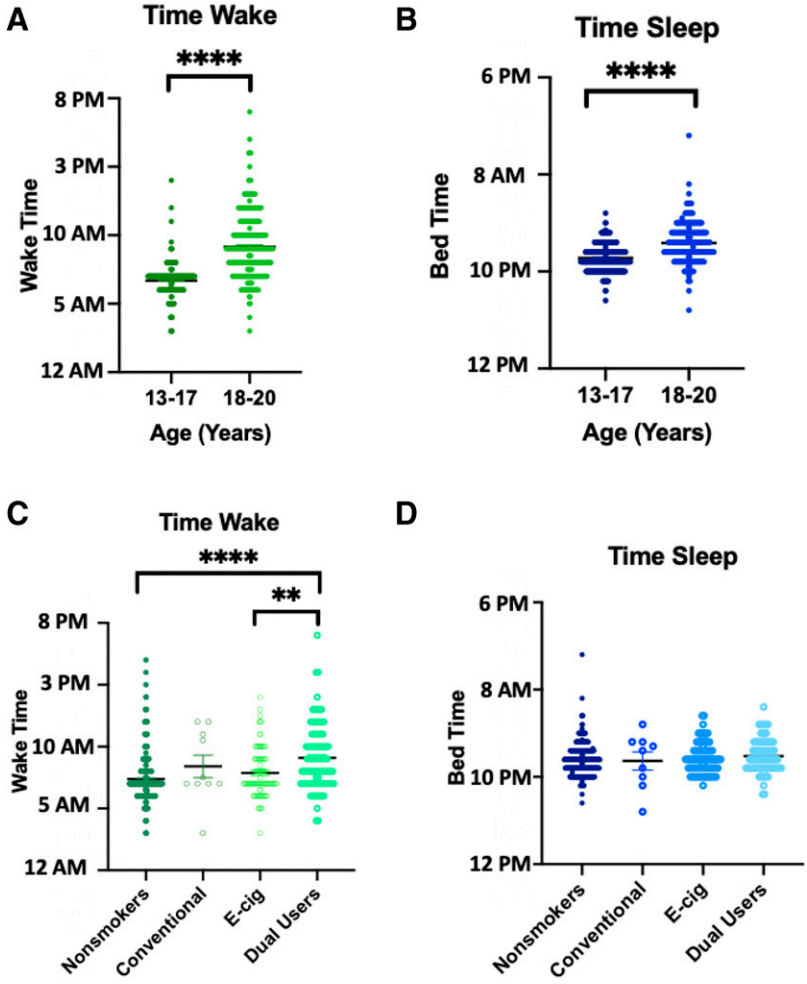
(A) Dual users and conventional users reported significantly longer sleep latency than nonsmokers. **(B)** In males, but not females, dual users reported significantly longer sleep latency than nonsmokers and e-cigarette users. *P = .042, **P < .01, ****P < .0001

Figure 3—Gender and age impact sleep duration.



(A) Older adolescent females reported longer sleep duration than younger ones. Nineteen-year-olds reported increased sleep duration over 14–16 year olds, and 20 year olds reported increased sleep duration over 14 year olds. **(B)** Males had no significant changes in sleep duration across ages. **(C)** In females, dual users reported significantly increased sleep duration over nonsmokers. **(D)** Inhalant use was not associated with changes in sleep duration in males. *P < .05, **P < .01.

Figure 4—Age and inhalant use lead to alterations in wake-up time and time at which participants fall asleep.



(A) Older adolescents (aged 18–20) reported a significantly later wake time than younger adolescents (age 13–17). **(B)** Older adolescents reported later bedtime than younger adolescents. **(C)** Dual users reported a later wake time than nonsmokers and e-cigarette users. **(D)** Inhalant use did not affect sleep time. $^{**}P < .01$, $^{****}P < .0001$.

18–20 years woke up later, which could be the driving factor for the increased sleep duration seen in this demographic, allowing females to catch up to and match the amount of sleep obtained by males. We hypothesize that females in the college age range have more control over their schedule, permitting them to sleep in to their preferred wake time.

Prior studies have found that a 9 to 9 hour and 15 minute sleep duration per night is optimal for adolescents to sustain attention and maximize cognitive abilities throughout the day.[24] This sleep duration is also important for emotional regulation, which may be particularly critical for teenagers.[25] However, adolescents currently only report an average of 7 hours of sleep on school nights, with males reporting more sleep on average than females.[26] These studies confirm the importance of moving high school start times later, as allowing adolescents to sleep longer would likely improve the health and cognitive ability of the developing brain.[24,27–29] Our work suggests that high school start times remain too early for females, as adolescents in college are able to self-regulate via setting their own wake times.

We observed no correlation between inhalant usage and cough severity and prevalence or anxiety and depression via Hospital Anxiety and Depression Scale. This result contradicted some existing data from adult inhalant users.[22,30] Our findings suggest that teenagers may respond differently than adults to inhalants. Further studies of adolescents are needed to explore these differences.

Our study had a number of strengths, such as a large sample size for all sleep-related data, an understudied area, a potentially vulnerable population, and a clinically relevant outcome. However, as with most novel research, we acknowledge a number of limitations. First, we lacked statistical power for some comparisons. For example, our group of conventional users was small, which signifies a shift away from solely tobacco smoking toward e-cigarette or dual usage. It could also signify a limited user response, so people who vape may have been more likely to respond than others. Second, because our methodology was social media-based surveys, our data may have been susceptible to both participation and sampling bias. For example, we had no control over those who

decided to complete the survey or the accuracy of reporting. People without access to social media may have been unlikely to respond. Moreover, we did not require responses to all questions, leading to incomplete data sets. However, we erred on the side of including as many participants as possible, rather than mandating responses from participants who may have been uncomfortable answering certain questions. We do not believe that the prize incentive led to false responses because participants were allowed to enter the prize lottery without completing the survey. Third, our questionnaire did not assess socioeconomic factors, leading to a lack of adjustments for some potential confounders in the statistical analyses. Our fourth limitation is the difficulty with assessing causation rather than correlation. Instead of inhalant usage causing changes in sleep, inadequate sleep could lead to inhalant usage or an external factor could cause both.[31,32] Despite these acknowledged limitations, we hope that our findings stimulate further mechanistic research.

Another consideration for this study is that the difference of 6.27 minutes found in sleep latency may be a small difference in a clinical setting. However, a study regarding medications to treat insomnia showed that the Food and Drug Administration-approved drug had improved sleep latency by 9.6 minutes relative to placebo controls.[33] Moreover our group has shown a 6 minute change in objective sleep latency with eszopiclone (Lunesta Sunovion Pharmaceuticals Inc. Marlborough, MA), ie, of similar magnitude to our findings in the present study.[34] With the similarity in the minutes of altered sleep latency, dual use of cigarettes and e-cigarettes may have a similar disruption in sleep as those who are being treated for insomnia. Moreover, some argue that insomnia can be self-perpetuating, suggesting that any deterioration in sleep onset latency may be problematic for some individuals.[35]

Interestingly, we detected no significant differences in overall sleep quality by PSQI score. It is possible that an increased sleep latency coupled with consistent disruption causes a later wake time, which balances duration and quality. The observation that significant changes in sleep latency and duration were detected led us to question whether the PSQI instrument is able to detect sleep quality in the adolescent population. In other words, the PSQI was designed for adults and may not be sensitive for the detection of sleep abnormalities in adolescents. Teenagers and young adults have a different perception of sleep quality, which may lead to differences in their responses to questions on the PSQI.[36] While few studies have analyzed the psychometric properties of PSQI in adolescents, a recent study determined that PSQI scores have a moderate-to-large correlation with adolescent emotional problems.[36,37]

Teenage vulnerability is often overlooked in favor of larger or adult-focused surveys regarding sleep or inhalant usage. However, today's adolescent health is the future and thus important for the health of future generations. Further data are required regarding the health impact of conventional tobacco and e-cigarettes on teenage health to define public health strategies.

CONCLUSIONS

Usage of nicotine-containing inhalants not only alters sleep in adults, but also is associated with changes in adolescent sleep health. Gender is known to play a role in both inhalant effects and sleep quality; here we show that gender may impact both the sleep quality of adolescent females and the sleep latency of adolescent male inhalant users.

ABBREVIATIONS

e-cigarette, electronic cigarette
PSQI, Pittsburgh Sleep Quality Index

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ACKNOWLEDGMENTS

Author contributions: Conception and design of the experiments: C.M., L.C.A., S.B., D.G., and I.A. Acquisition, analysis, and interpretation of data: C.M., D.G., I.A., S.B., S.N. and L.C.A. Manuscript composition: C.M., D.G., I.A. and L.C.A. All authors reviewed, contributed to, and approved the manuscript.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication December 12, 2020
Submitted in final revised form May 2, 2021
Accepted for publication May 3, 2021
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DISCLOSURE STATEMENT

All authors have seen and approved the manuscript. This study was funded by grants from the National Institutes of Health NHLBI R01HL147326 (to LCA), the American Heart Association Beginning Grant in Aid 16BGIA27790079 (to LCA), and the Tobacco-Related Disease Research Program T30IP0965 (to LCA). The authors report no conflicts of interest.