FREQUENCY OF CIGARETTE AND/OR E-CIGARETTE USE AND ITS ASSOCIATIONS WITH SLEEP HEALTH AMONG CANADIAN ADOLESCENTS

by

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ABSTRACT

Though the prevalence of cigarette use among Canadian adolescents has declined in recent decades, the prevalence of e-cigarette use is high and increasing. Both cigarettes and e-cigarettes usually contain nicotine, and this may impact adolescent sleep health. In Canada, 1 in 3 adolescents is not getting enough sleep. Both cigarette and e-cigarette use have been previously investigated with respect to sleep health, but previous studies have not considered both frequency of use and dual use of cigarettes and e-cigarettes.

The primary objectives of this study were to determine the associations between frequency of cigarette and/or e-cigarette use and: (1) Self-reported sleep duration; (2) Fulfilment of the national recommended sleep duration (8-10 hours per night); (3) Intensity of sleep-related problems (e.g., falling asleep during class). A fourth objective was to determine whether the associations between frequency of cigarette and/or e-cigarette use and sleep duration, fulfilment of the sleep recommendation, and sleep-related problems differ by sex.

This study was a secondary analysis of the 2018-19 Canadian Student Tobacco, Alcohol, and Drugs Survey (CSTADS), a cross-sectional survey that collects data on substance use behaviours and other national health priorities. The 2018-19 iteration included 62,850 students in grades 7-12 in all ten Canadian provinces, though only students grades 9-12 were included in this analytic sample (N = 38,229). Respondents were grouped by frequency and dual use of cigarettes and/or e-cigarettes in the past 30 days and this was used as the exposure variable. The association between the exposure and sleep duration was analyzed using multiple linear regression, the exposure and the fulfilment of the national sleep duration using multiple logistic regression, and the exposure and sleep-related problems using multiple linear regression of three separate dimensions of sleep-related problems: tiredness/fatigue, late sleeping, and falling asleep during class. An interaction of the exposure and sex was used to determine sex-specific interaction effects in each of the analyses. All analyses controlled for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

This study contributes four major findings to the literature: (1) High-frequency e-cigarette only, low-frequency cigarette only, and high-frequency dual users report fewer minutes of sleep per night on average than non-users; (2) High frequency e-cigarette only and e-cigarette dual using adolescents are the least likely group of cigarette and/or e-cigarette users to meet the national sleep duration recommendation of 8-10 hours per night compared to non-users; (3) Frequency of cigarette and/or e-cigarette use is associated with more reports of tiredness/fatigue among adolescents, but fewer reports of late sleeping and falling asleep during class; (4) The association between frequency of cigarette and/or e-cigarette use and sleep duration, meeting the national sleep duration recommendation, and sleep-related problems among adolescents is not modified by sex. These findings highlight the importance of addressing two public health concerns: adolescent cigarette and/or e-cigarette use and sleep health. The evidence from this study can be used to address both concerns in an effort to improve adolescent health.

LIST OF ABBREVIATIONS USED

24MG	The Canadian 24-Hour Movement Guidelines for Children and Youth
AOR	Adjusted odds ratio
CI	Confidence interval
CSTADS	Canadian Student Tobacco, Alcohol, and Drugs Survey
OR	Odds ratio

CHAPTER 1. INTRODUCTION

Despite decades of tobacco control efforts, smoking remains a leading cause of preventable death in Canada (Public Health Agency of Canada, 2016). In 1965, almost half of Canadians were smokers. Though the prevalence of smoking in Canada has decreased substantially since then (currently 15.8%), the burden of smoking-related illness and mortality remains high (Reid et al., 2019; Statistics Canada, 2019).

One in five deaths each year is attributed to smoking (Dobrescu et al., 2017). The many negative health effects of smoking are well-documented, and the list of smoking-related diseases continues to grow. Cardiovascular disease, respiratory disease, and cancers are all common health outcomes among smokers (Jayes et al., 2016; United States Department of Health and Human Services, 2014). Even among nondaily users, smoking increases morbidity and mortality severalfold (Inoue-Choi et al., 2019). In addition to the health effects of smoking, there are staggering costs to the Canadian economy. More than 6 billion dollars of expenditures result from the direct costs of smoking annually, including healthcare and pharmaceuticals (Dobrescu et al., 2017). An additional 9.5 billion dollars of expenditures are a result of indirect costs such as lost earnings (due to premature death and illness) and disability (Dobrescu et al., 2017).

An emerging topic of concern closely related to smoking is electronic cigarette use ("vaping"). Electronic cigarettes, or e-cigarettes, emerged in the mid-1990s but were not federally regulated in Canada until 2018 (Health Canada, 2019a; Leischow, 1994; Regan et al., 2013). E-cigarettes are battery-operated and contain liquid which is heated by the device and inhaled as an aerosol by the user, closely simulating the experience of smoking (Yingst et al., 2015). Though e-cigarettes have been cited as a tool for smoking

cessation, the evidence on their effectiveness for this purpose is mixed (Grabovac et al., 2020).

At least 15% of all Canadians have tried an e-cigarette at least once, but only one third of former or current smokers have used e-cigarettes for smoking cessation (Statistics Canada, 2020). Young Canadians have been especially quick to adopt these devices and the prevalence of e-cigarette use among adolescents well exceeds that of adults (Statistics Canada, 2020). Similarly, current use among Canadian adolescents exceeds use among adults in the United States and England (Dai & Leventhal, 2019; Hammond et al., 2019; McNeill et al., 2020). Among Canadian adolescents in 2018-19, more than 30% have tried an e-cigarette at least once and 20% are current users (Health Canada, 2019b). These figures represent a two-fold increase from 2016-17. This is in stark contrast to smoking among Canadian adolescents, whereas only 19% have ever tried smoking and 3% are current smokers (Health Canada, 2019b).

The unknown consequences of long-term vaping are of concern to public health (Palazzolo, 2013). Identifying the short-term harms of vaping may inform public health policies and actions that aim to reduce or eliminate e-cigarette use among adolescents before long-term harms occur. To date, research has revealed more frequent respiratory symptoms (e.g., cough) among adolescent e-cigarette users than non-users (McConnell et al., 2017). Of special concern are the chemical additives contained in e-cigarette products (e.g., flavoured e-juices), which could be harmful to the lungs (Barrington-Trimis et al., 2014; Tierney et al., 2016). One of these additives, vitamin E acetate, gained attention in August 2019 when an outbreak of lung injury associated with the use of e-cigarette products (EVALI) occurred in the United States and Canada (Kalininskiy et al., 2019).

As of August 2020, 2807 cases had been identified in the United States and 20 in Canada (Centers for Disease Control and Prevention, 2020; Health Canada, 2020). The United States Centers for Disease Control and Prevention have determined that the outbreak was primarily a result of vitamin E acetate, a chemical additive most often found in e-cigarettes containing tetrahydrocannabinol (Centers for Disease Control and Prevention, 2020).

Given that the majority of adolescent e-cigarette users vape products containing nicotine, they are especially vulnerable to nicotine dependence (Vogel et al., 2020). It is well evidenced that nicotine dependence facilitates continued cigarette use among adolescents (Rojas et al., 1998). Further, adolescents who are nicotine dependent as they enter adulthood experience more negative health effects (e.g., chest pain, dizziness) than adolescents who are not nicotine dependent entering adulthood (Griesler et al., 2016). Adolescents also become nicotine dependent more easily than adults, even when consuming low levels of nicotine. However, adolescents may be less sensitive to nicotinic effects and withdrawal symptoms than adults (DiFranza et al., 2007; US Department of Health and Human Services (HHS), 2016). Though nicotinic effects appear to be a motivation for vaping among adolescent e-cigarette users, with many users citing a nicotine/head rush as a positive aspect of vaping, negative nicotinic effects (e.g., withdrawal symptoms) are still commonly reported by adolescent e-cigarette users (Al-Hamdani et al., 2020; Kong et al., 2019).

Nicotinic effects and nicotine dependence, by way of cigarette use, e-cigarette use, or both, may impact adolescent sleep health. It is well documented that cigarette use is a risk factor for disrupted sleep among both adolescents and adults, including trouble

falling and staying asleep, daytime sleepiness, and snoring (e.g., Mak et al., 2010; Phillips & Danner, 1995). It is likely that cigarette use impacts sleep architecture, directly and indirectly, through nicotinic effects (Zhang et al., 2006). Despite the evidence on cigarette use and sleep, little research has examined the relationship between e-cigarette use and sleep among adolescents. Given that modern e-cigarettes can deliver nicotine quickly and in high quantities with few adverse sensations (e.g., odour, taste), as compared to combustible cigarettes and earlier generation e-cigarettes, the sleep-related harms of e-cigarette use may be more pronounced than for cigarette use (Al-Hamdani et al., 2020). These two major public health concerns, cigarette and e-cigarette use and sleep health among adolescents, warrant further investigation.

Poor sleep health has been identified as a problem among adolescents and is common worldwide (Chaput, 2019; Gariepy et al., 2020). In Canada, it is estimated that 1 in 3 adolescents is not getting enough sleep (Chaput & Janssen, 2016). The Canadian 24-Hour Movement Guidelines for Children and Youth (herein referred to as 24MG) was introduced in 2016 in an effort to provide evidence-based recommendations in the areas of physical activity, sleep, and sedentary behaviours among children and youth aged 5-17 years (Canadian Society for Exercise Physiology, 2019). This guideline was driven by evidence from systematic reviews and presents recommended sleep durations for adolescents. Hence, there is cause for concern and a need for evidence to help improve adolescent sleep health. The consequences of inadequate sleep among adolescents are severalfold. Sleep is fundamental for physical growth and cognitive development (Kopasz et al., 2010). Of interest with respect to the COVID-19 pandemic, sleep also affects one's immune response (Opp & Krueger, 2015). Inadequate sleep is associated

with poorer physical health (e.g., obesity), mental health, and academic performance (Chaput et al., 2016; Dewald et al., 2010).

The aim of this study was to determine whether the frequency of cigarette and/or e-cigarette use is associated with sleep health among Canadian adolescents. The next section will review the current state of knowledge on cigarette and e-cigarette use separately with respect to sleep health and identify gaps that were addressed by this study.

CHAPTER 2. LITERATURE REVIEW

2.1 PATHWAYS BY WHICH CIGARETTE AND/OR E-CIGARETTE USE AFFECTS SLEEP

The causal mechanism(s) by which cigarette and e-cigarette use impact sleep health remain undetermined. However, several researchers have pointed to nicotine as the most likely central mechanism of this relationship.

It has been hypothesized that nicotine impacts neurotransmitter release in a manner that disrupts the sleep-wake cycle and that nicotine withdrawal disturbs sleeping (Zhang et al., 2006). This theory is well supported by the research thus far that identifies a relationship between nicotine withdrawal and sleep (Ashare et al., 2017; Jaehne et al., 2015; Purani et al., 2019). It is possible that the effects of nicotine are more pronounced for e-cigarette users for several reasons. Unlike cigarettes, e-cigarettes can be used with varying concentrations of nicotine and delivery can be customized on some devices. Potentially related to this fact is the finding that regular e-cigarette users may experience faster absorption of nicotine and obtain higher plasma levels of nicotine compared to cigarette users (Farsalinos et al., 2015). For adolescents specifically, the convenience of being able to use e-cigarettes discreetly (e.g., in their bedrooms) compared to cigarettes could have implications for how much nicotine they consume before sleep (Al-Hamdani et al., 2020).

2.2 CIGARETTE USE AND SLEEP HEALTH

Decades of research investigating cigarette use and sleep health have resulted in inconsistent findings, drawing on diverse populations and employing a wide range of

measures and methods. These findings will be discussed with consideration of differences in methodology and in the context of both adult and adolescent populations.

One of the earliest findings concerning smoking and sleep among adolescents was that smoking among 14-year-olds in England was associated with later bedtimes and shorter sleep durations than in non-smoking peers (Macgregor & Balding, 1988). This cross-sectional study relied on self-report data, and this has continued to be a common method to assess sleep, particularly among adolescents. This is in line with the findings of another cross-sectional study that found that regular adolescent (ages 13-17) smokers (at least one cigarette per week) in the United Kingdom reported shorter sleep durations than never smokers (Townsend et al., 1991). However, it should be noted that the definition of smoking status by these authors does not correspond to contemporary definitions of regular smoking and may not differentiate experimental and regular smokers (Lee & Halpern-Felsher, 2011). It should also be noted that when comparing smokers to non-smokers, the results may be confounded by unmeasured latent constructs (e.g., risk taking) that make smokers and non-smokers characteristically different with respect to their sleep habits. This study did not identify any differences by sex (Townsend et al., 1991).

A longitudinal study of adults in the United States found that current smoking was associated with sleep, specifically difficulty falling asleep and waking up (i.e., getting out of bed) (Wetter & Young, 1994). This study identified sex differences, where smoking among females was associated with difficulty staying awake during the day and smoking among males was associated with nightmares/disturbing dreams. This study relied on self-report data for both smoking status and sleep. No conclusions were made with

respect to frequency of smoking. Similarly, another study analyzed self-report data for sleep among adults in the United States by comparing smokers to non-smokers and had similar findings (i.e., sleep-related problems more prevalent among smokers than non-smokers) (Mcnamara et al., 2014).

A cross-sectional study of individuals aged 14 to 84 years in the United States revealed that smoking was associated with several aspects of sleep such as sleep quality (e.g., problems falling/staying asleep) and impairment in daytime functioning (Phillips & Danner, 1995). However, after controlling for caffeine intake and depression symptoms, smoking was only associated with problems staying asleep and staying awake during the day, but not falling asleep. This study relied on author-generated measures concerning sleep. The authors also note that women reported more frequent sleep difficulties than men.

A longitudinal study examining adolescents aged 12 to 18 years in the United States found that smoking had a dose-response relationship with later development and recurrence of sleep problems. These authors also assessed depressive symptoms, which revealed no interaction with smoking status with respect to sleep problems (Patten et al., 2000). Other studies have assessed sleep problems and quality of sleep and found a similar relationship. For example, a cross-sectional study of adults in the United States found that smokers have two-fold odds of self-reported insufficient sleep in the past 30 days than non-smokers (Sabanayagam & Shankar, 2011). Similarly, a case-control study of German adults found that greater nicotine dependence and smoking frequency are associated with shorter sleep duration (Cohrs et al., 2014).

A sample of individuals aged 20 to 98 in the United States completed sleep diaries and self-reported smoking frequency. The findings of this retrospective study indicate that, after controlling for a set of physical, behavioural, and psychological health-related variables, only light smoking (less than 15 cigarettes per day), and not heavy smoking, was associated with chronic insomnia and reduced sleep duration (Riedel et al., 2004). This is in contradiction with earlier findings suggesting a dose-response relationship between smoking and sleep problems (Patten et al., 2000). However, a strength of this study is that it shed light on a multitude of factors that may be implicated in the relationship between smoking and sleep. The authors of this study explain their findings by suggesting that previous studies examining smoking and sleep have typically adjusted for only one related variable (e.g., depressive symptoms), rather than several simultaneously.

One of the limitations of studies examining the association between smoking and sleep health is the reliance on self-report data. In response to this, a study was conducted in the United States that used polysomnography to record sleep architecture among adults. The findings revealed that current smokers took longer to fall asleep, had shorter sleep durations, and less slow wave sleep (less deep sleep) than never smokers (Zhang et al., 2006). Similar findings were revealed in a later study, in addition to the findings that smokers experience more frequent sleep apnea and leg movements and rate their quality of sleep lower than non-smokers (Jaehne et al., 2012). Researchers have also considered objective measures of cigarette use instead of relying on self-reports. A study of adult participants in the Canadian Health Measures Survey found that exposure to tobacco smoke (measured by urinary cotinine) was associated with greater odds of inappropriate

sleep duration (too short or too long), difficulty falling or staying asleep, and sleep quality (Zandy et al., 2020).

More recent studies have considered the role of nicotine withdrawal in the relationship between smoking and sleep health. A cohort study of German adult smokers revealed that former smokers experienced greater nighttime arousal while attempting cessation than prior to attempting cessation (Jaehne et al., 2015). This finding has been extended to adult smokers in the United States receiving treatment for smoking cessation, where smokers who were assigned a treatment reported more frequent sleep disturbances than smokers who were assigned a placebo (Ashare et al., 2017). Conversely, adult smokers who report a lower degree of withdrawal, craving, and smoking urges experience better sleep quality than smokers who report higher degrees of these smoking-related symptoms (Purani et al., 2019).

2.3 E-CIGARETTE USE AND SLEEP HEALTH

There are few studies to date which have examined e-cigarette use and sleep health. The evidence that has been published so far suggests that there may be a relationship between e-cigarette use and sleep health. However, this evidence is mostly limited to mostly adult populations. Further, the wide variety of sleep-related outcomes examined in these studies makes comparing findings difficult.

A cross-sectional study of 2488 high-schoolers in the United States identified that e-cigarette users reported shorter weekend sleep durations, but not shorter weekday sleep duration or worse sleep quality, compared to non-users (Dunbar et al., 2017). No differences were found with respect to sleep health among cigarette-only users or dual users compared to e-cigarette only users. However, the authors of this study defined e-

cigarette and cigarette use as ever using either one of these products (or both) within the last year, which limits any conclusions that can be made with respect to frequency of cigarette and/or e-cigarette use and sleep health.

A cross-sectional study of 9588 adolescents aged 12 to 17 in the United States found that participants who reported past-year e-cigarette use were more likely to report sleep-related complaints (sleep-related complaints in the past year versus no sleep-related complaints in the last year) than non-users, and dual cigarette and e-cigarette users were even more likely to report these than e-cigarette only users (Riehm et al., 2019). Cigarette only users were also more likely to report sleep-related complaints than non-users, but not after adjusting for emotional and behavioural health. However, like Dunbar et al. (2017), this study is limited by defining cigarette and e-cigarette use as ever use in the past year, thus lacking a frequency measure.

A cross-sectional study of 1664 college students in the United States found that daily and non-daily e-cigarette users, in addition to cigarette users, experienced worse sleep health as a global score, as measured by the Pittsburgh Sleep Quality Index, than non-users. However, the authors found no association between sleep duration and cigarette and e-cigarette use (Brett et al., 2019). It is noteworthy that the authors of this study excluded dual users. Another cross-sectional study of 304 e-cigarette users in the United States found that global sleep quality was associated with e-cigarette dependence (Zvolensky et al., 2019).

A cross-sectional study of 19701 adults in the United States examined the relationship between e-cigarette use and sleep deprivation (< 7 hours per night) (Kianersi et al., 2021). The authors of this study did not consider dual use of cigarettes/e-cigarettes.

Their findings revealed a potential dose-response relationship between e-cigarette use and sleep deprivation (i.e., greater e-cigarette use associated with greater likelihood of sleep deprivation).

One of the few studies to date considering dual users and sleep duration examined 2889 adult participants in the United States and found that e-cigarette only users and dual users were more likely to report shorter sleep durations than never-users, even after adjusting for sociodemographic and other sleep-related (e.g., snoring) variables (Wiener et al., 2020). Interestingly, in contrast to most of the aforementioned literature, another recent study examining 14638 adolescents in the United States found that cigarette and e-cigarette use was not associated with insufficient sleep (Kwon et al., 2020). The authors suggest that the lack of relationship may be attributed to the fact that they controlled for computer use, which is an independent predictor of sleep, whereas many previous studies have not. However, this may also be attributed to the authors defining the outcome, insufficient sleep, dichotomously as either meeting or not meeting 8 hours of sleep duration per night, even though their participants ranged from 14 to 18 years old. Since recommended sleep durations vary within this age group, the cut-off of 8 hours per night may not be appropriate (Canadian Society for Exercise Physiology, 2019).

CHAPTER 3. LIMITATIONS OF EXISTING LITERATURE

From the existing evidence, there is sufficient evidence to suggest that cigarette use is associated with sleep health. Namely, that cigarette use may impact sleep duration and quality. However, there are still several limitations in this body of evidence that should be considered and, as such, further investigation of this relationship is needed. Several studies lack appropriate measures for defining smoking status that cannot speak to smoking frequency, which helps differentiate experimental and regular smokers (Lee & Halpern-Felsher, 2011; Macgregor & Balding, 1988; Wetter & Young, 1994). This limitation is compounded by the fact that most studies have relied on self-report data, which could be subject to recall bias and over- and under-reporting. Additionally, there are inconsistent findings on other factors that may impact the relationship between cigarette use and sleep, including important confounders such as caffeine intake, alcohol consumption, and poor mental health (Patten et al., 2000; Phillips & Danner, 1995).

In contrast, a select number of studies have investigated e-cigarette use and its relationship with a variety of sleep-related outcomes. However, only a handful of studies have examined large, representative adolescent populations. From the limited evidence available, it appears that e-cigarette use may be related to aspects of sleep that are similarly related to cigarette use. However, some caveats must be considered. Firstly, some authors have defined e-cigarette use as at least once in the past year and do not consider frequency of use (Dunbar et al., 2017; Riehm et al., 2019). Secondly, studies have not examined dual use of cigarettes and e-cigarettes (Brett et al., 2019; Kianersi et al., 2021). It is necessary to examine whether e-cigarette use is associated with sleep to reveal whether e-cigarette use impacts aspects of sleep health in a different or comparable

manner to cigarette use. Even though e-cigarettes and cigarettes are often viewed as complementary, or at least closely related, products, they may act differently when we consider how they could affect sleep. For instance, it is much easier for adolescents to hide their e-cigarette use, compared to cigarette use, from parents and this could mean that adolescents use e-cigarettes in their bedrooms near bedtime without detection (Ramamurthi et al., 2019). Further, it is necessary to differentiate how exclusive users (e.g., e-cigarette user only), dual users (e.g., e-cigarette and cigarette user), and non-users report their sleep. This is especially important given the complex relationship between e-cigarette and cigarette use. Specifically, e-cigarette users who have not otherwise used cigarettes may be attracted to using cigarettes because of nicotine addiction. Several studies to date have found evidence to support that e-cigarette use among youth is associated with later cigarette use (Berry et al., 2019; Hair et al., 2020; Hammond et al., 2017; Primack et al., 2015). If there is renewed interest in smoking among adolescents, whether a consequence of increases in vaping among this population or not, it is ideal to differentiate exclusive cigarette or e-cigarette users and dual users.

Thirdly, there has been a mix of sleep-related outcomes examined that do not depict a clear picture of the relationship between cigarette and/or e-cigarette use and sleep. It is valuable to examine subjective experiences related to sleep (e.g., falling asleep during a class), in addition to sleep duration, because duration alone does not capture the practical implications of lost sleep that may result from cigarette and/or e-cigarette use.

Finally, tobacco use is more prevalent among males than females and sex differences have been identified in previous studies concerning sleep health (Health Canada, 2019b; Mcnamara et al., 2014), but given the novelty of e-cigarette products,

there is limited evidence available on the role of sex in the relationship between cigarette and/or e-cigarette use and sleep health. Together, these limitations restrict what we can infer about the granular nature of the association between cigarette and/or e-cigarette use and sleep health.

CHAPTER 4. OBJECTIVES

4.1 OBJECTIVE 1

To determine the associations between frequency of cigarette and/or e-cigarette use and self-reported sleep duration among Canadian adolescents.

4.2 OBJECTIVE 2

To determine the associations between frequency of cigarette and/or e-cigarette use and fulfilment of the 24MG sleep duration recommendation (8-10 hours per night) among Canadian adolescents.

4.3 OBJECTIVE 3

To determine the associations between frequency of cigarette and/or e-cigarette use and the occurrence of sleep-related problems among Canadian adolescents.

4.4 OBJECTIVE 4

To determine whether the associations between frequency of cigarette and/or e-cigarette use and sleep duration, fulfilment of sleep duration recommendation, and occurrence of sleep-related problems among Canadian adolescents differ by sex.

CHAPTER 5. METHODS

5.1 DATA

This study was a secondary analysis of data from the 2018-19 Canadian Student Tobacco, Alcohol and Drugs Survey (CSTADS). CSTADS is a cross-sectional survey that collects data on substance use behaviours and other national health priorities (e.g., sleep) in a representative sample of Canadian students. A stratified single-stage cluster sampling procedure is used. Adolescents residing in institutions or attending special, First Nation reserves, or Canadian Armed Forces schools are not sampled. The 2018-19 iteration of the survey included 62,850 students in grades 7-12 in all ten Canadian provinces. Data collection took place in classrooms between October 2018 and June 2019.

This study examined students in grades 9-12. Given that the prevalence of current daily and current occasional smoking is less than 1% in grades 7-8, the conclusions that can be drawn about cigarette use is limited; these respondents were thus not included in this analysis (Health Canada, 2019b).

5.2 EXPOSURE VARIABLE

Respondents were asked “On how many of the last 30 days did you smoke one or more cigarettes?”. Response options included “none”, “1 day”, “2 to 3 days”, “4 to 5 days”, “6 to 10 days”, “11 to 20 days”, “21 to 29 days”, and “30 days (every day)”. Similarly, respondents were asked “In the last 30 days, did you use any of the following?” followed by the description “E-cigarettes (vape, vape pen, tank, and mod) with nicotine”. Response options included “daily or almost daily”, “less than daily, but at

least once a week", "less than weekly, but at least once in the last 30 days", "tried, but did not use in the last 30 days", and "I have never tried".

Respondents were grouped based on their frequency of cigarette and/or e-cigarette use in the 30 days prior to survey administration. There is no widely used standard classification of dual use of cigarettes and e-cigarettes, which presents challenges for comparing findings from other studies. Using a modified classification from other researchers who have attempted to classify dual use, cigarette and/or e-cigarette use was derived into a single categorical variable with nine levels (Figure 1; Azagba et al., 2019). What differs in this classification from that of Azabga et al. (2019) is that cigarette and e-cigarette only users were further categorized into low- and high-frequency groups, whereas Azagba et al. (2019) did not make this distinction. This measure not only characterizes past 30-day use of cigarettes and/or e-cigarettes, but also differentiate users who use e-cigarettes and/or cigarettes more compulsively (high frequency) than others (low frequency).

Respondents that reported cigarette use on 20 days or fewer were coded as low-frequency and those that report use on 21-30 days were coded as high-frequency. Respondents that reported no use were coded as non-users. The threshold of 21 days to represent high-frequency use, rather than 30 days, was chosen so that respondents who experience temporary lapses, for reasons such as such as financial restraints, were not excluded (Azagba et al., 2019). To allow comparisons between cigarette and e-cigarette use, "daily or almost daily" was coded as high-frequency, "less than daily, but at least once a week" and "less than weekly, but at least once in the last 30 days" as low-frequency, and "tried, but did not use in the last 30 days" and "I have never tried" as non-

user. This method has been used by other researchers working with CSTADS data to group users according to Azagba et al.'s (2019) classification (Shan et al., 2020).

Past-30-day cigarette use			
	High-frequency cigarette only user	High-frequency cigarette dual user	High-frequency dual user
	Low-frequency cigarette only user	Low-frequency dual user	High-frequency e-cigarette dual user
	Non-user	Low-frequency e-cigarette only user	High frequency e-cigarette only user
	Past-30-day e-cigarette use		

Figure 1: Classification of respondents by frequency of cigarette and/or e-cigarette use in the past 30 days (exposure variable).

5.3 OUTCOMES

5.3.1 Sleep Duration

The primary outcome measure was sleep duration, which is based on the self-reported average time between going to sleep and waking up on weeknights and weekends.

Respondents were asked "On a typical school night (Sunday to Thursday), what time do fall asleep? (Select option between 6:00pm and 4:45am)" and "On a typical school morning (Monday to Friday), what time do you wake up? (Select option between 5:00am and 4:45pm)." These questions were developed by CTSADS investigators but closely resemble other self-report measures of sleep duration (e.g., Meltzer et al., 2016). However, these questions as specifically phrased in the CSTADS questionnaire have not been validated. Sleep duration was coded as a single continuous variable that is an average of how many hours of sleep respondents reported per night on weekdays and weekends. This was further converted from hours to minutes to improve interpretability of the analyses.

5.3.2 24MG Recommendation

The second outcome measured whether respondents meet sleep durations as recommended by 24MG. For adolescents aged 14-17 years (the approximate age range of our sample), 8-10 hours of sleep per night, with consistent sleep and wake times, is recommended (Canadian Society for Exercise Physiology, 2019).

Average sleep duration was used to create a dichotomous outcome, meeting 24MG. More specifically, responses were coded as to whether their self-reported sleep duration either met or did not meet this recommended sleep duration. For the purpose of this study, all respondents were coded as meeting the sleep recommendation if they reported 8-10 hours per night, despite the fact that there may be a select number of students in grades 9 to 12 who are more than 18 years old. This is due to lack of an age variable available for this study.

5.3.3 Sleep-Related Problems

The third outcome measures the experience of sleep-related problems. Respondents were asked to report the frequency of 12 sleep-related problems in the past two weeks with response options of “every day/night”, “several times”, “twice”, “once”, and “never”. The sleep-related problems were:

1. Felt satisfied with your sleep?
2. Slept past noon?
3. Arrived late to class because you overslept?
4. Felt tired, dragged out, or sleepy during the day?
5. Fallen asleep in a morning class?
6. Needed more than one reminder to get up in the morning?
7. Fallen asleep in an afternoon class?
8. Had an extremely hard time falling asleep?
9. Stayed up until at least 3 a.m.?
10. Gone to bed because you just couldn’t stay awake any longer?
11. Stayed up all night?

12. Struggled to stay awake while reading, studying, or doing homework?

5.4 COVARIATES

The selection of covariates was informed by the Social-Ecological Model of Sleep Health, which includes a nested series of constructs believed to impact sleep health at the individual-, social-, and societal-levels (Grandner, 2019). Covariates were chosen from the CSTADS questionnaire if they have been associated with e-cigarette/cigarette use (more broadly nicotine use), sleep health, or both.

Sex was included because tobacco use is more prevalent among males than females and sex differences have been identified in previous studies concerning sleep health (Health Canada, 2019b; Mcnamara et al., 2014).

Use of controlled substances that are legal for purchase in Canada was included, including past 30-day alcohol use and cannabis use ("In the last 30 days, how often did you have a drink of alcohol that was more than one sip?" and "In the last 30 days, how often did you use marijuana or cannabis?"). Both alcohol and cannabis use have been found to have both positive and negative effects on sleep health (Babson et al., 2017; Ebrahim et al., 2013). Use of illicit and prescription substances may also affect sleep and were considered (e.g., McCann & Ricaurte, 2007; Rechtschaffen & Maron, 1964). Illicit substance use was coded as yes/no according to whether participants report ever-use of at least one illicit substance (MDMA, hallucinogens, heroin, cocaine, BZP/TFMPP, bath salts, 2C, tryptamines, glue/gasoline, and salvia) in the past year. Likewise, use of at least one prescription medication (sleeping medicine, stimulants, dextromethorphan, Gravol, hyperactivity or ADHD medication, sedatives/tranquilizers, oxycodone, and fentanyl) for non-medicinal purposes (e.g., to get high) in the past year was coded as yes/no.

Electronic device use before sleep ("Do you use electronics (e.g., TV, video games, computer, tablet, or smartphone) before bedtime?") was considered. Previous research has demonstrated that electronic device use, especially close to bedtime, negatively affects adolescent sleep health (Hysing et al., 2015).

The CSTADS questionnaire does not collect data with respect to socioeconomic status. Instead, median household income at the school level was obtained from Statistics Canada by the CSTADS researchers and matched to the first three digits of the school's postal code. Thus, median household income at the school level was considered as a proxy measure of socioeconomic status (SES). SES has been associated with both cigarette and e-cigarette use as well as sleep health (Grandner et al., 2010; Hiscock et al., 2012; Krishnan-Sarin et al., 2019).

5.5 STATISTICAL ANALYSIS

All analyses were conducted using Stata 16.0. Statistical significance for all objectives was defined as $p < 0.05$.

5.5.1 Sample Selection and Survey Weights

To account for the complex survey design of CSTADS and to derive population estimates, sampling and bootstrap weights provided by Statistics Canada were used in analyses. The Stata commands "svyset" and "svy" were used to apply these weights. The "subpopulation" command was used to specify the analytic sample.

5.5.2 Model Assumptions

Multicollinearity of the exposure and covariate variables was assessed by computing correlations and variance inflation factors (variance inflation factor > 10

considered high correlation and problematic). The distributions of each outcome were confirmed to be a normal distribution using histograms and quantile-quantile plots.

5.5.3 Objective 1

To estimate the association between frequency of cigarette and/or e-cigarette use (exposure defined in Figure 1) and sleep duration (in minutes) as the outcome, a multiple linear regression was used. Linear regression was chosen because the outcome was continuous and because of the linear relationship between the exposure and outcome variables. Unadjusted and adjusted beta coefficients and 95% confidence intervals were computed using sampling and bootstrapping weights. Adjusted analysis controlled for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

5.5.4 Objective 2

To estimate the association between frequency of cigarette and/or e-cigarette use (exposure; Figure 1) and meeting the 24MG sleep duration recommendation as the outcome, a multiple logistic regression was used. Logistic regression was chosen because the outcome is binary. Unadjusted and adjusted odds ratios and 95% confidence intervals were computed using sampling and bootstrapping weights. Adjusted analysis controlled for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

5.5.5 Objective 3

Exploratory factor analysis was conducted to determine whether the 12 sleep-related problem variables could be reduced into a fewer number of latent variables to

investigate the association between frequency of cigarette and/or e-cigarette use (exposure; Figure 1) and sleep-related problems (Yong & Pearce, 2013). This method allowed the reduction of the 12 variables into a fewer number of constructs that could be used as outcomes in this analysis.

Item 1 ("Felt satisfied with your sleep?") was reverse coded to reflect feeling unsatisfied with sleep to correspond with the remaining sleep-related problem variables.

A Kaiser-Meyer-Olkin test of sampling adequacy and a Bartlett's test of sphericity were performed to determine whether the 12 variables met the necessary conditions to perform exploratory factor analysis. Multicollinearity of variables was tested. Different rotation methods were tested to determine the appropriate method for the final factor solution. The number of factors in the final solution was chosen based on an eigen value greater than 1 and with a visual confirmation in a scree plot.

The predicted factor scores were estimated for each factor in the final solution using the least squares regression approach (DiStefano et al., 2009). This method standardizes the observed values (mean of 0) of the items in each factor, taking into consideration the correlation between the factors and observed variables and the correlation among observed variables. These scores were obtained for the final factor solution by using the "predict" command in Stata to produce new variables drawn from respondents' scores for each factor. Higher factor scores indicate a higher frequency of these problems.

The predicted scores were used as a continuous outcome variable for three multiple linear regressions (for each latent construct) with cigarette/e-cigarette use as the exposure (Figure 1). Unadjusted and adjusted beta coefficients and 95% confidence

intervals were computed using sampling and bootstrap weights. Adjusted analysis controlled for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

5.5.6 Objective 4

Within each of the previously described analyses an interaction of the exposure variable and sex was used to determine whether sex-specific interaction effects were observed. If the effect differed, it would suggest that the association between the frequency of cigarette and/or e-cigarette use and any of the given outcomes is modified by sex.

5.5.7 Missing Data

As the CSTADS questionnaire draws on respondent self-reports, several variables suffered from high rates of non-response (e.g., 11.8% missing data for sleep duration variables, 15.8% missing data for sleep-related problems variables). Respondents that were missing values for the exposure variable were not included in the analysis. Respondents that had missing data for any of the covariates were coded as "missing" within the covariate so that they could still be included in analyses. Respondents that had missing data for any given outcome variable were not included in the analysis for that particular outcome. This is an ideal approach for this study given the large sample size (Kang, 2013).

CHAPTER 6. RESULTS

6.1 SAMPLE CHARACTERISTICS

The sample consisted of 62,850 students, 38,229 of whom were in grades 9 through 12 and thus eligible for analysis. Nine hundred and ninety-five cases (2.6%) were missing data for the exposure variable and 11 cases (0.03%) were missing data for all outcomes and thus not included in analyses. The remaining analytic sample consisted of 37,223 respondents. Among the eligible population, 75.1% were classified as non-users, 11.6% as low-frequency e-cigarette only users, 6.0% as high-frequency e-cigarette only users, 1.0% as low-frequency cigarette only users, 0.4% as high-frequency cigarette only users, 1.8% as low-frequency dual users, 0.9% as high-frequency dual users, 0.5% as high-frequency cigarette dual users, and 2.6% as high-frequency e-cigarette dual users (Table 1). The descriptive characteristics of the sample are presented in Table 2. Respondents were equally distributed by sex. Most respondents did not use alcohol, cannabis, illicit drugs, or prescription drugs to get high in the past 30 days. Most respondents reported using electronic devices 0.5- to 2-hours before sleep. Median household income ranged from $67,140 to $80,741. The three outcomes by the exposure classification are presented in Table 3.

6.2 RESULTS FOR OBJECTIVE 1

Three thousand five hundred and twenty-six respondents (9.5%) were removed from analysis due to missing values for the sleep duration variables, leaving an analytic sample of 33,697 for objective 1. The average sleep duration for the entire sample was 475.45 minutes per night (standard error = 1.51). The smoothed distributions of the

outcome variable (average sleep duration) are presented in Figure 2 by the exposure variable.

The unadjusted and adjusted associations between frequency of cigarette and/or e-cigarette use, and self-reported sleep duration, are presented in Table 4. In the unadjusted analysis, high-frequency e-cigarette only users, low-frequency cigarette only users, low-frequency dual users, high-frequency dual users, high-frequency cigarette dual users, and high-frequency e-cigarette dual users reported significantly shorter sleep durations than non-users.

In the adjusted analysis, high-frequency e-cigarette only users ($\beta = -14.95$, $p < 0.01$, 95% CI: -25.27, -4.33), low-frequency cigarette only users ($\beta = -25.27$, $p < 0.05$, 95% CI: -44.99, -5.54), and high-frequency dual users ($\beta = -30.41$, $p < 0.05$, 95% CI: -55.02, -5.81) reported significantly shorter average sleep durations than non-users.

In both unadjusted and adjusted analyses, high-frequency dual users and low-frequency cigarette only users reported the shortest average sleep duration compared to non-users. Overall, all groups of e-cigarette users had similar sleep durations compared to non-users.

Three estimates were attenuated in the adjusted model (low-frequency dual users, high-frequency cigarette dual users, and high-frequency e-cigarette dual users). The estimates in the unadjusted model were highly attenuated by the inclusion of covariates in the adjusted model, particularly for the four dual user groups and high-frequency cigarette only users.

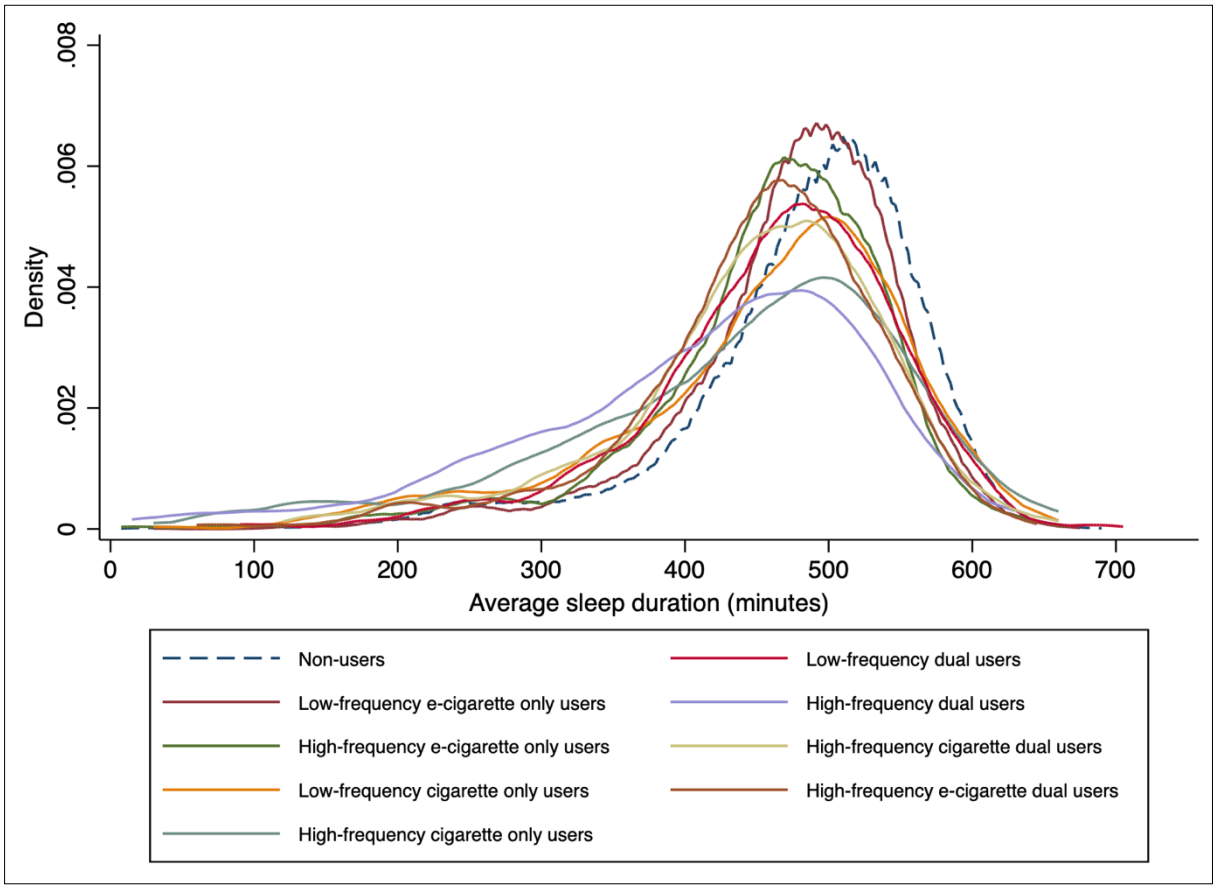

Figure 2: Kernel-Density plot depicting distributions of average sleep duration (minutes) by frequency of cigarette and/or e-cigarette use (exposure variable) of Canadian students grades 9-12 (2018-19 CSTADS), n = 33,697.

6.3 RESULTS FOR OBJECTIVE 2

Three thousand five hundred and twenty-six respondents (9.5%) were removed from the analysis due to missing values for sleep duration variables, leaving an analytic sample of 33,697 for objective 2. Overall, nearly 58% of the study population met the national sleep recommendation of 8-10 hours per night. The unadjusted and adjusted associations between frequency of cigarette and/or e-cigarette use and fulfilment of the 24MG sleep duration recommendation are presented in Table 5.

In the unadjusted analysis, low-frequency e-cigarette only users, high-frequency e-cigarette only users, low-frequency cigarette only users, low-frequency dual users,

high-frequency dual users, high-frequency cigarette dual users, and high-frequency e-cigarette dual users had lower odds of meeting the sleep duration recommendation of 8-10 hours per night compared to non-users.

In the adjusted analysis, high-frequency e-cigarette only users (AOR = 0.76, $p < 0.05$, 95% CI: 0.58, 0.99) and high-frequency e-cigarette dual users (AOR = 0.70, $p < 0.05$, 95% CI: 0.53, 0.93) had lower odds of meeting the sleep duration recommendation of 8-10 hours per night compared to non-users.

In the unadjusted analysis, high-frequency dual users were the least likely to meet the recommended sleep duration. In the adjusted analysis, the odds ratio for both high-frequency e-cigarette only users and high-frequency e-cigarette dual users were similar. Five estimates that were significant in the unadjusted model became non-significant in the adjusted model (low-frequency e-cigarette only users, low-frequency cigarette only users, low-frequency dual users, high-frequency dual users, and high frequency cigarette dual users). Estimates in the unadjusted model were slightly attenuated in the adjusted model but did not change the nature of the associations.

6.4 RESULTS FOR OBJECTIVE 3

Five thousand and thirty-seven respondents (13.5%) were removed from the analysis due to missing values for the sleep-related problems variables, leaving an analytic sample of 32,186 for objective 3.

6.4.1 Exploratory Factor Analysis

The result of Kaiser-Meyer-Olkin's test of sampling adequacy was 0.83 and a Bartlett's test of sphericity was significant ($p < .001$), suggesting that the primary

assumptions were met to conduct an exploratory factor analysis for the purpose of data reduction.

The varimax orthogonal-rotated three-factor solution is presented in Table 6 with rotated item loadings. This solution was also tested with an oblimin rotation and produced similar results, so varimax orthogonal solution was retained. No items crossloaded on another factor (loading > 0.32; Cabrera-Nguyen, 2010). Variables were retained for a specific factor if their loading was greater than 0.40. The three-factor solution accounted for 56.8% of the variance.

Six items loaded on factor 1 (items 1, 4, 6, 7, 10, and 12), four on factor 2 (items 3, 9, 11, and 2), and two on factor 3 (items 5 and 7). Item loadings ranged from 0.56 to 0.92. Based on the nature of the questions, items loading on factor 1 characterized tiredness/fatigue, those loading on factor 2 characterized late sleeping, and those loading on factor 3 characterized falling asleep during class (Table 6). The internal consistency of these items was tested using Cronbach's alpha coefficients: 0.82 for all items, 0.75 for factor 1 (tiredness/fatigue), 0.74 for factor 2 (late sleeping), and .86 for factor 3 (falling asleep during class). These results suggest that the data had acceptable/good internal consistency and fit the model well.

6.4.2 Tiredness/Fatigue (Factor 1)

The unadjusted and adjusted associations between frequency of cigarette and/or e-cigarette use and tiredness/fatigue scores are presented in Table 7.

In unadjusted analysis, all users scored higher in tiredness/fatigue than non-users ($p < 0.001$). In adjusted analysis, low-frequency e-cigarette only users ($\beta = 0.20$, $p < 0.001$, 95% CI: 0.13, 0.27), high-frequency e-cigarette only users ($\beta = 0.31$, $p < .001$,

95% CI: 0.20, 0.41), low-frequency cigarette only users (β = 0.60, p < .001, 95% CI: 0.26, 0.94), high-frequency cigarette only users (β = 0.58, p < .001, 95% CI: 0.24, 0.93), high-frequency dual users (β = 0.96, p < .001, 95% CI: 0.44, 1.47), high-frequency cigarette dual users (β = 0.25, p < .05, 95% CI: 0.03, 0.47), and high-frequency e-cigarette dual users (β = 0.42, p < .001, 95% CI: 0.29, 0.56) scored higher on tiredness/fatigue than non-users.

In the unadjusted and adjusted analysis, high-frequency dual users scored highest on tiredness/fatigue. Only one estimate that was significant in the unadjusted model became non-significant in the adjusted model (low-frequency dual users). The estimates in the unadjusted model were attenuated in the adjusted model, particularly among high-frequency dual users.

6.4.3 Late Sleeping (Factor 2)

The unadjusted and adjusted associations between frequency of cigarette and/or e-cigarette use and late sleeping scores are presented in Table 8.

In unadjusted analysis, low-frequency cigarette only users (β = -0.36, p < 0.001, 95% CI: -0.55, -0.18), high-frequency cigarette only users (β = -0.42, p < 0.001, 95% CI: -0.68, -0.15), high-frequency dual users (β = -1.07, p < 0.001, 95% CI: -1.69, -0.45), high-frequency cigarette dual users (β = -0.45, p < 0.001, 95% CI: -0.60, -0.30), and high-frequency e-cigarette dual users (β = -0.26, p < 0.001, 95% CI: -0.42, -0.11) scored lower on late sleeping than non-users. In adjusted analysis, low-frequency cigarette only users (β = -0.32, p < 0.001, 95% CI: -0.44, -0.20), high-frequency dual users (β = -0.31, p < 0.01, 95% CI: -0.53, -0.08), and high-frequency cigarette dual users (β = -0.21, p < 0.001, 95% CI: -0.34, -0.07) scored lower on late sleeping than non-users.

In unadjusted analysis, high-frequency dual users scored lowest on late sleeping, while in adjusted analysis, low-frequency cigarette only users scored lowest.

Two estimates that were significant in the unadjusted model became non-significant in the adjusted model (high-frequency cigarette only users and high-frequency e-cigarette dual users). The estimates for low-frequency cigarette only and high-frequency cigarette dual users were slightly attenuated in the adjusted model while the estimate for high-frequency dual users was highly attenuated.

6.4.3 Falling Asleep During Class (Factor 3)

The unadjusted and adjusted associations between frequency of cigarette and/or e-cigarette use and falling asleep during class scores are presented in Table 9.

In unadjusted analysis, high-frequency cigarette only users ($\beta = -0.36$, $p < 0.05$, 95% CI: -0.64, -0.07) and high-frequency cigarette dual users ($\beta = -0.15$, $p < 0.001$, 95% CI: -0.30, 0.00) scored significantly lower on the measure falling asleep during class compared to non-users. In adjusted analysis, both groups remained the only significant groups ($\beta = -0.38$, $p < 0.01$, 95% CI: -0.65, -0.11; $\beta = -0.18$, $p < 0.001$, 95% CI: -0.31, -0.04), though the estimates were slightly attenuated in the adjusted model.

In both unadjusted and adjusted analysis, low-frequency cigarette only users scored lowest on falling asleep during class.

6.5 RESULTS FOR OBJECTIVE 4

The associations between frequency of cigarette and/or e-cigarette use and sleep duration, fulfilment of the 24MG sleep duration recommendations, and sleep-related

problems did not differ by sex in any interaction models with the exposure variable: frequency of cigarette and/or e-cigarette use (Table 10).

CHAPTER 7. DISCUSSION

7.1 MAIN FINDINGS

This study contributes new findings to the literature by considering both frequency of use and dual use of cigarettes and e-cigarettes among a large, nationally representative sample of Canadian adolescents. Though cigarettes and e-cigarettes are distinct products and the prevalence of their use among adolescents differs, they are the primary method of nicotine consumption in this population and are sometimes used interchangeably (Berry et al., 2019). However, the products may be distinct enough that they differentially affect sleep, underscoring the importance of investigating both for the purpose of this study. This study also provides new evidence on the role of sex in the relationship between cigarette and/or e-cigarette use and sleep health. The results of this study contribute four major findings to the literature:

1. High-frequency e-cigarette only, low-frequency cigarette only, and high-frequency dual users report fewer minutes of sleep per night on average than non-users.
2. High frequency e-cigarette only and e-cigarette dual using adolescents are the least likely to meet the national sleep duration recommendation of 8-10 hours per night compared to non-users.
3. Frequency of cigarette and/or e-cigarette use is associated with greater reports of tiredness/fatigue among adolescents, but fewer reports of late sleeping and falling asleep during class.

4. The association between frequency of cigarette and/or e-cigarette use and sleep duration, meeting the national sleep duration recommendation, and sleep-related problems among adolescents is not modified by sex.

These four findings are discussed in detail below.

7.1.1 Average Sleep Duration

The first objective of this study was to determine the associations between frequency of cigarette and/or e-cigarette use and self-reported sleep duration among Canadian adolescents. A leading theory is that nicotine impacts neurotransmitter release in a manner that disrupts the sleep-wake cycle (Zhang et al., 2006). However, the findings from this objective suggest that only select groups of cigarette and/or e-cigarette using adolescents report fewer minutes of sleep per night on average than non-users after controlling for covariates. High-frequency e-cigarette only, low-frequency cigarette only, and high-frequency dual users were the only groups to report shorter average sleep durations than non-users. The group most vulnerable to shorter sleep durations was high-frequency dual users who reported 30 less minutes of sleep per night compared to non-users.

With respect to cigarette only use, most of the existing literature suggests that adolescent and adult cigarette only smokers report shorter sleep durations than non-users (e.g., Macgregor & Balding, 1988; Townsend et al., 1991; Cohrs et al., 2014). However, many of these studies lack a frequency measure of smoking. The current study reveals that low-frequency, but not high-frequency, cigarette only users report less sleep than non-users. This finding is consistent with previous studies that suggests that only light

smokers (less than 15 cigarettes per day) report reduced sleep durations (Riedel et al., 2004).

With respect to e-cigarette only use, only high-frequency users reported less sleep than non-users and this is consistent with the previous finding that higher frequencies of e-cigarette use among young adults are associated with sleep deprivation (Kianersi et al., 2021). Previous research has shown that experienced (at least daily over the past month) e-cigarette users experience faster absorption of nicotine and obtain higher plasma levels of nicotine compared to cigarette users (Farsalinos et al., 2015). Adolescents that use e-cigarettes in lower frequencies may not experience the same effect of nicotine compared to high-frequency users. Additionally, nicotine withdrawal has been shown to disturb sleep duration and users in higher-frequencies may be more sensitive to/prone to withdrawal symptoms than lower-frequency users (Zhang et al., 2006). The finding that only higher-frequency e-cigarette users experience shorter sleep durations contradicts the finding that only lower-frequency cigarette only users report shorter sleep durations than non-users. One reason for this contradiction may be that e-cigarettes can be more readily used in higher frequencies and closer to bedtime than cigarettes. For example, adolescents, in particular, are known to hide their cigarette and e-cigarette use from parents (Jackler & Ramamurthi, 2019). Adolescents have cited e-cigarettes as preferable to cigarettes because they can more easily hide their use due to a lack of odour (Al-Hamdani et al., 2020). As such, adolescents may use e-cigarettes closer to bedtime without having to leave their bedrooms.

With respect to dual use of cigarettes and e-cigarettes, only users of both in high frequencies reported shorter sleep durations than non-users. This finding is in line with

the few studies to date that have examined dual use (Riehm et al., 2019; Wiener et al., 2020). A plausible explanation for this finding is that higher-frequency dual users consume the greatest amount of nicotine which may negatively affect sleep due to its stimulant properties. Furthermore, as with higher-frequency e-cigarette only users, higher-frequency dual users may be more prone to withdrawal symptoms that negatively impact sleep (Zhang et al., 2006).

Considering the aforementioned findings, it is not surprising that lower-frequency users, with some exceptions, do not report shorter sleep durations than non-users. This may indicate that lower-frequency users (20 days or less in the past month) do not consume enough nicotine or experience different biological effects of nicotine (e.g., absorption rate, withdrawal) in a manner that affects sleep. However, it is surprising that dual users who report either the use of cigarettes or e-cigarettes only in higher frequencies do not report shorter sleep durations relative to non-users. It is possible that these types of dual users consume different amounts of nicotine when compared to higher-frequency dual users (e.g., using a lower concentration of nicotine in e-cigarettes). To fully address this relationship, more research is needed to establish the unique characteristics of dual users that may help to explain how sleep health is affected. Furthermore, the failure to observe associations in these groups may be attributed to the covariates that were included in adjusted models. Most estimates were attenuated in the adjusted model, suggesting that these covariates may play a more important role in shaping sleep duration than the frequency of cigarette and e-cigarette use.

7.1.2 National Sleep Recommendation

The second objective of this study was to determine the associations between frequency of cigarette and/or e-cigarette use and fulfilment of the 24MG sleep duration recommendation among Canadian adolescents. Overall, this study demonstrates that more than 40% of Canadian adolescents do not meet the recommended sleep duration of 8 to 10 hours per night. This proportion is higher than previous estimates (28%; Chaput et al., 2016). This study also offers the novel finding of cigarette and/or e-cigarette users being less likely to meet the national sleep duration recommendation.

After controlling for covariates, only high-frequency e-cigarette only users and high-frequency e-cigarette dual users have lower odds of meeting the national sleep duration recommendation than non-users and that the estimates for these two types of users were similar. This finding is in line with existing research that identified that e-cigarette users are less likely to meet their recommended sleep duration (Wiener et al., 2020). The mean sleep duration for non-users was just under 8 hours per night, suggesting that many Canadian adolescents are not meeting the sleep duration recommendation regardless of cigarette and/or e-cigarette use. Thus, the finding that most cigarette and/or e-cigarette users had similar chances of meeting the sleep duration recommendation compared to non-users is not surprising. The authors of a previous study found that alcohol and cannabis use, but not cigarette or e-cigarette use, were associated with lower odds of getting 8 hours of sleep per night (Kwon et al., 2020). Given that the adjusted analysis controlled for the use of alcohol and cannabis, the decreased association between cigarette and/or e-cigarette use and sleep may be explained by these other behaviours. The finding that only higher-frequency e-cigarette users, either used alone or with cigarettes, were less likely to meet the recommended sleep duration guideline

suggests that e-cigarette use may be more strongly associated with sleep than traditional cigarette use. Overall, there is limited research considering frequency of and dual use of cigarettes and/or e-cigarettes and sleep health; more research is needed to clarify this association.

7.1.3 Sleep-Related Problems

The third objective of this study was to determine the associations between frequency of cigarette and/or e-cigarette use and the occurrence of sleep-related problems among Canadian adolescents. Through exploratory factor analysis, this analysis separately examined three dimensions of sleep-related problems: tiredness/fatigue, late sleeping, and falling asleep during class. Findings suggest that the frequency of cigarette and/or e-cigarette use was associated with greater reports of tiredness/fatigue among adolescents, but fewer reports of late sleeping and falling asleep during class.

With the exception of lower-frequency dual users, all user groups scored higher on tiredness/fatigue than non-users. However, the magnitude of the association differed across user groups. Higher-frequency dual users scored considerably higher than all other users, a not surprising finding given that this same group reported the least amount of sleep compared to non-users (as per objective 1). Previous studies that have examined cigarette and e-cigarette use found that users experienced greater sleep impairment symptoms than non-users, akin to feelings of tiredness/fatigue (e.g., Phillips & Danner, 1995; Riehm et al., 2019). One of the few studies to examine dual use found that dual users were more likely to report sleep-related problems than e-cigarette only users, which is consistent with this study (Riehem et al., 2019).

With respect to late sleeping, lower-frequency e-cigarette only users, higher-frequency dual users, and high-frequency cigarette dual users scored lower than non-users. These results suggest that these "night owl" behaviours that depict late sleeping (e.g., staying up all night) are not as common among cigarette and/or e-cigarette users compared to non-users. Fewer studies have examined late sleeping as an outcome of cigarette and/or e-cigarette use; Phillips and Danner (1995) noted that cigarette use was associated with staying asleep and staying awake, but not falling asleep (Phillips & Danner, 1995). A possible explanation for this findings is that adolescents have fewer opportunities for late sleeping that might be limited to weekend mornings. For instance, adolescents could not readily sleep until noon on a weekday morning if they plan to attend school.

Higher-frequency cigarette only users and higher-frequency cigarette dual users scored lower on falling asleep during class than non-users, with high-frequency cigarette only users scoring almost two times lower than high-frequency cigarette dual users. As discussed, cigarette use has been associated with problems staying awake during the day (Phillips & Danner, 1995). Given the high proportion of adolescents who are not getting enough sleep (as revealed by objective 2), it is plausible that falling asleep during class is not an unusual experience for adolescents. As both groups did not report shorter sleep durations than non-users, it is logical that they do not experience greater problems staying awake during classes than non-users.

7.1.4 Sex

The fourth objective of this study was to determine whether the associations between frequency of cigarette and/or e-cigarette use and sleep duration, fulfilment of

sleep duration recommendation, and occurrence of sleep-related problems among Canadian adolescents, differed by sex. The results do not provide any evidence to suggest that these relationships are modified by sex. Of the existing literature that has examined cigarette and/or e-cigarette use and sleep health, there are mixed findings concerning the role of sex. While some studies have found that aspects of sleep quality (e.g., nightmares) are more common among a particular sex, others have found no relationship by sex across various sleep health outcomes (e.g., Townsend et al., 1991; Wetter & Young, 1994). Although the prevalence of tobacco use differs among males and females, the most recent evidence suggests that the prevalence of current e-cigarette use does not differ between male and female adolescents (Health Canada, 2019b).

7.2 STUDY LIMITATIONS

The primary limitation of this is that the data are cross-sectional and thus no conclusions about a causal relationship between cigarette and/or e-cigarette use and the aspects of sleep health studied can be drawn. Future research should consider longitudinal study designs to further investigate the temporality of the relationship between cigarette and/or e-cigarette use and sleep health. For instance, researchers could use sleep diaries to observe sleep behaviours (e.g., sleep duration) over a period of time in cigarette and/or e-cigarette using adolescents.

Second, the CSTADS questionnaire does not collect data with respect to nicotine concentration of e-cigarettes. This would be a valuable measure to improve what we can infer about a potential dose-response relationship between e-cigarette use (lower versus higher liquid nicotine concentrations) and sleep health and would make it easier to draw comparisons between cigarette and e-cigarette nicotine content. It also lacks data on

behaviours that may affect sleep health such as exercise, caffeine consumption, and mental health (Patten et al., 2000; Phillips & Danner, 1995) and thus confound the results of the current study.

Third, both the exposure and outcome variables are limited to subjective self-reported data that could be subject to recall bias, over- and under-estimation, and social desirability bias. However, the exposure measure was limited to past 30-day use which is a short recall period and is preferable to ever-use measures of cigarette and/or e-cigarette use. Future research efforts should consider objective measures of cigarette and/or e-cigarette use and sleep behaviours. For instance, portable polysomnography devices are a new technology that objectively measure sleep architecture and could be used to observe sleep patterns in cigarette and/or e-cigarette using youth.

Fourth, the outcome measures for sleep-related problems (objective 3) were created for the purpose of the CSTADS project and have not been tested for validity and reliability. Future research would benefit from the use of validated measures of sleep quality for adolescent populations.

Fifth, this study was limited by missing data, particularly for the outcome variables. Given the large sample size of this study, it was ideal to use listwise deletion to handle the amount of missing data.

7.3 STUDY STRENGTHS

The primary strength of this study is that it provides evidence on the association between cigarette and/or e-cigarette use and sleep health among a large, nationally representative sample of Canadian adolescents. To the author's knowledge, this is the

largest study sample to date investigating the relationship between cigarette and/or e-cigarette use and sleep health among an adolescent population.

Second, this study provides new evidence at a granular level by considering both frequency of use and dual use in the analyses. Though considerable work has been done investigating cigarette use and sleep, the existing literature on e-cigarette use and sleep is limited by not considering both frequency and dual use of cigarettes and e-cigarettes and thus the current study contributes new evidence to this body of literature.

Third, the current study examined several aspects of sleep health (sleep duration, meeting national sleep duration recommendation, and sleep-related problems) as opposed to focusing on one aspect of sleep health. This evidence provides insight into various subjective elements of sleep health among an adolescent population.

7.4 IMPLICATIONS OF STUDY FINDINGS

The findings of this study can be used in efforts to improve sleep health among adolescent populations. This study identified group differences by frequency of cigarette and/or e-cigarette use that can be directly translated into policy action that is targeted to groups at higher risk for loss of sleep and/or poor sleep health. Cigarette and/or e-cigarette use are modifiable behaviours and behaviour change may be informed through the evidence provided by this study suggesting that particular users may have their sleep impacted by cigarette and/or e-cigarette use. The findings of this study should be used in behaviour change messaging on platforms that resonate with adolescents (e.g., social media). Furthermore, these findings may be used in clinical settings for treating adolescents presenting with sleep-related problems (e.g., screening for cigarette/e-cigarette use). Finally, it is important to note that a large proportion of the study

population did not meet the national sleep duration recommendation and thus there is an immediate need to address sleep health among all Canadian adolescents. Considering that this sample consisted of a student population, it may be valuable to consider integrating sleep health into school-based substance use resources and programs.

CHAPTER 8. CONCLUSIONS

A significant proportion of Canadian adolescents are not getting enough sleep. The findings of this study suggest that cigarette and/or e-cigarette use may be one of the factors that contributes to loss of sleep among this population. Cigarette and/or e-cigarette use was associated with shorter sleep durations, not meeting the national sleep recommendation of 8-10 hours per night, and a variety of sleep-related problems. In addition to these findings, this study contributes the novel finding that frequency of cigarette and/or e-cigarette use affects this relationship. The value of this evidence is that it can be used as a way of targeting adolescents who are at greatest risk for loss of sleep. For instance, dual users may be targeted with interventions to reduce consumption or encourage cessation as a manner of improving sleep health. This would help further efforts to not only improve adolescent sleep health, but reduce the high prevalence of e-cigarette use among Canadian adolescents.

Table 1: Unweighted counts and weighted percentages of Canadian students grades 9-12 (2018-19 CSTADS) by the exposure classification, n = 37,223.

Exposure Variable	n	%
Total	37,223	100
Non-users	26,587	75.1
Low-frequency e-cigarette only users	4,707	11.6
High-frequency e-cigarette only users	2,555	6.0
Low-frequency cigarette-only users	486	1.0
High-frequency cigarette only users	196	0.4
Low-frequency dual users	827	1.8
High-frequency dual users	375	0.9
High-frequency cigarette dual users	343	0.5
High-frequency e-cigarette dual users	1,147	2.6

Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily.

Table 2: Descriptive characteristics of Canadian students grades 9-12 (2018-19 CSTADS) by frequency of cigarette and/or e-cigarette use, n = 37,223.

Variable	Non-users		Low-frequency e-cigarette only users		High-frequency e-cigarette only users		Low-frequency cigarette only users		High-frequency cigarette only users		Low-frequency dual users		High-frequency dual users		High-frequency cigarette dual users		High-frequency e-cigarette dual users		Total	
Sex																				
Female	13,450	(50.08)	2,340	(50.64)	896	(38.42)	280	(62.07)	106	(58.10)	433	(44.22)	117	(18.39)	160	(48.54)	460	(48.87)	18,242	(49.17)
Male	13,137	(49.92)	2,367	(49.36)	1,659	(61.58)	206	(37.93)	90	(41.90)	394	(55.78)	258	(81.61)	183	(51.46)	687	(51.13)	18,981	(50.83)
Used alcohol in past-30-days																				
No	18,822	(74.32)	1,355	(26.29)	528	(19.11)	131	(26.28)	48	(24.29)	144	(14.35)	50	(10.10)	74	(18.73)	147	(13.53)	21,299	(61.17)
Once or twice	5,704	(18.47)	2,365	(51.26)	1,147	(48.85)	194	(49.92)	80	(48.47)	381	(51.38)	86	(12.94)	122	(35.73)	433	(37.48)	10,512	(25.69)
Once or twice a week	744	(2.14)	664	(14.34)	561	(22.08)	89	(11.11)	20	(8.93)	195	(21.22)	83	(14.15)	74	(24.78)	357	(32.38)	2,787	(6.25)
3 or 4 times a week	157	(0.59)	124	(2.62)	106	(3.38)	22	(3.96)	10	(3.35)	54	(5.96)	36	(23.90)	29	(9.07)	92	(8.10)	630	(1.58)
5 to 6 times a week	41	(0.30)	24	(0.41)	26	(0.81)	5	(1.14)	8	(4.09)	14	(1.10)	26	(24.47)	9	(3.12)	36	(2.87)	189	(0.68)
Every day	35	(0.06)	8	(0.13)	47	(1.07)	3	(0.55)	9	(2.70)	3	(0.66)	71	(10.92)	11	(2.10)	17	(0.83)	204	(0.29)
Missing	1,084	(4.12)	167	(4.95)	140	(4.70)	42	(7.06)	21	(8.16)	36	(5.33)	23	(3.52)	24	(6.46)	65	(4.82)	1,602	(4.34)
Used cannabis in past-30-days																				
No	25,120	(95.03)	3,140	(65.30)	1,138	(42.71)	226	(33.63)	66	(29.53)	276	(26.19)	54	(11.06)	83	(26.68)	299	(24.28)	30,402	(83.32)
Once or twice	886	(2.80)	990	(21.61)	628	(24.50)	111	(35.96)	26	(17.79)	267	(42.41)	47	(10.49)	45	(9.93)	268	(22.54)	3,268	(8.04)
Once or twice a week	137	(0.38)	218	(5.68)	233	(10.25)	42	(9.35)	11	(4.69)	101	(9.72)	38	(5.40)	35	(9.75)	158	(9.50)	973	(2.20)
3 or 4 times a week	71	(0.19)	116	(1.93)	153	(5.19)	20	(3.20)	11	(2.59)	62	(7.71)	28	(3.91)	30	(7.90)	126	(10.56)	617	(1.22)
5 to 6 times a week	49	(0.16)	61	(1.75)	108	(5.77)	22	(4.29)	12	(7.24)	38	(3.38)	36	(18.53)	32	(10.85)	96	(14.43)	454	(1.41)
Every day	116	(0.64)	93	(2.21)	217	(8.21)	45	(8.26)	59	(32.12)	57	(8.47)	155	(47.45)	107	(33.33)	158	(12.90)	1,007	(2.53)
Missing	208	(0.79)	89	(1.50)	78	(3.37)	20	(5.32)	11	(6.04)	26	(2.13)	17	(3.16)	11	(1.57)	42	(5.80)	502	(1.28)
Used electronics before sleep																				
No	713	(2.28)	62	(1.74)	47	(1.29)	20	(3.24)	3	(0.77)	20	(1.57)	24	(3.60)	11	(1.53)	20	(0.91)	920	(2.12)
0.5-hour before sleep	17,252	(65.99)	3,479	(74.77)	1,848	(74.97)	266	(62.25)	108	(51.52)	555	(72.25)	216	(49.82)	206	(61.03)	790	(73.42)	24,720	(67.60)
1 hour before sleep	3,749	(13.97)	448	(8.92)	184	(8.20)	58	(11.12)	21	(12.44)	79	(8.51)	29	(26.70)	42	(11.69)	124	(11.37)	4,734	(12.94)
2 hours before sleep	3,984	(14.44)	540	(11.27)	318	(11.41)	111	(16.86)	43	(25.61)	129	(14.88)	62	(12.14)	57	(18.42)	145	(9.92)	5,389	(13.84)
Missing	889	(3.32)	178	(3.30)	158	(4.14)	31	(6.53)	21	(9.66)	44	(2.79)	44	(7.74)	27	(7.33)	68	(4.37)	1,460	(3.50)
Median household income ($)	77,070	(2619)	79,030	(3786)	80,741	(3987)	71,596	(3491)	70,953	(2509)	71,959	(3484)	78,016	(3357)	67,140	(2226)	79,943	(3395)	77,385	(2773)
Used illicit drugs in past-12-months																				
No	25,164	(95.25)	3,848	(82.12)	1,754	(67.59)	297	(63.08)	97	(57.39)	465	(44.07)	106	(20.53)	127	(31.02)	558	(47.39)	32,416	(88.40)
Yes	849	(2.89)	688	(13.87)	673	(27.20)	160	(31.96)	74	(32.72)	316	(51.34)	231	(73.66)	184	(61.22)	501	(47.29)	3,676	(9.02)
Missing	574	(1.86)	171	(4.01)	128	(5.21)	29	(4.96)	25	(9.88)	46	(4.59)	38	(5.81)	32	(7.77)	88	(5.31)	1,131	(2.58)
Used prescription drugs to get high in past-12-months																				
No	23,948	(90.26)	3,667	(77.22)	1,694	(66.91)	312	(71.65)	107	(63.84)	507	(52.74)	108	(21.44)	150	(41.53)	630	(52.26)	31,123	(84.50)

Yes	2,015	(7.78)	891	(19.36)	737	(28.44)	145	(25.05)	73	(28.77)	276	(43.16)	233	(73.21)	169	(52.59)	462	(44.19)	5,001	(13.04)
Missing	624	(1.96)	149	(3.42)	124	(4.65)	29	(3.31)	16	(7.40)	44	(4.10)	34	(5.35)	24	(5.88)	55	(3.56)	1,099	(2.46)

Note: Categorical variables are reported with unweighted counts and weighted percentages (%). Continuous variables are reported with the weighted mean and standard error. Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily.

Table 3: Study outcomes among Canadian students grades 9-12 (2018-19 CSTADS) by frequency of cigarette and/or e-cigarette use, n = 37,223.

Variable	Non-users		Low-frequency e-cigarette only users		High-frequency e-cigarette only users		Low-frequency cigarette only users		High-frequency cigarette only users		Low-frequency dual users		High-frequency dual users		High-frequency cigarette dual users		High-frequency e-cigarette dual users		Total	
Average sleep duration (minutes)*	479.94	(1.28)	473.30	(3.69)	452.98	(3.63)	446.20	(9.70)	456.45	(14.23)	454.66	(12.91)	411.20	(11.94)	450.19	(7.84)	451.57	(6.93)	475.45	(1.51)
Meet national sleep recommendation*																				
No	9,072	(39.65)	1,869	(46.21)	1,175	(54.20)	199	(57.66)	81	(42.81)	374	(57.44)	179	(67.33)	161	(53.31)	576	(59.73)	13,686	(42.52)
Yes	15,215	(60.35)	2,449	(53.79)	1,064	(45.80)	212	(42.34)	71	(57.19)	359	(42.56)	102	(32.67)	120	(46.69)	419	(40.27)	20,011	(57.48)
Sleep-related problems																				
Tiredness/fatigue score**	-0.02	(0.02)	0.23	(0.03)	0.31	(0.05)	0.30	(0.15)	0.28	(0.08)	0.25	(0.07)	0.22	(0.07)	0.12	(0.11)	0.35	(0.01)	0.05	(0.02)
Late sleeping score**	-0.08	(0.03)	-0.14	(0.04)	-0.37	(0.07)	-0.88	(0.25)	-0.96	(0.15)	-0.28	(0.15)	-1.61	(0.33)	-0.70	(0.09)	-0.70	(0.09)	0.03	(0.03)
Falling asleep during class score**	-0.19	(0.02)	-0.06	(0.03)	-0.09	(0.05)	-0.19	(0.18)	-0.20	(0.17)	-0.15	(0.13)	-0.92	(0.48)	-0.26	(0.08)	-0.28	(0.13)	-0.10	(0.02)

Note: Categorical variables are reported with unweighted counts and weighted percentages (%). Continuous variables are reported with the weighted mean and standard error. *N = 33,697 due to missing values for sleep duration variables. *N = 32,186 due to missing values for sleep-related problems variables. Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily.

Table 4: Multiple linear regression of self-reported sleep duration (in minutes) on frequency of cigarette and/or e-cigarette use and covariates among Canadian students grades 9-12 (2018-19 CSTADS) (n = 33,697).

Exposure Variable	Unadjusted				Adjusted			
	β	(95% CI)		p-value	β	(95% CI)		p-value
		Lower	Upper			Lower	Upper	
Non-users [ref]	.	.	.	.	.	.	.	.
Low-frequency e-cigarette only user	-6.64	-13.40	0.13	0.05	-0.96	-7.21	5.30	0.76
High-frequency e-cigarette only user	-26.97	-33.86	-20.07	0.00***	-14.95	-25.57	-4.33	0.01**
Low-frequency cigarette only user	-33.74	-52.71	-14.77	0.00***	-25.27	-44.99	-5.54	0.01*
High-frequency cigarette only user	-23.49	-51.50	4.52	0.10	-8.04	-31.68	15.60	0.50
Low-frequency dual user	-25.28	-50.18	-0.39	0.05*	-11.81	-30.65	7.03	0.22
High-frequency dual user	-68.74	-92.72	-44.76	0.00***	-30.41	-55.02	-5.81	0.02*
High frequency cigarette dual user	-29.76	-45.60	-13.91	0.00***	-12.06	-27.08	2.95	0.12
High-frequency e-cigarette dual user	-28.37	-42.41	-14.34	0.00***	-10.71	-22.35	0.93	0.07

*p < 0.05; **p < 0.01; ***p < 0.001. Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily. This analysis adjusted for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

Table 5: Multiple logistic regression of meeting 24MG sleep recommendation on frequency of cigarette and/or e-cigarette use and covariates among Canadian students grades 9-12 (2018-19 CSTADS), n = 33,697.

Exposure Variable	Unadjusted				Adjusted			
	OR	(95% CI)		p-value	OR	(95% CI)		p-value
		Lower	Upper			Lower	Upper	
Non-users [ref]	.	.	.	.	.	.	.	.
Low-frequency e-cigarette only user	0.76	0.63	0.92	0.01**	0.91	0.75	1.09	0.31
High-frequency e-cigarette only user	0.56	0.47	0.66	0.00***	0.76	0.58	0.99	0.04*
Low-frequency cigarette only user	0.48	0.25	0.92	0.03*	0.57	0.29	1.11	0.10
High-frequency cigarette only user	0.88	0.60	1.28	0.49	1.23	0.89	1.71	0.21
Low-frequency dual user	0.49	0.28	0.84	0.01**	0.70	0.45	1.08	0.11
High-frequency dual user	0.32	0.16	0.65	0.00***	0.71	0.35	1.47	0.36
High frequency cigarette dual user	0.58	0.40	0.82	0.00***	0.91	0.64	1.29	0.59
High-frequency e-cigarette dual user	0.44	0.35	0.57	0.00***	0.70	0.53	0.93	0.01*

*p < 0.05; **p < 0.01; ***p < 0.001. Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily. This analysis adjusted for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

Table 6: Three-factor solution of exploratory factor analysis of sleep-related problems variables among Canadian students grades 9-12 (2018-19 CSTADS), n = 32,186.

Item	Factor	Loading	Eigen	α
	Tiredness/fatigue (Factor 1)	.	2.50	0.75
1	Felt unsatisfied with your sleep	0.76		
4	Felt tired, dragged out, or sleepy during the day	0.65		
6	Needed more than one reminder to get up in the morning	0.64		
8	Had an extremely hard time falling asleep	0.59		
10	Gone to bed because you just couldn't stay awake any longer	0.56		
12	Struggled to stay awake while reading, studying, or doing homework	0.56		
	Late sleeping (Factor 2)	.	2.34	0.74
3	Arrived late to class because you overslept	0.80		
9	Stayed up until at least 3am	0.79		
11	Stayed up all night	0.74		
2	Slept past noon	0.49		
	Falling asleep during class (Factor 3)	.	1.9722	0.86
5	Fallen asleep in a morning class	0.92		
7	Fallen asleep in an afternoon class	0.91		

Table 7: Multiple linear regression of factor scores of tiredness/fatigue on (factor 1) on frequency of cigarette and/or e-cigarette use and covariates among Canadian students grades 9-12 (2018-19 CSTADS), n = 32,186.

Exposure Variable	Unadjusted				Adjusted			
	β	(95% CI)		p-value	β	(95% CI)		p-value
		Lower	Upper			Lower	Upper	
Non-users [ref]	.	.	.	.	.	.	.	.
Low-frequency e-cigarette only user	0.41	0.33	0.48	0.00***	0.20	0.13	0.27	0.00***
High-frequency e-cigarette only user	0.62	0.52	0.72	0.00***	0.31	0.20	0.41	0.00***
Low-frequency cigarette only user	0.96	0.62	1.30	0.00***	0.60	0.26	0.94	0.00***
High-frequency cigarette only user	1.01	0.74	1.27	0.00***	0.58	0.24	0.93	0.00***
Low-frequency dual user	0.56	0.28	0.84	0.00***	0.13	-0.19	0.44	0.42
High-frequency dual user	1.72	0.83	2.61	0.00***	0.96	0.44	1.47	0.00***
High frequency cigarette dual user	0.78	0.55	1.00	0.00***	0.25	0.03	0.47	0.02*
High-frequency e-cigarette dual user	0.93	0.77	1.09	0.00***	0.42	0.29	0.56	0.00***

*p < 0.05; **p < 0.01; ***p < 0.001. Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily. This analysis adjusted for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

Table 8: Multiple linear regression of factor scores of late sleeping (factor 2) on frequency of cigarette and/or e-cigarette use and covariates among Canadian students grades 9-12 (2018-19 CSTADS), n = 32,186.

Exposure Variable	Unadjusted				Adjusted			
	β	(95% CI)		p-value	β	(95% CI)		p-value
		Lower	Upper			Lower	Upper	
Non-users [ref]	.	.	.	.	.	.	.	.
Low-frequency e-cigarette only user	-0.01	-0.07	0.06	0.85	0.00	-0.07	0.07	0.98
High-frequency e-cigarette only user	-0.06	-0.18	0.05	0.27	0.07	-0.04	0.17	0.21
Low-frequency cigarette only user	-0.36	-0.55	-0.18	0.00***	-0.32	-0.44	-0.20	0.00***
High-frequency cigarette only user	-0.42	-0.68	-0.15	0.00***	-0.21	-0.45	0.03	0.08
Low-frequency dual user	-0.09	-0.37	0.18	0.51	0.05	-0.19	0.28	0.70
High-frequency dual user	-1.07	-1.69	-0.45	0.00***	-0.31	-0.53	-0.08	0.01**
High frequency cigarette dual user	-0.45	-0.60	-0.30	0.00***	-0.21	-0.34	-0.07	0.00***
High-frequency e-cigarette dual user	-0.26	-0.42	-0.11	0.00***	-0.11	-0.25	0.03	0.11

*p < 0.05; **p < 0.01; ***p < 0.001. Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily. This analysis adjusted for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

Table 9: Multiple linear regression of factor scores of falling asleep during class (factor 3) on frequency of cigarette and/or e-cigarette use and covariates among Canadian students grades 9-12 (2018-19 CSTADS), n = 32,186.

Exposure Variable	Unadjusted				Adjusted			
	β	(95% CI)		p-value	β	(95% CI)		p-value
		Lower	Upper			Lower	Upper	
Non-users [ref]	.	.	.	.	.	.	.	.
Low-frequency e-cigarette only user	0.05	-0.02	0.13	0.18	0.01	-0.08	0.09	0.89
High-frequency e-cigarette only user	-0.07	-0.14	0.01	0.07	-0.08	-0.16	0.00	0.06
Low-frequency cigarette only user	-0.32	-0.87	0.22	0.25	-0.39	-0.94	0.16	0.16
High-frequency cigarette only user	-0.36	-0.64	-0.07	0.01*	-0.38	-0.65	-0.11	0.01**
Low-frequency dual user	0.03	-0.10	0.16	0.67	-0.04	-0.16	0.09	0.54
High-frequency dual user	-0.22	-0.59	0.15	0.25	-0.12	-0.43	0.19	0.46
High frequency cigarette dual user	-0.15	-0.30	0.00	0.05*	-0.18	-0.31	-0.04	0.01**
High-frequency e-cigarette dual user	-0.12	-0.33	0.08	0.24	-0.11	-0.29	0.06	0.22

*p < 0.05; **p < 0.01; ***p < 0.001. Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily. This analysis adjusted for sex, alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income.

Table 10: Regression results including interaction term of frequency of cigarette and/or e-cigarette use and sex among Canadian students grades 9-12 (2018-19 CSTADS), n = 37,223.

Interaction Term	Objective 1[A]		Objective 2[A]		Objective 3[B]					
	β	p-value	AOR	p-value	Factor 1		Factor 2		Factor 3	
					β	p-value	β	p-value	β	p-value
Non-users [ref]	.	.	.	.	.	.	.	.	.	.
Low-frequency e-cigarette only users x Male	15.22	0.07	1.35	0.24	-.10	0.21	-0.11	0.29	0.21	0.80
High-frequency e-cigarette only user x Male	-0.90	0.93	0.96	0.81	-.08	0.48	0.09	0.51	0.09	0.49
Low-frequency cigarette only user x Male	11.01	0.60	1.45	0.56	-.27	0.06	-0.42	0.36	0.37	0.11
High-frequency cigarette only user x Male	6.51	0.83	0.84	0.68	-.02	0.93	0.42	0.13	0.61	0.06
Low-frequency dual user x Male	-27.58	0.10	0.39	0.02	-0.11	0.34	-0.12	0.68	-0.04	0.87
High-frequency dual user x Male	-26.18	0.21	0.29	0.24	0.10	0.66	0.42	0.07	0.49	0.21
High frequency cigarette dual user x Male	6.58	0.65	1.13	0.737	-0.27	0.07	-0.32	0.05	0.13	0.57
High-frequency e-cigarette dual user x Male	6.48	0.59	1.02	0.943	-0.05	0.61	0.32	0.20	-0.15	0.43

Non-user: did not use cigarettes and/or e-cigarettes in the past 30 days; Low-frequency e-cigarette only user: used e-cigarettes only less than daily/almost daily; High-frequency e-cigarette only users: used e-cigarettes only daily/almost daily; Low-frequency cigarette only users: used cigarettes only less than daily/almost daily; High-frequency cigarette only users: used cigarettes only daily/almost daily; Low-frequency dual user: Used both cigarettes and e-cigarettes less than daily/almost daily; High-frequency dual user: Used both cigarettes and e-cigarettes daily/almost daily; High-frequency e-cigarette dual user: Used e-cigarettes daily/almost daily and used cigarettes less than daily/almost daily; High-frequency cigarette dual user: used cigarettes daily/almost daily and used e-cigarettes less than daily/almost daily. These analyses adjusted for alcohol use, cannabis use, illicit drug use to get high, prescription drug use to get high, and median household income. [A]n = 33,697 due to missing outcome data. [B]n = 32,186 due to missing outcome data.

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APPENDIX

Table 1A: Effect estimates of covariates included in regression models for objectives 1, 2, and 3, n = 37,223.

Covariate	Objective 1[A]		Objective 2[A]		Objective 3[B]					
	β	p-value	AOR	p-value	Factor 1		Factor 2		Factor 3	
					β	p-value	β	p-value	β	p-value
Sex										
Male	-5.64	0.00	0.84	0.00	-0.59	0.00	0.20	0.00	0.01	0.49
Used alcohol in past-30-days										
Once or twice	-0.32	0.89	0.81	0.49	0.12	0.00	-0.05	0.09	0.21	0.00
Once or twice a week	-6.54	0.07	0.63	0.01	0.15	0.00	0.15	0.00	0.35	0.00
3 or 4 times a week	-5.20	0.27	0.54	0.12	0.00	0.97	0.22	0.00	0.32	0.02
5 to 6 times a week	-46.30	0.01	0.28	0.06	-0.16	0.61	0.96	0.00	0.91	0.04
Every day	-109.72	0.00	0.17	0.00	-0.22	0.14	0.87	0.00	1.02	0.00
Missing	-2.90	0.68	0.67	0.70	0.03	0.72	0.32	0.00	0.29	0.02
Used cannabis in past-30-days										
Once or twice	-7.67	0.13	0.69	0.27	0.00	0.96	0.19	0.00	0.06	0.48
Once or twice a week	8.94	0.20	1.01	0.04	-0.07	0.33	0.25	0.01	0.09	0.42
3 or 4 times a week	-7.95	0.20	0.65	0.59	-0.00	0.98	0.37	0.00	0.20	0.03
5 to 6 times a week	4.52	0.59	0.58	0.92	-0.06	0.52	0.34	0.00	-0.19	0.29
Every day	-13.68	0.04	0.51	0.08	-0.11	0.18	0.36	0.00	0.01	0.94
Missing	-5.10	0.00	0.27	0.05	0.10	0.45	0.60	0.00	0.28	0.20
Used electronics before sleep										
0.5-hour before sleep	2.45	0.71	0.64	0.01	0.41	0.00	0.02	0.79	-0.31	0.00
1 hour before sleep	14.92	0.02	0.88	0.34	0.18	0.03	-0.02	0.73	-0.22	0.00
2 hours before sleep	5.61	0.37	0.50	0.00	0.18	0.04	0.32	0.00	-0.06	0.42
Missing	6.13	0.53	0.60	0.37	0.28	0.00	0.11	0.34	-0.16	0.05
Median household income ($)	-0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.11	0.00	0.02
Used illicit drugs in past-12-months										
Yes	-5.35	0.06	0.65	0.06	0.13	0.07	0.05	0.52	0.13	0.03
Missing	-8.29	0.19	0.53	0.20	0.08	0.46	0.05	0.50	0.04	0.59
Used prescription drugs to get high in past-12-months										
Yes	-11.72	0.00	0.55	0.00	0.19	0.00	0.14	0.02	0.08	0.46
Missing	-4.17	0.46	0.73	0.76	-0.00	0.00	0.20	0.00	0.08	0.27
R^2	0.43		. [C]		0.36		0.29		0.30	

[A]n = 33,697 due to missing outcome data. [B]n = 32,186 due to missing outcome data. [C]Conditions are not met to estimate pseudo R^2 using survey commands in Stata.