Sleep troubles in adolescence relate to future initiation of ENDS USE: A longitudinal cohort design using the PATH study waves 4.5–5 (2017–2019)

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ABSTRACT

In a recent study, we demonstrated a relationship between self-reported sleep deprivation and youth susceptibility to initiate electronic nicotine delivery systems (ENDS) use; however, we were hampered by cross-sectional data. This study builds on our previous work by performing secondary analysis using the nationally representative Population Assessment of Tobacco and Health study datasets from wave 4.5 (2017–2018) and wave 5 (2018–2019) among respondents aged 12–17. Using a longitudinal cohort design, we assessed the extent self-reported sleep troubles at wave 4.5 related to transition from never-to-ever ENDS use by wave 5. We assessed youth who reported never having used any type of tobacco previously and who reported not using alcohol or other illicit substances the previous year. We ran four Poisson regression models on the dependent variable never-to-ever ENDS users at wave 5 and self-reported sleep troubles in the past year at wave 4.5. We controlled for demographic and sociographic factors and, in our final model, tobacco availability in home, exposure to ENDS advertising on social media, past year anxiety, depression, body mass index, physical activity, close friends that use ENDS, perceived harm of ENDS, school performance, sensation seeking, and the susceptibility of youth to initiate ENDS. Even when controlling for these factors, sleep troubles at wave 4.5 significantly and positively related to ENDS initiation by wave 5 (Past year sleep trouble: RR = 1.48 95 % CI = [1.14–1.93]). This key and novel finding has important implications for preventing youth ENDS use via protective self-care and social-environmental approaches.

1. Introduction

Adolescent electronic nicotine delivery systems (ENDS) use is a growing public health concern related to an array of detrimental health and behavioral outcomes (Tobore, 2019; Jones & Salzman, 2020). One health outcome that has been associated with nicotine use is sleep trouble, although the directionality of this association is still being explored. Mounting evidence shows that the stimulatory effects of nicotine harms sleep (Wiener et al., 2020; Mathews & Stitzel, 2019; Cohrs et al., 2012; Zhang et al., 2006); however, sleep problems may increase the odds that someone initiates ENDS use (Wiener et al., 2020). In this study, we assess whether self-reported sleep problems increase the risk of ENDS initiation one year later among youth who never used any tobacco product prior and who did not use alcohol or illicit substances in the past year.

Wong et al. (2010) was the first longitudinal study to assess the association between sleep troubles and nicotine use amongst a small sample of 300 high-risk families and found that sleep troubles in early childhood could predict later cigarette use in adolescence. Given the similarities between cigarettes and ENDS, could the same association exist between sleep troubles and ENDS among the larger population? If so, could this association occur across shorter time intervals?

Research suggests that adolescent brains require more than nine hours of sleep nightly, yet many youth fall short of this threshold, which can create serious detriments (Short and Louca, 2015; Short et al., 2018), including long-term damage to the brain (Jan et al., 2010), mood deficits (Short and Louca, 2015), lower performance at school (Pagel and Kwiatkowski, 2010), mental health disorders such as anxiety and catastrophic thinking (Jamieson et al., 2020; Talbot et al. 2010), risk-taking or sensation seeking behaviors (Telzer et al., 2013), delinquency and low self-control (Clinkinbeard et al., 2010; Meldrum et al., 2015), and substance abuse (Wong et al., 2010). Many of the outcomes related to sleep deprivation have also been associated with initiation of or susceptibility to initiate ENDS among adolescents.

We conducted a previous study on the association between self-reported average sleep durations and susceptibility to initiate ENDS.

Our previous cross-sectional study found that youth who reported averaging fewer than six hours of nightly sleep during the week before the survey self-reported significantly higher likelihoods of initiating ENDS use in the next month compared with adolescents who reported sleeping eight hours or more per night (Holtz et al., 2022). However, we were limited in our ability to compare the same adolescents at different time-points to assess directionality of the association and whether sleep durations were associated with later initiation of ENDS use.

In this paper, we overcome our previous limitations by using data from the Population Assessment of Tobacco and Health (PATH) study, a longitudinal, national tobacco use study of youths and adults in the United States (Hyland et al., 2016). Our primary objective is to assess how self-reported youth sleep troubles significantly relate to later transition from never-to-ever ENDS use. Because our previous study suggests that sleep deprivation relates to self-reported likelihood of future ENDs use, we hypothesize that reported sleep troubles predict actual initiation of ENDS use at later time-points.

2. Methods

We used the PATH study's anonymized public-use data files for this analysis (USDHHS, 2021a) with exemption from ethical compliance from KDH Research & Communication (KDHRC) internal IRB, FWA00011177, IRB 00005850. The PATH study was launched in 2011 through collaboration with the Food and Drug Administration (FDA) and the National Institutes of Health (NIH) to study tobacco use in the United States and track related health effects over time. Findings from the PATH study data have been used to inform the FDA's regulatory policies on tobacco marketing, manufacturing, and distribution (Hyland et al., 2016).

The PATH study used a four-stage stratified probability sampling to select youth and adult participants (Hyland et al., 2016). Strengths of the PATH study data include its complex longitudinal design, scope of behavioral and psychographic questions, and national representativeness. Analyses of non-response bias in the PATH study's wave 4.5 and wave 5 may be found in the PATH study non-response reports online (USDHHS, 2021b).

PATH study data have been collected from youth respondents and one of their parents/guardians in waves each year since the initial launch. Each observation in the data represents answers from a youth respondent and 99.4 % also include youth and household related information provided by one of the youth respondent's parents/guardians (USDHHS, 2021a). The sample was replenished at wave 4 to replace aged out youth, thus, there are two cohorts with baselines at wave 1 and wave 4. The weighted response rate was 83.5 % for wave 5 youth.

This study examines the most recent available youth data from waves 4.5 (December 2017 to December 2018) and 5 (December 2018 to November 2019). By comparing the same respondents across successive time-points, we can establish directionality of the association between sleep troubles and ENDS use. The PATH study treated "I don't know" answers and skip errors as missing in the data. We treated cases marked "prefer not to answer" as missing and excluded observations with missing data from our analyses for all variables. We used the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) for guidance in our reporting (von Elm et al., 2007).

Susceptibility measures have been developed to help predict which youth are most likely to initiate ENDS use. The Pierce measure (Pierce et al., 1996) was initially developed to forecast cigarette smoking but has been adapted in various forms to predict initiation of ENDS (Strong et al., 2015; Bold et al., 2017; Cheng et al., 2021). In this study we account for this measure of susceptibility and other variables associated with likelihood of ENDS initiation and sleep quality, including parental education (Vu et al., 2020), household income (Patel et al., (2021), availability of tobacco products in the home (Bailey et al., 2022; (Bouchard et al., 2018), prior use of tobacco, alcohol, and illicit substances (Brake, 2019), school performance (Nicksic and Barnes, 2019),

experiences with anxiety and depression (Green et al., 2018; Jamieson et al., 2020), perceptions of ENDs harmfulness (Tackett et al., 2021; Strong et al., 2019), sensation seeking (Case et al., 2017; Carey et al., 2019), having friends that use ENDS (Groom et al., 2021), exposure to ENDS promotions on social media (Holtz et al., 2021), Body Mass Index (BMI) (Moore et al., 2011) and physical activity (Youngstedt, 2005).

2.1. Study population

PATH study youth participant eligibility included nonincarcerated, noninstitutionalized citizens of the United States aged 12 to 17, living in the United States at the time of the survey. Because prior tobacco, alcohol, and other illicit substance use has been associated with both sleep trouble and ENDS use (Lozano et al., 2021; Brake, 2019) and any bidirectional associations between these substances and sleep could obscure the direction of the association between sleep troubles and ENDS initiation, we excluded youth who reported prior use of any type of tobacco product, past year alcohol and/or illicit substances at wave 4.5 (n = 5,131) and youth who had missing responses for at least one product or substance (n = 27). The final sample included 6,466 youth respondents, representing a population of 13,295,663 United States youth between the ages of 12 and 17 who had never used any type of tobacco product and no alcohol or illicit substances in the past year at wave 4.5.

2.2. Measures / data classification

Because stable demographic covariates were only inquired about at each baseline, age, sex, race, and ethnicity were all collected at wave 1 or wave 4, depending on the cohort of the respondent. Unless specified otherwise, each variable with the potential to change over time was pulled from wave 4.5 since we were controlling for its influence on an outcome occurring by the following year at wave 5. In Table 1, we provide operational definitions for each of the covariates used in our analyses.

3. Covariates

3.1. Independent variable

Past year sleep troubles: Youth respondents are asked, "*When was the last time that you had significant problems with sleep trouble, such as bad dreams, sleeping restlessly, or falling asleep during the day?*" Answer choices included, "*Past month,*" "*Two to twelve months ago,*" "*Over a year ago,*" and "*Never.*" Because there was a roughly even split between respondents who reported sleep trouble in the past year and respondents who reported never, we created a dummy variable where 1 represented a respondent who answered either "*Past month*" or "*Two to twelve months ago*", and 0 represented a respondent who answered either "*Over a year ago*" or "*Never.*" Because we were interested in the predictive ability of sleep troubles in determining future ENDS use, and the question about ENDS use inquired about the year prior to wave 5 (2017–2018) we pulled the main exposure variable from the previous wave, wave 4.5 (2016–2017).

3.2. Dependent variable

Never-to-ever ENDS use: In each PATH study wave youth respondents are asked, "*In the past 12 months, have you used an electronic nicotine product, even one or two times?*" with answer choices of "*Yes*" or "*No*". We used the results of this question to create a dummy variable where 1 represented a respondent who answered "*No*" at wave 4.5 but "*Yes*" at wave 5 and 0 represented a respondent who answered "*no*" at both wave 4.5 and wave 5. We used the never-to-ever ENDS use outcome variable from wave 5 because it is the most recent available.

Table 1
Covariates used in analyses.

Age:	The PATH study data use two youth age categories: 12–14 and 15–17. We created a dummy variable where 1 represented a respondent aged 15–17 and 0 represented respondents aged 12–14.
Sex:	We created a dummy variable for sex where 1 represented a respondent who was male and 0 represented a respondent who was female.
Race/ethnicity:	The PATH study data categorized race into three categories: Black, White, and Other. Ethnicity was categorized as either Hispanic or non-Hispanic. We combined the race and ethnicity variables to create dummy variables for each category: Hispanic White, non-Hispanic White (reference), Hispanic Black, non-Hispanic Black, Hispanic Other, and non-Hispanic Other. For each dummy variable 1 represented a respondent being in the respective race/ethnicity category and 0 represented a respondent not being in the respective race/ethnicity category.
Body Mass Index (BMI):	BMI percentiles for each youth respondent were calculated by the PATH study from self-reported height and weight according to age and sex.
Physical activity:	Youth respondents are asked, "*During the past 7 days, on how many days were you physically active for a total of at least 60 min per day? (Add up all the time you spent in any kind of physical activity that increased your heart rate and made you breathe hard some of the time)*" Answer choices included, "*0 days*" (reference); "*1 day,*" "*2 days,*" "*3 days,*" "*4 days,*" "*5 days,*" "*6 days,*" and "*7 days.*"
Parental education:	Parent/guardian respondents are asked, "*What is the highest grade or year of school that you or your spouse/guardian have completed?*" Answer choices included, "*Less than High School*" (reference), "*GED,*" "*High school graduate,*" "*Some college (no degree) or Associates degree,*" "*Bachelor's degree,*" and "*Advanced degree.*"
Household income:	Parent/guardian respondents are asked, "*Which of the following categories best describes your total household income in the past 12 months? This is the total income before taxes of all persons in your household combined.*" Answer choices included, "*less than $10,000*" (reference), "*$10,000 to $24,999,*" "*$25,000 to $49,999,*" "*$50,000 to $99,999,*" and "*$100,000 or more.*"
Tobacco products in home:	Parent/guardian respondents are asked, "*Do you think any tobacco products or electronic nicotine products (such as e-cigarettes) might be available at your home?*" Answer choices included, "*Yes*" and "*No.*" We created a dummy variable where 1 represented a respondent who reported "*Yes*" and 0 represented "*No.*"
Harmfulness of ENDS:	Youth respondents are asked, "*How much do you think people harm themselves when they use e-cigarettes or other electronic nicotine products?*" Answer choices included, "*No harm*", "*Little harm*", "*Some harm*", and "*A lot of harm.*" We created a dummy variable where 1 represented a respondent who reported any level of harm and 0 represented a respondent who reported no harm.
Sensation seeking score:	At each baseline interview, youth respondents are asked to rate their agreement with the following statements "*I like to do frightening things,*" "*I like new and exciting experiences, even if I have to break the rules,*" "*I prefer friends who are exciting and unpredictable.*" Responses for each are a subjective scale ranging from "*Strongly disagree*" (1) to *Strongly agree* (5). We averaged the subjective scores across all three questions to create a mean sensation seeking score (Case et al., 2017; Nicksic & Barnes, 2019).
Exposure to ENDS advertising:	Youth respondents are asked, "*In the past 30 days, have you noticed e-cigarettes or other electronic nicotine products being advertised in any of the following places?*" We created a dummy variable where 1 represented a respondent who selected, "*On websites or social media sites*" and 0 represented a respondent who did not.
School performance:	Parent/guardian respondents were asked, "*How would you describe how (youth respondent) has performed at school in the past 12 months?*" Answer choices included, "*Mostly A's,*" "*A's and B's,*" "*Mostly B's,*" "*B's and C's,*" "*Mostly C's,*" "*C's and D's,*" "*Mostly D's,*" "*D's and F's,*" "*Mostly F's,*" or "*Your child's school is ungraded.*" We created a

Table 1 (*continued*)

Age:	The PATH study data use two youth age categories: 12–14 and 15–17. We created a dummy variable where 1 represented a respondent aged 15–17 and 0 represented respondents aged 12–14.
	dummy variable where 1 represented respondents who reported "*mostly A's*" through "*mostly B's*" and 0 represented a respondent who reported "*Mostly B's and C's*" or lower as has been used previously (Nicksic & Barnes, 2019). Respondents who reported ungraded school performance were marked as missing and excluded from analyses.
Friends that use ENDS:	Youth respondents are asked, "*How many of your best friends use e-cigarettes or other electronic nicotine products?*" Answer choices included, "*None*" (reference), "*A few,*" "*Some,*" *Most,*" and "*All.*"
Past year anxiety:	Youth respondents are asked, "*When was the last time that you had significant problems with feeling very anxious, nervous, tense, scared, panicked, or like something bad was going to happen?*" Answer choices included, "*Past month,*" "*2 to 12 months ago,*" "*Over a year ago,*" and "*Never.*" We created a dummy variable where 1 represented a respondent who reported feeling this way either in the "*Past month*" or "*2 to 12 months*" and 0 represented a respondent who reported feeling this way "*Over a year ago*" or "*Never.*"
Past year depression:	Youth respondents are asked, "*When was the last time that you had significant problems with feeling very trapped, lonely, sad, blue, depressed, or hopeless about the future?*" Answer choices included, "*Past month,*" "*2 to 12 months ago,*" "*Over a year ago,*" and "*Never.*" We created a dummy variable where 1 represented a respondent who reported feeling this way either in the "*Past month*" or "*2 to 12 months*" and 0 represented a respondent who reported feeling this way "*Over a year ago*" or "*Never.*"
Susceptibility:	The adapted Pierce measure uses four questions to define overall susceptibility to initiating ENDS use among respondents who had not vaped before (Pierce et al., 1996). The questions youth respondents were asked include: "*Have you ever been curious about using an electronic nicotine product?,*" "*Do you think you will try an electronic cigarette or e-cigarette soon?,*" "*Do you think you will use an e-cigarette in the next year?,*" and "*If one of your best friends were to offer you an electronic cigarette or e-cigarette, would you use it?*" Answer choices for the first question include, "*Not at all curious,*" "*A little curious,*" "*Somewhat curious,*" or "*Very curious.*" Answer choices to the other three questions include, "*Definitely yes,*" "*Probably yes,*" "*Probably not,*" and "*Definitely not.*" To define ENDS susceptibility, we follow Cheng et al. (2021), who calculated susceptibility as any answer other than "*Not at all curious*" to the first question and "*Definitely not*" to the other three questions. We created a dummy variable for susceptibility where 1 represented a respondent who was considered susceptible to ENDS initiation and 0 represented a respondent who was not.

3.3. Statistical analysis

We used STATA 16.1 to conduct statistical analyses. We compared four multivariate Poisson regression models with robust error variance (Zou, 2004) to determine if self-reported sleep troubles in the past year at wave 4.5 was associated with self-reported initiation of ENDS use by wave 5. Model 1 was an unadjusted model. In Model 2, we adjusted for respondent socio-demographics and health related characteristics including age, sex, race/ethnicity, parental education, income, BMI, and physical activity. In Model 3, we inserted additional controls for exposure to ENDS advertising on social media, whether tobacco products were in the home, past year anxiety, past year depression, school performance, sensation seeking score, perceived harmfulness of ENDS, and how many of the youth respondent's best friends use ENDS. We further adjusted Model 4 to include all previous controls and added the adapted Pierce susceptibility measure. Statistical significance was set at $p < 0.05$.

The design of the PATH study oversamples tobacco users and is

susceptible to attrition due to its longitudinal nature; there are several available weights to adjust for these issues depending on the type of analyses and waves being assessed (Hyland et al., 2016). We used the svyset procedure with wave 5′s special collection all-waves cohort 4 weights to adjust for oversampling and nonresponse from wave 4.5 to wave 5. Our estimates were computed with balanced repeated replication (BRR) using a Fay's adjustment value of 0.3 based on the PATH study user guide (USDHHS, 2021a).

4. Results

Table 2 presents youths' characteristics according to whether they had initiated ENDS use by wave 5. Among youth who had never used any tobacco product before and not used alcohol or other illicit substances in the past year at wave 4.5, Non-Hispanic White was the most prevalent race (45.78 %), age groups were nearly equally represented with 50.04 % aged 12 to 14, and males had a slight majority (51.77 %). Less than half reported experiencing sleep troubles in the past year at wave 4.5 (42.30 %), and nearly 7 % initiated ENDS use by wave 5.

Table 3 presents the results of the four Poisson regression models that assess the relationship between self-reported past year sleep troubles at wave 4.5 and initiation of ENDS use by wave 5. In Model 1, respondents who reported having past year sleep troubles at wave 4.5 had statistically significantly higher risk of initiating ENDS use by wave 5 than respondents who reported no past year sleep troubles at wave 4.5 (Past year sleep trouble: RR = 1.75 95 % CI = [1.4–2.2]). The results of Model 2 maintain that significant relationship while controlling for age, sex, race/ethnicity, parental education, income, BMI, and physical activity (Past year sleep trouble: RR = 1.75 95 % CI = [1.4–2.2]). Likewise in Model 3, the significant positive relationship between sleep trouble at wave 4.5 and the initiation of ENDS use by wave 5 was upheld when also controlling for past year anxiety, past year depression, exposure to ENDS advertising on social media, having tobacco in the home, having best friends that use ENDS, school performance, sensation seeking score, and perceived harmfulness of ENDS (Past year sleep trouble: RR = 1.57 95 % CI = [1.2–2.0]). Finally, the statistically significant relationship remained in Model 4 when also controlling for susceptibility at wave 4.5 to initiate ENDS use (Past year sleep trouble: RR = 1.48 95 % CI = [1.1–1.9]).

4.1. Sensitivity analyses

The significance of sleep troubles reported at wave 4.5 was upheld across all four models, thus the results were not sensitive to changes in the variables included. To assess selection bias, we also ran each of the models after replacing all missing data with median values. The results were similar across all four models, suggesting that the missing values do not not cause selection bias.

We checked the variance inflation factor (VIF), which reveals how much of the coefficient estimate's variance is inflated due to multicollinearity (Senaviratna and Cooray, 2019). There were high VIF scores for two categories in the control variable perceived harm of ENDS; however, the VIF value for sleep problems at wave 4.5 in Model 4 was 1.48 showing low collinearity between the independent variable and the control variables.

Because unmeasured confounding may lead to overestimation of the relationship between reported sleep troubles at wave 4.5 and initiation of ENDS by wave 5, we calculated the e-value to approximate the minimum association an unmeasured confounder would require with both the exposure and outcome variables to fully explain their causal association. The higher the e-value the larger degree of unmeasured confounding is considered necessary in cancelling or explaining the estimated effect (VanderWeele & Ding, 2017). We used the online e-value calculator (Mathur et al., 2018) to calculate an e-value of 2.32 for the point estimate and 1.54 for the confidence interval. This means the observed RR of 1.48 could be explained away/turned null by an

Table 2

Youth characteristics and variable distributions by reported sleep trouble at wave 4.5.

Youth characteristics	Answered sleep problems question at wave 4.5 (n = 6,466)	Sleep trouble in past year wave 4.5 (n = 2,735)	No sleep trouble in past year wave 4.5 (n = 3,731)	p-value
Initiated ENDS by wave 5				<0.001
Yes	420 (6.55 %)	237 (8.71 %)	183 (4.96 %)	
No	5,990 (92.64 %)	2,478 (90.59 %)	3,512 (94.16 %)	
Prefer not to answer	56 (0.80 %)	20 (0.70 %)	36 (0.88 %)	
Age				0.20
12–14	2,839 (50.04 %)	1,174 (48.66 %)	1,665 (51.07 %)	
15–17	3,627 (49.96 %)	1,561 (51.34 %)	2,066 (48.93 %)	
Sex				<0.001
Female	2,991 (47.76 %)	1,486 (55.12 %)	1,505 (42.33 %)	
Male	3,445 (51.77 %)	1,241 (44.56 %)	2,204 (57.10 %)	
Prefer not to answer	30 (0.47 %)	8 (0.32 %)	22 (0.57 %)	
Race/ethnicity combined				<0.001
Non-Hispanic White	2,677 (45.78 %)	1,214 (48.48 %)	1,463 (43.78 %)	
Hispanic White	1,130 (14.06 %)	416 (12.09 %)	714 (15.51 %)	
Non-Hispanic Black	875 (13.46 %)	342 (12.26 %)	533 (14.34 %)	
Hispanic Black	134 (1.82 %)	52 (1.88 %)	82 (1.77 %)	
Non-Hispanic Other	634 (10.86 %)	287 (11.58 %)	347 (10.33 %)	
Hispanic Other	366 (4.95 %)	159 (5.15 %)	207 (4.80 %)	
Prefer not to answer	650 (9.08 %)	265 (8.56 %)	385 (9.47 %)	
Parental education				<0.001
Less than High School	719 (9.19 %)	253 (7.69 %)	466 (10.30 %)	
GED	195 (2.68 %)	87 (2.61 %)	108 (2.73 %)	
High School graduate	1,052 (15.19 %)	409 (14.04 %)	643 (16.04 %)	
Some college/ associates degree	1,892 (28.43 %)	835 (29.89 %)	1,057 (27.36 %)	
Bachelor's degree	1,298 (21.78 %)	566 (22.36 %)	732 (21.35 %)	
Advanced degree	1,246 (21.70 %)	565 (22.54 %)	681 (21.08 %)	
Prefer not to answer	64 (1.04 %)	20 (0.87 %)	44 (1.16 %)	
Household income				<0.01
Less than $10,000	484 (6.40 %)	199 (6.06 %)	285 (6.66 %)	
$10,000 to $24,999	942 (12.94 %)	365 (12.24 %)	577 (13.46 %)	
$25,000 to $49,999	1,414 (20.18 %)	592 (19.81 %)	822 (20.45 %)	
$50,000 to $99,999	1,510 (24.29 %)	666 (25.20 %)	844 (23.63 %)	
$100,000 or more	1,808 (31.22 %)	803 (32.42 %)	1,005 (30.34 %)	
Prefer not to answer	308 (4.96 %)	110 (4.27 %)	198 (5.47 %)	
Anxiety past year				<0.001

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Table 2 (*continued*)

Youth characteristics	Answered sleep problems question at wave 4.5 (n = 6,466)	Sleep trouble in past year wave 4.5 (n = 2,735)	No sleep trouble in past year wave 4.5 (n = 3,731)	p-value
Yes	2,593 (40.78 %)	1,937 (70.84 %)	656 (18.59 %)	
No	3,861 (58.99 %)	792 (28.87 %)	3,069 (81.22 %)	
Prefer not to answer	12 (0.23 %)	6 (0.28 %)	6 (0.19 %)	
Depression past year				<0.001
Yes	2,119 (32.75 %)	1,604 (57.69 %)	515 (14.34 %)	
No	4,329 (66.95 %)	1,122 (41.96 %)	3,207 (85.41 %)	
Prefer not to answer	18 (0.30 %)	9 (0.35 %)	9 (0.25 %)	
Grades in school				0.14
Mostly A's through mostly B's	4,655 (73.46 %)	1,995 (73.71 %)	2,660 (73.28 %)	
Mostly B's and C's or lower	1,685 (24.47 %)	696 (24.54 %)	989 (24.41 %)	
Ungraded or prefer not to answer	126 (2.07 %)	44 (1.75 %)	82 (2.31 %)	
Sensation seeking score				<0.001
Mean (SE)	3.58 (0.02)	3.41 (0.02)	3.71 (0.02)	
Missing (n)	1,010	431	579	
Harm of ENDS				<0.001
No harm	75 (1.15 %)	33 (1.05 %)	42 (1.23 %)	
A little harm	394 (6.20 %)	185 (6.42 %)	209 (6.04 %)	
Some harm	1,800 (27.46 %)	864 (31.25 %)	936 (24.66 %)	
A lot of harm	4,138 (64.18 %)	1,634 (60.51 %)	2,504 (66.88 %)	
Prefer not to answer	59 (1.02 %)	19 (0.78 %)	40 (1.19 %)	
ENDS ad exposure on social media				<0.001
Yes	1,067 (16.45 %)	618 (22.52 %)	449 (11.97 %)	
No	5,292 (82.02 %)	2,087 (76.33 %)	3,205 (86.23 %)	
Prefer not to answer	107 (1.53 %)	30 (1.15 %)	77 (1.81 %)	
Tobacco in home				<0.001
Yes	570 (9.00 %)	298 (11.01 %)	272 (7.52 %)	
No	5,830 (89.92 %)	2,417 (88.12 %)	3,413 (91.26 %)	
Prefer not to answer	66 (1.07 %)	20 (0.87 %)	46 (1.22 %)	
BMI				0.49
Mean (SE)	21.96	22.07	21.89	
Missing (n)	32	11	21	
Days per week physical activity				<0.001
0	541 (8.27 %)	221 (7.76 %)	320 (8.64 %)	
1	449 (6.50 %)	201 (6.77 %)	248 (6.29 %)	
2	600 (9.31 %)	273 (9.70 %)	327 (9.02 %)	
3	872 (13.35 %)	432 (15.68 %)	440 (11.63 %)	
4	688 (10.89 %)	327 (12.77 %)	361 (9.51 %)	
5	1,215 (18.89 %)	492 (17.99 %)	723 (19.55 %)	

Table 2 (*continued*)

Youth characteristics	Answered sleep problems question at wave 4.5 (n = 6,466)	Sleep trouble in past year wave 4.5 (n = 2,735)	No sleep trouble in past year wave 4.5 (n = 3,731)	p-value
6	584 (9.21 %)	251 (9.01 %)	333 (9.35 %)	
7	1,457 (22.70 %)	520 (19.63 %)	937 (24.96 %)	
Prefer not to answer	60 (0.89 %)	18 (0.69 %)	42 (1.04 %)	
How many best friends use ENDS				<0.001
None	5,469 (85.09 %)	2,184 (80.88 %)	3,285 (88.20)	
A few	697 (10.41 %)	390 (13.47 %)	307 (8.15 %)	
Some	183 (2.67 %)	101 (3.46 %)	82 (2.08 %)	
Most	69 (1.10 %)	38 (1.39 %)	31 (0.89 %)	
All	12 (0.18 %)	6 (0.24 %)	6 (0.13 %)	
Prefer not to answer	36 (0.56 %)	16 (0.57 %)	20 (0.55 %)	
Susceptible to ENDS at wave 4.5				<0.001
Yes	1,175 (17.92 %)	669 (23.96 %)	506 (13.46 %)	
No	4,981 (76.02 %)	1,970 (71.39 %)	3,011 (79.44 %)	
Missing	310 (6.05 %)	96 (4.65 %)	214 (7.09 %)	

Note: **Bold** = significant < 0.05.
n/(weighted %) for each column unless stated otherwise.

Table 3

Poisson regression analyses of the association between past year sleep troubles at wave 4.5 and past year initiation of ENDS at wave 5.

	Self-reported sleep troubles in past year at wave 4.5	
	No sleep troubles RR (95 % CI)	Sleep troubles in past year RR (95 % CI)
Model 1 (n = 6,410)	1 (ref)	1.75 (1.405–2.184)
Model 2 (n = 5,424)	1 (ref)	1.75 (1.406–2.187)
Model 3 (n = 4,447)	1 (ref)	1.57 (1.205–2.033)
Model 4 (n = 4,221)	1 (ref)	1.48 (1.142–1.926)

RR, risk ratio; CI, confidence interval.

Model 1: Crude model.

Model 2: Multivariate model adjusted for age, sex, race/ethnicity, parental education, household income, BMI, and physical activity.

Model 3: Multivariate model adjusted for age, sex, race/ethnicity, parental education, household income, BMI, and physical activity, past year anxiety, past year depression, exposure to ENDS advertising on social media, tobacco in home, having best friends use ENDS, school performance, sensation seeking score, and perceived harmfulness of ENDS.

Model 4: Multivariate model adjusted for age, sex, race/ethnicity, parental education, household income, BMI, and physical activity, past year anxiety, past year depression, exposure to ENDS advertising on social media, tobacco in home, having best friends use ENDS, school performance, sensation seeking score, perceived harmfulness of ENDS, and assessed susceptibility at wave 4.5.

unmeasured confounder that is associated with both the dependent and independent variables by an RR of 2.32.

5. Discussion

Longitudinal analyses across two successive waves of the PATH study illustrated that self-reported sleep troubles significantly and positively relate to future initiation of ENDS across all four models, showing that sleep trouble may not only be a result of using ENDS but also a precursor. This finding supports previous research suggesting that youth sleep deprivation potentially leads to increased risk-taking behaviors (Holm et al., 2009).

Adolescents in particular face an abundance of barriers to healthy sleep, including internalizing thought processes regarding social interactions and school performance (Hiller et al. 2014), intense emotional states (Gruber et al. 2017), environmental factors including light levels and unhealthy family environments (Bartel et al. 2015), stimulating behaviors such as video gaming (King et al. 2013), caffeine consumption, and phone or computer use (Bartel et al. 2015). While we were unable to control for all of these factors, future research may wish to establish whether certain types of sleep barriers are associated with higher behavioral risks than others.

Youth sleep quality is affected differently by age and sex due to shifts in puberty status (Knutson, 2005; Pesonen et al., 2014). Demanding school schedules may coincide with such changes and further deter youth from achieving healthy amounts of sleep. Owens et al. (2010) found that modestly delaying a high school's start time was related to significant improvements in mood, alertness, and health among students. Future research could explore whether initiation of ENDS differs between schools with later start times. Sleep hygiene classes for adolescents have been shown to reduce internalizing behaviors and benefit performance at school (Wolfson et al., 2015). Such sleep interventions may also serve as a protective factor, preventing initiation of ENDS use.

6. Study limitations

The findings in this study add important insights into the relationship between youth sleep troubles and their initiation with ENDS use. However, there are limitations worth noting. First, the PATH study sample has potential for response bias, it is possible that youth feared that their responses were not completely confidential and therefore may have answered questions less truthfully. Furthermore, we were limited in comparing different degrees of reported sleep trouble as the answer choices only included four timeframes. The PATH study questionnaire did not assess the frequency or duration of sleep troubles, so respondents who reported experiencing sleep troubles in the past year could have experienced sleep troubles anywhere from one night to every night. Future research may benefit from write-in answers for questions exploring average sleep durations and follow-up questions regarding average sleep quality. The PATH study questionnaire uses self-reported subjective feedback on sleep troubles rather than actigraphy or polysomnography leading to potential recall bias and measurement error which could bias results. A more accurate analytic approach may include more rigorously monitoring adolescents' rest and activity via existing technologies and assessing adolescents' behaviors more frequently than once a year.

Our analyses excluded youth who reported having used any type of tobacco product previously, alcohol, or illicit substances in the past year. Future research may wish to assess more waves of the PATH study data or use datasets with more frequent assessments to establish whether sleep trouble preceded other substances tried, and whether there are common pathways among youth with sleep troubles in terms of type of substance progression that relate to experimenting with ENDS use.

7. Conclusion

Using a nationally representative sample of adolescents aged 12 to 17 in the United States, we investigated the relationship between self-reported sleep troubles and later initiation of ENDS use among youth who had never used any type of tobacco product and had not used alcohol or illicit substances in the past year. We found that youth who reported sleep troubles in the previous year were at increased risk of transitioning to ever use of ENDs compared to youth who reported no sleep troubles the previous year, even while considering relevant covariates. These findings are essential to researchers, parents, mental health counselors, school nurses, and others directly engaged in prevention efforts and promotion of healthy adolescent behaviors. Preventing youths from initiating ENDS is a crucial public health goal that is informed by research but enacted by policy and proactive measures taken by parents, schools, and health workers. As research continues to unveil characteristics and risk behaviors with predictive ability, we can better identify youth most at risk of initiating ENDS and the measures necessary for tailoring an environment that supports the healthiest outcomes. Based on our findings, ensuring that youth receive optimal amounts and quality of sleep may be one such measure.

CRediT authorship contribution statement

Kristen Holtz: Project administration, Investigation, Supervision, Writing – review & editing. **Andrew Simkus:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Eric Twombly:** Writing – review & editing. **Morgan Fleming:** Writing – review & editing. **Nicole Wanty:** Supervision, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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