Addictive Behaviors Reports 12 (2020) 100303

Contents lists available at ScienceDirect

Addictive Behaviors Reports

journal homepage: www.elsevier.com/locate/abrep

Latent class trajectories: U.S. adolescents' nicotine use and its association with nicotine dependence

Carol J. Boyd[a,b,c,*], Philip Veliz[a,b], Rebecca Evans-Polce[a,b], Andria B. Eisman[d], Sean Esteban McCabe[a,b,e]

[a] Center for the Study of Drugs, Alcohol, Smoking and Health, School of Nursing, University of Michigan, 400 North Ingalls Street, Ann Arbor, MI 48109, USA
[b] School of Nursing, University of Michigan, 400 North Ingalls Street, Ann Arbor, MI 48109, USA
[c] Addiction Center, Department of Psychiatry, Rachel Upjohn Bldg, University of Michigan, 4250 Plymouth Road, Ann Arbor, MI 48109, USA
[d] Division of Kinesiology, Health and Sport Studies, College of Education, Wayne State University, 656 West Kirby, Detroit, MI 48202, USA
[e] Institute for Social Research, University of Michigan, 426 Thompson St, Ann Arbor, MI 48104, USA

ARTICLE INFO

Keywords:
E-cigarettes
Cigarette use
Adolescent nicotine/tobacco use trajectories

ABSTRACT

Introduction: Twenty-seven percent of adolescents used a nicotine/tobacco product in 2018. Our study analyzed three waves from the Population Assessment of Tobacco and Health (PATH) Study and examined adolescent nicotine/tobacco use trajectories over time to determine which latent classes were associated with symptoms of nicotine dependence.
Methods: The PATH Study used a four-stage, stratified area probability sample and annual household interviews with adolescents (12–17 years). Adolescents who indicated past 30-day nicotine/tobacco use at least once were included ($n = 1101$). We used latent class analysis (LCA) to identify nicotine/tobacco trajectories across three waves of PATH data and their association with six symptoms consistent with nicotine dependence from the Wisconsin Inventory of Smoking Dependence Motives (WISDM-68).
Results: All types of past 30-day nicotine/tobacco use increased across the three waves. An LCA model fit was assessed using both the CIV and entropy measures in conjunction with the Vuong-Lo-Mendell-Rubin LRT. A five latent class solution had the lowest BIC value (BIC = 9784.272), and resulted in: (1) "Stable/consistent multiproduct use trajectory", (2) "Increasing cigarette use trajectory", (3) "Increasing e-cigarette use trajectory", (4) "Experimental (poly-nicotine/tobacco) use trajectory", and (5) "Increasing other nicotine/tobacco use trajectory". The most prevalent was the "Experimental (poly-nicotine/tobacco) use trajectory" (33.8%) although sex, race, and social class were associated with different trajectories. Those represented by the "Increasing cigarette use trajectory" (19.4%) reported significantly more past-year nicotine dependence symptoms ($b = 1.73$, $p < 0.001$) compared to the "Increasing e-cigarette use trajectory". Findings varied by sex and race.
Conclusions: Results indicate that the relationship between e-cigarette use and other forms of nicotine/tobacco and substance use is complex and that adolescent nicotine/tobacco users are a heterogenous group with different risks for nicotine dependence. Findings can inform tailored prevention education and messaging for different groups of youth.

1. Introduction

Tobacco use remains the leading cause of preventable deaths in the U.S. (U.S. Department of Health and Human Services, 2014). Although cigarette use has declined, the use of e-cigarettes or pods has steadily increased, particularly among youth (Miech, Johnston, O'Malley, & Terry-McElrath, 2019). In 2018, adolescents' use of any nicotine/tobacco product was 27.1%, with e-cigarettes being the most common

Abbreviations: BIC, Bayesian information criterion; GEE, generalized estimating equations; LCA, latent class analysis; LRT, likelihood ratio test; NYTS, National Youth Tobacco Survey; PATH Study, Population Assessment of Tobacco and Health Study; SD, standard deviation; WISDM-68, Wisconsin Inventory of Smoking Dependence Motives

* Corresponding author at: Center for the Study of Drugs, Alcohol, Smoking and Health, 400 North Ingalls Street, Suite 2235, Ann Arbor, MI 48109, USA.
E-mail addresses: caroboyd@med.umich.edu (C.J. Boyd), ptveliz@umich.edu (P. Veliz), bjevans@umich.edu (R. Evans-Polce), aeisman@wayne.edu (A.B. Eisman), plius@med.umich.edu (S. Esteban McCabe).
@jacobofhume (C.J. Boyd)

https://doi.org/10.1016/j.abrep.2020.100303
Received 13 June 2020; Received in revised form 31 August 2020; Accepted 5 September 2020
Available online 09 September 2020

among students (Gentzke et al., 2019). With increases in the popularity of Suorin, JUUL, and other pods, youth are potentially exposed to higher nicotine content, (Goniewicz, Boykan, Messina, Eliscu, & Tolentino, 2019; Raven, 2018) particularly when also using combustible tobacco products. The higher nicotine content from some electronic devices also portends a significant health consequence: nicotine addiction. It is unknown to what extent the use of vaporized products is associated with nicotine dependence or tobacco use disorders among youth.

Responding to the immediate need for better epidemiological data on all nicotine/tobacco product use, the National Institute on Drug Abuse (NIDA) and Food and Drug Administration (FDA) initiated the *Population Assessment of Tobacco and Health* study (PATH), a prospective study with a U.S. national sample of 32,320 household residents aged 12 years and older. The PATH uses a multi-site design that includes 13,651 adolescents (12–17 years). The PATH data have been used to examine latent classes of U.S. adolescents and their harm perceptions of alternative tobacco products using Wave 1 data (Kong et al., 2019), and adolescents transitions across latent classes to nicotine/tobacco use during a one year period between Waves 1 and 2 (Simon et al., 2020). However, few studies have examined these trajectories beyond one year of follow-up.

Using the first two waves of PATH data, Simon et al. (2020) identified three nicotine/tobacco use classes—never use, non-past 30-day use, and past 30-day use. They also describe transitions between classes across waves noting that membership in the non-user class was generally stable and the probability of transitioning from the ever use cigarette/e-cigarette class to polytobacco use was 32%. There were significant differences by race/ethnicity and sex among adolescents: older White males were more likely to make this transition. The authors noted the need for future studies that examine additional waves and use alternative categorization for LCA since different classes could emerge if different indicators are used.

There is a general belief that e-cigarettes are healthier (Schneller et al., 2019) and presumably less addictive than combustible cigarettes (Raven, 2018; Wang, Trivers, et al., 2018). To characterize the nicotine content in the pods, Goniewicz and colleagues (2019) studied youth (*n* = 22) who only reported past 30-day use of pods (e.g., JUUL, Bo, Phix) and denied using combustible tobacco products. Goniewicz et al. (2019) measured the total nicotine concentration in the various pods, as well as the total inhaled nicotine yield and median urinary cotinine concentration. The median cotinine concentration measured in the urine was 244.8 ng/mL, notably higher than what was seen by Benowitz et al. (2018) with adolescents who only smoked cigarettes (155.2 ng/mL). For pod users, Goniewicz and colleagues (2019) product testing provided evidence for significant nicotine exposure. However, Goniewicz et al. (2019) did not expand their study beyond e-cigarettes and thus, did not determine whether adolescents' use of multiple nicotine/tobacco products was related to higher urinary cotinine concentration. Moreover, they did not examine whether high levels of nicotine were associated with symptoms of nicotine dependence.

At this time, the health community lacks sufficient information on the addictive potential of e-cigarettes or dual use of cigarettes, e-cigarettes, and other nicotine/tobacco products when used by adolescents. Consequently, there is an urgent need to understand the different ways adolescents use all forms of nicotine/tobacco products, and how their use behaviors might lead to nicotine dependence.

To address the issue of nicotine dependence, Veliz et al. (2020) examined three waves of youth data from the Population Assessment of Tobacco and Health (PATH) Study (2013–2014; 2014–2015; 2015–2016) (United States Department of Health and Human Services (HHS), 2018) to determine whether specific nicotine/tobacco products (e.g., cigarettes, cigars, e-cigarettes) were associated with increased risk for substance use disorders, including tobacco use disorder. They found that e-cigarette users did not have an increase in tobacco use disorder symptoms, while cigarette users and multiple nicotine/tobacco product users had an increase in these symptoms. One limitation of the Veliz et al. (2020) study is that they reported on multiple and small subgroups that were not adequately characterized, making it difficult to determine subgroup trajectories.

This study improves on previous characterizations of adolescents' poly-nicotine/tobacco use by focusing on latent classes using three waves from the PATH Study. As such, the study accounts for 100% of past 30-day nicotine/tobacco users. The aim of this study was to build a latent class model that would characterize adolescent users of nicotine/tobacco products and then, examine the relationship between adolescents' nicotine/tobacco use trajectories and symptoms of nicotine dependency. Furthermore, this study examined the association between a given latent class (over three waves) and the past 30-day nicotine/tobacco use, as well as lifetime use of other substances (e.g., marijuana). This study is one of the first to use latent class analysis (LCA) to characterize adolescents' use of multiple nicotine/tobacco products, and such use in association with symptoms of nicotine dependence.

2. Material and methods

This secondary analysis used three waves of PATH Study data (Wave 1: September 2013–December 2014; Wave 2: October 2014–October 2015; and Wave 3: October 2015–October 2016) (HHS, 2018). The PATH Study used a four-stage stratified area probability sample design and conducted interviews with a representative sample of youth (ages 12–17) who were interviewed at three separate time points. Response rates at Waves 1, 2, and 3 were 78.4%, 83.2%, and 83.3%, respectively. The retention rate within the adolescent sample was 88.4%. Youth who dropped out at Wave 2 were more likely to engage in nicotine/tobacco use when compared to those who continued to participate in the PATH Study. The average length between Wave 1 and Wave 2 was 12.8 months (mean = 12.8, standard deviation [SD] = 2.2, range = 2.8–26.5); the average length between Wave 2 and Wave 3 was 12.7 months (mean = 12.7, SD = 1.4, range = 8.8–23.0). The analytic sample was limited to 1101 youth who indicated past 30-day nicotine/tobacco use at least once during the study period. The PATH Study data provided to the authors was deidentified, and the Humans Subjects Review Board at the first author's university ruled it exempt.

2.1. Indicators: past 30-day nicotine/tobacco use

Past 30-day cigarette, e-cigarette, and other forms of nicotine/tobacco use were measured. Nicotine/tobacco use was measured with a set of items that asked respondents the following: "In the past 30 days on how many days did you smoke cigarettes?" and "In the past 30 days on how many days did you use an e-cigarette?". Other nicotine/tobacco use was captured with the same set of questions that asked about past 30-day use with the following items: "traditional-cigar", "cigarillo", "filtered-cigar", "pipe", "hookah", "smokeless-tobacco", "snus-pouches", "dissolvable-tobacco products", "bidis", and "kretek". For past 30-day use, the response options ranged between 0 and 30 days. The nicotine/tobacco items were recoded to dichotomous measures to reflect past 30-day use. Other forms of tobacco use were combined with the ten items listed above. Based on the items presented above, three additional outcome measures assessed past 30-day cigarette frequency (i.e., 0–30 days), e-cigarette frequency (i.e., 0–30 days), and other nicotine/tobacco product use frequency (i.e., 0–30 days).

2.2. Past-year symptoms of nicotine (tobacco) dependence

Nicotine dependence was assessed with six items at Waves 1, 2, and 3 among respondents who indicated any past-year nicotine/tobacco use. The symptoms were based on a subset of six questions from the Wisconsin Inventory of Smoking Dependence Motives (WISDM-68) (Shenassa, Graham, Burdzovic, & Buka, 2009; Smith et al., 2010): (1) "I frequently crave tobacco", (2) "My tobacco use is out of control", (3) "Using tobacco really helps me feel better if I've been feeling down", (4) "Using tobacco helps me think better", (5) "Would feel alone without my tobacco", and (6) "Usually want to use tobacco after waking up". The five response options ranged from: 1 (i.e., "not at all true of me") to 5 (i.e., "extremely true of me"). Dichotomous measures were created by recoding items to reflect past-year symptoms (i.e., "not true of me at all" versus a positive endorsement of responses 2 through 5). The sum of the six items was used in the current analysis. The internal reliabilities were Cronbach alphas of 0.875, 0.888, and 0.912 at Waves 1, 2, and 3, respectively.

2.3. Covariates

Demographic characteristics: Respondents answered questions about sex (male/female), race (White/Black/Other), ethnicity (Hispanic/non-Hispanic), age, household income, and geographic location (Northeast, South, Midwest, and West).

Substance use: Alcohol, marijuana, and other drug use. Substance use was asked with questions such as: "Have you ever used [alcohol at all, including sips of someone's drink or your own drink], [marijuana, hash, THC, grass, pot or weed]?" Nonmedical prescription drug use included measures for "Ritalin or Adderall" and "painkillers, sedatives or tranquilizers". Other drug use included measures for "cocaine or crack", "methamphetamine or speed", and "any other drugs like heroin, inhalants, solvents or hallucinogens". The measures of substance use were based on lifetime use at any wave.

3. Theory/calculation

First, LCA was used to create classes of adolescents' trajectories of nicotine/tobacco based on nine indicators (three dichotomous indicators from each of the three waves): past 30-day cigarette use (yes/no), past 30-day e-cigarette use (yes/no), and past 30-day other tobacco product use (yes/no). The LCA (with no covariates) was conducted using Mplus (version 8.0; Muthén & Muthén, Los Angeles, California, USA; code available upon request). Model fit was assessed using both the Bayesian information criterion (BIC) and entropy measures in conjunction with Vuong-Lo-Mendell-Rubin likelihood ratio test (LRT). Based on these fit indices, the appropriate class solutions were selected, and the resulting groups were then profiled and described. Class membership was determined using a modal approach, which involved identifying the highest posterior predicted probability of class membership for each of the respondents based on the best-fitting model (Collins & Lanza, 2010). We then went on to analyze both linear and logistic regression models.

Adjusted odds ratios and 95% confidence intervals were then estimated using multiple logistic regression to examine how the socio-demographic variables and substance use behaviors across the study period were associated with each nicotine/tobacco use trajectory. All variables were treated as time-invariant. Notably, allowing for uncertainty in predicted class membership using a three-step approach (i.e., R3STEP) in Mplus did not alter our conclusions with respect to this segment of the analysis (Asparouhov & Muthén, 2014).

Linear regression models were fitted using the generalized estimating equations (GEE) methodology with an autoregressive correlation structure to assess the overall association between the class trajectories (i.e., latent classes) and the time-varying outcomes of interest (i.e., number of nicotine dependence symptoms, frequency of past 30-day cigarette, e-cigarette, and other forms of nicotine/tobacco use) (Hanley, Negassa, Edwardes, & Forrester, 2003; Zeger, Liang, & Albert, 1988). Both the unstandardized regression coefficient along with the standard error (both unadjusted and adjusted results are presented) are reported in the GEE models.

All conducted analyses (including the LCA) used longitudinal weights (i.e., Wave 3 youth all-waves longitudinal weight) and designated variables (i.e., primary sampling unit and stratum indicator for variance estimation) to account for the complex sampling design (HHS, 2018). Stata 15.0 (StataCorp LLC, College Station, Texas, USA) was used for all the descriptive analyses, GEE models, and the logistic regression models presented. Mplus was used for the LCA portion of the analysis (note that missing values across nicotine/tobacco use items were handled using full information maximum likelihood estimation). Sample sizes vary across both the GEE models and logistic regression models given that listwise deletion was used when estimating these models in Stata.

4. Results

We first characterize the longitudinal sample with respect to past 30-day nicotine/tobacco use, past-year symptoms of nicotine dependence, and whether they varied by sex and race. Second, we describe the results from the LCA that maps the different trajectory groups of nicotine/tobacco use followed by what factors are associated with membership within each of these unique groups. Third, we demonstrate how these different trajectory groups are associated with the number of symptoms of nicotine dependence and frequency of past 30-day nicotine/tobacco use during the study period.

4.1. Descriptive results assessing nicotine/tobacco use and symptoms of nicotine dependence

Table 1 shows sample characteristics. All types of nicotine/tobacco use increased across the three waves of PATH Study data. For instance, 1.6% of youth indicated past 30-day use of e-cigarettes at Wave 1 and this increased to 5.7% at Wave 3. The frequency of past 30-day use of nicotine/tobacco use and the past-year symptoms of nicotine dependence increased during this time-period. Table 2 also show that females had higher rates of past 30-day cigarette use at Wave 3 when compared to males, while males had higher rates of past 30-day other nicotine/tobacco use at each wave when compared to females. It should also be highlighted that White respondents had the highest rates of e-cigarette use at Waves 2 and 3, and had a higher number of past-year symptoms of nicotine dependence.

4.2. Mapping trajectories of past 30-day cigarette, e-cigarette, and other nicotine/tobacco use

The LCA model fit was assessed using both the BIC and entropy measures in conjunction with the Vuong-Lo-Mendell-Rubin LRT. Table 2 shows that the analyses indicated that a five-class solution assessing past 30-day use of nicotine/tobacco use for three waves was determined to be the best fitting model. The five-class solution had the lowest BIC value of all solutions considered (BIC = 9784.272) and had a good entropy score (entropy = 0.831) indicating good separation of the latent classes. The adjusted LRT test (75.782) was significant at the 0.001 alpha level, indicating that a five-class solution was more appropriate when compared to a four-class solution (Celeux & Soromenho, 1996). Using indicators derived from nicotine/tobacco use, a five-class solution was also found with similar trajectory groups. (Supplemental tables for these additional analyses are available upon request.)

Based on the LCA (Table 3), there were five unique trajectories identified across the three waves: (1) "Stable/consistent multiproduct use trajectory", (2) "Increasing cigarette use trajectory", (3) "Increasing e-cigarette use trajectory", (4) "Experimental (poly-nicotine/tobacco) use trajectory", and (5) "Increasing other nicotine/tobacco use trajectory". The most prevalent nicotine/tobacco trajectory was the "Experimental (poly-nicotine/tobacco) use trajectory" (33.3% tobacco users). See Table 3 for the probabilities/past 30-day prevalence rate of cigarette use, e-cigarette use, and other tobacco use within each of the five-class trajectories.

Table 1
Sample Characteristics.

		Total sample %/mean (*SE*)	**Past 30-day** nicotine/tobacco users
	Total n	n = 7595	n = 1101
Sex[a]			
Male	3910	51.4 (0.006)	52.4 (0.018)
Female	3665	48.6 (0.006)	47.6 (0.018)
Race[b]			
White	4868	69.8 (0.013)	74.0 (0.018)
Black	1159	15.7 (0.010)	13.0 (0.015)
Other	1151	14.5 (0.007)	13.0 (0.011)
Hispanic ethnicity[b]			
Non-Hispanic	5225	77.2 (0.014)	79.7 (0.017)
Hispanic	2201	22.8 (0.014)	20.3 (0.017)
Age (Wave 1)[c]			
12–14 years of age	5733	75.1 (0.004)	61.9 (0.018)
15–17 years of age	1862	24.9 (0.004)	38.1 (0.018)
Household income[d]			
$24,999 or lower	1565	18.6 (0.009)	22.6 (0.017)
$25,000 to $49,999	1835	23.0 (0.006)	25.9 (0.015)
$50,000 to $99,000	2010	27.7 (0.007)	26.4 (0.014)
$100,000 or higher	1983	30.7 (0.013)	25.1 (0.022)
US region[e]			
Northeast	1061	16.6 (0.009)	17.8 (0.016)
Midwest	1698	21.8 (0.013)	24.6 (0.021)
South	2829	37.6 (0.015)	37.1 (0.024)
West	2007	24.0 (0.013)	20.5 (0.018)
Number of symptoms of nicotine dependence (0 to 6)			
Wave 1	100	0.048* (0.005)	0.316 (0.034)
Wave 2	174	0.092* (0.008)	0.578 (0.050)
Wave 3	204	0.116* (0.010)	0.758 (0.059)
Past 30-day nicotine/tobacco use			
Past 30-day cigarette use (Wave 1)	158	2.1 (0.002)	13.7 (0.011)
Past 30-day e-cigarette use (Wave 1)	121	1.6 (0.001)	10.8 (0.010)
Past 30-day other nicotine/tobacco use (Wave 1)	145	1.9 (0.002)	12.7 (0.011)
Past 30-day cigarette use (Wave 2)	255	3.5 (0.003)	23.1 (0.016)
Past 30-day e-cigarette use (Wave 2)	226	3.2 (0.003)	21.2 (0.015)
Past 30-day other nicotine/tobacco use (Wave 2)	301	4.0 (0.002)	26.8 (0.013)
Past 30-day cigarette use (Wave 3)	336	4.6 (0.003)	31.0 (0.017)
Past 30-day e-cigarette use (Wave 3)	401	5.7 (0.004)	38.0 (0.019)
Past 30-day other nicotine/tobacco use (Wave 3)	440	5.9 (0.004)	40.2 (0.017)

Notes: *SE* = standard error; n = unweighted sample size; percentages and means incorporate longitudinal survey weights for Wave 3.
*Represents mean value only rather than percent.
[a] Sex of respondent was a derived variable (i.e., Population Assessment of Tobacco and Health [PATH] Study constructed the variable) from the interview and included either "Male" or "Female".
[b] Race/ethnicity of respondent was a derived variable from the interview and included "White alone", "Black alone", or "Other". Hispanic was derived from the interview and included either "Hispanic" or "Not Hispanic".
[c] Age of respondent was a derived variable from the interview and included either "12 to 14 years old" or "15 to 17 years old".
[d] Household income was a derived variable from the interview and include five categories: "less than $10,000", "$10,00 to $24,999", "$25,000 to $49,999", "$50,000 to $99,999", and "$100,000 or more". The maximum income indicated in either Wave 1 or Wave 2 was used for the analysis. A derived variable for household income is not included at Wave 1.
[e] U.S. region was a derived variable from the interview.

4.3. Sociodemographic variables associated with trajectories of past 30-day nicotine/tobacco use

Logistic regression analyses were conducted to examine associations of sociodemographic characteristics with trajectories (see Table 4). Females had higher odds of being in either the "Increasing cigarette use trajectory" or the "Experimental (poly-nicotine/tobacco) use trajectory" compared to males. However, females had lower odds of being in the "Stable/consistent multiproduct use trajectory" and "Increasing other nicotine/tobacco use trajectory". Black respondents had lower odds of being in the "Increasing e-cigarette use trajectory" when compared to White respondents, while they had higher odds of being in the "Increasing other nicotine/tobacco use trajectory". Hispanics had lower odds of being in the "Stable/consistent multiproduct use trajectory" when compared to non-Hispanics, while Hispanics had higher odds of being in the "Experimental (poly-nicotine/tobacco) use trajectory". Respondents aged 15–17 had higher odds of being in the "Increasing cigarette use trajectory" when compared to their younger peers. With respect to other types of substance use, respondents who reported lifetime marijuana use had lower odds of being in the "Increasing e-cigarette use trajectory", while those reporting lifetime alcohol use and nonmedical prescription drug use had higher odds of being in the "Stable/consistent multiproduct use trajectory". Moreover, there were some socioeconomic status and regional differences as well as differences in other substance use (see Table 4 for these details).

4.4. Different trajectories are associated with symptoms of nicotine dependence

Table 5 provides the unadjusted and adjusted GEE analyses assessing how trajectory membership based on the LCA was associated with frequency of past 30-day nicotine/tobacco use and symptoms of nicotine dependence. Using the "Increasing e-cigarette use trajectory" as the referent category, we see that the frequency of past 30-day use of other nicotine/tobacco products and nicotine dependence symptoms are higher for each of the other classes. For instance, adolescents in the "Increasing cigarette use trajectory" reported almost two more nicotine symptoms ($b = 1.73$, $p < .001$) and reported using other nicotine/tobacco products on two more days when compared to adolescents in the "Increasing e-cigarette use trajectory" ($b = 2.10$, $p < .001$). Adolescents in the "Stable/consistent multiproduct use trajectory" and "Increasing cigarette use trajectory" indicated a higher number of days (about nine more days) that they used cigarettes when compared to adolescents in the "Increasing e-cigarette use trajectory". Additionally, while adolescents in the "Stable/consistent multiproduct use trajectory" indicated a greater number of days of e-cigarette use when compared to the "Increasing e-cigarette use trajectory", both the "Experimental (poly-nicotine/tobacco) use trajectory" and the "Increasing other nicotine/tobacco use trajectory" indicated a fewer number of days of e-cigarette use when compared to the "Increasing e-cigarette use trajectory". The results from the unadjusted models were relatively consistent with the results from the adjusted models.

5. Discussion

Our study differs from others in our statistical approach to understanding symptoms of nicotine dependence among adolescents, allowing us to examine the heterogeneity of nicotine/tobacco use to determine latent classes associated with symptoms of nicotine dependence and frequency of nicotine/tobacco use. Other studies often focus on selected subgroups of users, often unable to account for small subsamples. With LCA, we accounted for all past 30-day nicotine/tobacco users in our analyses and thus, we were able to demonstrate that several user trajectories had a greater risk of nicotine dependence compared to e-cigarette users. We did not find greater nicotine dependence in the "Increasing e-cigarette use trajectory", a finding that is inconsistent

Table 2
Symptoms of Nicotine Dependence and Past 30-Day Nicotine/Tobacco Use by Sex and Race.

Past 30-day nicotine/tobacco users n = 1101	**Male**	**Female**		**White**	**Black**	**Other**	
	n = 572	n = 528		n = 733	n = 144	n = 176	
Number of symptoms of nicotine dependence (0–6)	mean (*SE*)	mean (*SE*)	*p*-value[a]	mean (*SE*)	mean (*SE*)	mean (*SE*)	*p*-value[a]
Wave 1	0.378 (0.057)	0.250 (0.032)	p = .051	0.352 (0.044)	0.151 (0.072)	0.302 (0.074)	p = .078
Wave 2	0.659 (0.074)	0.493 (0.069)	p = .114	0.659 (0.065)	0.343 (0.112)	0.463 (0.290)	p = .033
Wave 3	0.843 (0.091)	0.668 (0.073)	p = .139	0.845 (0.075)	0.324 (0.096)	0.851 (0.123)	p < .001
Past 30-day nicotine/tobacco use	% (*SE*)	% (*SE*)	*p*-value[b]	% (*SE*)	% (*SE*)	% (*SE*)	*p*-value[b]
Past 30-day cigarette use (Wave 1)	12.2 (0.014)	15.5 (0.016)	p = .115	14.5 (0.015)	8.2 (0.021)	16.3 (0.028)	p = .096
Past 30-day e-cigarette use (Wave 1)	10.9 (0.014)	10.9 (0.014)	p = .974	10.3 (0.012)	9.8 (0.026)	14.7 (0.032)	p = .359
Past 30-day other nicotine/tobacco use (Wave 1)	15.2 (0.016)	10.0 (0.014)	p = .024	12.3 (0.012)	13.8 (0.029)	13.3 (0.028)	p = .848
Past 30-day cigarette use (Wave 2)	20.4 (0.020)	26.3 (0.024)	p = .065	25.4 (0.019)	15.2 (0.033)	20.7 (0.031)	p = .027
Past 30-day e-cigarette use (Wave 2)	22.3 (0.019)	20.4 (0.022)	p = .497	23.2 (0.018)	10.7 (0.028)	20.9 (0.036)	p = .007
Past 30-day other nicotine/tobacco use (Wave 2)	29.8 (0.019)	23.8 (0.020)	p = .042	25.2 (0.015)	32.6 (0.044)	29.6 (0.037)	p = .174
Past 30-day cigarette use (Wave 3)	27.2 (0.020)	35.3 (0.023)	p = .006	33.3 (0.019)	21.3 (0.045)	31.1 (0.039)	p = .055
Past 30-day e-cigarette use (Wave 3)	39.0 (0.026)	36.7 (0.025)	p = .520	41.5 (0.022)	24.4 (0.043)	34.5 (0.043)	p = .003
Past 30-day other nicotine/tobacco use (Wave 3)	46.0 (0.022)	34.0 (0.023)	p < .001	38.4 (0.019)	49.8 (0.051)	41.5 (0.041)	p = .080

Notes: *SE* = standard error; n = unweighted sample size; percentages and means incorporate longitudinal survey weights for Wave 3.
[a] *F*-test *p*-values indicate whether number of symptoms of nicotine dependence vary by sex or race.
[b] Rao-Scott chi-square *p*-values indicate differences in prevalence rates of past 30-day nicotine/tobacco use by sex or race.

with other research (Piper, Baker, Benowitz, Smith, & Jorenby, 2020). This is one of the first studies to examine latent classes of adolescents over three waves of PATH Study data, and for this reason the study makes an important contribution to understanding adolescents' nicotine/tobacco use.

5.1. Implications

Our findings differ from those of Wang, Trivers, et al. (2018a). They used National Youth Tobacco Survey (NYTS) data and found three nonlinear decreases in adolescents' tobacco use: (1) a decrease in the use of any nicotine/tobacco product, (2) a decrease in the use of two or more nicotine/tobacco products, and (3) a decrease in the use of any combustible tobacco product. They also found a non-linear increase in past 30-day e-cigarette use between 2011 and 2017. By contrast, we found that most types of nicotine/tobacco use increased between Wave 1 and Wave 3. We also observed that past-year symptoms of nicotine dependence increased. The design differences in the NYTS and PATH Study (e.g., school-based versus household surveys; cross-sectional time-trends versus longitudinal LCA) may account for the differences in our findings. Regardless, both studies have demonstrated that an alarming number of adolescents use nicotine/tobacco products (Gentzke et al., 2019).

We found some sociodemographic differences with Black youth having relatively lower prevalence of nicotine/tobacco use compared to other racial or ethnic groups and this is consistent with other studies by Wang and colleagues (Wang, Trivers, et al., 2018; Wang, Gentzke, et al., 2018). However, our trajectories provided a more nuanced characterization. We found that when compared to White adolescents, Black adolescents had lower odds of being in the "Increasing e-cigarette use

Table 3
Estimated Latent Class Analysis Based on Five Latent Classes (N = 1101): Past 30-Day Prevalence.

Estimated latent class analysis probabilities/past 30-day prevalence (Mplus results)	E-cig W1	E-cig W2	E-cig W3	Cig W1	Cig W2	Cig W3	Oth tob W1	Oth tob W2	Oth tob W3
Stable/consistent multiproduct use (n = 80)	0.572	0.502	0.464	0.709	0.636	0.683	0.720	0.715	0.711
Increasing cigarette use (n = 115)	0.087	0.262	0.408	0.442	1.000	1.000	0.000	0.372	0.426
Increasing e-cigarette use (n = 214)	0.017	0.081	1.000	0.004	0.000	0.180	0.017	0.005	0.000
Experimental (poly-nicotine/tobacco) use (n = 373)	0.138	0.278	0.135	0.127	0.215	0.216	0.137	0.283	0.112
Increasing other nicotine/tobacco use (n = 319)	0.000	0.082	0.254	0.002	0.052	0.196	0.066	0.274	1.000
Class	Entropy	BIC	AIC	LRT[a]	Sig.	Adj LRT[b]	Sig.		
1	–	10427.134	10410.684	–	–	–	–		
2	0.815	10013.162	9978.435	452.250	p < .001	445.883	p < .001		
3	0.891	9959.850	9906.845	91.590	p = .100	90.300	p = .103		
4	0.767	9899.102	9827.820	38.394	p = .175	37.853	p = .179		
5[c]	**0.831**	**9784.272**	**9694.713**	**76.864**	**p < .001**	**75.782**	**p < .001**		
6	0.870	9827.729	9719.892	−11.146	p = .731	−10.989	p = .729		
Prevalence based on the five latent classes (observed results)	E-cig W1	E-cig W2	E-cig W3	Cig W1	Cig W2	Cig W3	Oth tob W1	Oth tob W2	Oth tob W3
Stable/consistent multiproduct use (n = 80)	0.631	0.544	0.542	0.695	0.590	0.677	0.792	0.736	0.757
Increasing cigarette use (n = 115)	0.095	0.257	0.379	0.396	1.000	1.000	0.000	0.366	0.382
Increasing e-cigarette use (n = 214)	0.020	0.102	1.000	0.000	0.000	0.174	0.024	0.000	0.000
Experimental (poly-nicotine/tobacco) use (n = 373)	0.149	0.295	0.083	0.137	0.210	0.188	0.132	0.298	0.040
Increasing other nicotine/tobacco use (n = 319)	0.000	0.100	0.266	0.000	0.042	0.196	0.076	0.265	1.000

Notes: Mplus = Mplus software (Muthén & Muthén, Los Angeles, California, USA); E-cig = e-cigarette/electronic cigarette, W = wave, Cig = cigarette, Oth tob = other tobacco; BIC = Bayesian information criterion; AIC = Akaike information criterion; Sig. = significance level.
[a] Vuong-Lo-Mendell-Rubin likelihood ratio test (LRT).
[b] Lo-Mendell-Rubin Adjusted likelihood ratio test (Adj LRT).
[c] The five-class solution was chosen due to the following: The five-class solution had a lower BIC value of all the smaller solutions considered (BIC = 9784.272) and had an adequate entropy score (entropy = 0.831) indicating good separation of the latent classes. The LRT and Adj LRT tests indicate that a five-class solution is more appropriate when compared to a four-class or six-class solution.

Table 4
Sociodemographic Characteristics Associated with Past 30-Day Nicotine/Tobacco Latent Class Trajectories.

Past 30-day nicotine/tobacco use	Increasing e-cigarette use	Stable/consistent multiproduct use	Increasing cigarette use	Experimental (poly-nicotine/ tobacco use)	Increasing other nicotine/ tobacco use
	Model 1 *n* = 817 AOR (95% *CI*)	Model 2 *n* = 817 AOR (95% *CI*)	Model 3 *n* = 824[a] AOR (95% *CI*)	Model 4 *n* = 817 AOR (95% *CI*)	Model 5 *n* = 817 AOR (95% *CI*)
Sex					
Male	Referent	Referent	Referent	Referent	Referent
Female	0.987 (0.638, 1.52)	0.199** (0.072, 0.548)	2.21** (1.30, 3.76)	1.53** (1.12, 2.09)	0.601** (0.417, 0.864)
Race/ethnicity					
White	Referent	Referent	Referent	Referent	Referent
Black	0.444* (0.215, 0.918)	0.411 (0.076, 2.22)	0.699 (0.257, 1.90)	1.09 (0.608, 1.96)	1.95* (1.15, 3.30)
Other	1.11 (0.625, 1.98)	0.804 (0.297, 2.17)	0.610 (0.309, 1.20)	0.923 (0.586, 1.45)	1.31 (0.764, 2.26)
Ethnicity					
Non-Hispanic	Referent	Referent	Referent	Referent	Referent
Hispanic	1.21 (0.769, 1.90)	0.175* (0.031, 0.968)	0.534 (0.263, 1.08)	1.69** (1.13, 2.52)	0.690 (0.410, 1.15)
Age (at Wave 1)					
12–14	Referent	Referent	Referent	Referent	Referent
15–17	0.777 (0.524, 1.15)	0.622 (0.243, 1.59)	2.08** (1.26, 3.42)	1.19 (0.856, 1.65)	0.828 (0.564, 1.21)
Family income					
$24,999 or less	Referent	Referent	Referent	Referent	Referent
$25,000 to $49,999	1.06 (0.595, 1.91)	0.533 (0.192, 1.47)	1.03 (0.504, 2.13)	0.989 (0.627, 1.55)	1.09 (0.658, 1.82)
$50,000 to $99,999	1.19 (0.624, 2.26)	0.583 (0.188, 1.81)	0.635 (0.257, 1.56)	0.821 (0.515, 1.30)	1.48 (0.955, 2.31)
$100,000 or more	2.04* (1.03, 4.03)	1.13 (0.480, 2.65)	0.597 (0.224, 1.58)	0.602* (0.370, 0.977)	1.20 (0.724, 2.02)
Parents highest level of education					
Both parents have less than a BA	Referent	Referent	Referent	Referent	Referent
At least one parent has a BA	1.03 (0.656, 1.63)	0.865 (0.398, 1.87)	0.249** (0.090, 0.684)	1.40 (0.973, 2.02)	1.02 (0.666, 1.58)
U.S. region					
East	Referent	Referent	Referent	Referent	Referent
Midwest	1.04 (0.506, 2.13)	12.0*** (2.81, 51.5)	2.25 (0.792, 6.40)	1.49 (0.766, 2.92)	0.405*** (0.236, 0.694)
South	0.907 (0.467, 1.76)	10.7*** (2.73, 42.4)	2.04 (0.728, 5.74)	1.40 (0.766, 2.56)	0.562* (0.340, 0.930)
West	0.927 (0.479, 1.79)	5.83* (1.24, 27.3)	1.74 (0.606, 5.03)	1.31 (0.704, 2.46)	0.676 (0.396, 1.15)
Lifetime alcohol use (Waves 1–3)					
No	Referent	Referent	Referent	Referent	Referent
Yes	0.737 (0.535, 1.01)	3.90** (1.67, 9.11)	1.09 (0.545, 2.20)	0.925 (0.661, 1.29)	1.13 (0.807, 1.59)
Lifetime marijuana use (Waves 1–3)					
No	Referent	Referent	Referent	Referent	Referent
Yes	0.426* (0.230, 0.787)	2.24 (0.967, 5.22)	1.76 (0.952, 3.28)	1.00 (0.674, 1.51)	0.954 (0.630, 1.44)
Lifetime nonmedical Rx drug use (Waves 1–3)					
No	Referent	Referent	Referent	Referent	Referent
Yes	0.865 (0.455, 1.64)	3.33*** (1.63, 6.80)	1.01 (0.543, 1.91)	0.605 (0.338, 1.08)	1.26 (0.811, 1.95)
Lifetime illicit drug use (Waves 1–3)					
No	Referent	Referent	Referent	Referent	Referent
Yes	0.935 (0.198, 4.41)	6.30* (1.48, 26.8)	–[a]	1.47 (0.475, 4.57)	0.521 (0.119, 2.26)

Notes: Unweighted samples sizes are provided. e-cigarette = electronic cigarette; AOR = adjusted odds ratio; *CI* = confidence interval; BA = bachelor's degree; Rx = prescription.
[a]The variable for illicit drug use was dropped due to collinearity issues.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

trajectory", but higher odds of being in the "Increasing other nicotine/ tobacco use trajectory", increasing their risk for nicotine dependency. There were differences by family income as well, with youth from higher income homes (versus lower income) having a greater probability of being in the "Increasing e-cigarette use trajectory".

We found differences between males and females in the probability of being in a given trajectory. Compared to males, females had a greater probability of being in the "Experimental (poly-nicotine/tobacco) use trajectory" or "Increasing cigarette use trajectory." Others have found similar sex differences. Delk et al. (2019) used 2015 data from Wave 3 of the Texas Adolescent Tobacco and Marketing Surveillance System (n = 2733; N = 461,069) and found a four class solution emerged: "no risk class", "tobacco susceptible class", "tobacco ever use class", and "all product use class". Compared to their male peers, adolescent females had two times the odds of belonging to the all "product use class" versus the "tobacco susceptible class". Bold et al. (2019) surveyed students from the southeastern Connecticut high schools (N = 2945) and also found females had higher likelihood of being susceptible to e-cigarettes and some other tobacco products compared to the "mostly non-susceptible group". In our study like Delk et al. (2019) and Bold et al. (2019) adolescent females were more likely than boys to be poly-nicotine/tobacco users. As to why these differences occur between females and males, Becker, McClellan, and Reed (2017) explore the extant research on the sex and gender differences seen in substance use behaviors, including tobacco use. They note that among vulnerable populations to a given drug, females exhibit a greater rate of escalation of substance use behaviors than males. Based on their review, they argue that sex differences in substance use behaviors, including tobacco use, occur when biological factors interact with genetics, epigenetics, and socio-environmental factors to mediate the relationships among sex, gender, and behavior (Becker et al., 2017). Their insights into the broad domains involved in female substance use provide direction for future researchers interested in sex differences and the reasons females who use nicotine/tobacco seem to escalate their substance use more quickly.

Respondents who reported lifetime marijuana use had lower odds of

Table 5
Assessing the Association Between Latent Profile Trajectories and Past-Year Number of Nicotine Dependence Symptoms and Frequency of Use.

	Nicotine dependence and nicotine/tobacco use (Waves 1 through 3)			
	Nicotine dependence symptoms	Past 30-day cigarette frequency	Past 30-day e-cigarette frequency	Past 30-day other nicotine/tobacco frequency
Nicotine/tobacco use trajectories (Past 30 days)				
Unadjusted results[1]	n = 1,076	n = 1,092	n = 1,087	n = 969
Past 30-day nicotine/tobacco use	b (*SE*)	b (*SE*)	b (*SE*)	b (*SE*)
Increasing e-cigarette use	Referent	Referent	Referent	Referent
Stable/consistent multiproduct use	2.08 (0.227)***	9.05 (1.14)***	2.76 (0.722)***	7.23 (1.04)***
Increasing cigarette use	1.73 (0.162)***	9.56 (0.824)***	0.037 (0.525)	2.10 (0.424)***
Experimental (poly-nicotine/tobacco) use	0.161 (0.042)***	0.428 (0.232)	−1.62 (0.247)***	0.381 (0.091)***
Increasing other nicotine/tobacco use	0.317 (0.059)***	0.082 (0.217)	−1.54 (0.268)***	3.54 (0.323)***
Time	0.220 (0.028)***	1.34 (0.135)***	1.24 (0.124)***	1.37 (0.133)***
Intercept	−0.146 (0.034)***	−0.737 (0.180) ***	1.27 (0.196)***	−1.32 (0.136)

Notes: e-cigarette = electronic cigarette; *SE* = standard error.
*$p < .05$, **$p < .01$, ***$p < .001$.
[1] Unweighted samples sizes are provided. All estimates from the generalized estimating equation (GEE) regression models that only control for time.

being in the "Increasing e-cigarette use trajectory", while those reporting lifetime alcohol use and nonmedical prescription drug use had higher odds of being in the "Stable/consistent multiproduct use trajectory" group when compared to non-using counterparts. These findings clearly suggest that other types of substance use are associated with engaging in multiple types of tobacco use. However, the finding that respondents in the "Increasing e-cigarette use trajectory" group were less likely to use marijuana may suggest that these users may represent adolescents who are at lower risk to use other substances, but have initiated and continue to use e-cigarettes. Further investigation is needed to see if their increasing use of e-cigarettes will put them at greater risk to engage in other types of substance use.

Our results indicate that the relationship between e-cigarette use and other forms of nicotine/tobacco and substance use is complex and consistent with Siddiqui's (Siddiqui, Mishu, Marshall, & Siddiqi, 2019) ideas regarding common liability. He proposes that adolescent e-cigarette users may share risk classes with adolescents who use other nicotine/tobacco products, and this idea is consistent with Sawdey et al. (2019) findings using the baseline PATH Study (Goniewicz et al., 2018). Our results suggest that youth who use one nicotine product may be at higher risk for all forms of nicotine/tobacco use, including the use of e-cigarettes.

5.2. Limitations

There are some limitations with the PATH Study data that should be considered. This study relied on only three waves of data and thus, trajectories and conclusions were limited to a three-year period. As with all secondary data, there are limitations based on the type of data originally collected. The WISDM-68 is a very general measure and fails to adequately capture the severity of tobacco use disorder symptoms, and the language may be outdated (e.g., only uses the word "tobacco use" and does not specifically ask about vaping or aerosol use). We found that "Increasing e-cigarette use trajectory" did not have as many symptoms of nicotine dependence when compared to "Stable/consistent multiproduct use trajectory" and "Increasing cigarette use trajectory". This may be explained by the varying nicotine concentrations in e-cigarettes (e.g., only flavoring). It is a limitation that youth PATH data do not include measures of nicotine exposure. Finally, the PATH Study data are three years old and thus, excluded newer products and some higher use subpopulations leading to likely underestimation of nicotine/tobacco use.

6. Conclusions

Our findings offer both good and bad news for those concerned with U.S. adolescents' health. The most prevalent nicotine/tobacco use trajectory was the "Experimental (poly-nicotine/tobacco) use trajectory" (33.3% of 30-day nicotine/tobacco users). However, more concerning was the 18% of adolescents in either the "Increasing cigarette use trajectory" or "High prevalence of all nicotine/tobacco use trajectory". These youth showed a significant number of nicotine/tobacco dependence symptoms when compared to the referent group (increasing e-cigarette use). This study provides new insights into adolescents' use of a variety of nicotine/tobacco products and the relationship of nicotine use trajectory and nicotine dependence symptoms. Since nearly all nicotine/tobacco use begins in adolescence and early adulthood, understanding the different trajectories of use and their relationship to nicotine dependence may help clinicians develop their educational messaging and better craft their interventions for specific types of nicotine/tobacco users.

CRediT authorship contribution statement

Carol J. Boyd: Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition. **Philip Veliz:** Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Rebecca Evans-Polce:** Writing - review & editing. **Andria B. Eisman:** Writing - review & editing. **Sean Esteban McCabe:** 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.

Acknowledgement

The authors thank Kathryn Lundquist, Research Assistant, University of Michigan School of Nursing, for assistance with editing and formatting.

Funding sources

This study was supported by grants from the National Institute on Drug Abuse [R01 DA044157] and National Cancer Institute [R01 CA203809].

References

Asparouhov, T., & Muthén, B. (2014). Auxiliary variables in mixture modeling: Three-step approaches using Mplus. *Structural Equation Modeling, 21*(3), 329–341. https://doi.org/10.1080/10705511.2014.915181.

Becker, J. B., McClellan, M. L., & Reed, B. G. (2017). Sex differences, gender and addiction. *Journal of Neuroscience Research, 95*(1–2), 136–147. https://doi.org/10.1002/jnr.23963.

Benowitz, N. L., Nardone, N., Jain, S., Dempsey, D. A., Addo, N., St Helen, G., & Jacob, P., 3rd. (2018). Comparison of urine 4-(methylnitrosamino)-1-(3)pyridyl-1-butanol and cotinine for assessment of active and passive smoke exposure in urban adolescents. *Cancer Epidemiology, Biomarkers & Prevention, 27*(3), 254–261. https://doi.org/10.1158/1055-9965.EPI-17-0671.

Bold, K. W., Buta, E., Simon, P., Kong, G., Morean, M., Camenga, D., & Krishnan-Sarin, S. (2019). Using latent class analysis to examine susceptibility to various tobacco products among adolescents. *Nicotine and Tobacco Research, ntz216*. https://doi.org/10.1093/ntr/ntz216.

Celeux, G., & Soromenho, G. (1996). An entropy criterion for assessing the number of clusters in a mixture model. *Journal of Classification, 13*(2), 195–212. https://doi.org/10.1007/BF01246098.

Collins, L., & Lanza, S. (2010). *Latent class and latent transition analysis: With applications in the social, behavioral, and health sciences.* Hoboken, NJ: John Wiley & Sons Inc doi:10.1002/9780470567333.

Delk, J., Carey, F. R., Case, K. R., Creamer, M. R., Wilkinson, A. V., Perry, C. L., & Harrell, M. B. (2019). Adolescent tobacco uptake and other substance use: A latent class analysis. *American Journal of Health Behavior, 43*(1), 3–14. https://doi.org/10.5993/AJHB.43.1.1.

Gentzke, A. S., Creamer, M., Cullen, K. A., Ambrose, B. K., Willis, G., Jamal, A., & King, B. A. (2019). Vital signs: Tobacco product use among middle and high school students - United States, 2011–2018. *Morbidity and Mortality Weekly Report (MMWR), 68*(6), 157–164. https://doi.org/10.15585/mmwr.mm6806e1.

Goniewicz, M. L., Boykan, R., Messina, C. R., Eliscu, A., & Tolentino, J. (2019). High exposure to nicotine among adolescents who use Juul and other vape pod systems ('pods'). *Tobacco Control, 28*(6), 676–677. https://doi.org/10.1136/tobaccocontrol-2018-054565.

Goniewicz, M. L., Smith, D. M., Edwards, K. C., Blount, B. C., Caldwell, K. L., Feng, J., ... Hyland, A. J. (2018). Comparison of nicotine and toxicant exposure in users of electronic cigarettes and combustible cigarettes. *JAMA Network Open, 1*(8), Article e185937. https://doi.org/10.1001/jamanetworkopen.2018.5937.

Hanley, J. A., Negassa, A., Edwardes, M. D., & Forrester, J. E. (2003). Statistical analysis of correlated data using generalized estimating equations: An orientation. *American Journal of Epidemiology, 157*(4), 364–375. https://doi.org/10.1093/aje/kwf215.

Kong, G., Simon, P., Mayer, M. E., Barrington-Trimis, J. L., Pacek, L. R., Cooper, M., ... Stanton, C. A. (2019). Harm perceptions of alternative tobacco products among US adolescents. *Tobacco Regulatory Science, 5*(3), 242–252. https://doi.org/10.18001/TRS.5.3.3.

Miech, R., Johnston, L. D., O'Malley, P. M., & Terry-McElrath, Y. M. (2019). The national prevalence of adolescent nicotine use in 2017: Estimates taking into account student reports of substances vaped. *Addictive Behaviors Reports, 9*, Article 100159. https://doi.org/10.1016/j.abrep.2019.100159.

Piper, M. E., Baker, T. B., Benowitz, N. L., Smith, S. S., & Jorenby, D. E. (2020). E-cigarette dependence measures in dual users: Reliability and relations with dependence criteria and e-cigarette cessation. *Nicotine Tobacco Research, 22*(5), 756–763. https://doi.org/10.1093/ntr/ntz040.

Raven, K. (2018). Your teen is underestimating the health risks of vaping. Retrieved from Yale Medicine: https://www.yalemedicine.org/stories/teen-vaping/ (Accessed March 20, 2020).

Sawdey, M. D., Day, H. R., Coleman, B., Gardner, L. D., Johnson, S. E., Limpert, J., ... Ambrose, B. K. (2019). Associations of risk factors of e-cigarette and cigarette use and susceptibility to use among baseline PATH study youth participants (2013–2014). *Addictive Behaviors, 91*, 51–60. https://doi.org/10.1016/j.addbeh.2018.11.027.

Schneller, L. M., Bansal-Travers, M., Goniewicz, M. L., McIntosh, S., Ossip, D., & O'Connor, R. J. (2019). Use of flavored E-cigarettes and the type of E-cigarette devices used among adults and youth in the US-Results from Wave 3 of the Population Assessment of Tobacco and Health Study (2015–2016). *International Journal of Environmental Research and Public Health, 16*(16), 2991. https://doi.org/10.3390/ijerph16162991.

Shenassa, E. D., Graham, A. L., Burdzovic, J. A., & Buka, S. L. (2009). Psychometric properties of the Wisconsin Inventory of Smoking Dependence Motives (WISDM-68): A replication and extension. *Nicotine Tobacco Research, 11*(8), 1002–1010. https://doi.org/10.1093/ntr/ntp109.

Siddiqui, F., Mishu, M., Marshall, A. M., & Siddiqi, K. (2019). E-cigarette use and subsequent smoking in adolescents and young adults: A perspective. *Expert Review of Respiratory Medicine, 13*(5), 403–405. https://doi.org/10.1080/17476348.2019.1589371.

Simon, P., Buta, E., Gueorguieva, R., Kong, G., Morean, M. E., Camenga, D. R., ... Krishnan-Sarin, S. (2020). Transitions across tobacco use profiles among adolescents: Results from the Population Assessment of Tobacco and Health (PATH) study Waves 1 and 2. *Addiction, 115*(4), 740–747. https://doi.org/10.1111/add.14828.

Smith, S. S., Piper, M. E., Bolt, D. M., Fiore, M. C., Wetter, D. W., Cinciripini, P. M., & Baker, T. B. (2010). Development of the brief Wisconsin inventory of smoking dependence motives. *Nicotine & Tobacco Research, 12*(5), 489–499. https://doi.org/10.1093/ntr/ntq032.

U.S. Department of Health and Human Services. (2014). The Health Consequences of Smoking: 50 Years of Progress. A Report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health. http://www.surgeongeneral.gov/library/reports/50-years-of-progress/full-report.pdf (Accessed March 22, 2020).

United States Department of Health and Human Services (HHS). (2018). National Institutes of Health. National Institute on Drug Abuse, and United States Department of Health and Human Services. Food and Drug Administration. Center for Tobacco Products. Population Assessment of Tobacco and Health (PATH) Study [United States] Public-Use Files. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2018-05-01: https://www.icpsr.umich.edu/icpsrweb/NAHDAP/studies/36498/versions/V7 (Accessed July 15, 2018).

Veliz, P., Eisman, A., McCabe, S. E., Evans-Polce, R., McCabe, V. V., & Boyd, C. J. (2020). E-cigarette use, polytobacco use, and longitudinal changes in tobacco and substance use disorder symptoms among U.S. adolescents. *Journal of Adolescent Health, 66*(1), 18–26. https://doi.org/10.1016/j.jadohealth.2019.05.026.

Wang, T. W., Gentzke, A., Sharapova, S., Cullen, K. A., Ambrose, B. K., & Jamal, A. (2018b). Tobacco product use among middle and high school students - United States, 2011–2017. *Morbidity and Mortality Weekly Report (MMWR), 67*(22), 629–633. https://doi.org/10.15585/mmwr.mm6722a3.

Wang, T. W., Trivers, K. F., Marynak, K. L., O'Brien, E. K., Persoskie, A., Liu, S. T., & King, B. A. (2018a). Harm perceptions of intermittent tobacco product use among U.S. youth, 2016. *Journal of Adolescent Health, 62*(6), 750–753. https://doi.org/10.1016/j.jadohealth.2017.12.017.

Zeger, S. L., Liang, K. Y., & Albert, P. S. (1988). Models for longitudinal data: A generalized estimating equation approach. *Biometrics, 44*(4), 1049–1060.