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Original Investigation

Predictors of E-cigarette and Cigarette Use Trajectory Classes from Early Adolescence to Emerging Adulthood Across Four Years (2013–2017) of the PATH Study

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Abstract

Introduction: This study examines predictors of trajectories of cigarette and e-cigarette use among a cohort of US adolescents transitioning into young adulthood. Comparing trajectories of each tobacco product is important to determine if different intervention targets are needed to prevent progression to daily use.

Methods: Latent trajectory class analyses identified cigarette and e-cigarette use (never, ever excluding past 12-month, past 12-month (excluding past 30-day (P30D)), P30D 1–5 days, P30D 6+ days) trajectory classes, separately, among US youth (12–17; *N* = 10,086) using the first 4 waves (2013–2017) of data from the nationally representative PATH Study. Weighted descriptive analyses described the class characteristics. Weighted multinomial logistic regression analyses examined demographic, psychosocial, and behavioral predictors of class membership.

Results: Younger adolescents 12–15 years had lower tobacco use compared to 16–17 year olds and less stable classes. In the 16–17 year group, there were five unique trajectories of cigarette smoking, including a Persistent High Frequency class. Four e-cigarette use trajectories were identified; but not a persistent use class. Shared predictors of class membership for cigarettes and e-cigarettes included mental health problems, other tobacco use, marijuana use, and poorer academic achievement. Male sex and household tobacco use were unique e-cigarette trajectory class predictors.

Conclusions: There was no evidence that initiation with e-cigarettes as the first product tried was associated with cigarette progression (nor cigarettes as first product and e-cigarette progression). Interventions should focus on well-established risk factors such as mental health and other substance use to prevent progression of use for both tobacco products.

Implications: Using nationally representative data and definitions of use that take into account frequency and recency of use, longitudinal 4-year trajectories of e-cigarette and cigarette use among US adolescents transitioning into young adulthood were identified. Results among 16–17-year olds revealed a class of persistent high frequency cigarette smoking that was not identified for e-cigarette use. Cigarette use progression was not associated with e-cigarettes as the first product tried. Risk factors for progression of use of both products included mental health and other substance use, which are important prevention targets for both tobacco products.

Introduction

Electronic nicotine delivery systems (ENDS), referred to herein as e-cigarettes, were the most commonly used tobacco product in the past 30 days (P30D) among United States (US) middle school and high school students in 2020.[1] Compared to 2019, 1.8 million fewer US youth were P30D e-cigarette users in 2020.[2] Still, 3.6 million youth were P30D e-cigarette users in 2020.[2] From 2019 to 2020, no significant change

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occurred in the use of cigarettes. In 2020, 4.6% of high school and 1.6% of middle school students smoked cigarettes compared to 19.6% of high school and 4.7% of middle school students who used e-cigarettes.[1] In this evolving tobacco landscape, understanding tobacco use trajectories among youth and young adults, when tobacco use patterns are established,[3] could advance our ability to prevent escalation to daily tobacco use and improve public health.

Prior research on youth and young adult tobacco use trajectories that mostly pre-dates the emergence of e-cigarettes in the tobacco market has identified similar classes of three to five cigarette smoking trajectories among youths and young adults.[3–6] Hair and colleagues[3] identified three cigarette smoking trajectories among young adults (ages 18–34; 2011–2014): "never or ever users"; "dabblers" who experimented but do not smoke daily; and "rapid escalators" who started smoking and quickly escalated to daily smoking. Similarly, Berg et al.[4] identified three classes of cigarette smoking in their sample of young adults (ages 18–25; 2014–2016): "dabblers"; "college onset smokers"; and, "late onset smokers" who began regular smoking after college. Dutra and colleagues[5] identified similar cigarette smoking trajectory classes among 12–30-year olds (1997–2011) as did Hair et al.[3] (2011–2014) and Berg et al.[4] (2014–2016) but added a class of "quitters." All of these studies identified smoking trajectories that align with five trajectories identified in a 2000–2013 cohort of youth to young adulthood over 14 years[6] (nonuse, early-onset regular smokers, occasional smokers, late-onset smokers, and quitters).

Fewer studies have focused on noncigarette tobacco use trajectories and how use of multiple tobacco products affects trajectories. Examining e-cigarette use trajectories only, Westling et al.[7] (2014–2016) identified two trajectory classes between 8th and 9th grade: non- or infrequent users, and current and increasing users. Cho and colleagues[8] examined polytobacco use trajectories in a sample of students between 9th and 11th grade (2013–2014), identifying three trajectories of nonusers, polytobacco users who increased their cigarette smoking over time but decreased use of other products, and chronic polytobacco users who continued to use multiple tobacco products and escalated their cigarette and e-cigarette use.

Cross-sectional and relatively short-term (one-year) longitudinal analyses have examined associations between youth ever e-cigarette and cigarette use with recent work examining multiple year trajectories in state or regional samples.[9–13] Drawing from Wave 1 (2013/14) and Wave 2 (2014/15) of the Population Assessment of Tobacco and Health (PATH) Study, Simon et al.[14] created a three-category variable (never use, noncurrent use, and current use) for five tobacco products and identified three classes (nonusers, ever users of cigarettes and e-cigarettes, and current polytobacco users). This analysis grouped all 12–17-year olds together and examined transitions in class membership over one year finding nonusers had a 94% chance of remaining nonusers, a 6% chance of initiating use of e-cigarettes and cigarettes, and a 1% chance of initiating use of multiple tobacco products. Another analysis using Waves 1–3 (2013–2017) of PATH Study data examined a subset of adolescent (single group of 12–17-year olds) P30D nicotine/tobacco users and modeled dichotomous (yes/no) outcomes for P30D e-cigarette, cigarette, and other tobacco use. Authors identified five classes of consistent or inconsistent use, with the most prevalent labelled as an "Experimental (poly-nicotine/tobacco) use trajectory" (33.3% of 30-day nicotine/tobacco users).[15]

These recent studies explore how use of different tobacco products can be classified based on dichotomous current and noncurrent use variables and pave the way for the analyses we present herein that include multiple waves (eg, more than three measurement time points) and examines trajectories over time that take into account frequency of use of the individual products for different age groups. Drawing from nationally representative PATH Study data, our analyses focus specifically on cigarette and e-cigarette use between 2013 and 2017 (Waves 1–4), a period of time when e-cigarette initiation was rising in the United States and new device types, such as JUUL, were emerging as popular among youth.[16] Using longitudinal latent class analyses (LCA), also known as latent trajectory class analyses (LTCA), the first aim of these analyses is to identify and compare separate longitudinal trajectory classes of cigarette and e-cigarette use for US youth 12–17 years old at Wave (W) 1 transitioning into young adulthood over the subsequent three waves. Models are examined on the full 12–17-year old sample, as well as subsamples (12–13, 14–15, 16–17) to observe developmental differences in trajectories based on different levels of tobacco use prevalence reported among middle schoolers compared to high schoolers in the United States.[1] The second aim is to describe the characteristics of individuals in each identified trajectory classes for each respective product. Finally, the hypothesis that demographic, psychosocial, and behavioral predictors of class membership will be similar for each product is tested in weighted adjusted models. These timely analyses not only provide an examination of trajectory classes with four measurement time points during a period when e-cigarettes were increasing in availability, but this national study examines predictors of longitudinal trajectory classes using a measure created to include recency (past 30-day, past 12-month) and frequency of use in the past 30 days. Thus, identified classes for each product can capture early and late initiation, as well as progression of frequency of use across the four waves. Moreover, analyses compare predictors associated with class membership between e-cigarette and cigarette trajectories, including whether the first tobacco product tried at any of the first three waves predicts initiation or progression of use.

Methods

Study Design and Population

The PATH Study is an ongoing, nationally representative, longitudinal cohort study of adults and youth in the United States. The study uses audio computer-assisted self-interviews (ACASI) available in English and Spanish to collect self-reported information on tobacco-use patterns and associated health behaviors. The PATH Study recruitment employed a stratified address-based, area probability sampling design at W1. Full sample and replicate weights were created that adjust for the complex sample design and nonresponse at Waves 1–4. Further details regarding the PATH Study design and methods are published elsewhere.[17–19] The study was conducted by Westat and approved by the Westat Institutional Review Board. All 12–17-year old respondents provided assent along with parent/legal guardian consent. The current analysis uses the Restricted Use Files (RUF) and reports longitudinal estimates of youth with data at all four waves (N = 10,086), including those who "aged-into" the adult dataset at subsequent waves.

Measures

Tobacco product use- Cigarette use and e-cigarette use trajectories were examined separately. To identify trajectory classes, five-level mutually exclusively categories of use were created to classify respondents at each wave for each product. The five levels included: (1) never use, (2) ever use (excluding past 12-month (P12M) use), (3) P12M use (excluding P30D use), (4) P30D low frequency use (1–5 days), and (5) P30D high frequency use (6+ days).[11] This frequency cut-off was based on distribution of the variables (by wave and product) that were skewed with larger frequencies on the lower end of 1–5 days for both products and is consistent with frequency definitions used in other PATH Study analyses.[11,20] The PATH Study asked about "e-cigarettes" at W1 and "e-products" (ie, e-cigarettes, e-cigars, e-pipes, and e-hookah) at W2, W3, and W4.

Covariates: Based on prior research demonstrating associations with tobacco use initiation/progression, demographic and psychosocial variables were identified and full definitions and supporting literature for each are detailed in Supplementary Table 1. These demographic and psychosocial correlates at W1 included sex, race, ethnicity, sexual orientation (for those 14 years or older), education (current grade in school), academic performance, parent education, family structure, P30D substance use (alcohol use, binge drinking, marijuana use, other substances), current tobacco use (cigarettes, noncigarette combustible use, none-cigarette non-combustible use), tobacco use in household, home access to tobacco products, household tobacco use rules, lifetime Global Appraisal of Individual Needs - Short Screener (GAIN-SS)[21] scales (substance use, internalizing, and externalizing), sensation seeking, first product tried prior to or at one of the first three waves, and if first product tried was flavored. Missing data on sex, race and ethnicity were imputed as described in the PATH Study RUF User Guide.[18]

Statistical Analysis

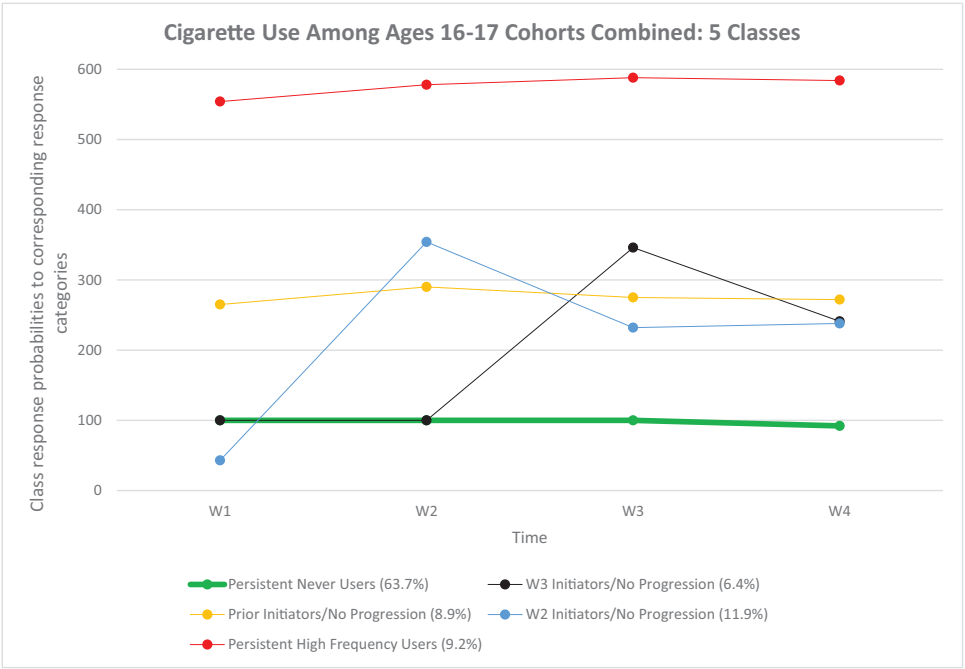
Unweighted LTCAs[22] were conducted to identify trajectory classes of US youth cigarette and e-cigarette use, separately. Conducting the unweighted LTCA is analogous to using observed variables to create a measure of a dependent variable for the study. Once this latent variable is created, it can be used just like other standard measures, to incorporate weights to obtain population estimates. Analytical processes involved three stages. First, for each product, 2–7 class models were run and examined; for each model, 500 sets of random starting values were generated; and fit statistics and agreement rates of the best fit model identified from solutions based on the 500 sets of random starting values were used to determine the best solution. Each set of sequential LTCA models were fit to a single age group separately (ie, 12-year-olds, 13-year-olds, …, 17-year-olds). Then, based on the best model identified for each age, the single age models were collapsed into three age groups (ages 12–13, 14–15, and 16–17). Decisions on how to collapse age groups were based on whether the classes demonstrated similar trajectory patterns and the number of classes that best fit the data. In the second stage, the best fit model generated posterior probability distributions to classify each individual into a trajectory class and then based on the individual's highest posterior probability class, membership was determined. Missing data in trajectory indicators were handled by maximum likelihood estimation in LTCA models. In the next stage, weighted descriptive analyses were performed to describe the characteristics of the classes based on class membership. In the final stage, weighted multinomial logistic regression analyses were conducted to examine predictors of class membership. As noted in each individual table, multinomial logistic regression models used the Persistent Never Use group as the reference group, except for analyses that were only applicable to classes that were comprised of tobacco users. For example, associations between "first tobacco product tried", "Product first tried was flavored" are only appropriate to compare among classes that include tobacco users. Weighted analyses produced estimates representative of the noninstitutionalized, civilian US population ages 12 years and older at W1 data collection, and variances were computed using the BRR method[23] with Fay's adjustment set to 0.3 to increase estimate stability.[24] All analyses were conducted using SAS 9.4 software (SAS Institute Inc., Cary, NC, USA).

Results

Longitudinal Trajectory Classes by Age Group

Fit statistics for three W1 youth age groups (12–13, 14–15, and 16–17 year olds; Supplementary Tables 2 and 3) were examined separately. The youngest age group of 12–13 year olds (Supplementary Figure 1) yielded three classes for each product (*Persistent Never Users, Prior Initiators/No progression, W3 Initiators/No progression*). The class-varying largest item-category-response probability estimates by wave from the best fit LTCA model were used to plot each of the figures respectively in this study (please refer to the notes for details under each figure). The 14–15 age group (Supplementary Figure 2) yielded four classes each. Three classes captured the same type of trajectory as identified for the 12–13 year olds, but one new class was also identified that differed for cigarettes (*Persistent High Frequency* use) and e-cigarettes (*Persistent Infrequent use)*. However, model identifiability/agreement rates were relatively low, <40% for both products. Estimates were unreliable in these younger age groups; therefore these classes were not further explored.

Model fit in the LCTA was based on balancing the strength of various fit statistics, such as Bayesian information criterion (BIC), entropy, and agreement rates (ie, model identifiability index).[22] Entropy is a summary statistical measure of classification quality based on estimated and all possible response probabilities to latent classes of the model. The entropy value is between 0 and 1, with values approaching 1 indicating clear separation of the classes (latent class membership fully determines responses when entropy = 1). The entropy was 0.97 (excellent) for the final best fit cigarette use model. Agreement rate is a summary model identifiablity index, ranging from 0% to 100%. When all sets of random starting values arrive at the same latent class solution, the agreement rate is 100%. This means that the data provide enough information and the model is very well identified based on data. In this study, the agreement rate was 100% for all the 2-class models. As models become more complicated and more parameters are estimated, models may not be well-identified given the data (those with a low agreement rate, eg, <10%). Assessing these statistics, a 5-class latent trajectory class model best fit the data for 16–17-year old cigarette use (Figure 1; Supplementary Table 2). Five cigarette use classes were identified: (1) youths who were never users throughout all waves (*Persistent Never Users*—63.7%), (2) youths who initiated before W1 and



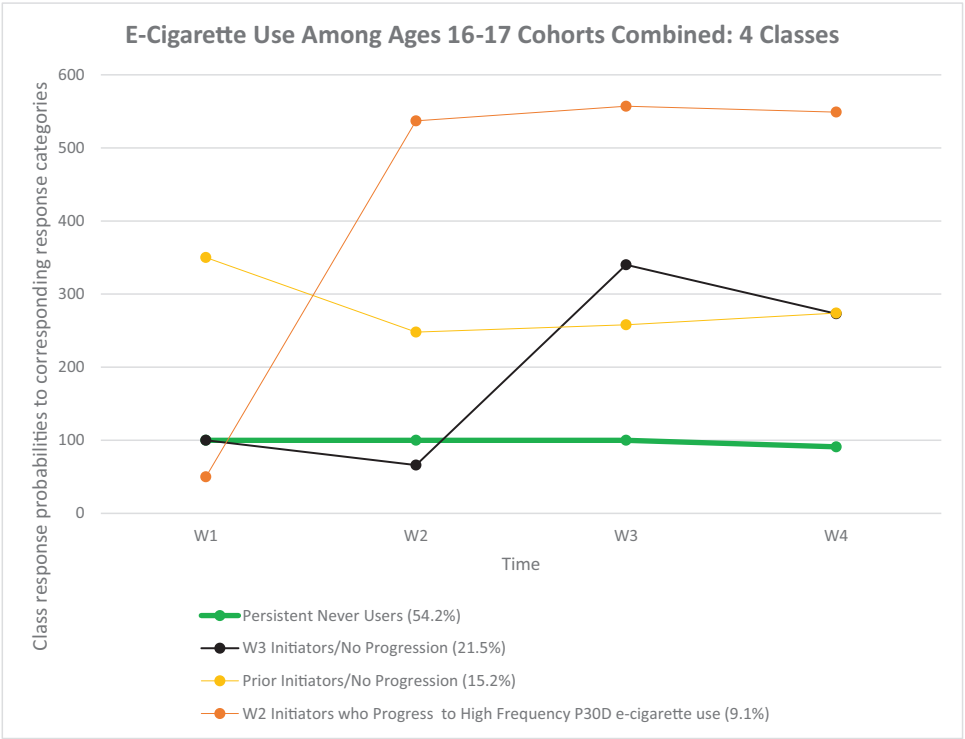


Figure 1. 16–17 year old cigarette and e-cigarette classes across four years (2013–2017) of the PATH Study. Notes: The *Y* axes are class response probabilities to corresponding response categories. The first digit of the *Y* axes stands for response categories 1–5 in the trajectory indicator variable and the units between two adjacent two gridlines above 200 stand for response probabilities (ranging from 0 to 100) to categories 2, 3, 4, and 5, respectively. For Persistent Never Users, the *Y* axes are directly response probabilities. Legend indicates weighted percent membership. Values of response categories are defined as 5 = P30D high frequency use (6+ days), 4 = P30D low frequency use (1–5 days), 3 = Past12- month use (excluding P30D use), 2 = Ever use (excluding P12M use), and 1 = Never use. This note applies to all Figures.

showed little progression to P30D cigarette smoking in subsequent waves (*Prior Initiators/No Progression*—8.9%), (3) youths who had late onset initiation at W3 but did not show progression to high frequency P30D use (6+ days in past 30) at W4 (*W3 Initiators/No Progression*—6.4%), (4) youths who had W2 initiation but little progression to P30D smoking (*W2 Initiators/No Progression*—11.9%), and (5) youths who were high frequency (6+ days in past 30) smokers across all 4 waves (*Persistent High Frequency Users*—9.2%). This model was relatively stable and estimates were more reliable (agreement rate was good at 71.2%) with an excellent entropy statistic (0.97) suggesting clear separation of the 5 classes.

Table 1. Summary of Weighted Multinomial Logistic Regression Predictors of Cigarette and E-cigarette Class Membership Among 16–17 Year Olds Across Four Years (2013–2017) of the PATH Study

	Cigarettes	E-Cigarettes
Prior Initiators/No Progression CIG: (*n* = 268; 8.9%) versus Persistent Never Users (*n* = 1975; 63.7%) ECIG: (*n* = 450; 15.2%) versus Persistent Never Users (*n* = 1708; 54.2%)	• Academic performance, B's and C's more likely • Parent education (up to 8th grade; HS diploma or GED) more likely • Parents separated more likely • E-cigarette use (ever, no P30D; P30D) more likely • Non-cigarette combusted use (P12M; P30D) more likely • Non-e-cigarette non-combusted use, ever no P12M more likely • Alcohol use, ever, no P12M more likely • Marijuana use (ever, no P12M; P12M; P30D) more likely • GAIN substance use (moderate; high) more likely	• Male sex more likely • Cigarette use (ever, no P30D; P30D) more likely • Non-cigarette combusted use (Ever, no P12M; P12M; P30D) more likely • Alcohol use (P12M, P30D) more likely • Marijuana use (P12M; P30D) more likely • GAIN Internalizing, high more likely • Tobacco user in household more likely
W3 Initiators/No Progression CIG: (*n* = 194, 6.4%) versus Persistent Never Users (*n* = 1975; 63.7%) ECIG (*n* = 663; 21.5%) versus Persistent Never Users (*n* = 1708; 54.2%)	• Other including multiracial race less likely • Non-E-Cigarette non-combusted use, P30D more likely • Alcohol use (P12M; P30D) more likely	• Education (less than 10th grade; other) less likely • Academic performance, C's and D's more likely • Cigarette use (ever, no P30D; P30D) more likely • Non-cigarette combusted use (P12M; P30D) more likely • Alcohol use (P12M; P30D) more likely • Marijuana use (P12M; P30D) more likely • GAIN Internalizing, high more likely • Tobacco User in Household more likely • Higher sensation seeking more likely
W2 Initiators/No Progression **CIGARETTE ONLY** (*n* = 357, 11.9%) versus Persistent Never Users (*n* = 1975; 63.7%)	• Black race less likely • Academic performance (B's and C's; C's and D's; D's and F's or F's) more likely • E-cigarette use (ever, no P30D; P30D) more likely • Non-cigarette combusted use (Ever, no P12M; P12M; P30D) more likely • Non-e-cigarette non-combusted use (Ever, no P12M; P30D) more likely • Alcohol use, P12M more likely • Marijuana use (ever, no P12M; P30D) more likely • GAIN Substance use, moderate more likely • Higher sensation seeking more likely	
Persistent High Frequency Use **CIGARETTE ONLY**(*n* = 273, 9.1%) versus Persistent Never Users (*n* = 1975; 63.7%)	• Black race less likely • Education, other more likely • Academic performance (B's and C's; C's and D's; D's and F's or F's) more likely • Parents education, HS diploma or GED more likely • Parents separated more likely • E-cigarette use (ever, no P30D; P30D) more likely • Non-cigarette combusted use (Ever, no P12M; P12M; P30D) more likely • Non-e-cigarette non-combusted use (P12M; P30D) more likely • Marijuana use (ever, no P12M; P12M; P30D) more likely • GAIN Substance use (moderate; high) more likely • Household access to tobacco products more likely • Higher sensation seeking more likely	

Table 1. Continued

	Cigarettes	E-Cigarettes
W2 Initiators who progress to High Frequency P30D e-cigarette use **E-CIGARETTE ONLY** (*n* = 245; 9.1%) versus Persistent Never Users (*n* = 1708; 54.2%)		• Male sex more likely • Black race less likely • Education, other less likely • Academic performance (B's and C's; C's and D's) more likely • Cigarette use (ever, no P30D; P30D) more likely • Non-cigarette combusted use (Ever, no P12M; P12M; P30D) more likely • Non-e-cigarette non-combusted use (P30D) more likely • Alcohol use, P12M more likely • Marijuana use, P30D more likely • GAIN Internalizing, high more likely • Higher sensation seeking more likely

Weighted multinomial logistic regression odds ratios can be found in detailed supplemental tables (Supplementary Tables 6 and 7).

For 16–17-year old e-cigarette use, LTCA identified a 4-class latent trajectory class model (Figure 1) as the best-fitted model (Supplementary Table 3) with acceptable agreement (58.2%) and excellent entropy (0.92). The four e-cigarette use trajectories identified included three classes similar to the cigarette models (*Persistent Never Users—54.2%*, *Prior Initiators/No Progression—15.2%*, *W3 Initiators/No Progression—21.5%*), and one unique class (*W2 Initiators who Progress to High Frequency P30D e-cigarette use—9.1%*). The "*Persistent High Frequency Use*" class identified for cigarettes was not identified for e-cigarettes.

Participant Characteristics by Class Membership among W1 16-17 Year Olds

Supplementary Tables 4 and 5 report 16–17-year old characteristics by cigarette and e-cigarette classes, respectively. Among cigarette classes, the majority of the *Prior Initiators* class (75%) and the *High Frequency* class (68.7%) indicated cigarettes were the first tobacco product tried, compared to only 11.7% of *W3 Initiators*. Among e-cigarette classes, first product tried was more evenly-distributed across products but e-cigarettes was not the most frequent first product tried among e-cigarette *W2 Initiators who Progress to High Frequency P30D e-cigarette use* (34.1% first used cigarettes and 18.7% first used e-cigarettes).

Predictors of Cigarette and E-cigarette Class Membership among W1 16–17 year olds

Weighted multinomial logistic regression results and odds ratios for predictors of cigarette classes (Supplementary Table 6) and e-cigarette classes (Supplementary Table 7) are summarized in a comparison chart of significant predictors of class membership for each product (Table 1). In general, similar risk factors such as sensation seeking, GAIN symptom subscales, other tobacco use, marijuana use, and poorer academic achievement emerged as predictors of initiation or higher use classes compared to the *Persistent Never Use* classes in both cigarette and e-cigarette models. However, models identified different predictors of e-cigarette trajectories compared to cigarette trajectories. For example, sex was not a significant predictor of cigarette trajectories; however, male sex emerged as a significant predictor of the e-cigarette *Prior Initiation* (aOR 1.5, 95% CI 1.0, 2.2, $p < .05$) and *W2 Initiation with Progression* (aOR 2.4, 95% CI 1.5, 3.9, $p < .001$) classes compared to the *Never e-cigarette use* class.

Separate models were conducted among the user classes to explore associations between "first tobacco product tried" and user class membership (Supplementary Tables 8 and 9). After controlling for correlates in separate cigarette and e-cigarette models, youth who were in classes characterized by progression of use or high frequency use had higher odds of continuing to use the first product they tried, which was cigarettes in the cigarette model and e-cigarettes in the e-cigarette model, compared to *W3 initiators/No progression*.

Class membership differences were identified for the variable "Product first tried was flavored" in the descriptive analyses for the e-cigarette classes (Supplementary Table 5), with 58% of *W2 Initiators who Progress to High Frequency P30D e-cigarette use*, 66% of *Prior Initiators with no progression*, and 42% of *W3 Initiators* endorsing their first product tried was flavored. However, in adjusted regression models controlling for demographics and other risk factors, "Product first tried was flavored" did not predict class membership for either product.

Discussion

Among youth at W1 (2013–2014) of the PATH Study, LTCA of separate cigarette and e-cigarette use models across four years did not fit well when examining the entire 12–17 age group. Younger adolescents (ie, 12–15 years) had low overall tobacco use resulting in unstable trajectory class structures. In contrast, the W1 group of 16–17 year olds had reliable estimates and clearer trajectories of use for both products. While recent studies of tobacco use using PATH Study data lump 12–17 year olds into one "youth" category, this analysis demonstrates very different levels and predictors of use within adolescents that may be masked if youth 12–17 years are analyzed as one homogenous group.[14,15] While analytic decisions about how to group specific ages or development periods will differ depending on study goals, variables, data structure, types of analysis/modeling approach, and other factors, results of the analyses presented herein highlight the need to examine these factors carefully, particularly when trying to optimize sensitivity to test hypotheses regarding initiation and progression of specific tobacco products.

Among the 16–17 year olds at W1 who transitioned to young adulthood over the subsequent three years, five trajectories of cigarette smoking were identified. Approximately 9% of the 16–17 group were in the *Persistent High Frequency* cigarette class. This trajectory pattern reflects initiation and progression to regular use taking place before ages 16–17. All other cigarette classes were defined by earlier or later initiation but no progression to regular use. The relatively low percentage of the 16–17-year old age group in a regular use class is in contrast to earlier studies that classified more regular smoking such as occasional/light and high/heavy cigarette smoking.[3–6] In the past several years, there has been a documented decline in cigarette smoking in the general population,[25,26] and in youth specifically.[27,28] The trajectories identified in these analyses reflect an overall downward trend in cigarette smoking during this time frame (2013–2017), even though e-cigarettes gained in popularity among youth.[27,29]

The four e-cigarette use trajectories identified were dominated by never use or initiation (prior either to W1 or at W3), with one e-cigarette class (*W2 Initiators Who Progress to High Frequency P30D e-cigarette use*) capturing 9% of this age group. In contrast to cigarette smokers, there was no class of persistent high frequency use for e-cigarettes. Although ever or current use of e-cigarettes has been rising among young people in the United States,[16,30,31] these analyses over a four-year period do not show a clear trajectory of progression over time to sustained regular use.[11,12,27,32,33] We note that these data were collected from 2013 to 2017, prior to reported increases in e-cigarette use between 2017 and 2019[29] and the escalation in use of nicotine salts and pod-based e-cigarettes, so it is possible that more recent cohorts may reveal different trajectories and correlates of e-cigarette use.[34]

Consistent with a robust literature on risk factors for cigarette smoking trajectories,[3–6,35–37] predictors of initiation and regular use classes for both products included sensation seeking, GAIN symptom subscales, other tobacco use, marijuana use, and poorer academic achievement. Models also identified different predictors of e-cigarette compared to cigarette trajectories. Male sex emerged as a significant predictor of the e-cigarette *Prior Initiation* and *W2 Initiation with Progression* classes; whereas sex was not a significant predictor of cigarette trajectories. A recent analysis of W1-W4 PATH Study 12–17 year olds reported an association between W1 P30D e-cigarette use and P30D cigarette smoking at follow-up waves was stronger for males than for females.[38] Further research is warranted to better understanding gender differences in trajectories of tobacco product use. Having a tobacco user in the household also predicted the e-cigarette *Prior Initiation* and *W3 Initiation* classes compared to the *Never e-cigarette use* class. The *W3 Initiation* class is a period for 18–19 year olds that likely coincides with transition to college or residing out of the home, where there may be more access to tobacco products. Identifying risk factors that are unique to specific products, or common to both, has implications for more effectively targeting early tobacco prevention interventions.

Recent research has explored whether e-cigarette trial may be a pathway to cigarette use, with reports supporting associations between youth ever any e-cigarette use and subsequent cigarette use.[10–13,32,39–44] We examined how 16–17 year olds transitioned through finely delineated levels of use that include frequency of use and can capture progression over time. Models were conducted among the user classes for each product to explore whether the tobacco product first tried was associated with class membership. After controlling for the other predictor variables, first use of cigarettes was the tobacco product most associated with a high frequency of cigarette use trajectory. There was no evidence of an association of e-cigarettes as the first product tried and riskier cigarette trajectories in these analyses. Similarly in the e-cigarette models controlling for the same variables, first use of e-cigarettes was the tobacco product most associated with progression of e-cigarette use. These results suggest that the tobacco product first tried may not be a risk factor for progression to greater use. As noted above, subsequent cohorts during a period of time when products like JUUL became even more accessible may detect different associations. Results also reinforce the importance of measuring levels of use including frequency and testing rigorous models that adjust for other risk factors to more fully understand progression of use at different developmental stages of adolescence and young adulthood.

Limitations of this report include recall bias from a self-report interview. Additionally, as previously noted, the PATH Study asked about "e-cigarettes" at W1 and "e-products" (ie, e-cigarettes, e-cigars, e-pipes, and e-hookah) at W2, W3, and W4. This data source does not include policy level variables during the data collection period. Nonetheless, among the strengths of our analytic approach, and advancement over other LCA approaches to-date, is the variable that was derived to model use over 4 time points included P12M and P30D frequent and infrequent use based on days smoked per month. Other reports have called for approaches that examine frequency and intensity of tobacco use and it has been suggested these may be critical factors in pathways such as discontinued use and switching.[5,17,20] Indeed, our analyses found that for each product, e-cigarettes and cigarettes, trajectories that differed by frequency of P30D use were identified and predictors of those classes varied accordingly. It is also noted that the period under study (2013–2017) was prior to nationwide implementation of Tobacco 21 and findings for W3 initiators (ie, 18–19 year olds who, depending on their state of residence, were legally able to purchase tobacco products at that time) may not generalize to the current policy environment.

Implications

Analyses identify a critical vulnerable period between ages 12 and 15 years to target tobacco prevention messages. Risk factors for later W3 initiation (18–19 years old) of e-cigarettes identify youth already using cigarettes and other substances to be particularly vulnerable to e-cigarette initiation. This age (18–19 years old) may be another period of developmental transition where targeted prevention and cessation programs could prevent late-onset initiation or further progression. As curiosity and experimentation with emerging products like e-cigarettes have been high among US youth, screening and interventions focused on well-established risk factors such as mental health and other substance use may still be critical targets to prevent progression to regular tobacco use in adulthood.

Supplementary Material

A Contributorship Form detailing each author's specific involvement with this content, as well as any supplementary data, are available online at https://academic.oup.com/ntr.

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Declaration of Interests

K. Michael Cummings has received grant funding from the Pfizer, Inc., to study the impact of a hospital-based tobacco cessation intervention. Dr. Cummings also receives funding as an expert witness in litigation filed against the tobacco industry. Maciej Goniewicz has received a research grant from Pfizer and served as a member of a scientific advisory board to Johnson & Johnson, a pharmaceutical company that manufactures smoking cessation medications. Wilson Compton reports holding stock in General Electric, 3M Companies and Pfizer. Jennifer Pearson is an expert witness for the Plaintiffs in a multi-district litigation invoking American Spirit Cigarettes.

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Data Availability

The data underlying this article are available through the United States Department of Health and Human Services. 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] Restricted-Use Files. Inter-university Consortium for Political and Social Research [distributor], 2021-06-29.

References

1. Gentzke AS, Wang TW, Jamal A, *et al*. Tobacco product use among middle and high school students—United States, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(50):1881–1888.
2. Wang TW, Neff LJ, Park-Lee E, *et al*. E-cigarette use among middle and high school students—United States, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(37):1310–1312.
3. Hair E, Bennett M, Williams V, *et al*. Progression to established patterns of cigarette smoking among young adults. *Drug Alcohol Depend*. 2017;177:77–83. doi:10.1016/j.drugalcdep.2017.03.040.
4. Berg CJ, Haardörfer R, Vu M, *et al*. Cigarette use trajectories in young adults: analyses of predictors across system levels. *Drug Alcohol Depend*. 2018;188:281–287. doi:10.1016/j.drugalcdep.2018.03.055.
5. Dutra LM, Glantz SA, Lisha NE, Song AV. Beyond experimentation: five trajectories of cigarette smoking in a longitudinal sample of youth. *PLoS One*. 2017;12(2):e0171808.
6. Lenk KM, Erickson DJ, Forster JL. Trajectories of cigarette smoking from teens to young adulthood: 2000 to 2013. *Am J Health Promot*. 2018;32(5):1214–1220.
7. Westling E, Rusby JC, Crowley R, Light JM. Electronic cigarette use by youth: prevalence, correlates, and use trajectories from middle to high school. *J Adolesc Health*. 2017;60(6):660–666.
8. Cho J, Goldenson NI, Stone MD, *et al*. Characterizing polytobacco use trajectories and their associations with substance use and mental health across mid-adolescence. *Nicotine Tob Res*. 2018;20(suppl_1):S31–S38.
9. Hair EC, Barton AA, Perks SN, *et al*. Association between e-cigarette use and future combustible cigarette use: evidence from a prospective cohort of youth and young adults, 2017–2019. *Addict Behav*. 2020;112:106593.
10. Leventhal AM, Strong DR, Kirkpatrick MG, *et al*. Association of electronic cigarette use with initiation of combustible tobacco product smoking in early adolescence. *JAMA*. 2015;314(7):700–707.
11. Stanton CA, Bansal-Travers M, Johnson AL, *et al*. Longitudinal e-cigarette and cigarette use among US youth in the PATH Study (2013-2015). *J Natl Cancer Inst*. 2019;111(10): 1088–1096.
12. Stanton CA, Sharma E, Edwards KC, *et al*. Longitudinal transitions of exclusive and polytobacco electronic nicotine delivery systems (ENDS) use among youth, young adults and adults in the USA: findings from the PATH Study Waves 1–3 (2013–2016). *Tob Control*. 2020;29(Suppl 3):s147–s154.
13. Watkins SL, Glantz SA, Chaffee BW. Association of noncigarette tobacco product use with future cigarette smoking among youth in the population assessment of tobacco and health (PATH) study, 2013-2015. *JAMA Pediatr*. 2018;172(2):181–187.
14. Simon P, Buta E, Gueorguieva R, *et al*. Transitions across tobacco use profiles among adolescents: results from the Population Assessment of Tobacco and Health (PATH) study waves 1 and 2. *Addiction*. 2020;115(4):740–747.
15. Boyd CJ, Veliz P, Evans-Polce R, Eisman AB, McCabe SE. Latent class trajectories: US adolescents' nicotine use and its association with nicotine dependence. *Addict Behav Rep*. 2020;12:100303.
16. Fadus MC, Smith TT, Squeglia LM. The rise of e-cigarettes, pod mod devices, and JUUL among youth: factors influencing use, health implications, and downstream effects. *Drug Alcohol Depend*. 2019;201:85–93. doi:10.1016/j.drugalcdep.2019.04.011.
17. Hyland A, Ambrose BK, Conway KP, *et al*. Design and methods of the Population Assessment of Tobacco and Health (PATH) Study. *Tob Control*. 2017;26(4):371–378.
18. United States Department of Health and Human Services. National Institutes of Health. National Institute on Drug Abuse aUSDoHaHSFaDA. *Population Assessment of Tobacco and Health (PATH) Study [United States] Restricted-Use User Guide*. 2019. https://www.icpsr.umich.edu/icpsrweb/NAHDAP/studies/36231.
19. Tourangeau R, Yan T, Sun H, Hyland A, Stanton CA. Population Assessment of Tobacco and Health (PATH) reliability and validity study: selected reliability and validity estimates. *Tob Control*. 2018;28(6):663–668:tobaccocontrol-2018-054561. .
20. Pearson JL, Sharma E, Rui N, *et al*. Association of electronic nicotine delivery system use with cigarette smoking progression or reduction among young adults. *JAMA Network Open*. 2020;3(11):e2015893–e2015893.
21. Conway KP, Green VR, Kasza KA, *et al*. Co-occurrence of tobacco product use, substance use, and mental health problems among youth: findings from wave 1 (2013-2014) of the population assessment of tobacco and health (PATH) study. *Addict Behav*. 2018;76:208–217. doi:10.1016/j.addbeh.2017.08.009.
22. Collins LM, Lanza ST. Latent class and latent transition analysis: with applications in the social behavioral, and health sciences. *Wiley series in probability and statistics*. Hoboken, NJ: John Wiley & Sons; 2010:285.
23. McCarthy PJ. *Pseudoreplication: further evaluation and applications of the balanced half-sample technique*. No. 31. US Health Services and Mental Health Administration, 1969.
24. Judkins DR. Fay's method for variance estimation. *J Off Stat*. 1990;6(3):223.
25. Wang TW, Asman K, Gentzke AS, *et al*. Tobacco product use among adults—United States, 2017. *MMWR Morb Mortal Wkly Rep*. 2018;67(44):1225–1232.
26. US Department of Health and Human Services. *The Health Consequences of Smoking—50 Years of Progress: A Report of the Surgeon General*. Atlanta, GA: US 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. 2014:943.
27. Gentzke AS, Creamer M, Cullen KA, *et al*. Vital signs: tobacco product use among middle and high school students — United States, 2011–2018. *MMWR Morb Mortal Wkly Rep*. 2019;68(6):157–164. doi:10.15585/mmwr.mm6806e1.
28. Jamal A, Gentzke A, Hu S, *et al*. Tobacco use among middle and high school students-United States, 2011-2016. *MMWR Morb Mortal Wkly Rep*. 2017;66(23):597.
29. Wang TW, Gentzke AS, Creamer MR, *et al*. Tobacco product use and associated factors among middle and high school students—United States, 2019. *MMWR Surveill Summ*. 2019;68(12):1.
30. Boykan R, Goniewicz ML, Messina CR. Evidence of nicotine dependence in adolescents who use Juul and similar pod devices. *Int J Environ Res Public Health*. 2019;16(12):2135. doi:10.3390/ijerph16122135. .
31. Vogel EA, Prochaska JJ, Ramo DE, Andres J, Rubinstein ML. Adolescents' e-cigarette use: increases in frequency, dependence, and nicotine exposure over 12 months. *J Adolesc Health*. 2019;64(6):770–775.
32. Stanton CA, Sharma E, Seaman EL, *et al*. Initiation of any tobacco and five tobacco products across 3 years among youth, young adults and adults in the USA: findings from the PATH Study Waves 1–3 (2013–2016). *Tob Control*. 2020;29(Suppl 3):s178–s190.
33. National Academies of Sciences, Engineering, and Medicine. *Public health consequences of e-cigarettes*. Washington, DC: The National Academies Press; 2018.
34. Hammond D, Reid JL, Rynard VL, *et al*. Prevalence of vaping and smoking among adolescents in Canada, England, and the United States: repeat national cross sectional surveys. *BMJ*. 2019;365:l2219. doi:10.1136/bmj.l2219.
35. Costello DM, Dierker LC, Jones BL, Rose JS. Trajectories of smoking from adolescence to early adulthood and their psychosocial risk factors. *Health Psychol*. 2008;27(6):811–818.
36. Brook DW, Brook JS, Zhang C, *et al*. Developmental trajectories of cigarette smoking from adolescence to the early thirties: personality and behavioral risk factors. *Nicotine Tob Res*. 2008;10(8):1283–1291.
37. Chassin L, Presson CC, Pitts SC, Sherman SJ. The natural history of cigarette smoking from adolescence to adulthood in a midwestern community sample: multiple trajectories and their psychosocial correlates. *Health Psychol*. 2000;19(3):223–231.
38. Duan Z, Wang Y, Huang J. Sex difference in the association between electronic cigarette use and subsequent cigarette smoking among US adolescents: findings from the PATH Study Waves 1–4. *Int J Environ Res Public Health*. 2021;18(4):1695.
39. Barrington-Trimis JL, Urman R, Berhane K, *et al*. E-cigarettes and future cigarette use. *Pediatrics*. 2016;138(1). doi:10.1542/peds.2016-0379.
40. Primack BA, Soneji S, Stoolmiller M, Fine MJ, Sargent JD. Progression to traditional cigarette smoking after electronic cigarette use among US adolescents and young adults. *JAMA Pediatr*. 2015;169(11):1018–1023.
41. Wills TA, Gibbons FX, Sargent JD, Schweitzer RJ. How is the effect of adolescent e-cigarette use on smoking onset mediated: a longitudinal analysis. *Psychol Addict Behav*. 2016;30(8):876–886.
42. Unger JB, Soto DW, Leventhal A. E-cigarette use and subsequent cigarette and marijuana use among Hispanic young adults. *Drug Alcohol Depend*. Jun 1 2016;163:261–264. doi:10.1016/j.drugalcdep.2016.04.027.
43. Park J-Y, Seo D-C, Lin H-C. E-cigarette use and intention to initiate or quit smoking among US youths. *Am J Public Health*. 2016;106(4):672–678.
44. Chaffee BW, Watkins SL, Glantz SA. Electronic cigarette use and progression from experimentation to established smoking. *Pediatrics*. 2018;141(4):e20173594.