Biostatistics and Biometrics
Open Access Journal
ISSN: 2573-2633

Research Article
Volume 11 Issue 1 - October 2022
DOI: 10.19080/BBOAJ.2022.11.555801

Biostat Biom Open Access J

Precise Estimation for the Age of Initiation of Tobacco Use Among U.S. Youth: Finding from the Population Assessment of Tobacco and Health (PATH) Study, 2013-2017

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Submission: October 07, 2022; **Published:** October 21, 2022

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Abstract

Context: Youth tobacco use remains a prominent United States public health issue with a high economic and health burden.

Method: We pooled never and ever users at youth's first wave of PATH participation (waves 1-3) to estimate age of initiation for hookah, e-cigarettes, cigarettes, traditional cigars, cigarillos, and smokeless tobacco prospectively (waves 2-4). Age of initiation of each tobacco product was estimated using weighted interval-censored survival analyses. Weighted interval censoring Cox-proportional hazards regression models were used to assess the association of ever use of the TP at the first wave of PATH participation, sex, and race/ethnicity on the age of initiation of ever use of each tobacco product. Sensitivity analyses were performed to understand the impact of the recalled age of initiation for the left-censored participants by replacing the recalled age of initiation with a uniform "6" years lower bound.

Results: The proportion of those who ever used each tobacco product at the first wave of PATH participation ranged from (N=580,056 of 32,625 206) for traditional cigars to (N=3,430,105 of 32,958,069) for cigarettes. There was a significant increase in ever use of each tobacco product after the age of 14, with e-cigarettes and cigarettes showing the highest cumulative incidence of initiation by age 21, while smokeless and cigarillos recorded the lowest cumulative incidence by age 21. The adjusted Cox models showed boys initiated at earlier ages for all of these tobacco products except for hookah, which showed no difference. Similarly, apart from ever use of hookah, non-Hispanic White youth were more likely to initiate each tobacco product at earlier ages compared to Hispanic, non-Hispanic Black, and non-Hispanic Other youth.

Conclusion: The increased sample size and the inclusion of ever users yielded greater precision for age of initiation of each tobacco product than analyses limited to never users at the first wave of PATH participation. These analyses can help elucidate population selection criteria for estimating the age of initiation of tobacco products.

Keywords: Hookah, E-Cigarette; Cigarette; Traditional Cigar; Cigarillo; Smokeless Tobacco; Left Truncated; Right Censored; Survival Analysis

Introduction

Tobacco product use remains high among United States (US) youth resulting in a substantial public health burden. A report from the 2021 National Youth Tobacco Survey (NYTS) showed that about 5.22 million high school students (aged 14-18) and 1.34 million middle school students (aged 11-14) reported having ever tried a tobacco product (TP) in the US [1]. This represents 34.0% and 11.3% of high school students and middle school students, respectively[1]. This high prevalence of tobacco use among youth has resulted in addiction, priming for use of other addictive substances, reduced impulse control, deficits in attention, a deficit in cognition, and mood disorder[2]. This has resulted in more

research using comprehensive data to understand the age of initiation of TPs in the contemporary TP marketplace [3-6].

Despite a recent decrease in youth prevalence of daily cigarette smoking since daily cigarette use doubled in the U.S. in 1980 [7, 8], the consumption of alternative TPs has increased, diminishing the public health gains that resulted from declining cigarette consumption [7,9]. The increase in the use of alternative TPs is noticeable, especially among youth [7, 10]. For example, within the past decade, there have been increases in TP use such as hookah among youth, which has tremendously increased the number of TP consumers [7]. The rising popularity of alternative TPs, including hookah, e-cigarettes, and cigarillos may quickly diminish the perception that TP use is dangerous and may increase consumption of these products [7, 11].

Within the past decade, efforts have been dedicated to understanding TP initiation behaviors across different products including cigarettes, e-cigarettes, hookah, and cigar products among never-users [4, 5, 10, 12-16]. Previous analyses of the Population Assessment of Tobacco and Health (PATH) study have been based on estimating initiation and the age of initiation prospectively among never-users of each of these TPs at the first wave of PATH participation [3-6]. Specifically, not included in these previous analyses are participants who are already users of a TP at their first wave of PATH participation, which in statistical terms means those participants are "left-truncated" [17]. This is a very common design employed by most epidemiological longitudinal studies [18]. However, this design is subject to a reduction in estimation precision and bias due to left truncation [19,20]. The bias is evident when the proportion of TP users is large or if the distribution of the TP users at the first wave of PATH participation is different from the distribution of the participants that are followed longitudinally for initiation of the TP, which is subject to right-censoring [21, 22]. In an effort to reduce bias and increase precision, in our analyses we have incorporated users of each TP, as well as never-users of each TP at the first wave of PATH participation. Thus, we included users who reported their recalled age of initiation and never-users to prospectively estimate the age of initiation of ever use of each TP. In this study, those who recalled initiating a TP at the first wave of PATH participation were considered left-censored, while those that were never-users at first wave of PATH participation, age of initiation was estimated prospectively, and those that never initiated the TP at the end of follow-up are considered right-censored. Incorporating both the users of each TP at first wave of PATH participation and prospective follow-up participants (including right-censored participants) in the analysis can improve the precision and reduce bias in estimating the age of initiation of ever use of these TPs [19,20]. We estimated the age of initiation of ever use of six TPs: hookah, e-cigarettes, cigarettes, traditional cigars, cigarillos, and smokeless tobacco [23]. Furthermore, we estimated the age at of youth ever use adjusting for ever use of the TP at first wave of PATH participation, sex, and racial/ethnicity.

Methods

Study Sample Participants. The PATH Study is a national longitudinal study of tobacco use in the U.S. and how it affects the health of its people. This study started in 2013 and employed a complex stratified area probability sampling method to generate a nationally representative sample of youth and adults in the U.S. representing approaximately 46,000 participants. [24, 25]. We used youth (aged 12-17) data from waves 1-4 : wave 1: 2013-2014, wave 2: 2014-2015, wave 3: 2015-2016, wave 4: 2016-2017. Participants who were aged 9 to 11 years at wave 1, (i.e., shadow youth) were invited to enter the study once they turned 12 at waves 2 and wave 3. When youth participants turned 18, they were invited to participate in the adult study for waves 2–4, respectively. All participants were followed-up through wave 4 [25].

Ever use of a TP at first wave of PATH participation

In the first wave of PATH participation, youth were asked if they ever used each of these TPs. In waves 1-4, PATH asked youth respondents "Have you ever smoked tobacco in a hookah, even one or two puffs?". Response options were "yes", and "no" [5, 26]. Less than 1% of the participants with unknown response, were dropped [5, 26]. In waves 1-4, PATH asked youth respondents" Have you ever smoked cigarettes, traditional cigar, cigarillo and smokeless, even one or two puffs? . Response options were "yes", and "no" [26, 27]. Similarly, less than 1% of participants were dropped for not selected either "yes" or "no". For e-cigarette in wave 1, PATH asked youth respondents: "Have you ever used an e-cigarette, such as NJOY, Blu, or smoking Everywhere, even one or two times?". Response options were "yes", and "no". In waves 2-4, question was modified: "Have you ever used an electronic nicotine product, even one or two times?". These questions were assumed to measure the same construct across waves. Response options were "yes", and "no" [4, 26, 27]. Furthermore, missing data, that is those who didn't select either "yes" or "no" were dropped [4,26,27].

Interval-Censored Outcome: Ever Age of Initiation of TP

Our outcome is interval-censored because the exact date of ever use of each TP is unknown for all participants. The restricted-use PATH data does not provide the date of birth for youth participants but does provide youth age in years at each wave and the number of weeks between waves. For our primary analyses, TP users at the first wave of PATH participation the lower bound was the recalled age of initiation as reported by the participants at their first wave of PATH participation while the upper bound was the age at the first wave of PATH participation. We also performed sensitivity analyses by replacing the recalled age of initiation of users with a six "6" years as the lower bound, that is, six uniform bound was assumed to be the recall age of initiation for all youth, which assumes a minimum age of 6 years old [28-30]. For the never-users at the first wave of PATH participation, their lower bound was the age at first wave of PATH participation while their upper bound was estimated by adding participants' age at their first wave of PATH participation (waves 1-3) to the number of

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weeks between relevant subsequent waves (waves 2-4) [4]. Never-users at the first wave of PATH participation who did not initiate the TP during the study period were considered right-censored, that is, their upper bound age of initiation was unbounded [28,29].

Covariates: Ever use of a TP at the first wave of PATH participation, Sex and Race/Ethnicity.

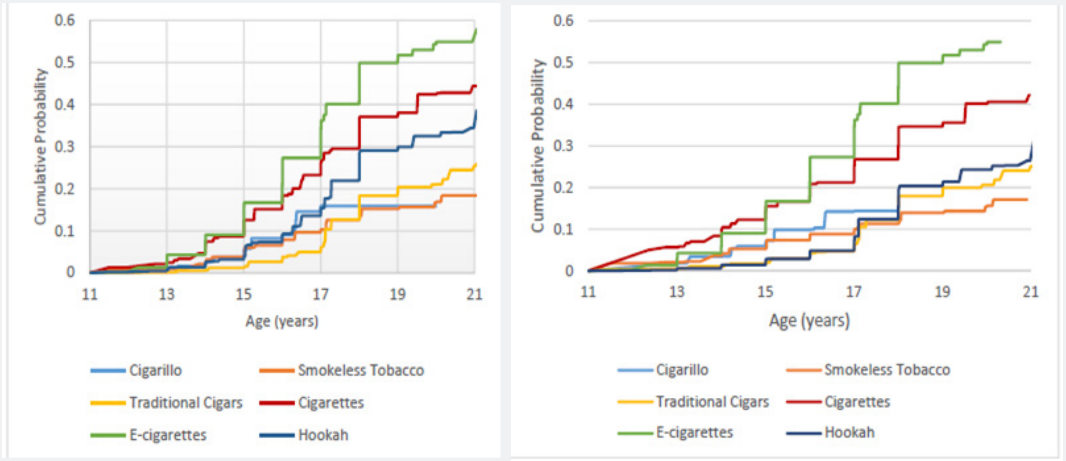
In the first wave of PATH participation, participants were asked if the used each of the TP (yes/no: cigarettes, e-cigarettes, hookah, traditional cigars, cigarillos, filtered cigars, and smokeless tobacco). This binary indicator variable for each TP at first wave of PATH participation was a covariate in the analysis of each one of the TP of interest. Sex was classified as female or male. This variable was imputed by PATH using the household information [23]. Race was assessed as non-Hispanic White, non-Hispanic Black, Asian, and Other (including multi-racial). Ethnicity was categorized as either Hispanic or non-Hispanic. To be comparable to those in prior Surgeon General's reports, we classified race/ethnicity into four categories: non-Hispanic White, Hispanic, non-Hispanic Black, and non-Hispanic Other (Asian, multi-race, and other races) [16, 31, 32].

Statistical Analysis

Survival analyses of the age of initiation of each TP were conducted among PATH youth (ages 12-17) at their first wave of PATH participation, waves 1-4[26]. These survival analyses were performed using Statistical Analysis System (SAS version 9.4) macros to estimate the overall distribution of the age of initiation of each of the six TPs PATH provided sampling weights, at their first wave of PATH participation, which is the number of individuals in the population each respondent in the sample is representing [23]. In addition, we incorporated the sampling weights and their corresponding 100 balance replicate weights to account for the complex survey design (see details in their methodology) [23]. A Fay's correction factor of 0.3 was applied to stabilize the estimates [36-40]. This correction factor provides an alternative to variance estimation which can correct for some of the linearization method's weaknesses by the replicate weights [39-41]. For each TP, our primary interpretation was based on the model with the recall age of initiation.

Furthermore, we performed weighted interval-censored Cox proportional hazards regression to estimate the association of ever use of the TP at the first wave of PATH participation, sex, and race/ethnicity, on the age of initiation of each TP [42]. A key assumption of this model is that these explanatory variables act directly on the baseline hazard function, not on the age of initiation and are constant over time [43]. We had less than 1% missing data in the covariates, we analyzed observation with complete information, that is, the model assumed that the missing data in covariates are non-informative, in other word, the missingness does not depend on the observed and will have little effect on the estimate of hazard ratios [44].

Results



Panel A: Based on recalled age of initiation of each tobacco product. Panel B: Based on uniform "6" lower bound.
Figure 1: Estimated hazard function of the age of initiation of ever use of tobacco products.

Weighted summary statistics for demographic characteristics for PATH youth (aged 12-17 at their first wave of PATH participation) are presented in table 1. The sample size for youth with complete data for each of the TPs was as follows: 17745 youth (representing 33 106 488 U.S. youth) for hookah; 17 594 (representing 32 839 325 U.S youth) for e-cigarettes; 17 667 youth(Representing 32 958 069 U.S youth) for cigarettes; 17 495 youth (representing 32 625 206 U.S. youth) for traditional cigars; 17 437 youth (representing 32 535 569 U.S. youth) for cigarillos; and 17 602 (representing 32 840 714 U.S youth) for smokeless tobacco. Among these youth, the proportions of those who indicated ever use of each TP at their first wave of PATH participation varied, with 5.7% for hookah, 8.1% for a cigarette, 10.4% for e-cigarettes, 1.8% for traditional cigars, 4.9% for cigarillos, and 3.5% for smokeless tobacco. The

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average age of participants at their first wave of PATH participation was 13.9 years old across all TPs. The distribution by sex was evenly distributed, with boys accounting for approximately 51%. The distribution by race/ethnicity was evenly distributed across TPs with approximately 54% non-Hispanic White, 23% Hispanic, 13% non-Hispanic Black, and 10% non-Hispanic Other (Table 2) and (Figure 1) (Panel A is based on the recall age and Panel B is based on "6" years uniform lower bound) present estimates for the cumulative incidence of the estimated age of initiation for each TP. We present estimates of the cumulative incidence based on the recalled age of ever use of each TP and the sensitivity analyses based on uniform "6" years lower bound for the left censored sample.

Table 1: Demographic characteristics for user and never user of tobacco products in PATH USA youth (age 12-17).

Variables		HOOKAH			E-CIGARETTES			CIGARETTES		
		n =17,745;			n =17,594;			n =17,667;		
		N = 33,106,488			N = 32,839,325			N = 32,958,069		
		n	N	Weighted %(SE)	n	N	Weighted %(SE)	n	N	Weighted %(SE)
Wave of entry into PATH Study	Wave 1 (2013-2014)	13,622	24,892,570	74.9(0.10)	13,607	24,777,390	75.4(0.20)	13,607	24,774,185	75.2(0.15)
	Wave 1 (2014-2015)	2,085	4,106,424	12.4(0.08)	2,010	3,964,885	12.1(0.13)	2021	3,984,220	12.1(0.13)
	Wave 1 (2015-2016)	2,038	4,197,494	12.7(0.14)	1,977	4,097,049	12.5(0.24)	2039	4,199,664	12.7(0.19)
Age at first wave of participation into PATH Study	Weighted mean (SE)		13.9 0.01			13.9 0.01			13.9 0.01	
Proportion of ever use of the TP at the first wave of PATH participation		1,025	1,885,88	5.7(0.26)	1,451	2,644,472	8.1(0.26)	1891	3,430,105	10.4(0.33)
Sex	Female	8,619	16,122,394	48.7(0.07)	8,562	16,029,625	48.8(0.08)	8583	16,056,863	48.7(0.08)
	Male	9,117	16,964,146	51.3(0.07)	9,025	16,797,151	51.2(0.08)	9075	16,881,257	51.3(0.08)
	Missing	9	16,791		7	13,065		9	16,790	
Race/ ethnicity	Non-Hispanic White	8,546	17,727,223	53.7(0.12)	8,484	17,610,898	53.7(0.12)	8,513	17,662,974	53.7(0.11)
	Hispanic	5,106	7,594,152	23.0(0.11)	5,052	7,495,711	22.9(0.13)	5,076	7,543,854	22.9(0.11)
	Non-Hispanic Black	2,373	4,460,283	13.5(0.07)	2359	4,439,139	13.5(0.08)	2,367	4,446,654	13.5(0.07)
	Non-Hispanic Other*	1,674	3,242,527	9.8(0.10)	1655	3,219,087	9.8(0.11)	1664	3,220,415	9.8(0.10)
	Missing	46	85,821		44	82,126		47	87,679	

Variables		**TRADITIONAL CIGARS**			**SMOKELESS TOBACCO**			**CIGARILLOS**		
		n =17,495;			**n =17,602;**			**n =17,437;**		
		N = 32,625,206			**N = 32,840,714**			**N = 32,535,569**		
		n	N	Weighted %(SE)	n	N	Weighted %(SE)	n	N	Weighted %(SE)
Wave of entry into PATH	Wave 1 (2013-2014)	13,388	24,355,484	74.7(0.14)	13,496	24,571,848	74.8(0.15)	13,324	2,425,196	74.6(0.14)
	Wave 1 (2014-2015)	2,078	4,088,765	12.5(0.13)	2,069	4,075,419	12.4(0.12)	2,085	4,105,263	12.6(0.12)
	Wave 1 (2015-2016)	2,029	4,180,593	12.8(0.19)	2,036	4,193,446	12.8(0.19)	2,028	4,178,389	12.8(0.19)

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Age at first wave of participation into PATH Study	Weighted mean (SE)		13.9 0.01			13.9 0.01			13.9 0.01	
Proportion of ever use of the TP at the first wave of PATH participation		302	580,056	1.8(0.10)	612	1,149,604	3.5(0.19)	879	1,600,972	4.9(0.21)
Sex	Female	8,516	15,924,639	48.8(0.08)	8,563	16,030,021	48.8(0.08)	8,488	15,880,595	48.8(0.09)
	Male	8,970	16,680,619	51.2(0.08)	9,029	16,790,744	51.2(0.08)	8,940	16,635,025	51.2(0.09)
	Missing	9	16,783		9	16,792		9	16,793	
Race/ ethnicity	Non-Hispanic White	8,403	17,421,335	53.5(0.12)	8474	17,578,635	53.7(0.12)	8,402	17,423,048	53.7(0.13)
	Hispanic	5,039	7,503,700	23.1(0.11)	5071	7,544,526	23.0(0.11)	5,009	7,459,158	23.0(0.12)
	Non-Hispanic Black	2,357	4,428,603	13.6(0.08)	2,354	4,422,462	13.5(0.07)	2335	4,389,394	13.5(0.09)
	Non-Hispanic Other*	1,649	3,187,395	9.8(0.11)	1,656	3,212,964	9.8(0.09)	1644	3,179,797	9.8(0.0)
	Missing	47	87,647		46	85,823		47	87,697	

Table 2: Estimated hazard function (95% confidence interval) of the age of initiation of ever use tobacco products for the overall sample of PATH (2013- 2017) USA youth.

	Hookah	E-Cigarettes	Cigarettes	Traditional Cigars	Smokeless Tobacco	Cigarillos
Age	**Primary analysis based on the recalled age of initiation**					
12	0.2% (0.2, 0.3)	1.3% (1.1, 1.5)	1.4% (1.1, 1.6)	0.1% (0.04,0.2)	0.7% (0.4,0.9)	0.4% (0.3,0.5)
13	0.7% (0.5, 0.9)	4.3% (1.6, 7.1)	2.5% (2.2, 3.0)	0.2% (0.1, 0.3)	1.1% (0.9, 1.3)	0.7% (0.5, 0.8)
14	1.4% (1.1, 1.6)	9.1% (7.9, 10.2)	7.1% (4.6, 9.5)	0.6% (0.5, 1.0)	2.4% (1.5, 3.3)	2.3% (1.1, 3.5)
15	3.2% (2.9, 3.6)	16.7% (15.8, 17.6)	12.6% (10.6, 14.5)	1.3% (0.7, 2.0)	4.2% (2.7, 5.6)	5.8% (3.2, 8.3)
16	7.4% (6.7, 8.0)	27.3% (22.3, 32.3)	18.4% (16.4, 20.4)	3.8% (2.4, 5.2)	7.9% (6.3, 9.5)	9.0% (8.3, 9.8)
17	13.6% (12.6, 14.6)	36.2% (32.5, 39.9)	26.9% (23.7, 30.1)	6.2% (4.2, 8.1)	10.3% (9.3, 11.4)	15.9% (14.8, 17.0)
18	22.0% (20.5, 23.3)	49.9% (46.3, 53.5)	37.1% (34.3, 40.0)	18.4% (16.2, 20.5)	13.0% (11.2, 14.7)	15.9% (14.8, 17.0)
19	29.1% (27.2, 30.9)	51.7% (49.2, 54.3)	38.1% (36.0, 40.1)	20.4% (18.5, 22.7)	15.3% (14.1, 16.5)	15.9% (14.8, 17.0)
20	32.6% (30.4, 34.6)	54.9% (52.3, 57.5)	42.5% (40.4, 44.5)	21.1% (19.3, 22.8)	16.9% (15.3, 18.5)	15.9% (14.8, 17.0)
21	38.6% (29.3, 47.8)	57.9 % (50.8, 64.9)	44.4% (40.5, 48.3)	25.5% (19.3, 31.6)	18.4% (15.0, 21.8)	18.4% (15.0, 21.8)
Age	**Sensitivity Analysis based on uniform six "6" years lower bound for left censored sample**					
12	0.1% (0.1, 0.1)	1.3% (1.1, 1.5)	5.0% (4.4, 5.7)	0.4% (0.3, 0.6)	1.8% (1.4, 2.2)	1.4% (1.0, 1.8)
13	0.6% (0.1, 1.2)	4.3% (1.6, 7.0)	5.7% (5.0, 6.3))	0.5% (0.3, 0.7)	2.1% (1.7, 2.5)	1.6% (1.2, 2.0)
14	1.4% (1.1, 1.6)	9.0% (7.9, 10.2)	10.1% (7.7, 12.5)	1.1% (0.9, 1.4)	3.7% (3.1, 4.3)	3.4% (2.8, 4.1)
15	2.9% (1.4, 4.4)	16.7% (15.8, 17.6)	15.5% (13.5, 17.5)	1.8% (1.2, 2.5)	5.3% (3.7, 7.0)	7.2% (4.8, 9.6)
16	4.8% (4.0, 5.6)	27.3% (22.3, 32.3)	20.8% (19.0, 22.7)	4.2% (2.7, 5.7)	8.9% (7.4, 10.3)	9.9% (8.8, 10.9)
17	8.2% (5.8, 10.7)	36.2% (32.5, 40.0)	26.8% (24.4, 29.1)	6.3% (3.8, 8.8)	10.0% (7.8, 12.2)	14.3% (13.3, 15.4)
18	19.7% (14.0, 25.4)	50.0% (46.3, 53.5)	34.6% (31.5, 37.7)	17.9% (15.8, 20.0)	11.5% (9.8, 13.2)	14.3% (13.3, 15.4)
19	21.4% (19.1, 23.6)	51.7% (49.2, 54.3)	35.5% (33.5, 37.5)	19.9% (17.6, 22.2)	14.0% (12.8, 15.1)	14.3% (13.3, 15.4)

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20	24.3% (22.2, 26.3)	54.9% (52.3, 57.5)	40.2% (38.2, 42.1)	20.6% (18.9, 22.4)	15.6% (14.1, 17.1)	14.3% (13.3, 15.4)
21	31.0% (20.8, 41.3)	57.9% (50.8, 64.9)	42.1% (38.2, 46.1)	25.0% (18.8, 31.2)	17.1% (14.0, 20.6)	14.3% (13.3, 15.4)

*Hazards are reported as cumulative percentages (i.e., cumulative incidence)
a: 95% CI: Turnbull 95% confidence interval
¥ PATH restricted file received disclosure to publish: March 02, 2020, and July 23, 2020. 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. ICPSR36231□v13. Ann Arbor, MI: Interuniversity
Consortium for Political and Social Research [distributor], November 5, 2019. https://doi.org/10.3886/ICPSR36231.v23

The estimates of the cumulative incidence from both recalled age of initiation and the analyses based on six "6" years lower bound for users at first wave of PATH participation are similar in most cases, suggesting the effects of recall bias on users at first wave of PATH participation to estimate age of initiation are minimal for most of the TPs. At age 14, the cumulative incidence of the age of initiation of e-cigarette was9.1% (7.9– 10.2) representing 2.9 million youth and by age 17: 36.2% (95% CI: 32.5-39.9%) of youth, representing about 11.9 million youth. The cumulative incidence of the age of initiation of cigarette use was second to e-cigarettes with 26.9% (95% CI: 23.7-30.1%) of youth initiating by age 17, representing approximately 8.9 million USA youth. By age 17, 13.6% (95% CI: 12.6 -14.6%) of youth initiated ever use of hookah. This increases to 38.6% (95% CI: 29.3-47.8%) by age 21. The cumulative incidence of the age of initiation of ever use of cigarillos was 15.9% (95% CI: 14.8 – 17.0%) by age 17. Furthermore, by age 21, the cumulative incidence of youth who initiated ever use of cigarillos was 18.4% (95% CI: 15.0 – 21.8%). By age 17, 10.3% (95% CI:9.3 – 11.4%) of youth representing approximately 3.3 million U.S. youth initiated ever use of smokeless tobacco, and this increases to about 6 million by age 21. Cumulative incidence of ever use of traditional cigars by age 17, was 6.2% (95% CI: 4.2 – 8.1%), but by age 21, the cumulative incidence was 25.5% (95% CI: 19.3 – 31.6).

Table 3 presents results from the interval-censored Cox proportional hazards models assessing the association of ever use of the TP at the first wave of PATH participation, sex, and race/ethnicity, on the age of initiation for each TP ever use. The analyses revealed the hazard ratios of boys relative to girls of initiating ever use of e-cigarettes, cigarettes, traditional cigars, smokeless and cigarillos at earlier age was 8%, 13%, 161%, 125%, and 18% higher respectively. Hispanic, non-Hispanic Black, and non-Hispanic Other had a 20%, 4%, and 20% increase in the hazard ratio for initiating ever use of hookah at earlier ages compared to non-Hispanic White youth. The hazard ratio of initiating ever use of e-cigarette at an earlier age was 27% lower in non-Hispanic Black youth, and 16% lower in non-Hispanic Other youth compared to non-Hispanic White youth. For cigarettes, the hazard ratio of initiating ever use of cigarette at an earlier age was 7% lower in Hispanic youth, 25% lower in non-Hispanic Black youth, and 11% lower in non-Hispanic Other youth compared to non-Hispanic White youth. The hazard ratio of initiating ever use of traditional cigars at earlier ages 41% lower in Hispanic youth, 53% lower in non-Hispanic Black youth, and 32% lower in non-Hispanic Other youth compared to non- Hispanic White youth. Similar results were found in smokeless tobacco, as the hazard ratio of initiating smokeless tobacco at an earlier age was 44% lower in Hispanic youth, 58% lower in non-Hispanic Black youth, and 34% lower in non-Hispanic Other youth compared to non-Hispanic White youth. Those who indicated ever use of a TP (i.e., hookah, e-cigarettes, cigarettes, traditional cigars, cigarillos, and smokeless tobacco) at their first wave of PATH participation had a higher risk of an earlier age of initiation across each of the TPs of interest. Similar results were found when we replaced the recall age of initiation with a uniform "6" years lower bound.

Discussion

Previous studies have examined cross-sectional prevalence of the recalled age of TP initiation among users or have examined age of initiation prospectively among those who are never-users of these TPs when they enter the study as they are followed-up longitudinally [3-6, 10]. Prior cross-sectional studies present only the median or average age of initiation whereas longitudinal studies present limited to prospective follow-up; no study estimating the age of initiation of TPs have combined left truncated and prospective follow-up. Moreover, excluding left-truncated data (i.e., data from users) could result in substantial bias in estimates, including standard errors that are severely underestimated [19]. Noticeably, our results agree with previously published cross-sectional studies and prospective longitudinal studies that a good proportion of initiation of these tobacco products occurs prior to age 16 [3-6,10]. This study is the first to combine left-truncated and prospective follow-up to estimate the age of initiation of ever use of six TPs. Our results showed a higher cumulative incidence of ever use of these TPs compared to previously published studies that were limited to non-users at the first wave of PATH participation into the study. For example, comparing previously published results versus ours, the cumulative incidence of initiation by age 18 was 19.7% (95% CI: 3.9 – 25.4%) versus 22.0% (95% CI: 20.5 – 23.3%) for hookah [5]; 41.7% (95% CI: 37.4 – 45.9%) versus 49.9% (95% CI: 46.3 – 53.5%) for e-cigarettes [4]; 24.3% (95% CI: 20.7– 28.0%) versus 37.1% (95% CI: 34.3 –40.0%) for cigarettes [6]; and 12.8% (95% CI:10.9 –14.6%) versus 18.4% (95% CI: 16.2 –20.5) for traditional cigars [3].

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Table 3: Adjusted hazard ratios and 95% confidence intervals for initiation of tobacco products, PATH 2013-2017.

	Hookah	E-Cigarettes	Cigarettes	Traditional Cigars	Smokeless Tobacco	Cigarillos
Variable	**Primary analysis based on the recalled age of initiation**					
Sex						
Female	1	1	1	1	1	1
Male	0.97(0.89, 1.05)	1.08(1.01, 1.14)	1.13(1.05, 1.21)	2.61(2.28, 2.99)	2.25(1.99, 2.54)	1.18(1.08, 1.30)
Race/ethnicity						
Non-Hispanic White	1	1	1	1	1	1
Hispanic	1.20(1.08, 1.33)	0.97 (0.90, 1.05)	0.93 (0.86, 0.99)	0.59 (0.50, 0.70)	0.56 (0.47, 0.65)	0.95 (0.83, 1.08)
Non-Hispanic Black	1.04(0.92, 1.19)	0.73 (0.66, 0.82)	0.75 (0.66, 0.84)	0.47 (0.37, 0.60)	0.42 (0.20, 0.59)	1.11 (0.92, 1.34)
Non-Hispanic Other*	1.20(1.02, 1.40)	0.84(0.75, 0.94)	0.89 (0.79, 1.01)	0.68 (0.53, 0.87)	0.66 (0.52, 0.85)	0.98 (0.81, 1.17)
Ever use of the TP at the first wave of PATH participation						
Yes	1	1	1	1	1	1
No	0.03(0.02, 0.03)	0.11(0.10, 0.11)	0.03(0.03, 0.04)	0.01(0.01, 0.02)	0.01(0.01, 0.03)	0.02(0.01, 0.02)
Sensitivity based on uniform six "6" years lower bound for left censored sample						
Sex						
Female	1	1	1	1	1	1
Male	0.91(0.82, 1.00)	1.08(1.00, 1.16)	1.15(1.06, 1.25)	2.70(2.36, 3.08)	2.56(2.22, 2.95)	1.24(1.05, 1.45)
Race/ethnicity						
Non-Hispanic White	1	1	1	1	1	1
Hispanic	1.23(1.06, 1.41)	0.94(0.85, 1.04)	0.91 (0.83, 1.00)	0.56 (0.48, 0.66)	0.49 (0.41, 0.59)	0.75 (0.61, 0.91)
Non-Hispanic Black	1.08(0.92, 1.26)	0.69(0.61, 0.78)	0.69 (0.61, 0.78)	0.45 (0.35, 0.56)	0.39 (0.28, 0.55)	1.18 (0.88, 1.59)
Non-Hispanic Other*	1.24(1.02, 1.51)	0.81(0.72, 0.92)	0.85 (0.74, 0.98)	0.66 (0.51, 0.85)	0.60 (0.45, 0.80)	0.82 (0.60, 1.14)
Ever use of the TP at the first wave of PATH participation						
Yes	1	1	1	1	1	1
No	0.01(0.0, 0.01)	0.02(0.02, 0.02)	0.01(0.01, 0.02)	0.01(0.00, 0.01)	0.01(0.00, 0.01)	0.01(0.00, 0.01)

*Non-Hispanic other includes Asian, multi-race, etc.

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We found differences when adjusted for sex and race/ethnicity in the age of initiation for different TPs. Our results agreed with a previous cross-sectional study of hookah use that showed no difference in initiation between boys and girls [10], but not with a prospective longitudinal study that showed girls are more likely to initiate hookah at earlier ages compared to boys [5,10]. For cigarettes and e-cigarettes, our results for the age of initiation by sex and race/ethnicity resulted in similar interpretations to previously published longitudinal studies [4,6]. Specifically, a previous study of the prospectively estimated age of e-cigarette initiation in PATH youth (aged 12-17 at their first wave of participation) showed boys were more likely to initiate e-cigarettes at earlier ages than girls, and non-Hispanic White youth were more likely to initiate e-cigarettes at earlier ages than non-Hispanic Black and non-Hispanic Other youth [4]. Similarly, in a different prospective study that examined the age of cigarette initiation among PATH youth (aged 12-17 at their first wave of participation) never-users, boys were more likely to initiate cigarettes at earlier ages than girls, and non-Hispanic White youth were more likely to initiate cigarettes at earlier ages than Hispanic, non-Hispanic Black, and non- Hispanic Other youth [6, 10]. These interpretations are similar to previously published studies on ever use of cigarettes and e-cigarettes; however, our hazard ratios are slightly higher [4,6,10,45].

Our results for the age of initiation of smokeless tobacco were similar by race/ethnicity to previous published cross-sectional but different by sex as this study showed no significant difference in initiation by sex [10]. Regarding traditional cigars and cigarillos, our estimates of the cumulative incidence of the age of initiation of these TPs slightly from previously published estimates [3, 10]. There was no significant difference by sex and race/ethnicity from a previously published study [3]. The primary strength of our study is finding that excluding left truncated data among users could introduce bias in estimates and reduction in precision [19]. This is shown in our study in which our confidence intervals are narrower as compared to previous studies that relied on cross-sectional data or prospective longitudinal samples of never-users at their first wave of PATH participation, indicating higher precision in our results [3-6, 10, 45]. As noted above, the inclusion of left-truncated data increases the estimate of the cumulative incidence of those who initiate TP use, as well. In addition to the primary analyses, we conducted sensitivity analyses for each model using a uniform "6" years lower bound and their age at first wave of PATH participation as the upper bound for this sample which is another strength. The greatest limitation of this study is that for the left-truncated sample, users might not remember their age of initiation accurately. However, this limitation is inherent in any study of the age of initiation that relies on participant recall.

Conclusion

Our results showed increases in the cumulative incidence of initiation of TPs compared to previously published prospective longitudinal studies (never-users at their first wave of participation) or cross-sectional studies of recall (users at the wave of the first wave of participation). Example, for e-cigarettes and cigarettes since the proportion of youth that indicated ever use of these TPs at their first wave of PATH participation were higher than in other TPs. Therefore, these analyses can help elucidate appropriate population by TPs for more accurately and more precisely estimation of the age of initiation of TPs. In some TPs such as traditional cigars, smokeless tobacco and cigarillos where the proportions of ever use at the first wave of PATH participation were 1.8%, 3.5% and 4.9%, respectively, including those that indicated ever use of a TP might be a waste of time, while in other TPs such as hookah, e-cigarettes and cigarettes were the these proportions were 5.7%, 8.1% and 10.4% respectively, might be helpful to include those who indicated ever use at the first wave of PATH participation in the analyses. Preventive intervention that incorporates these differences might help in reducing the use of these TPs.

Author Contribution

FDA, AP, MBH, and SEM, wrote the diversity supplement protocol. FDA, BC, MAB, AEK, and AP conducted the searches and screening, extracted, and analyzed the data, and wrote the first draft of the manuscript. MBH, SEM, KLS, CES, AP supervised and redrafted the manuscript. FDA and AP assembled the final draft and circulated it to all the authors who read and agreed on the final submitted draft. AP obtained funding.

Declarations

The institutional review board (IRB) approval for this study was obtained from the Committee for the Protection of Human Subjects at the University of Texas Health Science Center at Houston with the number HSC-SPH-17-0368.

Consent to Participate

PATH obtained parental or legal guardian consent of the youth and youth provided assent. Once youth turned 18 years old, they provided consent again to continue in the PATH study.

Competing Interests

Dr Harrell is a consultant in litigation involving the vaping industry. Other authors declare no competing interests.

Acknowledgement

We thank Dr. Cristine Delnevo for her directions and insightful comments of the manuscript.

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DOI: 10.19080/BBOAJ.2022.10.555801

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