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Tobacco use profiles by respiratory disorder status for adults in the wave 1-wave 4 population assessment of tobacco and health (PATH) study

Jamie Cordova [a,b], Ruth M. Pfeiffer [c], Kelvin Choi [d], Rachel Grana Mayne [a], Laura Baker [e], Jacqueline Bachand [f], Kristen Constantine [g], Sean Altekruse [h], Carolyn Reyes-Guzman [a,*]

[a] Tobacco Control Research Branch, Behavioral Research Program, Division of Cancer Control and Population Sciences, National Cancer Institute, National Institutes of Health, 9609 Medical Center Drive, MSC 9776, Bethesda, MD 20892, United States
[b] Noninfectious Disease Programs, National Foundation for the Centers for Disease Control and Prevention, P.O. Box 117300, Atlanta, GA 30368, United States
[c] Biostatistics Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, 9609 Medical Center Drive, MSC 9776, Bethesda, MD 20892, United States
[d] Division of Intramural Research, National Institute of Minority Health and Health Disparities, National Institutes of Health, 6707 Democracy Blvd., Suite 800, Bethesda, MD 20892, United States
[e] The Bizzell Group, LLC, 4500 Forbes Blvd., Suite 400, Lanham, MD 20706, United States
[f] US Department of Housing and Urban Development, Office of Policy Development and Research, 451 7th St. SW, Washington, D.C. 20410, United States
[g] Center for Medicare & Medicaid Innovation, U.S. Centers for Medicare & Medicaid Services. 7500 Security Boulevard, Baltimore, MD 21244, United States
[h] National Heart, Lung, and Blood Institute, National Institutes of Health, 31 Center Drive, Bethesda, MD 20892, United States

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ABSTRACT

Limited evidence exists on the association between electronic nicotine delivery systems (ENDS) and chronic respiratory disorders. This study examines the association of combustible tobacco and ENDS use with chronic respiratory disorders among US adults. Public-use data from the Population Assessment of Tobacco and Health (PATH) Study Wave 1 (2013–2014), Wave 2 (2014–2015), Wave 3 (2015–2016), and Wave 4 (2016–2018) were pooled. Analyses focused on adults with W1–W4 respiratory disorder data and current tobacco use at W4, as well as youth entering the adult cohort at W2 through W4 (N = 26,072). We fit weighted multivariable logistic regression models for each respiratory outcome (asthma, COPD, bronchitis) using W4 longitudinal weights. Cigarette smokers (adjusted odds ratio [AOR] = 0.8, 95 % CI 0.7–0.9) were less likely to report an asthma diagnosis ($p = 0.013$). In contrast, ENDS users (AOR = 6.5, 95 % CI 3.7–11.5), cigarette smokers (AOR = 6.1, 95 % CI 4.0–9.1), dual users of cigarettes and ENDS (AOR = 5.4, 95 % CI 3.4–8.7), current users of non-cigarette combustible, smokeless, and polytobacco products (AOR = 4.4, 95 % CI 3.1–6.4), and former users of any product (AOR = 3.0, 95 % CI 1.9–4.7) had significantly elevated odds of reporting a diagnosis of COPD ($p < 0.001$). Similar patterns to COPD were observed for bronchitis ($p < 0.001$). Current and former tobacco use, including ENDS, were significantly associated with prevalence of self-reported COPD and bronchitis after controlling for demographic and psychosocial confounders.

1. Introduction

Combustible cigarette smoking has been linked to multiple respiratory diseases and is known to exacerbate chronic respiratory disorders (Forey et al., 2011; Tamimi et al., 2012). The US Surgeon General has concluded that there is sufficient evidence to infer that smoking causes poor asthma control and asthma exacerbation in adults and is the dominant cause of chronic obstructive pulmonary disorder (COPD) (The Health Consequences of Smoking, 2014). However, national surveillance data show that many individuals with COPD and asthma in the US currently smoke cigarettes. Among adults of all ages, 38 % of those with COPD were current smokers in 2013 (Wheaton et al., 2019), and nearly 18 % of those with asthma were current smokers spanning from 2014 to 2017 (Deshpande et al., 2020).

Electronic nicotine delivery systems (ENDS, which include e-cigarettes) have been on the US market since 2007 and have sometimes been

* Corresponding author at: National Institutes of Health, National Cancer Institute, Division of Cancer Control & Population Sciences, Tobacco Control Research Branch, 9609 Medical Center Drive, Room 3E564, MSC 9761, Bethesda, MD, United States.
E-mail address: carolyn.reyes-guzman@nih.gov (C. Reyes-Guzman).

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marketed as a safer alternative to combustible cigarette smoking (Grana and Ling, 2014; Klein et al., 2016). Over the past decade, the prevalence of ENDS use has increased, especially among youth (Wang et al., 2018) and young adults aged 18–24 (Dai and Leventhal, 2019), who perceive e-cigarettes as less harmful and less addictive than cigarettes (E-Cigarette Use Among Youth and Young Adults, 2016). Additionally, current adult e-cigarette users often cite a desire to quit or reduce cigarette smoking, and believe that e-cigarettes pose less harm than cigarettes, as some of the main reasons for using them (Berg, 2016; Coleman et al., 2017). In particular, individuals who smoke and have respiratory disorders may be attracted by these perceived benefits of e-cigarettes. Studies have found that current smokers with asthma have higher odds of ever and current e-cigarette use compared to smokers without asthma (Deshpande et al., 2020; Kruse et al., 2017), and smokers with COPD have higher odds of ever e-cigarette use compared to those without COPD (Kruse et al., 2017).

Although ENDS liquids and aerosols typically contain lower levels of carcinogens than combustible cigarette smoke (Eaton et al., 2018), they contain numerous toxicants that can irritate or impair lung tissue, including some substances not found in combustible cigarettes (Clapp and Jaspers, 2017). E-cigarette users have reported adverse effects such as cough, dry or irritated mouth/throat, and shortness of breath (King et al., 2019). Cross-sectional studies of adolescents (Choi and Bernat, 2016; McConnell et al., 2017) and adults19 (Li et al., 2019) have found higher rates of wheezing, coughing, asthma attacks, and difficulty breathing among current e-cigarette users than among non-users. Further, a 2019 review of the respiratory effects of e-cigarette use concluded that e-liquids and aerosols have adverse biologic effects on organ and cellular health in humans, animals, and *in vitro*, but the impact on long-term health outcomes is unclear (Gotts et al., 2019).

Few epidemiological studies have examined the relationship between ENDS use and prevalence of chronic respiratory diseases. In this study, we examined the association of combustible tobacco and ENDS use with multiple chronic respiratory disorders in a sample of US adults weighted to represent the US adult population.

2. Methods

2.1. Data source and analytic population

The Population Assessment of Tobacco and Health (PATH) study is a US representative longitudinal cohort of approximately 49,000 adults (18 years and older) and youth (12–17 years). The study collects epidemiologic data on tobacco use patterns and associated health outcomes; data for Wave 1 were collected from 2013 to 2014, Wave 2 from 2014 to 2015, Wave 3 from 2015 to 2016, and Wave 4 from 2016 to 2018, which we analyzed in 2020. To recruit a sample representative of the civilian, non-institutionalized US population, PATH employed a stratified address-based, area-probability sample design with oversampling of tobacco users, young adults (18–24 years), and African Americans. Non-response adjusted population and replicate weights were created to account for oversampling of certain groups and possible deficiencies in the sampling frame. Further information regarding the PATH Study design and methods are available at https://www.icpsr.umich.edu. Our analysis was based on deidentified data and was deemed exempt from Institutional Review Board.

We pooled PATH adult questionnaire data from Wave 1 (W1, N = 32,320), Wave 2 (W2, N = 28,362), Wave 3 (W3, N = 28,148), and Wave 4 (W4, N = 33,822 to increase sample size and statistical power due to the small number of respondents in select tobacco user groups with respect to respiratory disorders. Analyses were restricted to adults, as well as youth who aged into the adult cohort during W2 to W4, who reported respiratory disorder data across all four waves and tobacco use data assessed at W4 (N = 26,072).

2.2. Respiratory disorder status

Respiratory disorder status was defined as either a lifetime diagnosis at W1 or a past 12-month diagnosis at W2, W3, or W4, of any of the following conditions: asthma, bronchitis, or COPD. At W1, respondents were asked to self-report an ever, or lifetime, diagnosis of a respiratory disorder: "Has a doctor, nurse or other health professional ever told you that you had any of the following lung or respiratory conditions?" At subsequent waves, respondents were asked to self-report a diagnosis of a respiratory disorder within the past 12 months: "In the past 12 months, has a doctor, nurse, or other health professional told you that you had any of the following lung or respiratory conditions?" Additionally, we included new baseline participants who reported a lifetime diagnosis of any condition.

2.3. Tobacco use profiles

Current tobacco use was determined by "someday" or "every day" use of at least one of the following products at W4: cigarettes, ENDS, hookah, smokeless tobacco, snus or snuff, traditional cigars, filtered cigars, cigarillos, or pipes. Former users were defined as individuals who met the lifetime threshold for established use of the product of interest, but who reported not currently using the product at the time of assessment or within the past 12 months. For cigarettes, the threshold for established use was smoking 100 cigarettes in lifetime and currently smoking at least "fairly regularly." For all other products, the threshold for established use was ever use of the product "fairly regularly."

We subsequently created a set of tobacco use profiles to represent different tobacco use histories and patterns. We used existing derived variables from the PATH W4 dataset to construct the tobacco use profiles. These were: (1) "ENDS only" (N = 621: current exclusive ENDS users), using the PATH derived variables for current use of ENDS and no current use of all other products; (2) "cigarettes only" (N = 5,776: current exclusive combustible cigarette smokers), using variables for current use of combustible cigarettes and no current use of all other products; (3) "dual cigarettes and ENDS" (N = 806: current concurrent users of only cigarettes and ENDS), using variables for current use of ENDS and cigarettes, and no current use of all other products; (4) "current users of non-cigarette combustible, smokeless, and polytobacco products" (N = 3,786: any combination of single or poly use of combustible cigarettes, ENDS, traditional cigars, filtered cigars, cigarillos, pipes, hookah, smokeless tobacco, and snus (with the exception of exclusive cigarette and ENDS use), using derived variables for each product; (5) "former users of any product" (N = 4,872: former established users of combustible cigarettes, ENDS, traditional cigars, filtered cigars, cigarillos, pipes, hookah, smokeless tobacco, and snus, using the derived former established use variables for each product; and (6) "non-current, non-former, or never users of any product" (N = 10,211), the reference group, included participants who did not report current or former use of any product or who were never users of any product. Groups 1–4 are illustrated in Fig. 1 "Scenario I."

2.4. Covariates

We examined sociodemographic characteristics assessed at W4 including age group (18–24, 23–34, 35–54, and ≥ 55 years); education (some high school or less, high school graduate or GED, some college or associate's degree, and college degree or greater); race/ethnicity (Non-Hispanic (NH) White, NH Black/African American, NH Other (including multi-racial), and Hispanic or Latino); annual household income (<$10,000, $10,000–$24,999, $25,000–$49,999, $50,000–$99,999, and ≥$100,000); and marital status (married, widowed, divorced, separated, and never married).

Behavioral health symptomatology was measured using the GAIN-SS screener. Per GAIN-SS guidelines, we calculated composite scores for internalizing behaviors (e.g., depression, anxiety), externalizing

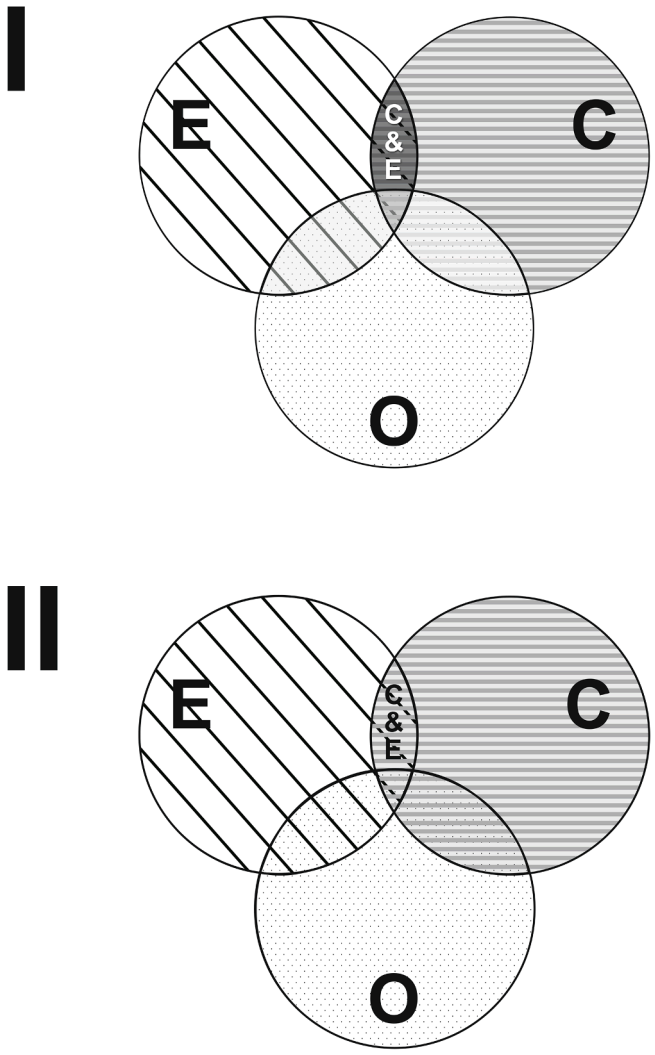

Fig. 1. Tobacco use profiles, PATH Study, 2013–2018.

behaviors (e.g., hyperactivity, impulsivity), and substance use, and classified individuals into two levels of severity: low/moderate versus high probability of a diagnosis.

2.5. Analyses

We examined weighted distributions of tobacco use, sociodemographic, and behavioral characteristics. Chi-squared tests assessed differences between respondents with or without asthma, COPD, or bronchitis. To examine associations of tobacco use profiles with each chronic respiratory outcome, we fit weighted logistic regression models with two different sets of adjustment variables. First, minimally adjusted models included only the aforementioned sociodemographic predictors. Then, we fit fully adjusted models for sociodemographic, internalizing behavior, externalizing behavior, substance use disorders, and other respiratory disorder covariates (i.e., models for COPD included asthma and bronchitis as adjustment variables). In minimally and fully adjusted models, no evidence of collinearity was found when assessing the variance inflation factor (VIF). Variances were estimated using the balanced repeated replications (BRR) method with Fay's adjustment = 0.3 to increase estimate stability (Judkins, 1990). All analyses were conducted in SAS 9.4 and SUDAAN 11.0 using PATH W4 all-wave (longitudinal) sample weights to account for data on respiratory conditions from W1–4. All tests were two-sided with significance level set at 5 %. However, when interpreting the results, we focused on findings that were still significant after a Bonferroni adjustment for multiple testing. We used a *p*-value of 0.05/30 = 0.0017 where 30 was the total number of tests conducted (6 models with 5 parameters).

3. Results

The final analytic sample contained 26,072 adults, a majority of whom were female (52.0 %), aged 35 years and older (70.4 %), married (51.8 %), NH White (65.1 %), had at least some college education (61.1 %), and reported an annual household income of at least $25,000 (64.8 %), as shown in Table 1. The overall prevalence of ever having been diagnosed with a respiratory disorder was 14.2 % for asthma, 4.5 % for COPD and 6.3 % for bronchitis, while the prevalence of high probability of a behavioral health disorder was: 22.8 % for an internalizing behavioral disorder, 9.0 % for an externalizing behavioral disorder, and 4.4 % for a substance use disorder. Additionally, 1.3 % were exclusive ENDS users; 13.6 % were exclusive cigarette smokers; 1.7 % were dual cigarettes and ENDS users; 8.7 % were current users of non-cigarette combustible, smokeless, and polytobacco products; 24.0 % were former users of any product; and 50.8 % were non-current, non-former, or never users of any product.

Table 2 summarizes results from minimally and fully adjusted models for asthma, COPD, and bronchitis. In minimally adjusted models, current users of non-cigarette combustible, smokeless, and polytobacco products (AOR = 1.3, 95 % CI 1.1–1.5) and former users of any product (AOR = 1.2, 95 % CI 1.1–1.4) had increased odds of reporting an ever asthma diagnosis as compared to non-current, non-former, or never users of any product ($p = 0.002$), while there was no significant association with asthma for exclusive ENDS users, exclusive cigarette smokers, and dual cigarettes and ENDS users. Conversely, in fully adjusted models, exclusive cigarette smokers (AOR = 0.8, 95 % CI 0.7–0.9) were less likely to report an asthma diagnosis as compared to non-current, non-former, or never users of any product ($p = 0.013$), while there was no significant association with asthma for exclusive ENDS users, dual cigarettes and ENDS users, current users of non-cigarette combustible, smokeless, and polytobacco products, and former users of any product.

In fully adjusted models, the odds of COPD were much higher for exclusive ENDS users (AOR = 6.5, 95 % CI 3.7–11.5), exclusive cigarette smokers (AOR = 6.1, 95 % CI 4.0–9.1), dual users of cigarettes and ENDS (AOR = 5.4, 95 % CI 3.4–8.7), current users of non-cigarette combustible, smokeless, and polytobacco products (AOR = 4.4, 95 % CI 3.1–6.4), and former users of any product (AOR = 3.0, 95 % CI 1.9–4.7), as compared to non-current, non-former, or never users of any product ($p < 0.001$). Compared to the reference group, exclusive cigarette smokers (AOR = 1.7, 95 % CI 1.3–2.2), exclusive dual cigarette and ENDS users (AOR = 2.3, 95 % CI 1.6–3.5), current users of non-cigarette combustible, smokeless, and polytobacco products (AOR = 1.8, 95 % CI 1.4–2.4), and former users of any product (AOR = 1.6, 95 % CI 1.2–2.1), had nearly twice the odds of reporting a diagnosis of bronchitis ($p < 0.001$). Supplemental Table 1 presents additional results from fully adjusted models for each respiratory disorder outcome. Of note, a participant's indication of an internalizing behavior disorder also increased the odds of reporting an asthma (AOR = 1.3, 95 % CI 1.1–1.4, $p = 0.001$) or bronchitis (AOR = 1.7, 95 % CI 1.4–2.1, $p < 0.001$) diagnosis.

As part of a sensitivity analysis, we created a second set of tobacco use profiles to assess whether altering the profiles would impact our findings. As illustrated in Fig. 1 "Scenario II," we grouped individuals differently from "Scenario I" to examine patterns of single and poly tobacco use as: (1) "any ENDS, single or poly" (N = 2,148), defined as exclusive use of ENDS or co-use of ENDS with any combustible or non-combustible product; (2) "Any cigarettes, single or poly (no ENDS)" (N = 7,095), including exclusive cigarettes or co-use with any other combustible or non-combustible product, excluding ENDS; (3) "Any other product without cigarettes or ENDS" (N = 1,746); (4) "former users of any product" (N = 4,872), as previously defined; and (5) "non-

Table 1
Weighted Demographic Characteristics and Tobacco Use Profiles at Wave 4. Pooled Adult Questionnaire Data from Waves 1–4 of the PATH Study, 2013–2018 (N = 26,072).

	Unweighted N	Weighted % (95 % CI)
Gender		
Male	12,615	48.0 (47.8, 48.2)
Female	13,456	52.0 (51.8, 52.1)
Missing	1	0.0 (0.0, 0.1)
Age		
18–24	8,021	12.1 (11.9, 12.3)
25–34	5,463	17.4 (16.8, 18.1)
35–54	6,885	32.7 (32.0, 33.4)
55+	5,700	37.7 (37.2, 38.3)
Missing	3	0.0 (0.0, 0.1)
Marital status		
Married	9,534	51.8 (50.7, 52.8)
Widowed, divorced, separated, never married	16,414	47.8 (46.8, 48.8)
Missing	124	0.5 (0.4, 0.6)
Race		
White, Non-Hispanic	15,034	65.1 (64.9, 65.2)
Black or African American, Non-Hispanic	3,941	11.7 (11.6, 11.8)
Other, Non-Hispanic (including multiracial)	2,007	7.8 (7.6, 7.9)
Hispanic or Latino	5,089	15.5 (15.4, 15.5)
Missing	1	0.0 (0.0, 0.1)
Highest education completed		
Some high school or less	3,272	10.9 (10.4, 11.4)
High school graduate or GED	7,761	27.7 (27.1, 28.3)
Some college or associate's degree	9,263	31.8 (31.2, 32.3)
College degree or greater	5,677	29.3 (28.9, 29.8)
Missing	99	0.3 (0.3, 0.5)
Annual household income		
<$10,000	4,095	10.5 (9.9, 11.1)
$10,000–$24,999	5,180	17.5 (16.8, 18.2)
$25,000–$49,999	5,537	20.8 (20.0, 21.6)
$50,000–$99,999	5,623	24.6 (23.8, 25.4)
≥$100,000	4,005	19.4 (18.5, 20.3)
Missing	1,632	7.3 (6.7, 7.8)
Ever use of any tobacco product [a]		
Yes	21,360	73.8 (72.6, 75.0)
No	4,485	24.6 (23.5, 25.6)
Missing	227	1.6 (1.4, 1.9)
Tobacco use profiles (scenario I) [b]		
ENDS only	621	1.3 (1.2, 1.5)
Cigarettes only	5,776	13.6 (13.1, 14.1)
Dual cigarettes and ENDS	806	1.7 (1.6, 1.8)
Current users of non-cigarette combustible, smokeless, and polytobacco products	3,786	8.7 (8.3, 9.1)
Former users of any product	4,872	24.0 (23.0, 24.9)
Non-current, non-former, or never users of any product	10,211	50.8 (49.5, 52.0)
Missing	0	0.0 (0.0, 0.0)
Internalizing behavior		
Low/moderate	17,936	76.3 (75.5, 77.0)
High	7,926	22.8 (22.0, 23.5)
Missing	210	0.9 (0.8, 1.1)
Externalizing behavior		
Low/moderate	22,187	89.9 (89.5, 90.4)
High	3,593	9.0 (8.6, 9.4)
Missing	292	1.1 (0.9, 1.3)
Substance use		
Low/moderate	23,965	94.4 (94.0, 94.7)
High	1,761	4.4 (4.1, 4.7)
Missing	346	1.2 (1.1, 1.4)
COPD [c]		
Yes	1,220	4.5 (4.1, 4.9)
No	24,844	95.5 (95.1, 95.9)
Missing	8	0.0 (0.0, 0.1)
Bronchitis[c]		
Yes	1,737	6.3 (5.9, 6.7)
No	24,327	93.7 (93.3, 94.1)
Missing	8	0.0 (0.0, 0.1)
Asthma[c]		
Yes	4,245	14.2 (13.6, 14.7)
No	21,819	85.8 (85.3, 86.3)
Missing	8	0.0 (0.0, 0.1)

Note:
Unweighted frequencies and weighted percentages (95% CI) are presented.
a.) Accounts for ever use of ENDS, combustible cigarettes, traditional cigars, filtered cigars, cigarillos, pipes, hookah, smokeless tobacco, snus.
b.) Current tobacco use assessed at W4:
ENDS only: current exclusive ENDS users.
Cigarettes only: current exclusive combustible cigarette smokers.
Dual cigarettes and ENDS: current concurrent users of only combustible cigarettes and ENDS.
Current users of non-cigarette combustible, smokeless, and polytobacco products: any combination of single or poly use of combustible cigarettes, ENDS, traditional cigars, filtered cigars, cigarillos, pipes, hookah, smokeless tobacco, and snus (with the exception of exclusive cigarette and ENDS use).
Former users of any product: former established users of combustible cigarettes, ENDS, traditional cigars, filtered cigars, cigarillos, pipes, hookah, smokeless tobacco, and snus.
Non-current, non-former, or never users of any product: participants who did not report current or former use of any product or who were never users of any product.
c.) Respiratory disorder (asthma, COPD, bronchitis) status accounts for W1 lifetime diagnosis, W2 past 12-month diagnosis, W2 new baseline lifetime diagnosis, W3 past 12-month diagnosis, W3 new baseline lifetime diagnosis, W4 past 12-month diagnosis, W4 new baseline lifetime diagnosis.
CI = confidence interval. COPD = chronic obstructive pulmonary disease. ENDS = electronic nicotine delivery system. PATH = Population Assessment of Tobacco and Health.

current, non-former, or never users of any product" (N = 10,211), as previously defined. Results were similar to those of the original tobacco use profiles and thus, were not discussed, but were presented in Supplemental Table 2.

4. Discussion

In a sample of approximately 26,000 US adults weighted to represent the US adult population, current and former use of combustible and non-combustible tobacco products, including ENDS, was significantly associated with higher odds of reporting a prior (prevalent) diagnosis of either asthma, bronchitis or COPD. For asthma, different covariate adjustments strongly impacted the estimates, but no effects were significant after adjusting for multiple testing, although a significant association remained for bronchitis and COPD.

Exclusive cigarette smokers and dual users had a much lower risk of reporting a prior bronchitis diagnosis compared with a prior COPD diagnosis, while ENDS users had a non-statistically significant lower risk. In another longitudinal study of older adults with or at-risk for COPD, ever use of e-cigarettes was associated with chronic bronchitis

Table 2
Associations of Tobacco Use (Scenario I) with Respiratory Disorder Status. Select Multivariable Logistic Regression Results with Pooled Adult Questionnaire Data from Waves 1–4 of the PATH Study, 2013–2018.

	Tobacco use (N)		Asthma [a]				COPD [a]				Bronchitis [a]			
			Minimal [b] (N = 24,303)		Full [c] (N = 23,788)		Minimal [b] (N = 24,303)		Full [c] (N = 23,788)		Minimal [b] (N = 24,303)		Full [c] (N = 23,788)	
	Minimal	Full		p-value		p-value		p-value		p-value		p-value		p-value
Tobacco use profiles (scenario I) [d]				0.002		0.013		<0.001		<0.001		<0.001		<0.001
ENDS only	575	564	0.9 (0.7, 1.2)		0.8 (0.6, 1.0)		**5.1 (2.7, 9.4)**		**6.5 (3.7, 11.5)**		1.2 (0.6, 2.2)		0.8 (0.5, 1.6)	
Cigarettes only	5,432	5,274	1.1 (0.9, 1.2)		**0.8 (0.7, 0.9)**		**5.9 (4.1, 8.5)**		**6.1 (4.0, 9.1)**		**2.4 (1.9, 3.0)**		**1.7 (1.3, 2.2)**	
Dual cigarettes and ENDS	763	740	1.1 (0.9, 1.4)		0.8 (0.6, 1.0)		**6.9 (4.6, 10.6)**		**5.4 (3.4, 8.7)**		**3.4 (2.4, 4.7)**		**2.3 (1.6, 3.5)**	
Current users of non-cigarette combustible, smokeless, and polytobacco products	3,576	3,481	**1.3 (1.1, 1.5)**		1.0 (0.9, 1.2)		**4.8 (3.3, 7.0)**		**4.4 (3.1, 6.4)**		**2.6 (2.0, 3.4)**		**1.8 (1.4, 2.4)**	
Former users of any product	4,601	4,509	**1.2 (1.1, 1.4)**		1.1 (0.9, 1.2)		**3.4 (2.3, 5.0)**		**3.0 (1.9, 4.7)**		**2.1 (1.6, 2.6)**		**1.6 (1.2, 2.1)**	
Non-current, non-former, or never users of any product	9,356	9,220	Ref.		Ref.		Ref.		Ref.		Ref.		Ref.	

Notes:
Unweighted frequencies and adjusted odds ratios (AORs, 95 % CIs) for asthma, COPD, and bronchitis are presented. Bolded estimates are statistically significant ($p < 0.05$).
a.) The outcome variable, respiratory disorder (asthma, COPD, bronchitis) status, accounts for W1 lifetime diagnosis, W2 past 12-month diagnosis, W2 new baseline lifetime diagnosis, W3 past 12-month diagnosis, W3 new baseline lifetime diagnosis, W4 past 12-month diagnosis, W4 new baseline lifetime diagnosis.
b.) Minimal model adjusts for gender, age, marital status, race/ethnicity, education, and annual household income.
c.) Full model adjusts for gender, age, marital status, race/ethnicity, education, annual household income, internalizing behavior, externalizing behavior, substance use, and respiratory disorders (i.e., model for asthma adjusts for COPD and bronchitis).
d.) Current tobacco use assessed at W4:
ENDS only: current exclusive ENDS users.
Cigarettes only: current exclusive combustible cigarette smokers.
Dual cigarettes and ENDS: current concurrent users of only combustible cigarettes and ENDS.
Current users of non-cigarette combustible, smokeless, and polytobacco products: any combination of single or poly use of combustible cigarettes, ENDS, traditional cigars, filtered cigars, cigarillos, pipes, hookah, smokeless tobacco, and snus (with the exception of exclusive cigarette and ENDS use).
Former users of any product: former established users of combustible cigarettes, ENDS, traditional cigars, filtered cigars, cigarillos, pipes, hookah, smokeless tobacco, and snus.
Non-current, non-former, or never users of any product: participants who did not report current or former use of any product or who were never users of any product.
AOR = adjusted odds ratio. CI = confidence interval. COPD = chronic obstructive pulmonary disease. ENDS = electronic nicotine delivery system.

and COPD exacerbations after adjusting for current cigarette smoking, while more rapid decline in lung function was not associated with e-cigarette use after controlling for current smoking (Bowler et al., 2017). Also, for both bronchitis and COPD, the risk of reporting either prior condition was lower for former users of any product compared to current users, but higher than among non-users. Although the effects of e-cigarette use on COPD remission remain unclear, the benefits of complete tobacco product cessation in slowing the progression of COPD and reducing the risk of respiratory complications are well documented (Coronini-Cronberg et al., 2011; Bai et al., 2017).

The findings for asthma should be interpreted with caution, as after applying a multiple-comparison correction (Bonferroni correction), the results were no longer statistically significant. Yet, prior to adjusting for multiple testing, we observed that individuals who exclusively smoked cigarettes were significantly less likely to report a diagnosis of asthma in the fully adjusted model, a reversal in the direction of association from the minimally adjusted model which only considered sociodemographic characteristics. Although the lower associations of cigarettes-only on asthma observed in the fully adjusted model may seem counterintuitive, we offer some possible explanations. First, when we did not adjust the model for composite scores for mental health and other respiratory disorder covariates, our findings for asthma were consistent with other studies, demonstrating that ENDS use was significantly associated with a higher prevalence of respiratory symptoms (Hedman et al., 2018; Wills et al., 2019; Wills et al., 2021). Individuals with behavioral health conditions are more likely to use tobacco products than those without such conditions, and tobacco product use is associated with worsened symptoms and reduced effectiveness of behavioral health treatment (Prochaska et al., 2017). Given that individuals with these conditions use tobacco products at disproportionately higher rates than the general population, it was necessary to adjust for behavioral health symptomatology in the fully adjusted models to control for potential confounding effects. The main drivers of the reversal of the association, however, were the inclusion of the other respiratory conditions as covariates (i.e., not the respiratory outcome of interest), which we included because of the correlation across the three respiratory conditions that we examined. For instance, asthma and COPD tend to be intercorrelated, and a subset of individuals experience exacerbated symptoms of both disorders, known as asthma-COPD overlap syndrome (ACOS) (Alshabanat et al., 2015). We observed overlap of respiratory disorders in our sample: among 4,245 respondents with asthma, 503 (13.2 %) also reported a COPD diagnosis and 743 (19.0 %) reported a diagnosis of bronchitis. Further, our minimally adjusted models (without other respiratory covariates) yielded qualitatively similar conclusions. It is possible that

conclusions from other studies that have examined ENDS and asthma or asthma-like respiratory conditions, such as wheezing (Li et al., 2019; Yao et al., 2017), differed due to non-adjustment for competing pulmonary outcomes. Second, nicotine has been shown to inhibit immune response and weaken the immune system overall. Individuals with immune disorders, such as asthma, may be averse to initiating or sustaining use of combustible tobacco products due to the immunosuppressive effects of nicotine (Alkhattabi et al., 2018; Piao et al., 2009). This is a potential explanation for the lower associations of exclusive cigarette use with asthma observed in the fully adjusted model, in addition to the possibility of selection bias.

The main strength of this study was the examination of a series of tobacco use profiles among US adults that captures the effect of combustible cigarettes alone, ENDS alone, dual cigarette and ENDS users, as well as combinations of current use of non-cigarette combustible, smokeless, and polytobacco products, and former use of any product. Cigarettes were categorized separately from other combustible tobacco products (i.e., cigars, pipes and hookah) because cigarettes remain the most common single-use tobacco product (Cornelius et al., 2020). This tobacco use categorization allowed us to examine the potential respiratory health consequences among US adults who used various tobacco products after diagnosis of a respiratory condition. The detailed observational data on tobacco use and respiratory outcomes also demonstrates another study strength. Our key limitation in this study was that tobacco use was assessed for the month prior to the questionnaire, while history of respiratory illnesses was ascertained for the prior year (W2-4) or ever/never (W1). Hence, it is possible that participants who were diagnosed with a respiratory disorder and were current smokers at the time of diagnosis could have changed their behavior and therefore self-reported as non-smokers at the time of the survey. The cross-sectional design, with tobacco use status measured at W4, precludes inference on causal relationships between tobacco use and respiratory disorders. Another limitation to our study is our inability to meaningfully disentangle the effects of "Group 4" (current user of non-cigarette combustible, smokeless, and polytobacco products) in relation to respiratory health, given the combination of single and poly use of combusted and non-combusted products (excluding exclusive cigarettes and ENDS). However, we were compelled to collapse these subgroups as we were unable to examine respiratory health effects among such a small number of participants. Furthermore, another limitation is the inclusion of former cigarette smokers within the "ENDS only" tobacco user group, which may introduce residual confounding effects when observing the association between current exclusive ENDS use and COPD. We were unable to disentangle former cigarette smokers from the "ENDS only" tobacco user group due to an extremely small number of respondents that reported current exclusive ENDS-only with no history of former combustible cigarette use. In the minimally adjusted models, of 575 ENDS only users, 366 respondents reported former combustible cigarette use. In the fully adjusted models, of 564 ENDs only users, 357 respondents reported former combustible cigarette use. Our study also does not address cigarettes or ENDS use with respect to acute respiratory effects of exposure to these products as was seen during the outbreak of e-cigarette or vaping product associated lung injury (EVALI) in Fall 2019.

In summary, our goals were to better understand the relationships between use of several types of tobacco products, particularly cigarettes and ENDS, on the common respiratory conditions of bronchitis, COPD, and asthma, and examine whether dual use of cigarettes and ENDS had a differential effect on these conditions compared to the single use of products. We observed a sixfold risk of reporting a prior COPD diagnosis for the individual use of either ENDS or cigarettes, consistent with other research on ENDS (Wills et al., 2019), and a fivefold risk associated with the dual use of these products. Additionally, the significant estimates observed for internalizing behaviors for asthma and bronchitis also agree with other research showing that anxiety and depression are associated with a greater risk of asthma, and poorer asthma control and asthma-related quality of life (Del Giacco et al., 2016; Li et al., 2020).

5. Conclusion

Our study found a strong association between dual cigarette and ENDS use on the prevalence of COPD and bronchitis. Further research examining tobacco product use over time can further clarify the observed inverse association between tobacco use and asthma. In particular, a greater understanding of the timing of smoking behavior change and asthma (which has a shorter latency period for development and clearing of symptoms, compared to COPD and bronchitis) and a more precise assessment of the temporality of the effect of tobacco use on respiratory conditions is warranted. Additionally, longitudinal studies can examine whether adult smokers who develop any of the respiratory disorders we studied are more likely to quit smoking or to transition to ENDS use (exclusively or dually with cigarettes), compared to adult smokers without respiratory disorders. Healthcare providers are uniquely positioned to discuss tobacco use with their patients as part of respiratory disorder treatment; they are particularly well-suited to emphasize to their patients that complete cessation of all tobacco products is required to improve lung functioning and asthma symptoms.

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Declaration of Competing Interest

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

Data availability

Data is publicly available at https://www.icpsr.umich.edu/web/NAHDAP/studies/36231

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