Behavioral heterogeneity among cigarette and e-cigarette dual-users and associations with future tobacco use: Findings from the Population Assessment of Tobacco and Health Study

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Abstract

Dual-users of cigarettes and e-cigarettes are commonly treated as a single group. Our study applied a more nuanced classification of this complex behavior to examine its associations with future tobacco use behaviors using data from Waves 1 and 3 of the Population Assessment of Tobacco and Health. Dual-users at Wave 1 (n=1,665) were categorized into 4 groups based on the frequency with which they used each product (i.e., some days, daily). Analyses identified sociodemographic correlates of group membership and the prevalence of (1) completely switching to e-cigarettes and (2) quitting both products by Wave 3. Dual-users who smoked cigarettes every day and used e-cigarettes some days (69.6%) were the majority and more likely to have lower education (p<.001). Although some day smoking and daily e-cigarette use was the least common category (5.9%), these individuals were most likely to have completely switched to e-cigarettes by Wave 3 (aOR=6.19, 95% CI=3.91, 9.79). Dual-users who smoked and used e-cigarettes some days were most likely to have completely quit tobacco by Wave 3 (aOR=3.98, 95% CI=2.93, 5.40). In general, dual-users who had higher education or income were more likely to have completely switched to e-cigarettes or quit tobacco use by Wave 3. Adults who concurrently use cigarettes and e-cigarettes exhibit considerable heterogeneity in their use of these tobacco products. Dual-users that are higher on the socioeconomic gradient are more likely to engage in plausibly less harmful dual-use behaviors, which are more strongly associated with harm reduction and cessation behaviors. Future research should consider this variation to more accurately characterize the public health impact of dual-use.

Keywords

Cigarette smoking; e-cigarette vaping; dual-use; harm reduction; health disparities

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Introduction

Cigarette and e-cigarette dual-use (hereafter referred to as "dual-use") is a common tobacco use behavior. Among U.S. adults, nearly 70% of current e-cigarette users also currently smoke cigarettes [5]. E-cigarettes have been lauded as a safer means of nicotine delivery than cigarettes [26] because they eliminate the combustion byproducts from cigarettes that are responsible for most of the health consequences of smoking [10]. In order for measurable harm reduction to occur, smokers must completely switch from cigarettes to e-cigarettes [32]. However, there is inconclusive evidence that dual-use meaningfully reduces exposure to the toxicants present in cigarettes. Many cigarette smokers who engage in dual-use report using e-cigarettes to transition off of cigarettes or as a nicotine quitting aid, [22] but population patterns of complete switching and cessation among dual-users are understudied. Dual-use may operate as a transition phase en route to harm reduction or complete cessation. Conversely, this behavior may reduce the likelihood of quitting cigarettes if it is associated with continued use of both products or relapse back to smoking. Thus, there is a crucial need to study dual-use and its association with tobacco use trajectories to better characterize public health implications of dual-use.

Nicotine and tobacco researchers have generally treated cigarette and e-cigarette dual-use as a homogeneous behavior [19, 20, 25, 30, 24]. Recognizing that dual-use may actually comprise a number of conceptually distinct tobacco use behaviors, scientists have recently begun to consider nuanced classification schemes for describing individuals who concurrently use both products [28, 2]. These classification schemes often specify four distinct dual-use behaviors that vary by individual frequencies of cigarette and e-cigarette use. Epidemiological studies that apply these classification schemes often examine cross-sectional and longitudinal associations of these four dual-use behaviors. For example, Borland et al. [3] found that predominant smoking was the most common dual-use behavior among adult tobacco users in the U.S., Canada, England, and Australia while light dual-use was the least common. The authors also found differences in beliefs and attitudes towards smoking and vaping among the four dual-use behaviors. For example, predominant smokers and heavy dual-users had the most positive attitudes toward smoking and the least positive attitudes toward vaping [3]. At least one qualitative study also found differences in psychosocial factors for dual-use among e-cigarette users with varying frequencies of smoking [27]. Therefore, the fourfold classification schemes of dual-use reflect the heterogeneity inherent specifically in dual-use and in tobacco use more generally.

Less understood is the longitudinal relationship between dual-use typologies and associated smoking trajectories. One recent study highlighted the variability in e-cigarette use transitions, noting that a substantial number of dual-users may discontinue e-cigarette use in the future while continuing to smoke cigarettes, but the authors did not account for behavioral differences among dual-users [4]. Heterogeneity in dual-use is particularly important to consider in the context of tobacco harm reduction efforts because some dual-use behaviors may undermine efforts to reduce harm from tobacco use or completely quit, while others may facilitate cessation. Moreover, these differences could impact smoking disparities if dual-use categories are associated with sociodemographic characteristics known to be linked with smoking behaviors. It is crucial to consider how these sources of

heterogeneity affect tobacco harm reduction and cessation efforts, particularly to minimize health disparities and ensure equitable impact.

Using longitudinal data from Waves 1 and 3 of the Population Assessment of Tobacco and Health (PATH) Study, we sought to examine heterogeneity in dual-use with respect to variations in frequencies of cigarette and e-cigarette use and sociodemographic characteristics. Our study also sought to examine prospective associations between dual-use behaviors and two tobacco use outcomes, (1) completely switching to e-cigarettes and (2) completely quitting tobacco use. These outcomes are important to examine because they are the stated end goals of harm reduction and tobacco control efforts, respectively. The findings of our study will improve estimation of the public health impact of dual-use as well as improve its measurement.

Methods

Participants and procedures

Data for our study came from Waves 1 and 3 of the PATH Study [15], a nationally representative, longitudinal cohort study of U.S. adults (ages 18 years) and adolescents (ages 12 to 17). The PATH Study collects information on tobacco use behaviors such as cigarette smoking, psychosocial determinants of these behaviors, and related health outcomes using Audio Computer-Assisted Self-Interviewing. Waves 1 and 3 of PATH were conducted during 2013–2014 and 2015–2016, respectively. Detailed information on the design and methods of the PATH Study are available elsewhere [15]. Our analytic sample included 1,665 U.S. adults who currently smoked every day or some days and currently used e-cigarettes (i.e., "vaped") every day or some days at Wave 1 and had complete data on tobacco use and sociodemographic variables at Waves 1 and 3. Columbia University Medical Center's Institutional Review Board approved all study procedures.

Measures

Sociodemographic variables included age, sex, race and ethnicity (white, non-Hispanic; or other), sexual orientation (gay, lesbian, or bisexual; or straight), education (< high school, high school degree or equivalent, some college or associate degree, or college degree or higher), and poverty (below federal poverty level, at or near poverty level, or at or above twice poverty level).

Cigarette and e-cigarette dual-use

Current cigarette smoking was defined as having ever smoked at least 100 cigarettes and now smoking every day or some days [16]. Current e-cigarette users were adults who reported ever vaping and now vape every day or some day [7]. We classified participants' dual-use behavior based on their smoking and vaping frequencies. Adults who were every day smokers and vapers were classified as *heavy dual-users*. Those who were every day smokers and some day vapers were classified as *predominant smokers*. Adults who were some day smokers and every day vapers were classified as *predominant vapers*. Finally, adults who were some day smokers and vapers were classified as *light dual-users*.

Harm reduction and tobacco cessation

The primary outcomes were harm reduction and tobacco cessation at Wave 3. *Harm reduction* was defined as exclusively vaping every day or some days, and *tobacco cessation* was defined as neither smoking nor vaping.

Statistical analysis

We calculated weighted sample characteristics and prevalence rates of the four dual-use behaviors. To characterize sociodemographic heterogeneity among adult dual-users with respect to dual-use behavior, we used the Rao-Scott χ^2 test to examine differences in the prevalence of dual-use behaviors by sociodemographic characteristics. We present weighted prevalence of dual-use behaviors within a sociodemographic subgroup (e.g., gay, lesbian, or bisexual adults).

We used multivariate logistic regression to examine how the adjusted odds of harm reduction and tobacco cessation at Wave 3 varied by dual-use behaviors at Wave 1 while controlling for sociodemographics characteristics. We modeled the odds of the outcome behavior of interest against all other outcomes. In these analyses, predominant smokers were the referent group because they were the largest group of dual-users. We initially used separate models to examine the unadjusted prospective associations of harm reduction and tobacco cessation with dual-use behaviors and each of the sociodemographic characteristics. We then estimated adjusted associations with a single model that included the main independent variable as well as all sociodemographic characteristics.

We used R (ver. 3.5.3) [31] with the survey package (ver. 3.36) [18] to account for complex survey design and weights when estimating point estimates, confidence intervals, tests of association, and multivariate logistic regression models. Analyses used a critical alpha of .05 (or equivalent 95% confidence intervals).

Results

One-fifth (20.2%) of dual-users were young adults between the ages of 18 and 25 years (Table 1). Approximately half (49.2%) were female and three-quarters were white, non-Hispanic. Over a third had a household income that was below the federal poverty line (35.5%) while 10.2% were gay, lesbian, or bisexual.

At Wave 1, the vast majority of dual-users were predominant smokers (69.6%, 95% CI: 67.8%, 71.4%). Light dual-use was the second most prevalent dual-use behavior (14.6%, 95% CI: 13.3%, 15.8%), followed by heavy dual-use (9.9%, 95% CI: 8.7%, 11.1%) and predominant vaping (5.9%, 95% CI: 4.9%, 6.9%).

Sociodemographic heterogeneity in dual-use behaviors

The prevalence of dual-use behaviors differed by age ($p < .001$), the differences being driven largely by young adults (between the ages of 18 and 25) and older adults (ages 55 and above). More specifically, light dual-use was slightly more common among young adults (22.8%), and predominant smoking was slightly less common (62.6%). In contrast, heavy dual-use was more common (13.3%) and light dual-use (7.3%) were less common among

older adults. The patterns of dual-use prevalence among other age groups generally mirrored patterns in the overall sample.

The prevalence of dual-use behaviors also differed by sex ($p = .02$), race/ethnicity ($p < .001$), and education ($p < .001$). A larger percentage of males were heavy dual-users (11.3%) than females (8.5%) while a larger percentage of females (71.4%) were predominant smokers than males (67.9%). Among adults from non-White racial/ethnic backgrounds, light dual-use (23.3%) was more common while heavy dual-use (5.9%) was less common. Additionally, light dual-use (25.9%) was more common among adults with a college degree or higher while predominant smoking (59.0%) was less common.

Harm reduction

Overall, 6.8% (95% CI = 5.6, 8.0) of dual-users engaged in harm reduction by switching to exclusive vaping at Wave 3. Heavy dual-users were more likely to engage in subsequent harm reduction than predominant smokers (8.9% v. 4.5%, aOR = 2.00, 95% CI = 1.21, 3.30) and predominant vapers were much more likely to do so (22.7% v. 4.5%, aOR = 6.19, 95% CI = 3.91, 9.79). Light dual-users were also more likely to completely switch to vaping (10.2% v. 4.5%, aOR = 2.28, 95% CI = 1.44, 3.61). Females were less likely to engage in harm reduction than males (5.4% v. 8.1%, aOR = 0.70, 95% CI = 0.52, 0.93). Dual-users who had a household income at or above twice the federal poverty level were more likely to engage in harm reduction than dual-users who had a household income below the poverty level (10.0% v. 4.5%, aOR = 2.22, 95% CI = 1.51, 3.28).

Tobacco cessation

Overall, 9.3% (95% CI = 8.3, 10.4) of dual-users stopped using both cigarettes e-cigarettes at Wave 3. Light dual-users were much more likely to engage in subsequent tobacco cessation than predominant smokers (23.1% v. 6.6%, aOR = 3.98, 95% CI = 2.93, 5.40). Dual-users between the ages of 26 and 34 or 35 and 44 were less likely to engage in subsequent tobacco cessation than young dual-users (9.5 v. 13.3, $aOR_1 = 0.53$, 95% $CI_1 = 0.35 - 0.80$; 6.7, 13.3, $aOR_2 = 0.65$, 95% $CI_2 = 0.44 - 0.96$). Females were somewhat less likely to engage in subsequent tobacco cessation than males (8.0 v. 10.5, aOR = 0.77, 95% CI = 0.61, 0.98). Dual-users who had at least a high school degree or equivalent were much more likely to engage in subsequent tobacco cessation than dual-users with less than a high school education (8.5 v. 3.6, $aOR_1 = 2.53$, 95% $CI_1 = 1.23, 5.21$; 11.1 v. 3.6, $aOR_2 = 3.38$, 95% $CI_2 = 1.67, 6.83$; 11.5 v. 3.6, $aOR_3 = 3.12$, 95% CI3 = 1.39, 6.99).

Discussion

Among U.S. adults who concurrently used cigarettes and e-cigarettes, we observed heterogeneity in dual-use owing to two sources, smoking and vaping frequencies and sociodemographic characteristics. The overwhelming majority of dual-users were predominant smokers; heavy and light dual-use were much less prevalent while predominant vaping was the least prevalent dual-use behavior. Plausibly less harmful dual-use behaviors (e.g., light dual-use) tended to be more common among more educated and wealthier dual-users, patterns that follow from previous research on e-cigarettes [23, 13]. Although harm

reduction by completely switching to e-cigarettes and tobacco cessation were not very common between waves, dual-use behaviors and some sociodemographic characteristics (e.g., education, income) were associated with both. Our results suggest that cigarette and e-cigarette dual-use should not be treated as a single risk behavior, but instead refers to a group of distinct behaviors with different epidemiological profiles.

While completely switching to e-cigarettes eliminates the health harms of cigarette smoking originating from the combustion byproducts [8], the observed heterogeneity in dual-use behaviors suggests that these benefits may not be realized by all dual-users in the context of harm reduction efforts. Most notable in this regard is our finding that predominant smokers, the largest group of dual-users, were less likely to engage in harm reduction by Wave 3. Furthermore, predominant smokers and heavy dual-users were similarly unlikely to engage in subsequent tobacco cessation. It is possible that these dual-users, who were all daily smokers, had greater nicotine dependence so that vaping did not sufficiently aid them in transitioning to exclusive e-cigarette use or quitting tobacco use altogether [17, 29]. Another plausible explanation is that these individuals largely used e-cigarette devices with product characteristics that did not facilitate tobacco use transitions. To this end, a number of studies have already noted great diversity in available e-cigarette devices and how they are marketed and used [33, 12]. Future studies should explore these possibilities in greater detail given that they may account for why the largest proportion of dual-users may be less likely to engage in harm reduction.

Also notable is that the likelihood of harm reduction or tobacco cessation essentially followed the socioeconomic gradient. Generally speaking, dual-users with higher levels of education or income were more likely to engage in harm reduction or tobacco cessation by Wave 3. This is problematic given that plausibly less harmful dual-use behaviors were more prevalent among dual-users with higher levels of education or income. Therefore, observed patterns of harm reduction have the potential to reinforce long-standing smoking-related health disparities along the socioeconomic gradient through inequitable impact [9] a common unintended consequence of many tobacco control policies [11]. This is particularly true given that people with higher levels of education or income have generally reported greater awareness of e-cigarettes and ever use [14]. A health equity perspective should be adopted when designing, implementing, and evaluating harm reduction policies [21].

Our study, like other recently published studies [3], essentially treated dual-use as a manifest variable with directly observable levels (e.g., heavy dual-use). Such an approach assumes that the frequencies of cigarette and e-cigarette use are perfectly measured (i.e., do not have measurement error) and are sufficient variables for classifying dual-use. That predominant smoking was overwhelmingly prevalent while the other three dual-use behaviors were much less prevalent raises questions about whether predominant smokers can be further classified into distinct groups or whether one or more of the other dual-use behaviors can be considered a single behavior. Future research should consider dual-use as a latent variable and employ latent class analysis [6] to refine dual-use behavior categories. Such an approach permits the inclusion of psychosocial characteristics such as risk perceptions of tobacco products that may further discriminate between dual-users beyond just self-reported cigarette and e-cigarette use.

Strengths of our study include the use of longitudinal data from PATH and complex survey procedures to calculate nationally representative prevalence rates and odds ratios. Our general findings also have face validity given that the associations of predominant vaping with harm reduction and light dual-use with complete quitting both at a later time follow from prior expectations. A limitation is that, although there is variability in defining e-cigarette use [1] potentially leading to alternate dual-use classification schemes, we did not explore other classification schemes due to the possibility of exceedingly small cell sizes. Future studies should explore alternate dual-use classification schemes based on varying definitions of e-cigarette use (e.g., those involving puffs per day or time to first puff).

Conclusions

Predominant smokers account for the overwhelming majority of U.S. adults who concurrently use cigarettes and e-cigarettes. Other dual-use behaviors are not negligible even if they are less prevalent and especially so given their differential associations with subsequent harm reduction and complete quitting. Researchers should continue to refine the measurement of dual-use behaviors to better understand the mechanisms through which they may lead to optimal smoking cessation outcomes, and to assess the impact on priority populations, including vulnerable groups.

Acknowledgments

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Table 1:

Dual-users of cigarettes and e-cigarettes, Wave 1 of the Population Assessment of Tobacco and Health ($n =$ 1,665)

	%	95% CI
Age (years)		
18–25	20.2	19.0, 21.5
26–34	24.6	22.9, 26.2
35–44	20.6	18.9, 22.4
45–54	19.0	17.6, 20.4
55+	15.6	14.2, 17.0
Sex		
Male	50.8	48.8, 52.8
Female	49.2	47.2, 51.2
Race		
White	75.0	73.3, 76.8
Other	25.0	23.2, 26.7
Sexual orientation		
Gay, lesbian, or bisexual	10.2	9.1, 11.3
Straight	89.8	88.7, 90.9
Education		
< high school	12.7	11.5, 14.0
High school degree or equivalent	35.2	33.3, 37.1
Some college or Associate's degree	38.9	36.7, 41.0
College degree or higher	13.2	12.0, 14.4
Poverty		
Below poverty level	35.5	33.7, 37.3
At or near poverty level	27.6	25.7, 29.5
At or above twice poverty level	36.9	34.7, 39.1
Dual-use behavior		
Heavy dual-user	9.9	8.7, 11.1
Predominant smoker	69.6	67.8, 71.4
Predominant vaper	5.9	4.9, 6.9
Light dual-user	14.6	13.3, 15.8
Tobacco use outcomes		
Harm reduction	6.8	5.6, 8.0
Tobacco cessation	9.3	8.3, 10.4

Notes. Includes respondents with data from Waves 1 and 3. *Heavy dual-users* were every day smokers and vapers. *Predominant smokers* were every day smokers and some day vapers. *Predominant vapers* some day smokers and every day vapers. *Light dual-users* were some day smokers and vapers. *Harm reduction* was defined as exclusively vaping every day or some days at Wave 3. *Tobacco cessation* was defined as neither smoking nor vaping at Wave 3.

Table 2:

Prevalence of dual-use behaviors by sociodemographic groups, Wave 1 of the Population Assessment of Tobacco and Health ($n = 1,665$)

	Predominant smoker	Heavy dual-user	Predominant vaper	Light dual-user	p
Age (years)					
18–25	62.6	8.7	6.0	22.8	
26–34	70.4	9.5	5.6	14.4	
35–44	70.6	10.1	5.9	13.4	< .001
45–54	73.7	8.7	4.3	13.3	
55+	71.1	13.3	8.2	7.3	
Sex					
Male	67.9	11.3	6.7	14.1	.02
Female	71.4	8.5	5.0	15.0	
Race					
White	70.9	11.2	6.2	11.7	< .001
Other	65.8	5.9	4.9	23.3	
Sexual orientation					
Gay, lesbian, or bisexual	70.5	6.4	7.8	15.3	.10
Straight	69.5	10.3	5.7	14.5	
Education					
< high school	72.2	9.2	5.9	12.6	< .001
High school degree or equivalent	72.8	11.5	5.5	10.1	
Some college or Associate's degree	69.4	8.9	6.3	15.4	
College degree or higher	59.0	9.3	5.8	25.9	
Poverty					
Below poverty level	71.5	8.9	6.5	13.1	.23
At or near poverty level	70.4	10.5	5.3	13.8	
At or above twice poverty level	67.2	10.5	5.8	16.5	

Notes. Includes respondents with data from Waves 1 and 3. *Heavy dual-users* were every day smokers and every day vapers. *Predominant smokers* were every day smokers and some day vapers. *Predominant vapers* were some day smokers and every day vapers. *Light dual-users* were some day smokers and vapers were.

Table 3:

Associations between Wave 1 dual-use behaviors and Wave 3 tobacco use outcomes, Population Assessment of Tobacco and Health (*n* = 1,665)

	Harm reduction			Tobacco cessation		
	Weighted %	OR [95 % CI]	aOR [95% CI]	Weighted %	OR [95 % CI]	aOR [95% CI]
Dual-use behavior						
Predominant smoker	4.5	1	1	6.6	1	1
Heavy dual-user	8.9	2.09 [1.27, 3.44]	2.00 [1.21, 3.30]	8.7	1.36 [0.87, 2.12]	1.31 [0.83, 2.07]
Predominant vaper	22.7	6.30 [4.17, 9.52]	6.19 [3.91, 9.79]	8.2	1.27 [0.73, 2.20]	1.20 [0.69, 2.08]
Light dual-user	10.2	2.42 [1.61, 3.63]	2.28 [1.44, 3.61]	23.1	4.25 [3.21, 5.64]	3.98 [2.93, 5.40]
Age (years)						
18–25	6.6	1	1	13.3	1	1
26–34	8.2	1.26 [0.81, 1.94]	1.31 [0.82, 2.10]	9.5	0.68 [0.48, 0.97]	0.78 [0.54, 1.12]
35–44	6.4	0.96 [0.60, 1.53]	0.95 [0.58, 1.56]	6.7	0.47 [0.32, 0.68]	0.53 [0.35, 0.80]
45–54	5.0	0.75 [0.44, 1.27]	0.81 [0.45, 1.46]	7.5	0.53 [0.35, 0.79]	0.65 [0.44, 0.96]
55+	7.5	1.15 [0.72, 1.84]	1.14 [0.67, 1.95]	7.3	0.67 [0.44, 1.02]	0.97 [0.62, 1.50]
Sex						
Male	8.1	1	1	10.5	1	1
Female	5.4	0.65 [0.49, 0.87]	0.70 [0.52, 0.93]	8.0	0.75 [0.59, 0.94]	0.77 [0.61, 0.98]
Race						
White	7.0	1	1	8.7	1	1
Other	6.1	0.86 [0.57, 1.30]	0.90 [0.57, 1.40]	11.3	1.34 [1.06, 1.68]	1.14 [0.89, 1.47]
Sexual orientation						
Gay, lesbian, or bisexual	6.9	1	1	9.6	1	1
Straight	6.8	1.02 [0.55, 1.89]	1.12 [0.61, 2.06]	7.2	0.73 [0.44, 1.22]	0.71 [0.40, 1.24]
Education						
< high school	6.0	1	1	3.6	1	1
High school degree or equivalent	5.5	0.92 [0.56, 1.50]	0.78 [0.47, 1.28]	8.5	2.47 [1.16, 5.24]	2.53 [1.23, 5.21]
Some college or Associate's degree	7.0	1.19 [0.72, 1.94]	0.90 [0.51, 1.57]	11.1	3.34 [1.65, 6.75]	3.38 [1.67, 6.83]
College degree or higher	10.4	1.82 [0.96, 3.44]	1.1 [0.50, 2.05]	11.5	3.46 [1.59, 7.40]	3.12 [1.39, 6.99]
Poverty						
Below poverty level	4.5	1	1	8.2	1	1

	Harm reduction			Tobacco cessation		
	Weighted %	OR [95 % CI]	aOR [95% CI]	Weighted %	OR [95 % CI]	aOR [95% CI]
At or near poverty level	5.3	1.19 [0.77, 1.82]	1.19 [0.76, 1.85]	10.7	1.34 [0.95, 1.90]	1.21 [0.85, 1.72]
At or above twice poverty level	10.0	2.33 [1.68, 3.24]	2.22 [1.51, 3.28]	9.4	1.16 [0.86, 1.56]	0.92 [0.67, 1.26]

Notes. Includes respondents with data from Waves 1 and 3. *Heavy dual-users* were every day smokers and vapers. *Predominant smokers* were every day smokers and some day vapers. *Predominant vapers* were some day smokers and every day vapers. *Light dual-users* were some day smokers and vapers were. *Harm reduction* was defined as exclusively vaping every day or some days at Wave 3. *Tobacco cessation* was defined as neither smoking nor vaping at Wave 3.