**E-Cigarette Product Characteristics and Subsequent Frequency of Cigarette Smoking**

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**Abbreviations**: CHS – Children’s Health Study; OR – odds ratio; CI – confidence interval

**Table of Contents Summary:** This study sought to determine whether e-cigarette product characteristics were associated with past 30-day frequency of cigarette smoking approximately one year later.

**What’s Known on This Subject:** E-cigarette use has been associated with cigarette initiation and with greater frequency of smoking among adolescents. It is not yet known whether there are certain product characteristics of the e-cigarettes that may increase the frequency of cigarette smoking at follow-up.

**What This Study Adds:** Young adults using mod (vs. pen-like) e-cigarette devices at baseline smoked more than 6 times as many cigarettes in the past 30 days at follow-up. Regulation of e-cigarette product characteristics might reduce transitions from e-cigarettes to heavier cigarette smoking patterns.

**CONTRIBUTORS**

Dr. Barrington-Trimis formulated the research question, interpreted the results, wrote and edited the manuscript, and approved the manuscript as submitted.

Ms. Yang conducted the analysis, contributed to interpretation of results, and approved the manuscript as submitted.

Ms. Schiff and Drs. Unger, Cruz, Urman, Cho, Samet, and Leventhal contributed to formulating the research question, interpretation of results and to editing the manuscript, and approved the manuscript as submitted.

Dr. Berhane contributed to interpretation of the results, oversight of statistical analyses, and to editing the manuscript, and approved the manuscript as submitted.

Dr. McConnell designed the study, collected data, and contributed to formulating the research question and interpretation of the results, critically reviewed the manuscript, and approved the manuscript as submitted.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

**ABSTRACT**

**Background.** Evidence that use of e-cigarettes with certain product characteristics may increase adolescent and young adult risk of unhealthy tobacco use patterns—such as frequency of combustible cigarette smoking—can inform regulation of e-cigarettes.

**Methods.** Data were collected via online survey from participants in the Southern California Children’s Health Study in 2015-2016 (baseline) and 2016-2017 (follow-up) (N=1312). We evaluated the association of binary categories of three non-mutually exclusive characteristics of the e-cigarette used most frequently with number of cigarettes smoked in the past 30 days at 1-year follow-up. Product characteristics included device (pen-like/mod [modifiable device]), use of nicotine in eliquid solutions (yes/no), and use for dripping (directly dripping eliquid onto the device for high levels of nicotine; yes/no).

**Results.** Relative to never e-cigarette users, past 30-day e-cigarette use with any product characteristic was associated with greater frequency of past 30-day cigarette smoking at follow-up. Among past 30-day e-cigarette users at baseline, participants who used mods smoked more than 6 times as many cigarettes as those using vape pens at follow-up (mean: 20.8 vs. 1.3 cigarettes; RR=6.33; 95%CI:1.64,24.5), after adjustment for sociodemographic characteristics, baseline frequency of cigarette smoking and number of days of e-cigarette use. After adjustment for device, neither nicotine eliquid nor dripping were associated with frequency of cigarette smoking.

**Conclusions.** Use of mods (vs. vape pens) at baseline was associated with subsequently smoking more cigarettes in the past 30-days. Regulation of e-cigarette devices warrants consideration as a strategy to reduce cigarette smoking among adolescents and young adults who vape.

**Key Words:** e-cigarettes; product characteristics; cigarettes; young adults; longitudinal studies; epidemiology; prospective cohort studies

**Introduction**

The recent increase in the prevalence of past 30-day e-cigarette use among high school students in the National Youth Tobacco Survey (up 78% from 11.3% in 2017 to 20.8% in 20181) and in the Monitoring the Future Study (up 90% from 11.0% in 2017 to 20.9% in 20182) has heightened concern regarding the public health impact of e-cigarettes among the youth and young adult populations. E-cigarettes are drawing in at least some low-risk youth unlikely to have otherwise smoked combustible cigarettes,3,4 and a growing number of studies show that among both youth and young adults, e-cigarette users (vs. never users) are more likely (a) to subsequently initiate combustible cigarette use,5-21 and (b) to follow a similar trajectory into more regular smoking as smokers who did not first use e-cigarettes.22,23 Yet, it is unclear whether there are e-cigarette product characteristics that may impact these transitions. If so, such characteristics could be prime targets for regulation to reduce the overall adverse public health burden of e-cigarettes in adolescent and young adult populations.

Data are urgently needed on factors that differentiate the risk of transition from e-cigarettes to heavier patterns of combustible cigarette use to help guide regulatory strategies. Use of e-cigarettes with a higher nicotine level has been associated with increased likelihood of combustible cigarette initiation17,24 and with both greater frequency of cigarette use in the past month and more cigarettes smoked per day at follow-up.24 Other product characteristics that are amenable to regulation may also promote or discourage the transition to combustible tobacco use but have not yet been thoroughly investigated. For example, later generation e-cigarette devices (e.g., modifiable devices [“mods”] or vape pens) that deliver nicotine more efficiently are more commonly used than cig-a-like devices (devices that look like cigarettes) among youth and young adults,25 and have been associated with greater number of days of cigarette use and symptoms of dependence.26 Mod devices are also often used for “dripping”27 – directly dropping eliquid solution onto coils of the e-cigarette to produce thick smoke and a high level of nicotine – though no data are available on whether the use of devices for dripping increase the likelihood or frequency of combustible tobacco product use.

In the current study, we examine whether use of e-cigarettes with varying product characteristics – device type, use of nicotine, and use for dripping – is associated with the number of cigarettes smoked in the past 30 days approximately one year later among young adults in the Southern California Children’s Health Study (CHS).

**Methods**

*Participants*

Data for the current study were collected from students participating in the CHS. We first collected data on specific characteristics of e-cigarettes from past 30-day users from April 2015-October 2016 (baseline for the current study; mean age=18.9 years, SD=0.6); follow up data were collected approximately one year later from October 2016-November 2017 (follow-up; mean age=20.2 years, SD 0.6). Analyses were restricted to participants who reported whether they had ever used e-cigarettes or used e-cigarettes in the past 30 days at baseline, and who completed a follow-up questionnaire at follow-up (N=1312; see Figure 1).

*Ethics Statement*

This study was approved by the University of Southern California Institutional Review Board. All participants were 18 years of age or older at baseline and provided informed consent prior to data collection.

*Measures*

E-cigarette Use. Participants reported the age at which they had first used e-cigarettes and the number of days that they had used e-cigarettes in the past 30 days. Participants who reported that they had never used e-cigarettes were classified as “never users”; those who reported an age of first use of e-cigarettes but no use in the past 30 days were considered “prior users”; those who reported use on at least 1 of the past 30 days were considered “past 30-day users.” Participants missing data on e-cigarette use at baseline were excluded from analyses (N=105).

E-cigarette Characteristics. Among past 30-day e-cigarette users, four e-cigarette characteristics were assessed: (1) device type, (2) nicotine level, and (3) dripping. Participants were asked to select the type of e-cigarette device they had used most often in the past 30 days (disposable/cig-a-like, vape pen/pen-like device, mod/mech-mod/box mod). For analyses, type of device was dichotomized (vape pen vs. mod) as there were few participants reporting primary use of a disposable device (N=2). All past 30-day e-cigarette users were asked to report the level of nicotine used; nicotine level was dichotomized for analysis (any use of nicotine, yes vs. no). Participants also reported whether they had ever “dripped” with an e-cigarette device (yes vs. no). Participants missing data for product characteristic variables were excluded from analyses for the corresponding exposure (N=31 participants missing data for all e-cigarette characteristics).

Cigarette Use. Questionnaire items assessed cigarette smoking using similar questions to those for e-cigarette use; participants who reported that they had “never tried” a product were classified as “never users,” participants who reported the age they first smoked cigarettes but did not report use of cigarettes in the past 30 days were classified as “prior users,” and participants who had smoked cigarettes on at least 1 of the past 30 days were classified as “past 30-day users”. In addition, participants who reported use of cigarettes in the past 30 days were also asked about the number of cigarettes they had smoked in the past 30 days at each wave. Participants with missing data on cigarette use at either baseline (N=14) or follow-up (N=61) were excluded from analyses.

Sociodemographic Characteristics. Self-administered questionnaires were used to assess gender, ethnicity (Hispanic white, non-Hispanic white, and other), and parental education (highest level of education of either parent: ≤12th grade, some college, college degree or higher). Missing data on covariates were accounted for by a missing indicator approach to allow inclusion in analyses in order to maintain a complete sample.28

*Statistical Analysis*

Descriptive analyses. The distribution of number of cigarettes smoked was highly right-skewed and zero-inflated. Violin plots combined with boxplots were used to illustrate the distributions of the number of cigarettes smoked in the past 30 days at follow-up by strata of each demographic variable (gender, race/ethnicity, parental education) and e-cigarette use among all participants (Figure 1a), and among past 30-day e-cigarette users (Figure 1b); similar plots were used to describe the number of cigarettes smoked in the past 30 days at follow-up among baseline past 30-day e-cigarette users by strata for each e-cigarette characteristic (device type, use of nicotine, use for dripping; Figure 2).

Model selection. Given the highly right-skewed distributions of number of cigarettes used in the past 30 days at follow-up, multiple models were evaluated to determine which best fit the data, including linear regression (with log-transformed outcome), Poisson regression, negative binomial regression, zero-inflated Poisson regression, zero-inflated negative binomial regression, generalized Poisson regression, generalized negative binomial regression, and hurdle models. Models reported herein are those that were determined to be the best fit, based on the Akaike information criterion (AIC),29 which was assessed separately for each model, in combination with evaluation of the significance of additional dispersion parameters in complex models to determine whether a complex model is a better fit to the data than a simple model.

Association of baseline e-cigarette use with varying product characteristics with number of cigarettes smoked at follow-up. In a first set of models (Model 1), we evaluated the association of e-cigarette use across different strata of a given product characteristic at baseline in the entire sample (e.g., never use, prior e-cigarette use, e-cigarette use in the past 30 days using a vape pen, e-cigarette use in the past 30 days using a mod) with number of cigarettes smoked in the past 30 days at follow-up, adjusted for demographic characteristics, number of cigarettes smoked at baseline, and number of days e-cigarettes were used in the past 30 days at baseline. A second set of models (Model 2) was restricted to past 30-day e-cigarette users at baseline to compare the effect of each product characteristic (e.g., for device type: vape pen vs. mod) among recent users on subsequent frequency of cigarette smoking. In a third set of models (Model 3), we included statistically significant product characteristics identified in Model 2 in order to examine whether some product characteristics were stronger risk factors for cigarette smoking frequency after adjusting for other product characteristics. For all models, rate ratio (RR) estimates were calculated by exponentiating each beta estimate; 95% confidence intervals are also reported.

All models were adjusted for gender, ethnicity, highest parental education, number of cigarettes smoked at baseline, and number of days of e-cigarette use at baseline; a random effect for community was included when significant. All statistical analyses were based on two-sided hypotheses tested at a 0.05 level of significance. Analyses were performed using SAS, version 9.4 and data manipulation and graphics were generated using the ggplot2 package in R, version 3.4.4.

**Results**

**Descriptive Analyses.**

Demographic Characteristics. More participants were female (52.2%), and approximately half the sample was Hispanic White (48.4%); a plurality had parents who had completed some college (35.0%), with similar proportions of the sample reporting parents with a high school degree or less (29.8%) or with a college degree (29.4%) (Table 1). Overall, 36.9% of youth reported having ever used e-cigarettes, with 26.4% of participants reporting prior use but no use in the past 30 days and 10.5% of participants reporting past 30-day e-cigarette use.

The number of cigarettes smoked in the past 30 days at follow-up was higher for males (vs. females) and for those with parents who had some college or a college degree or higher (vs. a high school degree or less) (Figure 1A; Table 1). No differences were observed by ethnicity. Similar patterns emerged in the sample restricted to past 30-day e-cigarette users (Figure 1B).

Association of e-cigarette use and subsequent smoking frequency. Participants who reported prior or past 30-day e-cigarette use at baseline reported a higher average number of cigarettes smoked in the past 30 days at follow-up (mean number of cigarettes smoked [SD] among never e-cigarette users = 1.9 [25.4]; among prior users = 13.0 [118]; among past 30-day users = 15.4 [51.6]; Figure 1A; Table 1). Participants reporting prior e-cigarette use but no use in the past 30 days at baseline smoked an average of 3.47 (95%CI: 2.46, 4.91) times as many cigarettes at follow-up as never baseline e-cigarette users, and past 30 day e-cigarette users at baseline smoked an average of 5.42 (95%CI: 2.56, 11.5) times as many cigarettes at follow-up in adjusted models.

**Cigarette Smoking at Follow-Up by Use of E-cigarettes with Varying Product Characteristics**

Descriptive Analyses. As illustrated in Figure 2, the number of cigarettes smoked in the past 30 days differed by some e-cigarette characteristics among participants who had used e-cigarettes in the past 30 days at baseline. Adolescents using a pen-like device (N=36; 26.5% of past 30-day e-cigarette users) smoked on average very few cigarettes in the past 30 days at follow-up (mean number of cigarettes smoked [SD] = 1.3 [3.89]; Figure 2, Table 2), compared to those using a mod device (N=100; 73.5%; mean number of cigarettes smoked at follow-up [SD]=20.8 [59.8]). The number of cigarettes smoked at follow-up did not vary substantially by baseline use of nicotine (no [N=20; 17.5%]; mean number of cigarettes [SD] = 15.8 [64.0] vs. yes [N=94; 82.5%]; mean number cigarettes smoked = 17.7 [54.7]) or by use of e-cigarettes for dripping (no [N=17; 13.5%]; mean number of cigarettes smoked [SD] = 14.1 [36.2] vs. yes [N=109; 86.5%]; mean number of cigarettes smoked = 17.1 [56.2]).

E-cigarette Use (vs. Never Use) and Frequency of Cigarette Smoking (MODEL 1). Participants using a pen-like e-cigarette device smoked 2.83 times (95%CI: 1.26, 6.35) as many cigarettes in the past 30 days at follow-up as those who had never used e-cigarettes, and participants using a mod device smoked 8.38 times (95%CI: 4.87, 14.4) as many cigarettes in the past 30 days at follow-up (vs. never e-cigarette users; See Model 1, Table 2), after adjustment for sociodemographic characteristics, and number of cigarettes smoked and days of e-cigarette use in the past 30 days at baseline. Elevated rate ratios were also observed for past 30-day use of e-cigarettes with and without nicotine, and for use of e-cigarettes for dripping and not.

Among Past 30-Day E-cigarette Users, Association of E-cigarette Use Across Varying Product Characteristics and Frequency of Cigarette Smoking (MODEL 2). In analyses restricted to participants reporting past 30 day use of e-cigarettes, adolescents using mods smoked an average of 5.11 (95% CI: 1.74, 15.0) times as many cigarettes in the past 30 days at follow-up relative to adolescents using a pen-like e-cigarette device at baseline (see Model 2, Table 2). Adolescents using nicotine-containing e-cigarette products smoked an average of 3.69 (95% CI: 0.99,13.7) times the number of cigarettes in the past 30 days at follow-up as those using e-cigarettes without nicotine. No association was observed for use of dripping and subsequent number of cigarettes smoked (RR=1.07; 95%CI: 0.35, 3.20).

Among Past 30-Day E-cigarette Users, Multiply Adjusted Models of E-cigarette Use with Varying Product Characteristics and Frequency of Cigarette Smoking (MODEL 3). Given the associations of both device type and nicotine with frequency of cigarette smoking, a third set of models included both predictors simultaneously. When modelling both device type and use of nicotine in one model, only the association of device type with number of cigarettes smoked at follow-up remained elevated and statistically significant (RR = 6.33, 95% CI: 1.64, 24.5).

**Discussion**

Results were consistent with previous findings also showing that e-cigarette use in the past 30 days (vs. no use) was associated greater frequency of smoking at subsequent follow-up.22,23 In addition, we provide new evidence indicating that the type of device used (mod vs. pen-like device) is strongly associated with frequency of cigarette smoking at follow-up, while other product characteristics – including use of nicotine and use of e-cigarettes for dripping – were not associated with frequency of cigarette smoking.

We recently reported in a paper pooling estimates across 8 different studies that the majority of youth and young adults were using later generation devices (vape pens or mods), while few were using cig-a-like devices.25 In the current study mod devices were more commonly used than vape pens. Given the wide variability in nicotine delivery across different devices, it is plausible that different devices may confer differential risks of transition between nicotine products. A large cross-sectional study of e-cigarette users reported that the transition from vape pens to mods was far more common than that of the reverse, and that a majority of later generation device users reported use of a later generation device to “obtain a more satisfying hit.”30,31 Given the higher rates of nicotine delivery of later generation devices, our findings that mods are associated with greater frequency of cigarette smoking at follow-up could be explained by higher levels of nicotine consumption and nicotine dependence in these individuals. Exposure to greater levels of nicotine may increase dependence on nicotine and thereby result in increases in smoking behavior to attain sufficient nicotine levels. Alternatively, adolescents and young adults may enjoy the sensations that accompany nicotine use and seek out other forms of nicotine. Findings of several smoke-machine studies31-33 and laboratory studies31,34,35 have shown that later generation devices (e.g., “mods”) produce a greater volume of aerosol and higher nicotine yield than earlier generation devices (e.g., cigalikes or pen-like devices), even when nicotine in the e-cigarette solution is held constant. While nicotine dependence may explain part of this association, it remains unclear as to why those using a device that efficiently delivers nicotine would begin or maintain use of combustible cigarette products.

We hypothesized that use of e-cigarette solutions with nicotine would be associated with subsequent greater frequency of cigarette smoking, because nicotine would cause dependence, but differences in cigarettes smoked were small and not statistically significant after adjustment for the type of device used. The level of nicotine in the eliquid has been shown to impact nicotine delivery,36-38 and previous studies have reported that level of nicotine in e-cigarette eliquid was associated with frequency of e-cigarette use, cigarette use, and likelihood of cigarette initiation.17,24 However, no prior studies examining this association have accounted for the type of device used. It is possible that use of eliquids with nicotine was not associated with number of cigarettes smoked because the type of device was a better predictor of effective nicotine dose than whether participants reported using nicotine. Participants who reported using e-cigarettes without nicotine may also be exposed to nicotine - numerous studies have shown that solutions labeled “nicotine-free” may contain nicotine.39-47 It is also possible that if we had accurate estimates of eliquid nicotine concentration that stronger associations would have been observed with subsequent smoking. Although some studies have reported *decreasing* levels of nicotine in eliquids in later generation e-cigarette devices, the effective dose may have been greater from the more efficient and powerful later generation mod devices available at the time of this study.48 Further observational and experimental study is warranted to understand the relationship between nicotine level in eliquids, device type and effective nicotine dose and dependence.

This study is subject to some limitations. Most participants reported use of multiple non-traditional e-cigarette flavors which a) reduced power to detect differences between traditional and non-traditional flavors and b) did not permit for the evaluation of the impact of specific flavors (e.g., sweet vs. fruit flavors) on the frequency of cigarette smoking. This study used data from a cohort study of young adults in Southern California; as such, results may not be generalizable to younger adolescents or older adults, and may not generalize to other geographic regions within or outside of the United States with different regulatory environments. An important limitation was that the study largely took place prior to the popularization of pod-based e-cigarette products. Thus, continued research is needed to investigate whether and how such associations may change as the e-cigarette market evolves.

**Conclusion**

Use of mods (vs. pen-like) e-cigarette devices was strongly, positively associated with the number of cigarettes smoked approximately 1 year later at follow-up. Additional research is needed to explore causal pathways for the observed associations. If these associations were causal, device type and characteristics may be a target for regulation to reduce the burden of tobacco related disease that may result from adolescent and young adult vaping.

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Figure Legends

**Figure 1**. The distribution of past-30-day cigarette use at follow-up for the (A) overall sample, and (B) sample of past 30-day e-cigarette users, by demographics, i.e., gender, race and highest parental education, and by e-cigarette use in the overall sample. The points (jittered for clarity) show number of past-30-day cigarettes smoked at follow-up by demographics, along with violin plots and boxplots describing corresponding distributions.

**Figure 2.** The distribution of past-30-day cigarette use at follow-up by four e-cigarette characteristics of current e-cigarette at baseline, i.e., device type, preference for non-traditional flavor, nicotine and use of e-cigarettes for dripping. The points (jittered for clarity) show number of past-30-day cigarettes smoked at follow-up by four e-cigarette characteristics, along with violin plots and boxplots describing corresponding distributions.

**Tables**

**Table 1.** Participant characteristics at baseline and association of each characteristic with number of cigarettes smoked in the past 30 days at follow-up; *N* = 1312

|  |  |  |  |
| --- | --- | --- | --- |
|  | Total a  *N* (%) | Mean number of cigarettes smoked at follow-up (SD) | RR (95% CI)b |
| Gender |  |  |  |
| Female | 685 (52.2) | 5.40 (82.0) | Ref |
| Male | 627 (47.8) | 7.11 (42.7) | 1.55 [1.10, 2.17] |
| Race/ethnicity |  |  |  |
| Non-Hispanic white | 171 (13.0) | 13.1 (156) | 1.00 [0.59, 1.70] |
| Hispanic white | 635 (48.4) | 3.79 (32.0) | 0.88 [0.51, 1.53] |
| Other | 506 (38.6) | 6.94 (43.7) | Ref |
| Education (highest parental) |  |  |  |
| 12th grade | 391 (29.8) | 1.95 (14.5) | Ref |
| Some college | 459 (35.0) | 8.24 (53.1) | 2.45 [1.53, 3.90] |
| College degree or higher | 386 (29.4) | 3.70 (24.3) | 2.38 [1.45, 3.88] |
| E-cigarette use |  |  |  |
| Never | 828 (63.1) | 1.86 (25.4) | Ref |
| Prior | 346 (26.4) | 13.0 (118) | 3.35 [2.16, 5.18] |
| Past 30-day | 138 (10.5) | 15.4 (51.6) | 5.84 [3.51, 9.71] |

CI = confidence interval; RR = rate ratio.

aMay not sum to total due to missing values

bCo-adjusted for gender, race/ethnicity, parental education, community, log-transformed number of cigarettes at baseline, e-cigarette use at follow-up and number of days of e-cigarette use in the past 30 days at baseline using Poisson regression models

**Table 2.** Association between e-cigarette characteristics at baseline and number of cigarettes smoked in the past 30 days at follow-up; N=1312a

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | Association with Number of Cigarettes Smoked in Past 30 Days  at Follow-up | | |
|  | Mean Number of Cigarettes Smoked at Follow-up (SD) | Model 1  RR (95% CI)b | Model 2  RR (95% CI)c | Model 3  RR (95% CI)d |
| No e-cigarette use (N=828) | 1.9 (25.4) | Refe | -- | -- |
| Device type |  |  |  |  |
| Pen-like (N=36) | 1.3 (3.89) | 2.83 (1.27, 6.35) | Reff | Reff |
| Mods (N=100) | 20.8 (59.8) | 8.38 (4.87, 14.4) | 5.11 (1.74, 15.0) | 6.33 (1.64, 24.5) |
| Nicotine |  |  |  |  |
| No (N=20) | 15.8 (64.0) | 3.90 (1.56, 9.74) | Refg | Reff |
| Yes (N=94) | 17.7 (54.7) | 6.52 (3.65, 11.6) | 3.69 (0.99, 13.7) | 1.65 (0.47, 5.71) |
| Dripping |  |  |  |  |
| No (N=17) | 14.1 (36.2) | 4.64 (1.97, 10.9) | Reff |  |
| Yes (N=109) | 17.1 (56.2) | 6.83 (3.98, 11.7) | 1.07 (0.35, 3.20) |  |

RR = rate ratio; CI = confidence interval

a*Ns* range from 1289 to 1310 for each analysis due to different patterns of missing data for exposures.

bCo-adjusted for gender, race/ethnicity, parental education, community, log-transformed number of cigarettes at baseline, and number of days of e-cigarette use in the past 30 days at baseline.

cModel restricted to past 30-day e-cigarette users

dModel additionally simultaneously adjusted for device type and nicotine.

eGeneralized Poisson model

fGeneralized Negative Binomial model

gNegative Binomial model