

UCSF

Tobacco Control Policy Making: United States

Title

The Association between E-cigarette Characteristics and Stopping Smoking and Vaping among Adult Dual Users of Cigarettes and E-cigarettes

Permalink

<https://escholarship.org/uc/item/0js1n2t2>

Authors

Wang, Yingning, PhD

Sung, Hai-Yen, PhD

Glantz, Stanton, PhD

et al.

Publication Date

2026-04-01

The Association between E-cigarette Characteristics and Stopping Smoking and Vaping among Adult Dual Users of Cigarettes and E-cigarettes

Yingning Wang, PhD.¹

Hai-Yen Sung, PhD.¹

Stanton Glantz, PhD.²

Wendy Max, PhD.¹

¹Institute for Health & Aging, School of Nursing, and Center for Tobacco Control Research and Education, University of California, San Francisco, CA

²Retired from Department of Medicine, University of California San Francisco, San Francisco, CA

March 2026

This report is available in the University of California eScholarship repository at

<https://escholarship.org/uc/item/0js1n2t2>

Abstract

Objectives: This longitudinal study examines how baseline use of e-cigarette product characteristics are associated with probabilities of smoking and vaping cessation three years later among U.S. adults who use both cigarettes and e-cigarettes (dual users).

Methods: We analyzed data from 1,048 dual users at Wave 3 (baseline) and Wave 5 (follow-up) of the Population Assessment of Tobacco and Health Study. Using multinomial logistic regression, we examined how baseline e-cigarette characteristics (nicotine concentration, adjustable voltage, flavoring, and device type) relate to the probabilities of stopping smoking only, stopping vaping only, stopping both, or continuing both.

Results: At follow-up, 7.5% stopped smoking only, 38.4% stopped vaping only, and 7.8% stopped both. None of the baseline e-cigarette characteristics were associated with stopping smoking only. Using nicotine levels ≥ 13 mg/ml (vs. 0 mg/ml) decreased the probability of stopping vaping only and increased the probability of continuing both, while using e-cigarettes with adjustable voltage increased the probability of stopping both. Using menthol/mint-flavor only and other flavor only (vs. tobacco flavor only) decreased the probability of stopping vaping only and using a combination of flavors decreased the probability of stopping both. Device type was not associated with cessation behaviors.

Conclusion: Vaping with adjustable voltage increased the likelihood of quitting both, whereas using non-zero nicotine or exclusive use of non-tobacco flavors reduced the likelihood of quitting vaping only. Use of a combination of flavors decreased the likelihood of quitting both. These findings may inform regulations on nicotine limits and flavored e-cigarettes, including menthol and mint.

Introduction

Electronic cigarettes (e-cigarettes) have been marketed as a cigarette smoking cessation tool, with over half of U.S. adult smokers using them in their last quit attempt in 2014-2016.^{1,2} Recent meta-analyses of randomized controlled trials (RCTs) show the effectiveness of e-cigarettes when used in structured smoking cessation programs (often with counseling).³⁻⁶ In contrast, meta-analyses of actual use of e-cigarettes as consumer products^{4,5} and subsequent large epidemiological studies⁷⁻⁹ found no significant or even a negative association with smoking cessation.

A key limitation of much of this population-based research is that it often treats e-cigarettes as a single, uniform product. In reality, e-cigarette characteristics, including nicotine concentration, adjustable voltage, flavorings, and device type, can vary widely and may shape cigarette smokers' behavior—either prompting them to stop or continue smoking—by affecting nicotine delivery, enhancing sensory experiences, or easing the adverse effects of smoking cessation, like craving symptoms.^{10,11} A thorough examination of these characteristics is essential to understand their impact on smoking cessation.¹²

Higher nicotine concentrations in e-cigarettes can enhance nicotine delivery and potentially intensify vaping's rewarding effects.¹³ The power level of e-cigarette devices, which can be altered by manipulating the voltage, also influences the amount of nicotine aerosolized and total particulate matter.¹⁴ Understanding the relationship between nicotine levels, voltage, and smoking cessation is crucial for smokers, clinicians, and policymakers. Previous research on nicotine levels and stopping smoking have yielded conflicting findings.^{3,6,15} A meta-analysis of RCTs, providing free e-cigarettes for current smokers (dual use of cigarettes and e-cigarettes) as a clinical smoking cessation intervention, reported a positive association between nicotine vs.

non-nicotine e-cigarettes and cessation success.^{3,6} In contrast, a population-based study of e-cigarettes as consumer products among adults who had recently used e-cigarettes to quit smoking found no significant association between cessation and nicotine content, whether comparing nicotine vs non-nicotine e-cigarettes or by preferred nicotine concentration.¹⁵ The effect of adjustable voltage and the interaction between nicotine concentration and voltage on subsequent cessation has not been studied.

A few studies have explored the relationship between e-cigarette flavorings and smoking cessation among dual users.¹⁵⁻¹⁸ Findings from these studies, along with three systematic reviews,¹⁵⁻²¹ have varied in their conclusions on the role of e-cigarette flavorings in smoking cessation. Some found that non-tobacco-flavored e-cigarette use facilitates stopping smoking,^{16,17} while others did not.^{15,18-21} The inconsistent results may stem from different definitions of e-cigarette flavorings and stopping smoking. Some studies defined specific flavors use as any usage of that particular flavor, regardless of whether other flavors are also used.^{16,17} Other studies required exclusive use of one flavor.¹⁸ For definitions of stopping smoking, some defined it as non-current smoking, while others defined it based on different durations of stopping smoking.^{16,18} Many studies have indicated that a duration of at least 6 months should be used as a benchmark to evaluate the effectiveness of smoking cessation.²²

The association between e-cigarette flavorings and stopping smoking may differ for menthol and non-menthol cigarette smokers. Menthol smokers are more likely to use menthol e-cigarettes and to consider using e-cigarettes to stop smoking.^{23,24} One study found higher smoking cessation rates among dual users who smoked menthol cigarettes than those who smoked non-menthol cigarettes.²⁵ However, little research has explored how menthol cigarette

use moderates the relationship between e-cigarette flavorings and tobacco cessation among dual users.

Two of the above three studies that examined e-cigarette flavors also investigated the association between e-cigarette device type and smoking cessation.^{15,18} One study,¹⁵ using cross-sectional data, found that dual users who preferred rechargeable pod and mod device types (vs. cig-a-likes) had longer durations of abstinence. The other study,¹⁸ using longitudinal data, found modifiable e-cigarette devices helped current e-cigarette users who were current smokers at baseline transition to exclusive e-cigarette use. In addition, a longitudinal study analyzed PATH Waves 1-3 data and found that using rechargeable e-cigarettes (vs. disposable) were associated with subsequent smoking cessation over a two-year period.¹⁶ These studies were limited by reliance on cross-sectional data, short follow-up windows, early PATH waves when the e-cigarette market was less diverse, or definitions of cessation that did not distinguish between stopping smoking only, stopping vaping only, and stopping both.

This longitudinal study examines whether baseline e-cigarette use with nicotine concentration (vs. zero nicotine level), adjustable voltage (vs. non-adjustable), flavors (vs. tobacco flavor), or device types (vs. cartridge devices) is associated with different probabilities of smoking and vaping cessation three years later among U.S. adult dual users.

Methods

Data

We analyzed data from the nationally representative adult Population Assessment of Tobacco and Health (PATH) Study (Wave 3, Oct 2015 - Oct 2016, baseline; and Wave 5, Oct 2018 - Oct 2019, follow-up) conducted by the National Institutes of Health and the Food and

Drug Administration (FDA). The PATH study tracks U.S. adult tobacco use and health outcomes. Wave 3 was selected because it uniquely collected information on adjustable voltage.¹⁴ Wave 5 provided the most recent complete adult data at the time of this analysis, allowing a three-year follow-up. Data are publicly available and de-identified, and the UCSF Institutional Review Board deemed this study exempt.

Study cohort

At baseline, 1,930 adults were dual users. After excluding dual users lost to follow-up (n=397) or missing data on dependent and independent variables (n=485), 1,048 dual users remained in the final study sample. Dual users were defined as those who had smoked ≥ 100 cigarettes in their lifetime, currently smoked cigarettes daily or some days (current smokers) and who currently used e-cigarettes every day, some days, or had used e-cigarettes in the past 30 days (current e-cigarette users).

Measures

The dependent variable is smoking and vaping status at follow-up and is categorized as: stopping smoking only (i.e., stopped smoking but not vaping), stopping vaping only (i.e., stopped vaping but not smoking), stopping both smoking and vaping, and continuing smoking and vaping. Stopping behaviors required ≥ 6 months of abstinence. Full coding details are provided in the Supplements.

Key baseline independent variables were e-cigarette characteristics: nicotine concentration (0, 1–12, ≥ 13 mg/ml, unknown), adjustable voltage (yes/no), flavor categories (tobacco only, menthol/mint only, other flavors only, and a combination of flavors), and device type (cartridge, tank/mod, disposable, and other). Full coding details are provided in the Supplements.

Other baseline independent variables included menthol cigarette smoking, heavy smoking (smoked ≥ 20 cigarettes per day), daily e-cigarette use, past 12-month attempts to quit cigarette smoking, used e-cigarettes to help quit cigarette smoking, time to the first cigarette after awakening, past 30-day other tobacco use, past 30-day marijuana use, past 30-day alcohol use, and socioeconomic characteristics based on the literature.^{9,26-30} We included marijuana and alcohol use at Wave 3, given their frequent role as substitutes or complements to cigarettes and e-cigarettes and associations with smoking and vaping behavior.²⁶⁻²⁸ Full coding details are provided in the Supplements.

Statistical analysis

Main analysis. We generated descriptive statistics of the sample distribution and estimated the prevalence of each dependent variable category by independent variables. We used a multinomial logistic regression model to estimate the association between baseline e-cigarette characteristics and their smoking and vaping status at follow-up, controlling for other baseline independent variables. Using Stata's "Margins, dydx" command, we calculated the average marginal effects (AME) after fitting the logistic regression model to show how the probability of the dependent variable changes with a discrete change from one category to another in nicotine levels, adjustable voltage, flavoring, or device type, holding other variables constant. We report AMEs of e-cigarette characteristics in the main text, AMEs for all independent variables in the Supplements, and, adjusted odds ratios (AORs) in the Supplements for completeness.

Sub-analyses. We conducted two sub-analyses: (I) adding an interaction between e-liquid nicotine concentration and adjustable voltage to examine if these two characteristics reinforce one another in relation to cigarette and e-cigarette use, and (II) adding the interaction terms between e-cigarette flavors and menthol cigarette smoking to determine if the association

between the e-cigarette flavors and cigarette and e-cigarette use differs between menthol and non-menthol smokers.

Sensitivity analyses. We conducted five sensitivity analyses: (1) restricting the sample to baseline daily smoking dual users; (2) restricting to baseline dual users aged ≥ 35 ; (3) restricting to dual users who plan to quit cigarette smoking for good; (4) using more granular e-cigarette flavoring categories—tobacco only, menthol/mint only, fruit only, candy/dessert/other sweet only, other flavors only (excluding the preceding categories), and combination flavors (any mix of the above); and (5) examining a binary outcome: stopped smoking (regardless of vaping status) versus continued smoking.

To assess selection bias, we compared the 1,048 included dual users with the 882 excluded dual users using a multivariable logistic regression model, with exclusion status as the outcome and nicotine concentration, sex, age, and income as predictors (other variables omitted due to missing data).

We used SAS version 9.4 and Stata SE 14.2 to conduct the analyses. We applied PATH longitudinal weights and replicate weights.³¹ We used the balanced repeated replication with Fay's adjustment (0.3) to calculate 95% confidence intervals (CIs) and P values, with significance set at $P < .05$ (two-tailed).

Results

Among 1,048 baseline dual users, 13.7% used nicotine-free e-cigarettes, 37.5% and 23.6% used e-cigarettes with 1-12 mg/ml and ≥ 13 mg/ml nicotine concentrations; 43.5% used adjustable voltage e-cigarettes; 22.9% used tobacco flavor only, 13.8% used menthol/mint flavor only, and 51.9% used other flavors only; 53.7% used tank; 10.3% used disposable, and 13.3% used cartridge devices (Table 1).

At follow-up three years later, 7.5% had stopped smoking only, 38.4% had stopped vaping only, 7.8% had stopped both, and 46.2% had continued smoking and vaping (Table 1).

Multinomial logistic regression (Table 2) AME results indicated that (1) using ≥ 13 mg/ml nicotine level decreased the probability of stopping vaping only by 0.16 (95% CI: -0.29, -0.04) and increased the probability of continuing both by 0.18 (95% CI: 0.04, 0.32); (2) using e-cigarettes with adjustable voltage (vs. those without), increased the probability of stopping both smoking and vaping by 0.07 (95% CI: 0.02, 0.13) ; (3) using menthol/mint-flavor only decreased the probability of stopping vaping only by 0.14 (95% CI: -0.27, -0.01), while using other flavors only decreased the probability of stopping vaping only by 0.13 (95% CI: -0.25, -0.01); (4) using a combination of flavors (vs. tobacco flavor only) decreased the probability of stopping both by 0.06 (95% CI: -0.11, -0.02).

Sub-analysis I (Table S1_4) found no significant interactions between nicotine levels and adjustable voltage, indicating neither moderated the other's association with cessation. Table 3 presents AMEs for each characteristic for sub-analysis I. The results were consistent with the main analyses, with only minor changes in magnitude.

Sub-analysis II (Table S1_5) showed no significant differences in outcomes by menthol vs. non-menthol cigarette smokers using menthol/mint only or other-flavor only (vs. tobacco-flavor only) e-cigarettes. A small positive difference in stopping both smoking and vaping was observed with the use of combination flavors. Table 4 presents AMEs for each characteristic for sub-analysis II. The results were largely consistent with the main analyses, with only a small positive association between combination flavors and stopping both.

The first sensitivity analysis for daily smoking dual users (n=710) produced results (Table S1_7) consistent with the main findings. Using adjustable voltage (vs. without) increased the probability of stopping both by 0.09 (95% CI: 0.01,0.17), while any combination of flavors (vs. tobacco flavor only) decreased the probability of stopping both by 0.05 (95% CI: -0.11,0.00). However, the sample distribution indicated small sample sizes (< 10 cases) for certain cells, limiting the generalizability of these estimates (Table S1_6).

The second sensitivity analysis for dual users aged ≥ 35 years (n=439) showed that using a disposable e-cigarette device (vs. cartridge) decreased the probability of stopping vaping only (Table S1_9), which was not significant in the main analyses). The AMEs of other e-cigarette characteristics became non-significant. The sample distribution showed that many cells had <10 cases, suggesting limited robustness (Table S1_8).

The third sensitivity analysis for dual users who planned to quit smoking for good (n=861) produced the same significant results as the main analyses, with minor variations in magnitude (Table S1_10).

The fourth sensitivity analysis using more granular e-cigarette flavoring categories indicated that nicotine levels ≥ 13 mg/ml (vs. 0 mg/ml) decreased the probability of stopping vaping only and increased the probability of continuing both smoking and vaping. Using menthol/mint flavor only, candy/other sweet flavor only, and a combination of flavors (vs. tobacco-flavor only) e-cigarettes decreased the probability of stopping vaping only. No significant results were found for e-cigarette device type (Table S1_11).

The fifth sensitivity analysis using a binary variable outcome — stopped vs. continued smoking — showed no significant associations (Table S1_12).

The results from the multivariable logistic regression analysis to compared the included vs. excluded dual users suggested no selection bias (Table S1_13).

Discussion

This study examined how four baseline e-cigarette characteristics—e-liquid nicotine concentration levels, adjustable voltage, e-cigarette flavoring, and device type— relate to cigarette and e-cigarette use three years later among baseline dual users. We found no significant association between e-cigarette characteristics and the probability of stopping smoking only. Higher nicotine levels (≥ 13 vs. 0 mg/ml) and exclusive use of menthol/mint or other flavored (vs. tobacco-flavored) e-cigarettes were associated with a reduced probability of stopping vaping only. Using e-cigarettes with a combination of flavors (vs. tobacco only) reduced the probability of stopping both. Using e-cigarettes with adjustable voltage (vs. without) increased the probability of stopping both smoking and vaping. No significant association was found between e-cigarette device type and the outcomes. The results of sensitivity analyses indicate the robustness of our findings.

Our finding of no association between e-liquid nicotine concentration and stopping smoking only or stopping both three years later among dual users differs from a meta-analysis of RCTs of supervised e-cigarette use, which suggested that non-zero nicotine e-cigarettes aid smoking cessation.^{3,6} RCTs have specific recruitment requirements and often involve giving participants free e-cigarettes and providing smoking cessation counseling. Therefore, RCTs differ fundamentally from the studies examining the general population's real-world use, which include diverse products, use patterns, and motivations for using e-cigarettes.⁴ Our study also had a longer follow-up (3 years vs. weeks or months in RTCs). Our results align with a cross-sectional study in 2021 showing no significant association between nicotine levels and quitting

smoking among dual users attempting to quit smoking.¹⁵ We also found that using e-cigarettes with ≥ 13 mg/ml (vs. 0 mg/ml) nicotine decreased the probability of stopping vaping only and increased the probability of continuing both, suggesting that capping nicotine concentration in e-cigarettes might reduce long-term vaping.

Using e-cigarettes with adjustable voltage was associated with increased probability of stopping both smoking and vaping. By allowing users to titrate nicotine intake more precisely, adjustable voltage may help them better manage withdrawal symptoms and cravings, which in turn could facilitate complete cessation of both products.^{11,14} This association may also indicate that users who select adjustable-voltage devices are more experienced or intentional in using e-cigarettes specifically for quitting, reflecting a subgroup with greater motivation to quit. Our finding contributes to the literature on device features, as most prior studies have focused on device type rather than device functionality.^{15,16,18} Our sub-analyses found the interaction between nicotine concentration and adjustable voltage was not significant, suggesting that the association of adjustable voltage with cessation might not be explained by the nicotine strength, but may reflect the functionality of adjustable voltage itself. The results remained robust when restricting the study sample to daily smokers. Given the relatively wide confidence intervals and the fact that PATH assessed adjustable voltage only at Wave 3, we interpret this result cautiously. Future research should examine how users engage with adjustable voltage settings in practice and whether this feature directly promotes cessation or primarily serves as a marker of other cessation-related behaviors.

Our finding of no significant association between e-cigarette flavorings and the probability of stopping smoking only aligns with earlier studies.^{15,19,21} We observed that using e-cigarettes with a combination of flavors (vs. tobacco flavor only) decreased the probabilities of

stopping both. Exclusive use of menthol/mint or other flavored (vs. tobacco-flavored) e-cigarettes did not have a significant difference in the probability of stopping both smoking and vaping. These results are broadly consistent with Harlow et al.,¹⁸ who found that dual users who vaped mint/menthol only and other flavor only had lower odds of stopping both than those who vaped tobacco-flavored e-cigarettes. Neither Harlow et al.¹⁸ nor our study showed that flavors increased the probability of stopping smoking, vaping, or both among cigarette smokers. Findings from our sensitivity analysis with more granular flavor categories further support these conclusions: no significant association between e-cigarette flavorings and the probability of stopping smoking only; exclusive use of menthol/mint flavors, exclusive use of candy/sweet flavors, and use of a combination of flavors reduced the probability of stopping vaping only.

Moreover, we found no significant moderating effects of menthol cigarette smoking, except for the minimal effects on the association between the use of combination flavors and stopping both smoking and vaping. It suggests that the associations between e-cigarette flavorings and stopping smoking or vaping do not differ by menthol cigarette smoking. These findings imply that banning flavored e-cigarettes, including menthol-flavored e-cigarettes, might not affect adult smoking cessation, even in areas where menthol cigarette sales are already prohibited.

There were no significant associations between device types and the behavior of stopping smoking or vaping, which diverges from prior research.^{15,16,18} This difference may stem from variations in study designs, as previous studies used cross-sectional analyses,¹⁵ or defining stopping smoking or vaping as becoming former users two years later without specifying the duration of stopping behaviors,¹⁸ and still others categorized device types differently or did not distinguish between stopping smoking only, stopping vaping only, and stopping both.¹⁶

We treated stopping smoking only (while continuing e-cigarette use) and stopping both as distinct outcomes because completely stopping both tobacco products is the most favorable from a public health perspective, as vaping and smoking both carries health risks.³² While many smokers initiate e-cigarette use to quit smoking, a significant proportion become long-term dual users, maintaining nicotine dependence and potentially delaying or preventing full cessation.³³ Moreover, dual use is associated with greater health risks than using either product alone.³²

Although our sample size limited the ability to stratify across four combinations of smoking and vaping frequency (daily smoking and daily vaping, non-daily smoking and non-daily vaping, daily smoking and non-daily vaping, and non-daily smoking and daily vaping), we controlled for daily vaping and heavy smoking in our model. We found that daily vaping (vs. non-daily vaping) was more likely to be associated with stopping smoking only, consistent with prior evidence.^{4,9} And our sensitivity analysis restricted to daily smoking dual users produced results largely consistent with the main findings. We also examined adults aged ≥ 35 years, who are more likely to smoke daily and heavily than younger adults.³⁴ In this subgroup, most associations were attenuated and became non-significant, likely reflecting smaller sample sizes and reduced statistical power, but the general pattern of results was similar to the main analysis. Taken together, these adjustments and checks suggest that residual confounding by smoking frequency is unlikely to explain the observed associations.

Our sensitivity analysis which restricted to dual users who reported using e-cigarettes to quit smoking for good showed the same results as the main analyses in terms of the significance level. This finding suggests that even among individuals most motivated to quit, nicotine concentration, voltage settings, flavors, and device type did not translate into higher success in stopping smoking. Our study has several limitations. First, residual confounding is always

possible in an observational study despite controlling for potential factors. Second, e-cigarette characteristics were measured at baseline, with the outcome assessed three years later, and dual users might have changed the characteristics of e-cigarettes they used during this time. Third, categorizing characteristics into multiple groups reduced sample sizes in some cells, limiting power and precision. Fourth, dual users varied in smoking frequency and quit intentions. We did not further subcategorize due to small cell counts, but we controlled for these factors and confirmed robust results in sensitivity analyses. Fifth, some e-cigarette characteristics had small sample sizes (<30), but supplementary analyses with combined categories showed consistent null results, suggesting low power was not the main explanation. Sixth, our measures of e-cigarette characteristics were based on data from Wave 3 and may not capture the newer products introduced in subsequent years. Last, some variability in reporting is also possible, especially for users with less consistent e-cigarette use patterns.

Conclusion

While using e-cigarettes with adjustable (vs. non-adjustable) voltage increases the probability of stopping both vaping and smoking, e-liquid nicotine levels (vs. zero nicotine) and e-cigarette flavors, such as menthol-flavored e-cigarettes (vs. tobacco flavor), used by dual users decreases the probability of stopping vaping only. Using a combination of flavors reduces the probability of stopping both, and non-zero nicotine levels increases the probability of continuing both products. Additionally, using different e-cigarette devices does not make a difference in the probability of smoking or vaping status three years later. These findings could inform regulatory discussions about e-cigarettes, including setting nicotine limits in e-liquids and eliminating flavored e-cigarettes, such as menthol/mint.

Acknowledgments

We appreciate helpful comments from the UCSF Tobacco Center of Regulatory Science members.

References

1. Babb S, Malarcher A, Schauer G, Asman K, Jamal A. Quitting Smoking Among Adults - United States, 2000-2015. *MMWR Morb Mortal Wkly Rep.* 2017;65(52):1457-1464.
2. Caraballo RS, Shafer PR, Patel D, Davis KC, McAfee TA. Quit Methods Used by US Adult Cigarette Smokers, 2014-2016. *Prev Chronic Dis.* 2017;14:E32.
3. Hartmann-Boyce J, McRobbie H, Butler AR, et al. Electronic cigarettes for smoking cessation. *Cochrane Database of Systematic Reviews.* 2021(9).
4. Wang RJ, Bhadriraju S, Glantz SA. E-Cigarette Use and Adult Cigarette Smoking Cessation: A Meta-Analysis. *Am J Public Health.* 2021;111(2):230-246.
5. Hedman L, Galanti MR, Ryk L, Gilljam H, Adermark L. Electronic cigarette use and smoking cessation in cohort studies and randomized trials: A systematic review and meta-analysis. *Tob Prev Cessat.* 2021;7:62.
6. Lindson N, Butler AR, McRobbie H, et al. Electronic cigarettes for smoking cessation. *Cochrane Database of Systematic Reviews.* 2025(1).
7. Kaplan B, Galiatsatos P, Breland A, Eissenberg T, Cohen JE. Effectiveness of ENDS, NRT and medication for smoking cessation among cigarette-only users: a longitudinal analysis of PATH Study wave 3 (2015-2016) and 4 (2016-2017), adult data. *Tob Control.* 2023;32(3):302-307.
8. Krishnan N, Berg CJ, Elmi AF, Klemperer EM, Sherman SE, Abroms LC. Trajectories of ENDS and cigarette use among dual users: analysis of waves 1 to 5 of the PATH Study. *Tobacco Control.* 2024;33(e1):e62.
9. Pierce JP, Benmarhnia T, Chen R, et al. Role of e-cigarettes and pharmacotherapy during attempts to quit cigarette smoking: The PATH Study 2013-16. *PloS one.* 2020;15(9):e0237938.

10. Audrain-McGovern J, Strasser AA, Wileyto EP. The impact of flavoring on the rewarding and reinforcing value of e-cigarettes with nicotine among young adult smokers. *Drug and alcohol dependence*. 2016;166:263-267.
11. Blank MD, Pearson J, Cobb CO, et al. What factors reliably predict electronic cigarette nicotine delivery? *Tobacco Control*. 2020;29(6):644-651.
12. Steeger CM, Harlow AF, Barrington-Trimis JL, Simon P, Hill KG, Leventhal AM. Longitudinal associations between flavored tobacco use and tobacco product cessation in a national sample of adults. *Prev Med*. 2022;161:107143.
13. Dawkins LE, Kimber CF, Doig M, Feyerabend C, Corcoran O. Self-titration by experienced e-cigarette users: blood nicotine delivery and subjective effects. *Psychopharmacology (Berl)*. 2016;233(15-16):2933-2941.
14. DeVito EE, Krishnan-Sarin S. E-cigarettes: Impact of E-Liquid Components and Device Characteristics on Nicotine Exposure. *Current neuropharmacology*. 2018;16(4):438-459.
15. Bold K, O'Malley S, Krishnan-Sarin S, Morean M. E-cigarette Use Patterns, Flavors, and Device Characteristics Associated With Quitting Smoking Among a U.S. sample of Adults Using E-cigarettes in a Smoking Cessation Attempt. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco*. 2023;25(5):954-961.
16. Glasser AM, Vojjala M, Cantrell J, et al. Patterns of E-cigarette Use and Subsequent Cigarette Smoking Cessation Over 2 Years (2013/2014-2015/2016) in the Population Assessment of Tobacco and Health Study. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco*. 2021;23(4):669-677.

17. Friedman AS, Xu S. Associations of Flavored e-Cigarette Uptake With Subsequent Smoking Initiation and Cessation. *JAMA network open*. 2020;3(6):e203826.
18. Harlow AF, Fetterman JL, Ross CS, et al. Association of device type, flavours and vaping behaviour with tobacco product transitions among adult electronic cigarette users in the USA. *Tob Control*. 2022;31(e1):e10-e17.
19. Lindson N, Butler AR, Liber A, et al. An exploration of flavours in studies of e-cigarettes for smoking cessation: secondary analyses of a systematic review with meta-analyses. *Addiction*. 2023;118(4):634-645.
20. Meernik C, Baker HM, Kowitt SD, Ranney LM, Goldstein AO. Impact of non-menthol flavours in e-cigarettes on perceptions and use: an updated systematic review. *BMJ open*. 2019;9(10):e031598.
21. Liber AC, Knoll M, Cadham CJ, et al. The role of flavored electronic nicotine delivery systems in smoking cessation: A systematic review. *Drug and alcohol dependence reports*. 2023;7:100143.
22. Piper ME, Bullen C, Krishnan-Sarin S, et al. Defining and Measuring Abstinence in Clinical Trials of Smoking Cessation Interventions: An Updated Review. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco*. 2020;22(7):1098-1106.
23. Webb Hooper M, Smiley SL. Comparison of E-Cigarette Use among Menthol and Non-Menthol Smokers: Findings from a Community Based Sample. *Ethn Dis*. 2018;28(3):153-160.

24. Kotlyar M, Shanley R, Dufresne SR, Corcoran GA, Hatsukami DK. Effect of restricting menthol flavored cigarettes or E-cigarettes on smoking behavior in menthol smokers. *Prev Med.* 2022;165(Pt B):107243.
25. Cook S, Hirschtick JL, Patel A, et al. A longitudinal study of menthol cigarette use and smoking cessation among adult smokers in the US: Assessing the roles of racial disparities and E-cigarette use. *Preventive Medicine.* 2022;154:106882.
26. Zhuang YL, Cummins SE, Sun JY, Zhu SH. Long-term e-cigarette use and smoking cessation: a longitudinal study with US population. *Tob Control.* 2016;25(Suppl 1):i90-i95.
27. Chen R, Pierce JP, Leas EC, et al. E-Cigarette Use to Aid Long-Term Smoking Cessation in the US: Prospective Evidence from the PATH Cohort Study. *American Journal of Epidemiology.* 2020.
28. Cameron L, & Williams, J. Cannabis, Alcohol, and Cigarettes: Substitutes or Complements? *Economic Record.* 2002;77(236):19-34.
29. McClure EA, Baker NL, Hood CO, et al. Cannabis and Alcohol Co-Use in a Smoking Cessation Pharmacotherapy Trial for Adolescents and Emerging Adults. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco.* 2020;22(8):1374-1382.
30. West JC, Peasley-Miklus C, Graham AL, et al. Impact of alcohol and drug use on smoking and cessation in socioeconomically disadvantaged young adults. *Addictive Behaviors.* 2020;110:106486.
31. United States Department of Health and Human Services. National Institutes of Health. National Institute on Drug Abuse aUSDoHaHSFaDA.

32. Glantz SA, Nguyen N, Oliveira da Silva AL. Population-Based Disease Odds for E-Cigarettes and Dual Use versus Cigarettes. *NEJM evidence*. 2024;3(3):EVIDoa2300229.
33. Hamoud J, Hanewinkel R, Andreas S, et al. A systematic review investigating the impact of dual use of e-cigarettes and conventional cigarettes on smoking cessation. *ERJ open research*. 2025;11(3).
34. Kasza KA, Ambrose BK, Conway KP, et al. Tobacco-Product Use by Adults and Youths in the United States in 2013 and 2014. *The New England journal of medicine*. 2017;376(4):342-353.

Supporting information

S1 File (PDF)

Table 1: Study sample by the outcome and independent variables at PATH Waves 3&5, n=1,048

Independent variables at baseline (Wave 3)		Sample distribution by independent variables		The outcome at 3-year follow-up (Wave 5)							
				Stopping cigarette smoking only		Stopping vaping only		Stopping both smoking and vaping		Continuing smoking and vaping	
		n	Column w%	n	row w%	n	row w%	n	row w%	n	row w%
	Total	1048	100	85	7.5	402	38.4	80	7.8	481	46.2
Nicotine concentration level	0 mg/ml	159	13.7	7	3.9	72	48.8	12	9.2	68	38.2
	1-12 mg/ml	393	37.5	42	9.3	142	35.4	27	8.1	182	47.1
	≥13 mg/ml	236	23.6	16	6.3	84	33.5	16	6.0	120	54.2
	Unknown	260	25.2	20	8.0	104	41.8	25	8.4	111	41.8
Adjustable voltage	No	589	56.5	39	6.9	245	42.2	35	5.6	270	45.3
	Yes	459	43.5	46	8.3	157	33.5	45	10.7	211	47.4
E-cigarette flavor	Tobacco flavor only	215	22.9	11	4.2	106	52.2	12	5.3	86	38.2
	Menthol/mint flavor only	145	13.8	9	6.3	55	38.1	15	10.2	66	45.3
	Other flavors only	563	51.9	54	8.5	193	32.8	52	9.9	264	48.7
	A combination of flavors	125	11.4	11	11.1	48	36.6	1	0.3	65	52.0
E-cigarette device type	Tank/mod	555	53.7	55	8.8	193	33.5	45	8.9	262	48.8
	Disposable	114	10.3	6	5.4	46	43.1	11	9.0	51	42.5
	Other	245	22.7	19	7.9	98	41.9	16	6.2	112	44.0
	Cartridge	134	13.3	5	3.3	65	48.7	8	5.3	56	42.7

Note: W% indicates weighted %; the full results are in the S1 file Table S1_2.

Table 2: Average marginal effects (AME) of the main analyses among dual users at baseline Wave 3, n=1,048

		Stopping cigarette smoking only		Stopping vaping only		Stopping both vaping and smoking		Continuing both	
		AME (95% CI)	P> t	AME (95% CI)	P> t	AME (95% CI)	P> t	AME (95% CI)	P> t
Nicotine concentration level	0 mg/ml	Reference		Reference					
	1-12 mg/ml	0.04 (-0.01, 0.09)	0.131	-0.12 (-0.23, 0.00)	0.054	-0.03 (-0.10, 0.04)	0.453	0.11(-0.02,0.23)	0.107
	≥13 mg/ml	0.02 (-0.03, 0.07)	0.381	-0.16 (-0.29, -0.04)	0.013	-0.04 (-0.11, 0.03)	0.302	0.18 (0.04,0.32)	0.012
	Unknown	0.07 (0.00, 0.14)	0.049	-0.14 (-0.26, -0.01)	0.030	0.02 (-0.05, 0.10)	0.565	0.05 (-0.08,0.18)	0.442
Adjustable voltage	No								
	Yes	-0.02 (-0.07, 0.03)	0.365	-0.01 (-0.09, 0.08)	0.903	0.07 (0.02, 0.13)	0.013	-0.05 (-0.14,0.05)	0.320
E-cigarette flavor	Tobacco flavor only								
	Menthol/mint flavor only	0.03 (-0.05, 0.11)	0.506	-0.14 (-0.27, -0.01)	0.035	0.05 (-0.04, 0.13)	0.267	0.06 (-0.07,0.20)	0.356
	Other flavors only	0.02 (-0.04, 0.09)	0.502	-0.13 (-0.25, -0.01)	0.029	0.03 (-0.03, 0.08)	0.371	0.09 (-0.03,0.20)	0.144
	A combination of flavors	0.05 (-0.03, 0.14)	0.209	-0.10(-0.24, -0.05)	0.181	-0.06 (-0.11, -0.02)	0.009	0.11 (-0.04,0.26)	0.147
E-cigarette device types	Tank/mod	0.04 (-0.01, 0.10)	0.088	-0.09 (-0.22, 0.05)	0.200	0.01 (-0.06, 0.08)	0.711	0.03 (-0.11,0.17)	0.694
	Disposable	0.02 (-0.05, 0.10)	0.567	-0.1 (-0.23, 0.03)	0.115	0.06 (-0.03, 0.016)	0.175	0.02 (-0.13,0.16)	0.826
	Other	0.05 (0.00, 0.10)	0.072	-0.05 (-0.17, 0.07)	0.403	0.01 (-0.07, 0.08)	0.868	-0.01 (-0.12,0.11)	0.916
	Cartridge-based device								

Note: Bold values indicate statistical significance at two-tailed $P < .05$. The regression controlled all other covariates: menthol cigarettes, heavy smoking, daily e-cigarette use, past 12-month quit attempt, e-cigarette use to help quit smoking, had the first cigarette within 30 minutes after waking up, other tobacco use, past 30-day marijuana use, past 30-day alcohol use, and socio-demographic characteristics. The AME results for all covariates are in Table S1_3.

Table 3: Average marginal effects of sub-analysis I (interaction between nicotine concentration levels and adjustable voltage) among dual users at baseline, n=1048

		Stopping cigarette smoking only		Stopping vaping only		Stopping both vaping and smoking		Continuing both	
		AME (95% CI)	P> t	AME (95% CI)	P> t	AME (95% CI)	P> t	AME (95% CI)	P> t
Nicotine concentration level	0 mg/ml								
	1-12 mg/ml	0.03 (-0.04, 0.09)	0.429	-0.09 (-0.21, 0.02)	0.102	-0.02 (-0.10, 0.05)	0.537	0.09 (-0.04,0.22)	0.163
	≥13 mg/ml	0.01 (-0.06, 0.08)	0.817	-0.13 (-0.26, 0.00)	0.048	-0.04 (-0.12, 0.04)	0.299	0.16 (0.02,0.31)	0.030
	Unknown	0.06 (-0.04, 0.16)	0.210	-0.10 (-0.24, 0.03)	0.119	0.02 (-0.07, 0.11)	0.709	0.03 (-0.11,0.16)	0.705
Adjustable voltage	No								
	Yes	-0.02 (-0.07, 0.04)	0.541	-0.01 (-0.10, 0.08)	0.789	0.07 (0.01, 0.13)	0.015	-0.05 (-0.15,0.06)	0.372
E-cigarette flavor	Tobacco flavor only								
	Menthol/mint flavor only	0.03 (-0.06, 0.11)	0.522	-0.14 (-0.27, -0.01)	0.038	0.04 (-0.04, 0.12)	0.302	0.07 (-0.06,0.21)	0.300
	Other flavors only	0.02 (-0.05, 0.09)	0.537	-0.13 (-0.26, -0.01)	0.028	0.02 (-0.03, 0.08)	0.415	0.09 (-0.02,0.20)	0.117
	A combination of flavors	0.05 (-0.03, 0.14)	0.227	-0.10 (-0.25, 0.04)	0.166	-0.06 (-0.12, -0.01)	0.012	0.11 (-0.03,0.26)	0.125
E-cigarette device types	Tank/mod	0.04 (-0.01, 0.09)	0.128	-0.09 (-0.22, 0.05)	0.211	0.01 (-0.06, 0.09)	0.697	0.03 (-0.12,0.18)	0.675
	Disposable	0.03 (-0.06, 0.11)	0.524	-0.12 (-0.25, 0.01)	0.072	0.07 (-0.03, 0.16)	0.155	0.03 (-0.13,0.18)	0.730
	Other	0.05 (-0.01, 0.11)	0.079	-0.05 (-0.17, 0.06)	0.367	0.01 (-0.07, 0.08)	0.850	-0.00(-0.12,0.11)	0.952
	Cartridge								

Note: Bold values indicate statistical significance at two-tailed P <.05. The AMEs for e-cigarette nicotine concentration levels and adjustable voltage reflect the combined effects of the main and interaction terms. The regression controlled the interaction between nicotine concentration levels and adjustable voltage and all other covariates: menthol cigarettes, heavy smoking, daily e-cigarette use, past 12-month quit attempt, e-cigarette use to help quit smoking, had the first cigarette within 30 minutes after waking up, other tobacco use, past 30-day marijuana use, past 30-day alcohol use, and socio-demographic characteristics. The AME results for all covariables are in Table S1_4.

Table 4: Average marginal effects (AME) of sub-analysis II (interaction between e-cigarette flavor and menthol cigarettes) among dual users at Wave 3, n=1,048

		Stopping smoking only		Stopping vaping only		Stopping both smoking and vaping		Continuing both	
		AME (95% CI)	P> t	AME (95% CI)	P> t	AME (95% CI)	P> t	AME (95% CI)	P> t
Nicotine concentration level	0 mg/ml								
	1-12 mg/ml	0.04 (-0.01,0.09)	0.142	-0.12 (-0.24, 0.00)	0.047	-0.03 (-0.10, 0.04)	0.431	0.11 (-0.02,0.24)	0.089
	≥13 mg/ml	0.02 (-0.03,0.07)	0.408	-0.17 (-0.30, -0.04)	0.012	-0.04 (-0.11, 0.03)	0.302	0.18 (0.04,0.32)	0.01
	Unknown	0.07 (0.00,0.14)	0.047	-0.14 (-0.27, -0.02)	0.028	0.02 (-0.05,0.09)	0.593	0.05(-0.07,0.18)	0.412
Adjustable voltage	No								
	Yes	-0.02 (-0.07, 0.03)	0.386	-0.01 (-0.09, 0.08)	0.897	0.07 (0.02, 0.13)	0.013	-0.05 (-0.15,0.05)	0.316
E-cigarette flavor	Tobacco flavor only								
	Menthol/mint flavor	0.09 (-0.11, 0.29)	0.384	-0.12 (-0.40, 0.16)	0.39	0.13 (-0.16, 0.43)	0.373	-0.1(-0.34,0.14)	0.4
	Other flavors only	0.04 (-0.04, 0.11)	0.363	-0.13 (-0.29, 0.04)	0.13	0.04 (-0.01, 0.10)	0.107	0.05 (-0.11,0.21)	0.558
	A combination of flavors	0.07 (-0.05, 0.18)	0.267	-0.08 (-0.28, 0.11)	0.39	-0.05 (-0.09, 0.00)	0.031	0.06 (-0.14,0.27)	0.535
E-cigarette device types	Tank/mod	0.05 (-0.01, 0.10)	0.084	-0.09 (-0.22, 0.05)	0.199	0.01 (-0.06, 0.08)	0.721	0.03 (-0.11,0.17)	0.685
	Disposable	0.02 (-0.05, 0.10)	0.544	-0.10 (-0.23, 0.03)	0.115	0.06 (-0.03, 0.15)	0.165	0.02 (-0.14,0.17)	0.832
	Other	0.05 (0.00, 0.10)	0.057	-0.05 (-0.16, 0.07)	0.445	0.01 (-0.07, 0.08)	0.85	-0.01 (-0.13,0.10)	0.83
	Cartridge								

Note: Bold values indicate statistical significance at two-tailed $P < .05$. The AMEs for e-cigarette flavor reflect the combined effects of the main and interaction terms. The regression controlled the interaction between e-cigarette flavor and menthol cigarettes and all other covariates: menthol cigarettes, heavy smoking, daily e-cigarette use, past 12-month quit attempt, e-cigarette use to help quit smoking, had the first cigarette within 30 minutes after waking up, other tobacco use, past 30-day marijuana use, past 30-day alcohol use, and socio-demographic characteristics. The AME results for all covariables are in Table S1_5.