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Changes in E-cigarette Use and Subsequent Cigarette Smoking Cessation in the United States: Evidence from a Prospective PATH Study, 2013–2018

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Abstract

Aims—To examine the relationship between changes in e-cigarette use and subsequent cigarette smoking cessation.

Methods—Using data from the Population Assessment of Tobacco and Health Study (Wave 1Wave 4), we analyzed a study cohort of 3,014 current adult cigarette smokers at Wave 1 who tried to quit during the past 12 months. We categorized changes in e-cigarette use from Wave 1 to Wave 2 as: daily initiation, nondaily initiation, increase to daily use, increase to nondaily use, stable daily use, stable nondaily use, decrease from daily use, quit nondaily use, and non-use. We estimated multivariable logistic regressions on short-term (≥1 month and <12 months) cigarette smoking cessation at Wave 3 and long-term (≥12 months) cigarette smoking cessation at Wave 4. We conducted sensitivity analyses using alternative study cohorts.

Results—Among the study cohort, 2.4% initiated daily, 7.5% initiated nondaily, 1.0% increased to daily, 1.4% increased to nondaily, 1.5% maintained daily, 3.0% maintained nondaily, 2.4% decreased from daily, and 3.8% quit nondaily e-cigarette use between Waves 1 and 2; 7.9% and 6.9% reported short-term and long-term cigarette smoking cessation. 15.1% of short-term and 16.3% of long-term cigarette quitters used e-cigarettes. Compared to non-users, smokers who initiated daily, increased to daily, or quit nondaily e-cigarette use between Waves 1 and 2 had higher odds of short-term cigarette smoking cessation at Wave 3. These results are robust to different study cohort specifications.

Conclusion—The findings suggest a complex relationship between changes in e-cigarette use and subsequent cigarette smoking cessation.

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CONTRIBUTORSHIP STATEMENT

YW planned the study. YW, HYS, and WM designed the methodology. YW conducted the literature review and statistical analysis. YW wrote the original draft of the manuscript. YW, HYS, and WM reviewed, edited, and revised the manuscript.

ETHICS APPROVAL STATEMENT

This study uses publicly available data and does not quantify a human subject's research.

Declaration of Interests: None declared.

INTRODUCTION

Given the growing popularity of electronic cigarettes (e-cigarettes), it is essential to understand their public health impact, especially their effect on cigarette abstinence. Many studies—including randomized controlled trials (RTCs),[1–5] cross-sectional studies,[6–8] and longitudinal cohort studies[9–22]—have examined the role of e-cigarette use in cigarette smoking cessation.[23–27] The results of these studies have been mixed. Some studies found a positive association between e-cigarette use and cigarette smoking cessation or reduction,[1–4,6,9–14,20] while others found either a non-significant or negative association.[5,7,8,15–19,22,28] The inconsistent results could be partially caused by different study designs.[26,27,29,30] RCTs are usually the gold standard for assessing the effectiveness of an intervention. However, RCTs may be infeasible for ethical reasons, and their participant samples and lab settings may make it challenging to generalize study findings to the general population.[24] Cross-sectional studies cannot be used to ascertain causality. On the other hand, prospective observational (cohort) studies are the best option for deriving a realistic and potentially causal relationship between e-cigarette use and cigarette smoking cessation.[24] However, if self-selection and confounding issues are not addressed correctly, prospective cohort studies may also suffer from estimation bias, yielding inconsistent results.

The 2018 report of the US National Academies of Sciences, Engineering, and Medicine (NASEM)[24] recommended three criteria for an optimal prospective cohort study design to assess the efficacy of e-cigarettes for cigarette smoking cessation: 1) identify and follow a large cohort of smokers who want to quit or are making a quit attempt, 2) assess e-cigarette exposure in detail before the cigarette smoking cessation is assessed, and 3) adjust for multiple potential confounders associated with e-cigarette use and with cigarette smoking cessation. Many prospective cohort studies examining the role of e-cigarette use in cigarette smoking cessation do not meet these criteria.[31,32] Some failed to restrict the study cohort to smokers trying to quit, hence overestimating the benefit of e-cigarette use on cigarette smoking cessation.[9–20] some measured e-cigarette exposure and cigarette smoking cessation in the same period, thus introducing the possibility of reverse causality;[14,19,20] and others failed to control for potential confounders.[12,18] Two studies met the NASEM criteria. Using data from the PATH Study, Chen and colleagues identified a study cohort of current smokers at Wave 2 reporting a past-year quit attempt at Wave 3, and compared cigarette abstinence of ≥12 months at Wave 4 between those who used and did not use e-cigarettes to quit.[21] After using propensity-score matching to adjust for non-comparability between users and non-users, they found that e-cigarette users did not have higher rates of long-term cigarette abstinence. Similarly, using the PATH study data, Pierce and colleagues identified a study cohort of daily smokers at Wave 1 reporting a past-year quit attempt at Wave 2 to compare cigarette abstinence at Wave 3 between e-cigarette users and non-users. After using propensity-score methods, the results showed that these two groups were not different in cigarette abstinence of either ≥12 months or ≥30 days at Wave 3.[22]

However, these two studies measured e-cigarette exposure based on e-cigarette use in the last quit attempt at a one-time point without considering changes in e-cigarette use over time. Villanti and colleagues proposed a hierarchy of methodological criteria when determining whether a study provides sufficient evidence to evaluate the role of e-cigarettes

in cigarette abstinence.[25] One of the criteria is to assess the duration, frequency, and dose of e-cigarette exposure for a sufficient time. E-cigarette use patterns can be measured at a one-time point as ever use, current use, daily or nondaily use,[10–12,15–18] and two-time points as initiation,[13,14,19] increased use, or persistent use.[9,14,20] The literature has documented that individual users' e-cigarette use patterns are highly variable over time. Less than 30% of e-cigarette users reported the same e-cigarette use frequency at follow-up.[33] Therefore, assessing e-cigarette use at two-time points can capture more information and improve the accuracy of e-cigarette exposure measurement.

This study used a prospective cohort study design to examine the relationship between changes in e-cigarette use and subsequent cigarette smoking cessation. We followed the recommendation of NASEM by following a cohort of current smokers who tried to quit in the past 12 months at Wave 1, measuring the changes in e-cigarette use from Wave 1 to Wave 2, assessing cigarette smoking cessation at Waves 3 and 4, and adjusting for covariates identified by NASEM and the literature.

METHODS

Data

We analyzed data on adults from the PATH Study for Wave 1 (Sep 2013-Dec 2014), Wave 2 (Oct 2014-Oct 2015), Wave 3 (Oct 2015-Oct 2016), and Wave 4 (Dec 2016-Jan 2018). The PATH Study is a nationally representative, longitudinal cohort study of US adults aged 18+ and youth aged 12–17 conducted by the National Institutes of Health (NIH) and the Food, and Drug Administration's (FDA) Center for Tobacco Products (CTP). The weighted response rates for the Wave 1 adult cohort were 83.2% (Wave 2), 78.4% (Wave 3), and 73.5% (Wave 4). The PATH Study collects information on tobacco use patterns and tobacco-related health outcomes. Further details regarding the PATH Study design and methods are published elsewhere.[34]

Study cohort

We identified a cohort of 3,553 current adult cigarette smokers at Wave 1 "who want to quit or are making a quit attempt" (the first criteria recommended by NASEM), participated in 4 Waves of the survey, and answered "Yes, I have tried to quit completely" or "Yes, I have tried to quit by reducing or cutting back" to the question: "In the past 12 months, have you tried to quit using tobacco products (including cigarettes)?" Current smokers are those who have smoked 100 cigarettes and currently smoke every day or some days. After excluding 539 respondents with missing values for the dependent and independent variables, the final study sample included 3,014 smokers (see Figure 1).

Measures

Figure 2 depicts the study design, including dependent variables assessed at Waves 3 and 4, the key independent variable derived using Waves 1 and 2 data, and other independent variables assessed at Wave 1.

Dependent variables

Short-term cigarette smoking cessation at Wave 3—Short-term cigarette smoking cessation at Wave 3 was "yes" if respondents quit cigarette smoking for ≥ 1 and < 12 months at Wave 3.

Long-term cigarette smoking cessation at Wave 4—Long-term cigarette smoking cessation at Wave 4 was "yes" if respondents quit smoking for at least 12 months or reported being former smokers at Wave 3 and Wave 4. Former cigarette smokers are those who have smoked 100 cigarettes in their lifetime and currently do not smoke at all.

Key independent variable

Changs in e-cigarette use from Wave 1 to Wave 2—Changs in e-cigarette use from Wave 1 to Wave 2 is the key independent variable and was categorized as: 1) initiation to daily use (never users at Wave 1 who became daily users at Wave 2); 2) initiation to nondaily use (never users at Wave 1 who became nondaily users at Wave 2); 3) increase to daily use (former or nondaily users at Wave 1 who became daily users at Wave 2; 4) increase to nondaily use (former users at Wave 1 who became nondaily users at Wave 2); 5) stable daily use (daily users at both Waves); 6) stable nondaily use (nondaily users at both Waves); 7) decrease from daily use (daily users at Wave 1 who became nondaily or former users at Wave 2); 8) quit from nondaily use (nondaily users at Wave 1 who became former users at Wave 2; and 9) non-use (never or former users at Wave 1 and Wave 2; the reference group). Those who answered "No" to the question: "Have you ever used e-cigarettes fairly regularly?" are never e-cigarette users; those who answered "Yes" and now use them every day (daily users) or some days (nondaily users) are current e-cigarette users; and those who answered "Yes" but now do not use them at all are former e-cigarette users.

Other independent variables

Other independent variables were measured at Wave 1 and selected based on the criteria recommended by NASEM[24] and previous literature,[20,22,28] including socio-demographic characteristics, perceived harm of cigarettes, perceived relative harm of e-cigarettes, externalizing and internalizing mental health problems, other tobacco use, alcohol use, marijuana use, and nicotine dependence.

Socio-demographic characteristics—Socio-demographic characteristics included sex (male and female), age (18–34, 35–64, and 65+), education (< high school, high school graduates or GED, some college, and college degree or above), income (<100% of Federal Poverty Level (FPL), 100–199% FPL, ≥200% FPL, and unknown), race/ethnicity (Non-Hispanic White, Hispanic, Non-Hispanic Black, and Non-Hispanic Other), and region (Northeast, Midwest, South, and West). Income was assessed by calculating the ratio of annual family income to the federal poverty threshold,[35,36] with family size taken into account. We included missing family income as a separate "unknown" category in the analyses because income might not be missing at random.

Perceived harm of cigarettes—Perceived harm of cigarettes was a dichotomous variable categorized as "low harm perception" if the answer to the survey question: "How

harmful do you think cigarettes are to health?" was "not at all", "slightly" or "somewhat" harmful, and as "high harm perception" if the answer was "very" or "extremely" harmful.

Relative perceived harm of e-cigarettes—Relative perceived harm of e-cigarettes was defined based on the response to the question: "Is using e-cigarettes less harmful, about the same, or more harmful than smoking cigarettes?" It was constructed as a 5-point categorical variable as "less harmful", "about the same", "more harmful", "never heard of or seen e-cigarettes", and "don't know".

Externalizing mental health problems—Externalizing mental health problems were assessed by respondents' responses (yes/no) to seven questions about whether they experienced externalizing symptoms in the past 12 months. The number of affirmative answers to these questions was summed and coded as a 3-level severity indicator: low level (0–1 affirmative answers), moderate level (2–3 affirmative answers), and high level (≥4 affirmative answers).

Internalizing mental health problems—Internalizing mental health problems were assessed by respondents' responses (yes/no) to four questions about whether they experienced internalizing symptoms in the past 12 months. The number of affirmative answers to these questions was summed and coded as a 3-level severity indicator: low level (0–1 affirmative answers), moderate level (2–3 affirmative answers), and high level (4 affirmative answers).

Other tobacco use—Other tobacco use was "yes" if respondents were current users of any of the following products: traditional cigars, cigarillos, filtered cigars, pipes, hookah, snus, smokeless tobacco, and dissolvable tobacco; and "no" otherwise. Current users of a product are those who have ever used the product fairly regularly and currently use it some days or every day.

Past 30-day alcohol use—Past 30-day alcohol use was "yes" if respondents used alcohol in the past 30 days; and "no" otherwise.

Past 30-day marijuana use—Past 30-day marijuana use was "yes" if respondents used marijuana, hash, THC, or grass in the past 30 days; and "no" otherwise.

Nicotine dependence—Nicotine dependence was determined by the responses to 15 questions related to emotional and physical reactions to nicotine products ranging from 1= "Not true of me at all" to 5= "Extremely true of me". Following the approach by Chen and colleagues,[21] we first rescaled the original response 1 as 0, responses 2 or 3 as 50, and responses 4 or 5 as 100. Then, we summed rescaled values and divided the total by the number of statements with non-missing values to derive the average nicotine dependence score ranging from 0 to 100.

Statistical analysis

We generated descriptive statistics of the sample distribution and estimated cigarette smoking cessation rates by all independent variables. We also examined current e-cigarette

use at Wave 3 among short-term cigarette quitters at Wave 3 and current e-cigarette use at Wave 4 among long-term cigarette quitters at Wave 4 (Appendix Table A1). We used multivariable logistic regression to model each dependent variable as a function of changes in e-cigarette use from Wave 1 to Wave 2 and other independent variables at Wave 1.

We also conducted two sensitivity analyses using different measures to select the cohort of smokers "who want to quit or are making a quit attempt". In the first sensitivity analysis, the study cohort (n=3,944) comprised current smokers at Wave 1 who answered "2" or more to the question, "Overall, on a scale of 1 to 10 where 1 is not at all interested, how interested are you in quitting tobacco products]?" In the second sensitivity analysis, the study cohort (n=2,117) comprised current smokers at Wave 1 who answered "Yes" to the question: "In the past 12 months, have you stopped using tobacco products (including cigarettes) for one day or longer because you were trying to quit?"

We conducted all analyses in SAS version 9.4 using the Wave 4 all-Waves longitudinal sampling weights and replicate weights. The balanced repeated replication approach with Fay's adjustment (0.3) was used to calculate 95% confidence intervals (CIs) and P values. We considered a 2-tailed P <.05 to be statistically significant.

RESULTS

Table 1 shows that between Waves 1 and 2, among 3,014 current smokers, 2.4% initiated daily, 7.5% initiated nondaily, 1.0% increased to daily, 1.4% increased to nondaily, 1.5% maintained daily, 3.0% maintained nondaily, 2.4% decreased from daily, and 3.8% quit nondaily e-cigarette use between Wave 1 and Wave2. Moreover, 7.9% and 6.9% of the study cohort reported short-term cigarette smoking cessation at Wave 3 and long-term cigarette smoking cessation at Wave 4. The short-term cigarette smoking cessation was lowest among those who increased to nondaily e-cigarette use (2.9%) and highest among stable daily e-cigarette users (23.0%). In contrast, the long-term cigarette smoking cessation was lowest among those who decreased from daily e-cigarette use (3.2%) and highest among those who initiated daily e-cigarette use (12.0%).

At Wave 3, 15.1% of short-term cigarette quitters were current e-cigarette users. Current e-cigarette use was highest among stable nondaily e-cigarette users (100%) and lowest among those who increased to nondaily e-cigarette use (0%) and those who quit from nondaily e-cigarette use (0%) between Waves 1 and 2. At Wave 4, 16.3% of long-term cigarette quitters were current e-cigarette users. Current e-cigarette use was highest among those who increased to daily e-cigarette use (100%) and lowest among those who decreased from daily e-cigarette use (0%) and those who quit from nondaily e-cigarette use (0%) between Waves 1 and 2 (Appendix Table A1).

Multivariable logistic regression results show that, compared to e-cigarette non-users, smokers who initiated daily, increased to daily, maintained daily, or quit nondaily e-cigarette use between Waves 1 and 2 had higher odds of short-term cigarette smoking cessation at Wave 3, while none of the e-cigarette use subgroups had significantly different odds of

long-term cigarette smoking cessation at Wave 4 (Table 2). The completed results are in Appendix Table A2.

The first (Appendix Tables A3–A4) and second (Appendix Tables A5–A6) sensitivity analyses found higher odds of short-term cigarette smoking cessation for smokers who initiated daily, increased to daily, or quit nondaily e-cigarette use. Moreover, the first sensitivity analysis found positive associations between stable daily e-cigarette use and short-term cigarette smoking cessation and between daily e-cigarette initiation and long-term cigarette smoking cessation. In contrast, the second sensitivity analysis found a positive association between nondaily e-cigarette initiation and long-term cigarette smoking cessation.

DISCUSSION

This study examined the relationship between changes in e-cigarette use and subsequent cigarette smoking cessation among a cohort of cigarette smokers who had tried to quit at baseline. We found a positive association with short-term cigarette smoking cessation for smokers who initiated daily e-cigarette use, increased to daily e-cigarette use, had stable daily e-cigarette use, and quit nondaily e-cigarette use. However, the positive association between stable daily e-cigarette use and short-term cigarette smoking cessation was not significant in the second sensitivity analysis, probably due to the smaller sample size. In addition, 15.1% of short-term cigarette quitters used e-cigarettes at Wave 3, and 16.3% of long-term cigarette quitters used e-cigarettes at Wave 4.

Earlier prospective cohort studies that found positive associations between e-cigarette initiation[13] or daily e-cigarette initiation[19] and cigarette smoking cessation either did not restrict the study cohort to smokers trying to quit[13,19] or measured e-cigarette initiation and cigarette smoking cessation within the same period.[19] After improving the study design, our results also indicate that daily e-cigarette initiation was positively associated with subsequent short-term cigarette smoking cessation among current smokers who have tried to quit.

Our results indicate that increased daily e-cigarette use was positively associated with short-term but not long-term cigarette smoking cessation. Glasser and colleagues found that increased/stable daily e-cigarette use had higher odds of short-term and long-term cigarette smoking cessation.[14] This discrepancy is likely caused by different study designs: they measured e-cigarette use and cigarette smoking cessation within the same period, did not restrict their study cohort to smokers who tried to quit, and did not separate stable daily e-cigarette use from increased daily use.

A growing body of evidence from observational studies[9–14,19,26,37] has shown that more frequent e-cigarette use may help smokers quit cigarette smoking, but intermittent or infrequent e-cigarette use may not. Our results are consistent with these research; we found positive and significant associations with short-term cigarette smoking cessation for “ initiation to daily e-cigarette “ and “increase to daily e-cigarette use”, but not for “stable nondaily e-cigarette use” and “increase to nondaily e-cigarette use”. However, we also

found significantly higher odds of short-term cigarette smoking cessation for smokers who quit nondaily e-cigarette use. These results imply that nondaily e-cigarette use may not facilitate cigarette smoking cessation and quitting nondaily e-cigarette use could be helpful for subsequent quitting smoking. Future studies are needed to examine the mechanisms by which changes in e-cigarette use facilitate or impede cigarette abstinence.

A study found that compared to daily smokers who use e-cigarettes nondaily, nondaily smokers who use e-cigarettes daily had higher odds of cigarette abstinence at the 2-year follow-up.37 Their results suggest that the association of e-cigarette use with cigarette abstinence might also depend on smoking frequency. The sample size did not allow us to further disaggregate e-cigarette use by smoking frequency. However, we found that most stable nondaily e-cigarette users smoked cigarettes daily (daily smoking rates ranged from 82.5% at Wave 1 to 74.4% at Wave 4). In contrast, across all Waves, stable daily e-cigarette users had the lowest daily smoking rates (34.8% at Wave 1 to 41.0% at Wave 4 (Appendix Table A7)). Future research needs to examine the moderating role of smoking frequency in the association between e-cigarette use and cigarette smoking cessation.

Although we found that smokers who initiated daily or increased to daily e-cigarette use between Waves 1 and 2 had higher odds of short-term cigarette smoking cessation than e-cigarette non-users, many continued e-cigarette use after quitting smoking. The net health impact for those who stop smoking but become regular e-cigarette users is unknown. Chen and colleagues also found that those who quit cigarette smoking by using e-cigarettes were more likely to use other tobacco products and continue using e-cigarettes after quitting smoking, compared with those who quit smoking with pharmaceutical aids.[28] An increasing number of studies have found that e-cigarette use is associated with adverse health effects.[38–41] Recent evidence suggests that e-cigarette use may pose unique health harms, including harms to the respiratory and cardiovascular systems.[42] Therefore, when measuring the health impact of using e-cigarettes to aid in cigarette smoking cessation, one also needs to consider the potential harm of continued e-cigarette use.[22,28] Future research that examines e-cigarette use patterns among former cigarette smokers and evaluates the net impact of using e-cigarettes to quit cigarette smoking is warranted.

We acknowledge several limitations. First, our analysis was based on self-reported data and did not confirm cigarette smoking cessation using biomarker measures. Second, e-cigarette use changes were measured at two points a year apart. We may not capture rapid changes in e-cigarette use that happened within a year. Third, the sample sizes of some e-cigarette use subgroups were small, which might limit the statistical power to detect significant associations between these subgroups and cigarette smoking cessation. Fourth, for some smokers who also use other tobacco products at Wave 1, we did not know which product they tried to quit because of the wording of the survey questions. Last, we did not have data on newer e-cigarette products (e.g., JUUL) that may affect cigarette smoking cessation differently.

In conclusion, our results indicate a complex relationship between changes in e-cigarette use and subsequent cigarette smoking cessation. Future research is needed to examine the mechanisms by which changes in e-cigarette use facilitate or impede cigarette smoking

cessation and to understand the moderating role of the use frequency of both products in the association.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Caponnetto P, Campagna D, Cibella F, Morjaria JB, Caruso M, Russo C, Polosa R. Efficiency and safety of an eLectronic cigAreTte (ECLAT) as tobacco cigarettes substitute: a prospective 12-month randomized control design study. PLoS One. 2013 Jun 24;8(6):e66317. doi: 10.1371/journal.pone.0066317. Erratum in: PLoS One. 2014;9(1). doi:10.1371/annotation/e12c22d3-a42b-455d-9100-6c7ee45d58d0. [PubMed: 23826093]
2. Bullen C, Howe C, Laugesen M, McRobbie H, Parag V, Williman J, Walker N. Electronic cigarettes for smoking cessation: a randomised controlled trial. Lancet. 2013 Nov 16;382(9905):1629–37. doi: 10.1016/S0140-6736(13)61842-5. Epub 2013 Sep 9. [PubMed: 24029165]
3. Adriaens K, Van Gucht D, Declerck P, Baeyens F. Effectiveness of the electronic cigarette: An eight-week Flemish study with six-month follow-up on smoking reduction, craving and experienced benefits and complaints. Int J Environ Res Public Health. 2014 Oct 29;11(11):11220–48. doi: 10.3390/ijerph111111220. [PubMed: 25358095]
4. Tseng TY, Ostroff JS, Campo A, Gerard M, Kirchner T, Rotrosen J, Shelley D. A Randomized Trial Comparing the Effect of Nicotine Versus Placebo Electronic Cigarettes on Smoking Reduction Among Young Adult Smokers. Nicotine Tob Res. 2016 Oct;18(10):1937–1943. doi: 10.1093/ntr/ntw017. Epub 2016 Jan 17. [PubMed: 26783292]
5. Watson NL, Mull KE, Bricker JB. The association between frequency of e-cigarette use and long-term smoking cessation outcomes among treatment-seeking smokers receiving a behavioral intervention. Drug Alcohol Depend. 2021 Jan 1;218:108394. doi: 10.1016/j.drugalcdep.2020.108394. Epub 2020 Nov 1. [PubMed: 33203525]
6. Brown J, Beard E, Kotz D, Michie S, West R. Real-world effectiveness of e-cigarettes when used to aid smoking cessation: a cross-sectional population study. Addiction. 2014 Sep;109(9):1531–40. doi: 10.1111/add.12623. [PubMed: 24846453]
7. Christensen T, Welsh E, Faseru B. Profile of e-cigarette use and its relationship with cigarette quit attempts and abstinence in Kansas adults. Prev Med. 2014 Dec;69:90–4. doi: 10.1016/j.ypmed.2014.09.005. Epub 2014 Sep 16. [PubMed: 25230365]
8. McQueen N, Partington EJ, Harrington KF, Rosenthal EL, Carroll WR, Schmalbach CE. Smoking Cessation and Electronic Cigarette Use among Head and Neck Cancer Patients. Otolaryngol Head Neck Surg. 2016 Jan;154(1):73–9. doi: 10.1177/0194599815613279. Epub 2015 Oct 30. [PubMed: 26519457]
9. Biener L, Hargraves JL. A longitudinal study of electronic cigarette use among a population-based sample of adult smokers: association with smoking cessation and motivation to quit. Nicotine Tob Res. 2015 Feb;17(2):127–33. doi: 10.1093/ntr/ntu200. Epub 2014 Oct 9. [PubMed: 25301815]
10. Hitchman SC, Brose LS, Brown J, Robson D, McNeill A. Associations Between E-Cigarette Type, Frequency of Use, and Quitting Smoking: Findings From a Longitudinal Online Panel Survey in Great Britain. Nicotine Tob Res. 2015 Oct;17(10):1187–94. doi: 10.1093/ntr/ntv078. Epub 2015 Apr 20. [PubMed: 25896067]

11. Brose LS, Hitchman SC, Brown J, West R, McNeill A. Is the use of electronic cigarettes while smoking associated with smoking cessation attempts, cessation and reduced cigarette consumption? A survey with a 1-year follow-up. Addiction. 2015 Jul;110(7):1160–8. doi: 10.1111/add.12917. Epub 2015 Apr 23. [PubMed: 25900312]
12. Kalkhoran S, Chang Y, Rigotti NA. Electronic Cigarette Use and Cigarette Abstinence Over 2 Years Among U.S. Smokers in the Population Assessment of Tobacco and Health Study. Nicotine Tob Res. 2020 Apr 21;22(5):728–733. doi: 10.1093/ntr/ntz114. [PubMed: 31298296]
13. Friedman AS, Xu S. Associations of Flavored e-Cigarette Uptake With Subsequent Smoking Initiation and Cessation. JAMA Netw Open. 2020 Jun 1;3(6):e203826. doi: 10.1001/jamanetworkopen.2020.3826. [PubMed: 32501490]
14. Glasser AM, Vojjala M, Cantrell J, Levy DT, Giovenco DP, Abrams D, Niaura R. 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 Tob Res. 2021 Mar 19;23(4):669–677. doi: 10.1093/ntr/ntaa182. [PubMed: 32939555]
15. Pasquereau A, Guignard R, Andler R, Nguyen-Thanh V. Electronic cigarettes, quit attempts and smoking cessation: a 6-month follow-up. Addiction. 2017 Sep;112(9):1620–1628. doi: 10.1111/add.13869. Epub 2017 Jun 26. [PubMed: 28504457]
16. Manzoli L, Flacco ME, Fiore M, La Vecchia C, Marzuillo C, Gualano MR, Liguori G, Cicolini G, Capasso L, D'Amario C, Boccia S, Siliquini R, Ricciardi W, Villari P. Electronic Cigarettes Efficacy and Safety at 12 Months: Cohort Study. PLoS One. 2015 Jun 10;10(6):e0129443. doi: 10.1371/journal.pone.0129443. [PubMed: 26061661]
17. Al-Delaimy WK, Myers MG, Leas EC, Strong DR, Hofstetter CR. E-cigarette use in the past and quitting behavior in the future: a population-based study. Am J Public Health. 2015 Jun;105(6):1213–9. doi: 10.2105/AJPH.2014.302482. Epub 2015 Apr 16. Erratum in: Am J Public Health. 2015 Sep;105(9):e7. [PubMed: 25880947]
18. Shi Y, Pierce JP, White M, Vijayaraghavan M, Compton W, Conway K, Hartman AM, Messer K. E-cigarette use and smoking reduction or cessation in the 2010/2011 TUS-CPS longitudinal cohort. BMC Public Health. 2016 Oct 21;16(1):1105. doi: 10.1186/s12889-016-3770-x. [PubMed: 27769302]
19. Berry KM, Reynolds LM, Collins JM, Siegel MB, Fetterman JL, Hamburg NM, Bhatnagar A, Benjamin EJ, Stokes A. E-cigarette initiation and associated changes in smoking cessation and reduction: the Population Assessment of Tobacco and Health Study, 2013–2015. Tob Control. 2019 Jan;28(1):42–49. doi: 10.1136/tobaccocontrol-2017-054108. Epub 2018 Mar 24. [PubMed: 29574448]
20. 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 Oct;25(Suppl 1):i90–i95. doi: 10.1136/tobaccocontrol-2016-053096. [PubMed: 27697953]
21. Chen R, Pierce JP, Leas EC, White MM, Kealey S, Strong DR, Trinidad DR, Benmarhnia T, Messer K. Use of Electronic Cigarettes to Aid Long-Term Smoking Cessation in the United States: Prospective Evidence From the PATH Cohort Study. Am J Epidemiol. 2020 Dec 1;189(12):1529–1537. doi: 10.1093/aje/kwaa161. Erratum in: Am J Epidemiol. 2020 Dec 1;189(12):1640. [PubMed: 32715314]
22. 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 Sep 2;15(9):e0237938. doi: 10.1371/journal.pone.0237938. [PubMed: 32877429]
23. National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health. E-Cigarette Use Among Youth and Young Adults: A Report of the Surgeon General [Internet]. Atlanta (GA): Centers for Disease Control and Prevention (US); 2016.
24. National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Population Health and Public Health Practice; Committee on the Review of the Health Effects of Electronic Nicotine Delivery Systems. Public Health Consequences of E-Cigarettes. Eaton DL, Kwan LY, Stratton K, editors. Washington (DC): National Academies Press (US); 2018 Jan 23.
25. Villanti AC, Feirman SP, Niaura RS, Pearson JL, Glasser AM, Collins LK, Abrams DB. How do we determine the impact of e-cigarettes on cigarette smoking cessation or reduction? Review

and recommendations for answering the research question with scientific rigor. Addiction. 2018 Mar;113(3):391–404. doi: 10.1111/add.14020. Epub 2017 Oct 3. [PubMed: 28975720]

26. Wang RJ, Bhadriraju S, Glantz SA. E-Cigarette Use and Adult Cigarette Smoking Cessation: A Meta-Analysis. Am J Public Health. 2021 Feb;111(2):230–246. doi: 10.2105/AJPH.2020.305999. Epub 2020 Dec 22. [PubMed: 33351653]
27. El Dib R, Suzumura EA, Akl EA, et al. Electronic nicotine delivery systems and/or electronic non-nicotine delivery systems for tobacco smoking cessation or reduction: a systematic review and meta-analysis. BMJ Open. 2017 Feb 23;7(2):e012680. doi: 10.1136/bmjopen-2016-012680. Erratum in: BMJ Open. 2020 Jan 10;10(1):e012680corr1.
28. Chen R, Pierce JP, Leas EC, et al. Use of Electronic Cigarettes to Aid Long-Term Smoking Cessation in the United States: Prospective Evidence From the PATH Cohort Study. Am J Epidemiol. 2020 Dec 1;189(12):1529–1537. doi: 10.1093/aje/kwaa161. Erratum in: Am J Epidemiol. 2020 Dec 1;189(12):1640. [PubMed: 32715314]
29. Kalkhoran S, Glantz SA. E-cigarettes and smoking cessation in real-world and clinical settings: a systematic review and meta-analysis. Lancet Respir Med. 2016 Feb;4(2):116–28. doi: 10.1016/S2213-2600(15)00521-4. Epub 2016 Jan 14. [PubMed: 26776875]
30. Patil S, Arakeri G, Patil S, Ali Baeshen H, Raj T, Sarode SC, Sarode GS, Awan KH, Gomez R, Brennan PA. Are electronic nicotine delivery systems (ENDs) helping cigarette smokers quit?-Current evidence. J Oral Pathol Med. 2020 Mar;49(3):181–189. doi: 10.1111/jop.12966. Epub 2019 Nov 8. [PubMed: 31642553]
31. Pierce JP, Leas EC, Benmarhnia T, McMenamin SB, Strong DR, Chen R, Messer K. E-cigarettes and Cessation: The Introduction of Substantial Bias in Analyses of PATH Study. Nicotine Tob Res. 2021 May 4;23(5):876–877. doi: 10.1093/ntr/ntaa234. [PubMed: 33188408]
32. Pierce JP, Messer K, Leas EC, Kealey S, White MM, Benmarhnia T. A Source of Bias in Studies of E-Cigarettes and Smoking Cessation. Nicotine Tob Res. 2020 Apr 21;22(5):861–862. doi: 10.1093/ntr/ntz143. [PubMed: 31398246]
33. Coleman B, Rostron B, Johnson SE, Persoskie A, Pearson J, Stanton C, Choi K, Anic G, Goniewicz ML, Cummings KM, Kasza KA, Silveira ML, Delnevo C, Niaura R, Abrams DB, Kimmel HL, Borek N, Compton WM, Hyland A. Transitions in electronic cigarette use among adults in the Population Assessment of Tobacco and Health (PATH) Study, Waves 1 and 2 (2013–2015). Tob Control. 2019 Jan;28(1):50–59. doi: 10.1136/tobaccocontrol-2017-054174. Epub 2018 Apr 25. [PubMed: 29695458]
34. Hyland A, Ambrose BK, Conway KP, et al. Design and methods of the Population Assessment of Tobacco and Health (PATH) Study. Tob Control. 2017 Jul;26(4):371–378. doi: 10.1136/tobaccocontrol-2016-052934. Epub 2016 Aug 8. [PubMed: 27507901]
35. Bureau USC. How the Census Bureau Measures Poverty. http://wwwcensusgov/hhes/www/poverty/povdefhtml 2003.
36. Budget OoMa. Statistical Policy Directive No. 14 Definition of poverty for Statistical Purposes. http://wwwcensusgov/hhes/www/poverty/povmeas/ombdir14html. 1978.
37. Baig SA, Giovenco DP. 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. Addict Behav. 2020 May;104:106263. doi: 10.1016/j.addbeh.2019.106263. Epub 2020 Jan 8. [PubMed: 32028096]
38. Tzortzi A, Kapetanstrataki M, Evangelopoulou V, Beghrakis P. A Systematic Literature Review of E-Cigarette-Related Illness and Injury: Not Just for the Respirologist. Int J Environ Res Public Health. 2020 Mar 27;17(7):2248. doi: 10.3390/ijerph17072248. [PubMed: 32230711]
39. Bjurlin MA, Matulewicz RS, Roberts TR, Dearing BA, Schatz D, Sherman S, Gordon T, Shahawy OE. Carcinogen Biomarkers in the Urine of Electronic Cigarette Users and Implications for the Development of Bladder Cancer: A Systematic Review. Eur Urol Oncol. 2021 Oct;4(5):766–783. doi: 10.1016/j.euo.2020.02.004. Epub 2020 Mar 16. [PubMed: 32192941]
40. Chaumont M, van de Borne P, Bernard A, Van Muylem A, Deprez G, Ullmo J, Starczewska E, Briki R, de Hemptinne Q, Zaher W, Debbas N. Fourth generation e-cigarette vaping induces transient lung inflammation and gas exchange disturbances: results from two randomized clinical trials. Am J Physiol Lung Cell Mol Physiol. 2019 May 1;316(5):L705–L719. doi: 10.1152/ajplung.00492.2018. Epub 2019 Feb 6. [PubMed: 30724099]

41. Yang I, Sandeep S, Rodriguez J. The oral health impact of electronic cigarette use: a systematic review. Crit Rev Toxicol. 2020 Feb;50(2):97–127. doi: 10.1080/10408444.2020.1713726. Epub 2020 Feb 11. Erratum in: Crit Rev Toxicol. 2020 Apr 14;:1. [PubMed: 32043402]

42. Initiative T. E-cigarettes: Facts, stats and regulations. 2020.

What this paper adds

What is already known on this topic

- Mixed results have been reported on the role of e-cigarette use in cigarette smoking cessation.

What this study adds

- Following the criteria for an optimal prospective observational cohort study design that were recommended in a 2018 report of the National Academies of Sciences, Engineering, and Medicine, this study assessed the relationship between changes in e-cigarette use and subsequent cigarette smoking cessation among current cigarette smokers who tried to quit smoking cigarettes in the past 12 months.
- Cigarette smokers who initiated daily e-cigarette use, increased to daily e-cigarette use, or quit nondaily e-cigarette use had higher odds of reporting subsequent short-term cigarette smoking cessation. These results were robust to alternative specifications of the study cohort.
- Cigarette smokers with stable daily e-cigarette use had higher odds of reporting subsequent short-term cigarette smoking cessation. However, the result was not robust to different specifications of the study cohort.
- Cigarette smokers who increased e-cigarette use from former to nondaily use or who maintained nondaily e-cigarette use were not different from smokers who did not use e-cigarettes at both Wave 1 and Wave 2 in terms of subsequent short-term or long-term cigarette smoking cessation. These results were robust to alternative specifications of the study cohort.

How this study might affect research, practice or policy

- Our findings suggest a complex relationship between changes in e-cigarette use and subsequent cigarette smoking cessation. Future research is needed to examine the mechanisms by which changes in e-cigarette use affect cigarette smoking cessation.

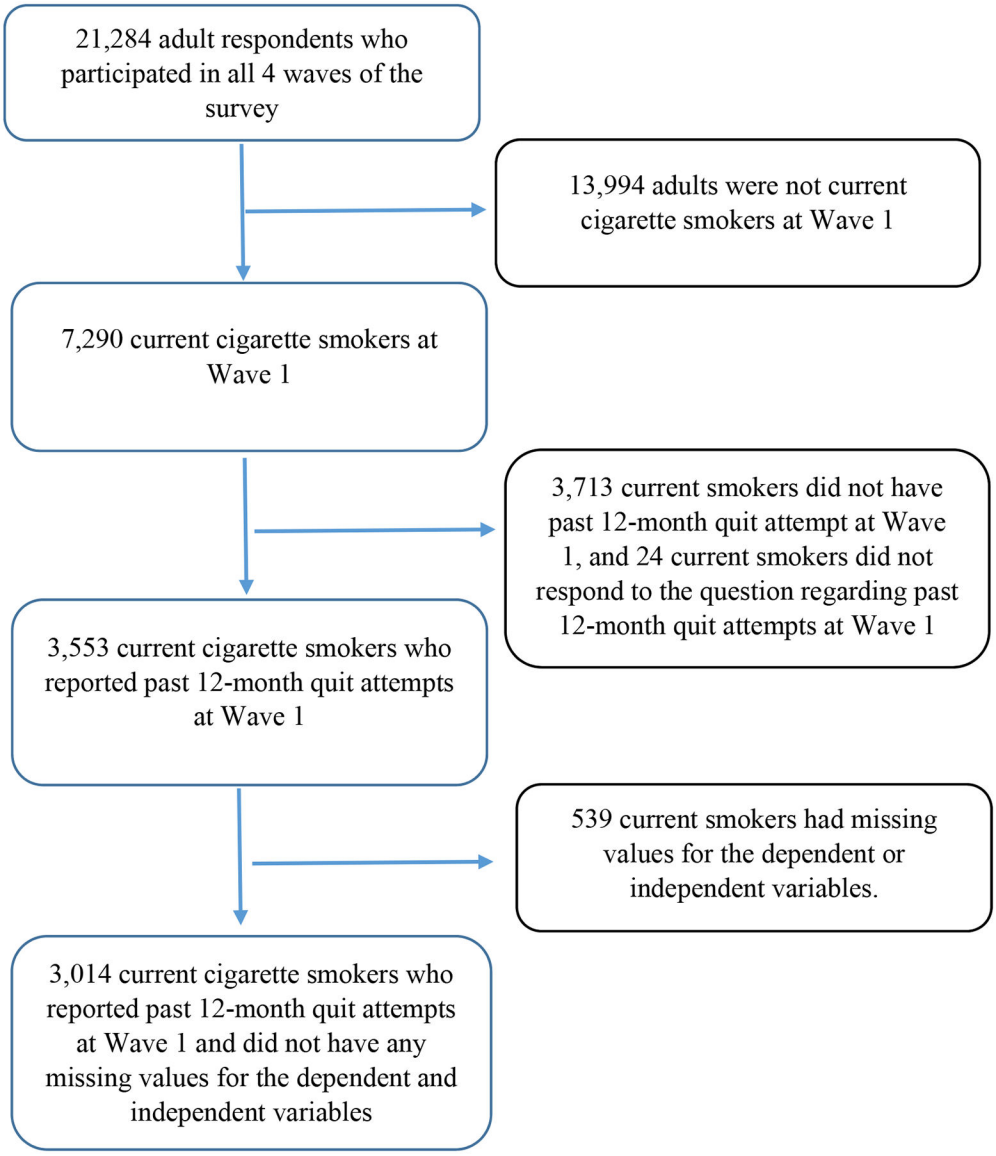

Figure 1:
Selection of the final study sample

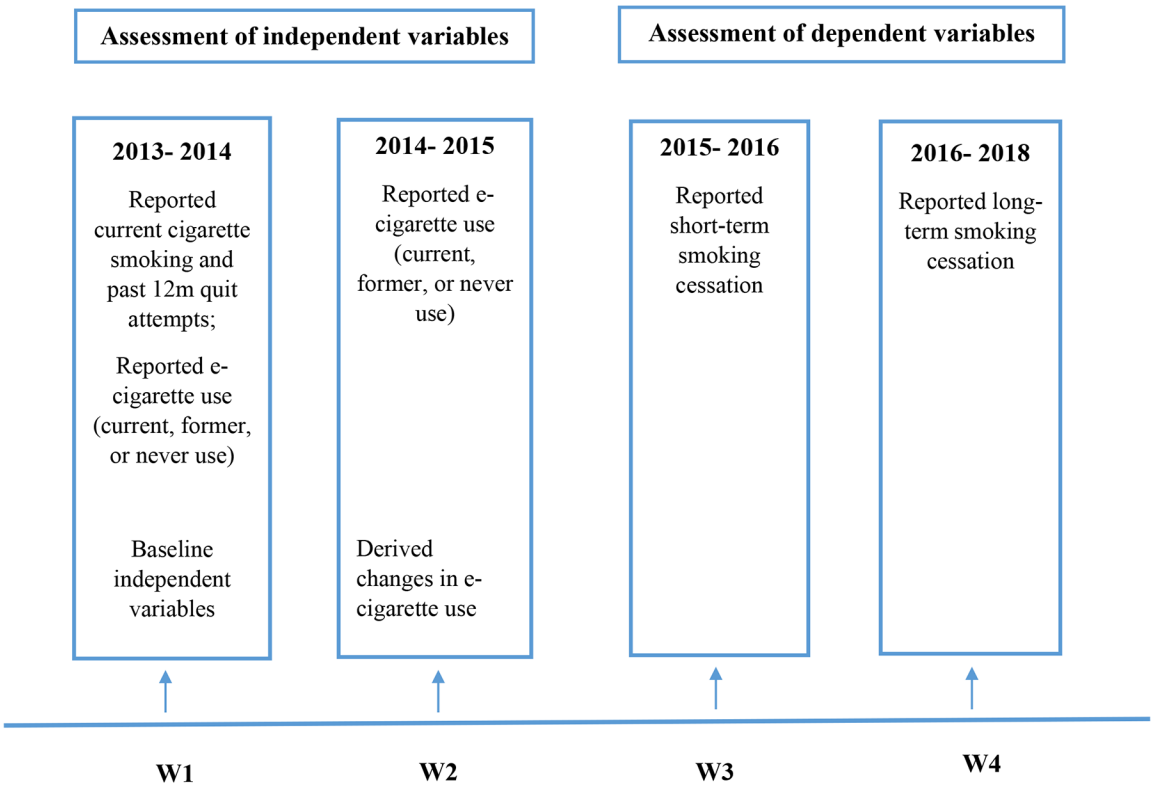

Figure 2:
Diagram of the study design

Table 1.

Sample distribution and the rates of short-term and long-term cigarette smoking cessation by the changes in e-cigarette use from Wave 1 to Wave 2 and other independent variables at Wave 1, PATH Study Waves 1–4 (n=3,014 current smokers at Wave 1 who reported having tried to quit using tobacco products in the past 12 months)

Independent variables		Sample distribution		Short-term cigarette smoking cessation rate		Long-term cigarette smoking cessation rate	
		n	col w%	n	row w%	n	row w%
All		3,014	100	224	7.9	202	6.9
Changes in e-cigarette use from Wave 1 to Wave 2	Initiation to daily e-cigarette use	69	2.4	13	19.1	10	12.0
	Initiation to nondaily e-cigarette use	233	7.5	24	10.5	20	11.0
	Increase to daily e-cigarette use	32	1.0	6	20.3	2	4.0
	Increase to nondaily e-cigarette use	44	1.4	1	2.9	3	7.3
	Stable daily e-cigarette use	49	1.5	11	23.0	6	10.8
	Stable nondaily e-cigarette use	93	3.0	3	3.6	5	5.9
	Decrease from daily e-cigarette use	69	2.4	3	7.6	1	3.2
	Quit from nondaily e-cigarette use	114	3.8	15	13.2	6	4.2
	E-cigarette non-use	2,311	77.0	148	6.8	149	6.6
Sex	Male	1,386	51.4	112	8.2	107	7.7
	Female	1,628	48.6	112	7.5	95	6.1
Age	18–34	1,379	41.8	113	9	94	7.6
	35–64	1,494	52.6	103	7.3	97	6.2
	65+	141	5.6	8	5.6	11	8.7
Education	<HS	482	14.8	27	6.4	32	6
	HS or GED	1,036	36.2	56	5.7	55	5.7
	Some college	1,424	46.9	132	9.7	107	7.8
	College degree or above	72	2.1	9	16.3	8	16.1
Income	<100 FPL	1,191	35.5	71	6.4	68	5.4
	100–199% FPL,	822	27.2	64	8.1	57	7.3
	≥200% FPL	819	30.7	76	9.8	62	8.3
	missing	182	6.6	13	6.7	15	7.4
Race/ethnicity	NH White	,1914	67.8	155	8.2	128	7.1
	Hispanic	429	12.4	34	9.3	34	7.6
	NH Black	451	13.5	18	3.7	25	4.6
	NH Other	220	6.3	17	11.4	15	9

Independent variables		Sample distribution		Short-term cigarette smoking cessation rate		Long-term cigarette smoking cessation rate	
		n	col w%	n	row w%	n	row w%
Region	Northeast	441	17.3	39	9.6	35	9.3
	Midwest	860	24.5	64	9	53	6.2
	South	1,147	39.2	72	6	69	6.2
	West	566	19.1	49	8.8	45	7.1
Perceived harm of cigarettes	Low harm perception	545	17.9	30	5	30	5.5
	High harm perception	2,469	82.1	194	8.5	172	7.3
Perceived relative harm of e-cigarettes	Less harmful	1,552	51.5	129	8.8	96	6.4
	About the same	1,130	36.8	75	6.7	87	8.1
	More harmful	160	5.1	4	4.3	10	5.7
	Never heard of or seen e-cigarettes	102	3.6	7	7.5	3	2.2
	Don’t know	70	3	9	13.5	6	9.5
Externalizing mental health problems	Low	1,593	54.7	111	7.2	108	6.8
	Moderate	801	25.7	80	10.5	61	8.3
	High	620	19.6	33	6.5	33	5.6
Internalizing mental health problems	Low	1,346	46.7	111	8.5	105	7.9
	Moderate	818	26.5	60	8.2	50	6.4
	High	850	26.8	53	6.6	47	5.8
Other tobacco use	Yes	517	16.2	39	8.9	39	8.6
	No	2,497	83.8	185	7.7	163	6.6
Past 30-day alcohol use	Yes	1,797	60	143	8.4	125	7.1
	No	1,217	40	81	7.1	77	6.7
Past 30-day marijuana use	Yes	672	20.7	36	5.4	35	5.1
	No	2,342	79.3	188	8.6	167	7.4
Nicotine dependence (continuous)		57.9 (3.7) *		48.6 (13.4) *		50.2 (13.5) *	

Note: PATH = Population Assessment of Tobacco and Health; w% = weighted percentage; HS = high school; GED = general education degree; FPL = federal poverty level; NH = non-Hispanic;

* mean (standard error). All the independent variables other than changes in e-cigarette use were measured at Wave 1

Table 2.

Estimated associations of the changes in e-cigarette use from Wave 1 to Wave 2 with subsequent short-term and long-term cigarette smoking cessation from the multivariate logistic regression models, PATH Study Waves 1–4 (n=3,014 current smokers at Wave 1 who reported having tried to quit using tobacco products in the past 12 months)

Independent variables		Model on short-term cigarette smoking cessation at Wave 3				Model on long-term cigarette smoking cessation at Wave 4			
		AOR	95% CI		P	AOR	95% CI		P
Changes in e-cigarette use from Wave 1 to Wave 2	Initiation to daily e-cigarette use	3.52	1.61	7.69	0.002	1.84	0.69	4.91	0.223
	Initiation to nondaily e-cigarette use	1.71	0.90	3.25	0.100	1.75	0.92	3.32	0.087
	Increase to daily e-cigarette use	5.61	1.61	19.49	0.007	0.83	0.12	5.88	0.848
	Increase to nondaily e-cigarette use	0.40	0.03	4.73	0.462	1.13	0.24	5.30	0.872
	Stable daily e-cigarette use	3.61	1.49	8.79	0.005	1.61	0.63	4.11	0.318
	Stable nondaily e-cigarette use	0.56	0.12	2.55	0.447	1.03	0.33	3.21	0.959
	Decrease from daily e-cigarette use	1.33	0.27	6.55	0.723	0.55	0.04	7.54	0.653
	Quit from nondaily e-cigarette use	2.42	1.01	5.78	0.047	0.70	0.23	2.09	0.519
	E-cigarette non-use	Reference				Reference			

Note: AOR = adjusted odds ratio; P=P values; PATH = Population Assessment of Tobacco and Health. The model also controlled for all other independent variables at Wave 1: sex, age, education, income, race/ethnicity, region, perceived harm of cigarettes, perceived relative harm of e-cigarettes, externalizing and internalizing mental health problems, other tobacco use, past 30-day alcohol use, past 30-day marijuana use, and nicotine dependence. The completed estimated results from the models are contained in Appendix Table A2.