Longitudinal study of e-cigarette use and onset of cigarette smoking among high school students in Hawaii

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ABSTRACT

Objective Use of electronic cigarettes (e-cigarettes) is prevalent among adolescents, but there is little knowledge about the consequences of their use. We examined, longitudinally, how e-cigarette use among adolescents is related to subsequent smoking behaviour.

Methods Longitudinal school-based survey with a baseline sample of 2338 students (9th and 10th graders, mean age 14.7 years) in Hawaii surveyed in 2013 (time 1, T1) and followed up 1 year later (time 2, T2). We assessed e-cigarette use, tobacco cigarette use, and psychosocial covariates (demographics, parental support and monitoring, and sensation seeking and rebelliousness). Regression analyses including the covariates tested whether e-cigarette use was related to the onset of smoking among youth who had never smoked cigarettes, and to change in smoking frequency among youth who had previously smoked cigarettes.

Results Among T1 never-smokers, those who had used e-cigarettes at T1 were more likely to have smoked cigarettes at T2; for a complete-case analysis, adjusted OR=2.87, 95% CI 2.03 to 4.05, p<0.0001. Among ever-smokers at T1, using e-cigarettes was not related to significant change in their frequency of smoking at T2. Uptake of e-cigarette use among T1 never-users of either product was predicted by age, Caucasian or Native Hawaiian (vs Asian-American) ethnicity, lower parental education and parental support, higher rebelliousness, and perception of e-cigarettes as healthier.

Conclusions Adolescents who use e-cigarettes are more likely to start smoking cigarettes. This result together with other findings suggests that policies restricting adolescents' access to e-cigarettes may have a rationale from a public health standpoint.

BACKGROUND

Adolescent use of electronic cigarettes (e-cigarettes) is an emerging public health issue.[1][2] The prevalence for ever use among US high school students increased from 1–3% in 2010–2011 to 10–20% in 2013–2014.[3][4] Similar increases have occurred in European and Asian countries.[5][6] Recent US studies of regional samples have shown prevalence rates in the range from 25% to 29%,[7–9] and e-cigarette use has surpassed cigarette use in some studies.[4][10]

These findings have sparked a debate about adolescent e-cigarette use.[1][11–13] E-cigarettes could produce a public health benefit if they help smokers to quit smoking tobacco cigarettes.[12][13] Alternatively, being exposed to e-cigarettes marketing[14–16] and e-cigarette use in smoke-free areas may contribute to renormalising smoking,[11] which could increase smoking initiation and deter quitting among adolescents. However, there is little evidence from longitudinal studies on the relationship between adolescent e-cigarette use and smoking. One study with adolescents[17] and one with young adults[18] have found that e-cigarette use is positively related to initiation of smoking. Furthermore, cross-sectional studies have reported a relationship between e-cigarette use among adolescent and young adult non-smokers, and intention[19][20] and willingness[21] to smoke. Because of the policy implications,[1][11][12] it is important to have evidence from different settings on the relation between e-cigarette use and smoking.

To address this question, we measured e-cigarette use and smoking on two occasions (1 year apart) among high school students. Our primary aim was to test whether e-cigarette use is related to the onset of smoking; thus, among adolescents who had never smoked at time 1 (T1), we determined the likelihood of smoking at time 2 (T2) as a function of previous e-cigarette use. A second aim was to determine longitudinal predictors for e-cigarette uptake, as most previous studies have been cross-sectional.[1][2] A third aim was to determine if e-cigarette use was associated with smoking reduction among baseline smokers.[13] All analyses controlled for a range of demographic and psychosocial covariates, variables that could be correlated with e-cigarette use and with smoking.

METHODS

Schools on the island of Oahu, Hawaii, were selected to be representative of school systems in Hawaii. Previous studies have shown that predictive relationships found in Hawaii for adolescent substance use are similar to results obtained in other areas.[9][21][22]

Participants and procedure

Six of the seven invited high schools participated in the study; there were four public and two private schools. At T1 (2013; N=2338), 49% of the participants were 9th graders, 42% were 10th graders and 9% were 11th graders, and the age range was 14–16 years (M age 14.7 years, SD=0.7). The participants were resurveyed approximately 1 year later at T2 (2014; N=2239) when M age was 15.8 years (SD=0.9). The T1 sample was 53% female, 24% were of Asian-American background (Chinese, Japanese or Korean), 19% were Caucasian, 27% were Filipino-American, 20% were

Native Hawaiian or other Pacific Islander, and 10% were of other race/ethnicity. Regarding family structure, 17% of participants lived with a single parent, 12% were in a step-parent family (one or both parents being step-parent), 60% lived with two biological parents, and 11% were in an extended family structure (two parents plus two or more relatives in the household). The mean for a father's education, on a 1–6 scale, with anchor-points grade school and post-college was 4.2 (SD=1.2).

The sampling frame at both assessments was all students in the target grades with adequate English language ability. The research was approved by the Institutional Review Boards of the University of Hawaii and the Hawaii State Department of Education. Signed parental consent and signed student assent were required at each assessment. The response rates were 70% at T1 and 67% at T2.

The paper survey took 40 min and was administered by trained research staff in school classrooms. Students were instructed that data were completely confidential and that they should not write their name on the survey. Participants were assigned an arbitrary numerical code to de-identify surveys while linking participants across data collection points. Most non-participation was due to parents not returning the consent form (71% of missing cases at both waves).

Measures

The same previously validated measures[22–25] were administered at both assessments. Variables were all scored such that a higher score reflects a higher level of the indicated variable.

Demographic variables included gender and age (written in years), family structure ('What adults do you live with right now?' with nine response alternatives); parental education ('What is the highest level of education your father/mother has completed?' with six fixed responses from grade school to post-college); and ethnicity (14 options: Native American/Alaska Native, Black (African-American), Chinese, Hispanic (Latino), Native Hawaiian, Filipino, Japanese/Okinawan, Korean, Micronesian, Portugese, Samoan, Southeast Asian, Tongan, White (Caucasian)). Students who checked more than one ethnicity were asked 'If you had to choose only one, what would you say?' and this item was used to index primary perceived ethnicity.

E-cigarette and cigarette measures: Two items with No/Yes responses asked, 'Have you ever heard of or seen an electronic cigarette (e-cigarette, Volcanos) before?', and 'Do you think smoking electronic cigarettes is healthier than regular cigarettes?' The item on e-cigarette use asked: 'Which of the following is most true for you about smoking electronic cigarettes (e-cigarettes, Volcanos)? (Check One)'. A 0–6 scale had response points 'I have never smoked an e-cigarette in my life', 'I have smoked e-cigarettes 1–2 times', 'I have smoked e-cigarettes 3–4 times', 'I usually smoke a few e-cigarettes a year', 'I usually smoke a few e-cigarettes a month', 'I usually smoke a few e-cigarettes each week', and 'I usually smoke e-cigarettes every day'. The item on cigarette use had the stem, 'Which of the following is most true for you about smoking cigarettes? (Check One)', and also had a 0–6 response scale ('I have never smoked cigarettes in my life' to 'I usually smoke cigarettes every day'). T1 never-smokers who reported any smoking at T2 were considered to have initiated smoking.

Several variables were included as psychosocial covariates because they could be correlated with e-cigarette use and with cigarette use (for sources, see ref. 9 24 25). Items were introduced with the stem, 'Here are some things that people may say about themselves. Read each one and circle a number (from 1

to 5) to show what is true for you'. Responses were on five-point Likert scales ('Not at All True for Me' to 'Very True for Me'). Parental support was a seven-item scale (α =0.94 and 0.94 for T1 and T2, respectively) assessing the perceived availability of emotional and instrumental support from parents (eg, 'When I feel bad about something, my parent will listen'). Parental monitoring was a five-item scale (α=0.75 and 0.75) indexing the extent to which parents were aware of the youth's activities ('My parent knows where I am after school'). Sensation seeking was a five-item scale (α=0.75 and 0.75) indexing the extent to which the youth desired novel and exciting activities ('I like to do dangerous things for fun'). Rebelliousness was a five-item scale (α=0.84 and 0.81) indexing the extent to which the youth liked to do things he/she was not supposed to ('I like to break the rules').

Analysis methods

Univariate frequency distributions described the prevalence of e-cigarette use and cigarette use at each time point. To determine the proportions of participants in various user groups, we classified participants into four ever use groups at each time point (Cigarette Only Use, E-cigarette Only Use, Dual Use (Cigarettes + E-cigarettes), and Non-user (never used either product)), and a cross-classification of usage status at both time points was performed. All multivariable analyses controlled for demographics, parenting and personality variables, and adjusted for clustering within schools. To obtain an empirical basis for defining use, a preliminary logistic regression analysis, conducted for persons who had never smoked cigarettes, modelled the likelihood of T2 smoking onset (ever used vs never used) in relation to level of T1 e-cigarette use. On the basis of this analysis, ever use of e-cigarettes was selected as the basic definition of use for subsequent analyses. To determine the relationship between e-cigarette use and smoking initiation, a multilevel logistic regression analysis using the SAS V.9.4 SURVEYLOGISTIC procedure, adjusting for covariates, and clustering within schools, tested how T1 e-cigarette use predicted onset of smoking at T2 among persons who had never smoked cigarettes at T1. To address the predictors of e-cigarette uptake, a multinomial regression analysis including covariates determined which of the study variables predicted T2 change in e-cigarette usage status among the T1 non-user group. To address whether e-cigarette use is related to reduction in smoking, a multilevel linear regression analysis using the SAS V.9.4 MIXED procedure tested how T1 e-cigarette use predicted change in the 0–6 smoking score from T1 to T2 among persons who had ever smoked cigarettes at T1. Because of convergence issues, parental education and the psychosocial covariates were analysed as tertiles. Sensation seeking and parental monitoring were substantially correlated with other covariates, and did not show significant unique contributions to outcomes when entered together with the other covariates in a multivariable model. Hence, the models reported here included age, gender, ethnicity, parental education, parental support and rebelliousness as the covariates.

We analysed attrition between T1 and T2 using t tests to compare baseline data for participants who were surveyed at both T1 and T2 with data for participants who provided data at T1 but not at T2. Consistent with typical findings in longitudinal studies of adolescents,[26] there was some differential attrition (ie, more attrition among persons with higher rebelliousness or lower parental support scores). However, the effect sizes were small (for Cohen d, range=0.10 to 0.23, mean=0.18), and a multivariable analysis showed that these variables together accounted for only 3% of the variance in

attrition, which was also consistent with previous studies.[26] [27] We conducted parallel analyses for persons having complete data at T1 and T2 (complete-case analysis; N=1302), and also including those who did not (full-information analysis; N=2772).[28] The full-information analysis was based on multiple imputation, employing Proc MI in SAS with 20 imputations using the Markov Chain Monte Carlo method,[29] so as to use all data from the 2338 T1 cases plus 434 T2 only cases.[30]

RESULTS

As shown in table 1, 31% of the sample had ever used e-cigarettes at T1, and 38% at T2; while 15% of the sample had ever smoked cigarettes at T1, and 21% at T2. The increase in use over time for both products is consistent with age trends typically observed in adolescent research.[27] [31] Prevalence rates for e-cigarette use are similar to, although somewhat higher than, rates from several recent studies,[5] [7] [8] but rates for cigarette smoking tend to be lower in Hawaii, which has been attributed to high taxation and strict restrictions on sales of tobacco to the underaged.[32] Data for T1 indicated that 96% of participants were aware of e-cigarettes, and that 68% considered them healthier than cigarettes.

Longitudinal patterns based on cross-classification of the four usage categories at both time points are presented in table 2. Of the original e-cigarette-only group (second row of table 2), 20% had initiated smoking at T2. This compared with a lower onset rate among persons who were non-users of either product at T1 (first row of table 2). Of the group who were non-users of either product at T1 (first row of table 2), 10% had initiated only e-cigarette use at T2, 2% only cigarette smoking, and 4% both.

Of the T1 ever-users of e-cigarettes, 28% had used e-cigarettes once or twice, 38% had used them 3–4 times, and 34% had used them more often. A preliminary logistic regression analysis including covariates, conducted for the subsample of adolescents who had never smoked a cigarette at T1, modelled the probability of T2 smoking status (never smoked vs ever smoked) as a function of level of e-cigarette use at T1. Results for a complete-case analysis (table 3) indicated that ORs for the likelihood of onset of smoking by T2 were significant for each level; that is, any level of T1 e-cigarette use was related to a significantly higher likelihood of onset of smoking. Pairwise comparisons with Tukey-Kramer adjustment indicated that each level of e-cigarette use differed significantly from never used, but the four levels of e-cigarette use did not differ significantly from each other; this is analogous to a pattern previously observed for attitudinal willingness to smoke.[21] Accordingly, we employed ever use of e-cigarettes as the basic definition of use for subsequent analyses. Supplementary analyses were performed using progressively stricter criteria for defining smoking status at T2 (ie, 3–4 times or higher, yearly or higher, and monthly or higher). These indicated that any level of e-cigarette use at T1 was related to smoking 1–2 times or 3–4 times at T2, but regular (yearly or monthly) smoking at T2 was only related to higher levels of e-cigarette use at T1 (see online supplementary table S1).

Logistic regression analysis

For the overall test of onset of smoking, a multilevel (students nested within schools) logistic regression analysis, based on participants who had never smoked cigarettes at T1, predicted T2 smoking status (never smoked vs ever smoked) from T1 e-cigarette ever use, including the covariates. Effect sizes were stronger for the complete-case analysis than the full-information analysis, but were significant in both analyses (table 4). In each model, the OR for T1 e-cigarette ever use predicting T2 onset of smoking was positive and significant. For example, in the first analysis, the model-computed probability of being a T2 smoker was 5% for T1 e-cigarette never-users and was 14% for T1 ever-users. That is, the multivariable analysis indicated that participants were about three times more likely to start smoking if they had ever used e-cigarettes.

Three covariates (age, ethnicity and rebelliousness) independently predicted onset of smoking. Onset of smoking was more likely for adolescents who were older (OR=1.49, CI 1.08 to 2.06, p=0.02). Compared with Asian-Americans, Caucasians were more likely to begin smoking (OR=2.67, CI 1.69 to 4.26, p<0.0001), as were Native Hawaiians (OR=2.27, CI 1.17 to 4.38, p=0.02). Additionally, onset of smoking was more likely for adolescents who scored high at T1 on rebelliousness (OR=2.09, CI 1.22 to 3.59, p=0.01). Gender, parental support and parental education were not significantly related to onset of smoking in the multivariable model.

A sensitivity analysis determined whether the onset results were dependent on how use was defined (see online supplementary tables 2A,B). The multiple logistic regression analyses were re-run using two more stringent cut-off levels to define e-cigarette use and cigarette smoking. For example, in the first

Table 1 Prevalence of e-cigarette and cigarette use (% of adolescent population) at two time points

Frequency	E-cigarettes (%)		Cigarettes (%)	
	Time 1	Time 2	Time 1	Time 2
Never used	69	62	85	79
Used 1–2 times	9	10	6	10
Used 3–4 times	12	15	4	5
Used few times past year	2	5	2	2
Used few times past month	3	3	2	2
Used few times past week	3	2	1	1
Use every day	2	3	<1	1

Time 1 N=2338; Time 2 N=2239.

Table 2 Results (cell n and row %) for cross-tabulation of e-cigarette (e-cig) and cigarette (cig) usage categories at two time points

Time 1 status	Time 2 status				
	Non-user (%)	E-cig only (%)	Cig only (%)	Dual-user (%)	Marginal n/(%)
Non-user	784 (85)	92 (10)	15 (2)	35 (4)	926 (71)
E-cig only	22 (10)	151 (70)	1 (<1)	41 (19)	215 (17)
Cig only	5 (17)	1 (3)	14 (48)	9 (31)	29 (2)
Dual-user	9 (7)	6 (5)	7 (5)	110 (83)	132 (10)
Marginal n	820	250	37	195	1302
(Marginal %)	(63)	(19)	(3)	(15)	

Status categories based on ever use of e-cigarettes and/or tobacco cigarettes.

Table 3 Probability of smoking onset (ever use) at T2 among T1 never-smokers as a function of level of e-cigarette use at T1, with ORs and 95% CIs

Level of T1 e-cigarette use	Probability of (T2 smoker) (%)	OR	CI	p Value
Never	5	1.00		
1–2 times	14	2.88	1.96 to 4.22	<0.0001
3–4 times	11	2.29	1.35 to 3.87	0.002
Yearly/monthly	19	4.17	2.03 to 8.57	0.0001
Weekly/daily	19	4.09	2.43 to 6.88	<0.0001

Analysis conducted for T1 never-smokers, analytic N=1070. Criterion variable is never smoked versus ever smoked at T2. Cells for the highest levels of use are collapsed to avoid small cell sizes. Results are adjusted for demographics, parenting and personality variables, and for clustering within school.

definition, a non-regular user was defined as the first two points on the scale (never used, or used 1–2 times), and a regular user as someone who had used 3–4 times or more.

The results were similar to those for 'ever use'. The OR for onset of smoking was 3.45 (CI 2.09 to 5.69) with the first definition, and 6.36 (CI 3.10 to 13.08) with the second definition, indicating that the observed relationship between e-cigarette use and onset of smoking does not depend on a particular definition of use.

Other transition analyses

For predicting onset of e-cigarette use, a multinomial regression model, including covariates, predicted change in usage category membership among the T1 never-user group (first row of table 2). Results are shown in table 5 for the complete-case analysis (similar for the full-information analysis). Using a conservative probability level (p<0.01) for interpretation, adolescents were more likely to transition from never-user to dual-user status (ORs >1) if they were older; Caucasian or Native Hawaiian (compared with Asian-American); more rebellious; and perceived e-cigarettes as healthier. Adolescents with higher parental support, and from families with more education, were less likely to make this transition (OR<1). The transition to use of e-cigarettes-only had many of the same predictors, but rebelliousness had a smaller effect, whereas perception of e-cigarettes as healthier had a larger effect. Transition to cigarette-only status had similar predictors, but results were not consistently significant.

To determine whether e-cigarette use was related to reduction in smoking, a multiple regression analysis based on T1 ever-

Table 4 Adjusted OR and probability of ever smoking at T2 as a function of T1 e-cigarette use among T1 never-smokers, for complete-case analysis and full-information analysis

Subgroup	Probability of (T2 smoker) (%)	OR	CI	p Value
For complete-case analysis				
Non-e-cig user at T1	5	1.00		
E-cig user at T1	14	2.87	2.03 to 4.05	0.0001
For full-information analysis				
Non-e-cig user at T1	15	1.00		
E-cig user at T1	22	1.67	1.17 to 2.39	0.005

Regression model includes T1 e-cigarette use, age, gender, ethnicity, parental education, parental support and rebelliousness. Classifications are based on ever use.

smokers predicted T2 smoking score (log transformed) from T1 e-cigarette ever use and the covariates, including T1 smoking score (log transformed) as a control. In the complete-case analysis, the regression coefficient for T1 e-cigarette use predicting change in smoking score over time was b=0.08 (SE=0.10) which is non-significant (p=0.44). The coefficient for T1 smoking was significant (b=0.73, SE=0.09, p<0.0001), reflecting the stability of smoking over time, but none of the covariates predicted change in the smoking score. This analysis did not show e-cigarette use predicting a reduction over time in the frequency of smoking. A similar conclusion was provided by the full-information analysis.

DISCUSSION

The aim of this research was to determine whether e-cigarette use in adolescence is longitudinally related to transitions in cigarette smoking. Prospective analyses tested the effect of e-cigarette use for onset of smoking, including demographic and psychosocial covariates that were themselves predictors of smoking. Results showed the probability of onset of smoking was higher among adolescents who used e-cigarettes, independent of the covariates. Sensitivity analyses indicated this finding was not dependent on a particular definition of use. We also demonstrated that several of the study variables predicted onset of e-cigarette-only use, or dual use. However, a test of whether e-cigarette use by adolescent smokers was related to reduction in their frequency of smoking did not show a significant effect.

Table 5 Multinomial regression results for prediction of T2 usage category membership among T1 non-user group

T1 predictor	T2 status contrast	OR	CI	p Value
Age	Dual-user vs non-user	2.05	1.42 to 2.96	0.0001
	Cig only vs non-user	1.38	0.74 to 2.55	0.31
	E-cig only vs non-user	1.27	0.96 to 1.66	0.09
Native Hawaiian*	Dual-user vs non-user	3.10	2.36 to 4.06	<0.0001
	Cig only vs non-user	2.47	0.87 to 7.03	0.09
	E-cig only vs Non-user	2.36	1.60 to 3.48	<0.0001
Caucasian*	Dual-user vs non-user	2.15	1.36 to 3.38	0.001
	Cig only vs non-user	2.56	1.20 to 5.45	0.02
	E-cig only vs non-user	1.48	1.05 to 2.11	0.03
Filipino	Dual-user vs non-user	1.52	1.05 to 2.20	0.03
	Cig only vs non-user	1.38	0.48 to 3.98	0.55
	E-cig only vs non-user	1.33	1.07 to 1.65	0.01
Parental support	Dual-user vs non-user	0.76	0.62 to 0.92	0.005
	Cig only vs non-user	0.65	0.46 to 0.91	0.01
	E-cig only vs non-user	0.79	0.67 to 0.92	0.004
Rebelliousness	Dual-use vs non-user	3.32	2.58 to 4.27	<0.0001
	Cig only vs non-user	2.50	1.69 to 3.70	<0.0001
	E-cig only vs non-user	1.83	1.49 to 2.23	<0.0001
Father's education	Dual-user vs non-user	0.65	0.54 to 0.78	<0.0001
	Cig only vs non-user	1.09	0.77 to 1.54	0.62
	E-cig only vs non-user	0.77	0.62 to 0.94	0.01
E-cigs healthier	Dual-user vs non-user	2.59	1.67 to 4.00	<0.0001
	Cig only vs non-user	2.38	1.37 to 4.13	0.002
	E-cig only vs non-user	3.18	2.24 to 4.50	<0.0001

p Value for contrast is from Wald χ^2 test with 1 df. Gender, sensation seeking and parental monitoring were included in the initial model but did not have any significant effects.
*Reference group is Asian-Americans.

E-cigarette use and health policy

These findings have implications for the current debate about e-cigarettes.[11–13] We found that e-cigarettes had a risk-promoting effect for onset of smoking, and this study provided a relatively strong test of the question, because at T1 there were a substantial number of participants who had only used e-cigarettes, and hence, were susceptible to transition. While some of the transition to dual use was attributable to other variables that are correlated with e-cigarette use (eg, ethnicity and rebelliousness), the effect of e-cigarettes for onset of smoking was independent of these variables. The present results converge with findings from other studies of adolescents[9 17–18 19–21] and provide support for the hypothesis that e-cigarette use may promote initiation of smoking.[1 5] This suggests that e-cigarette use among adolescents is not without behavioural costs. These findings should be considered for policy discussions about the availability of e-cigarettes to adolescents.[33]

Some investigators have suggested that even if e-cigarette use has costs, it may still provide a net public health benefit if e-cigarettes enable smokers to quit or reduce smoking.[13] This has not generally been found in longitudinal studies of adult smokers,[1] and our analyses did not show a significant relation of e-cigarette use to reduction in smoking among adolescents, parallel to findings from a study of Finnish adolescents.[34] However, the present study did not provide a strong test of the question because the sample contained relatively few persons who only smoked cigarettes. From a methodological standpoint, it should also be noted that there was a certain level of error in the data, as some persons who said at T1 that they had ever smoked cigarettes or ever used e-cigarettes indicated at T2 that they were never-users. This type of error has been observed in national studies of adolescents,[35 36] and is found across ages and waves of data collection.[37] Our supplemental analyses addressed this issue, testing definitions more stringent than ever use; results showed the findings on onset of smoking remained significant with these alternative definitions.

Reasons for transition

The reasons for the effect of e-cigarette use on transition to smoking remain to be clarified, but plausible hypotheses have been suggested.[1 2 38 39] One is that some e-cigarettes mimic the look and feel of cigarettes, and the inhaling and exhaling of e-cigarette aerosol produces some of the same sensory experiences as smoking a cigarette. This similar experience may contribute to an inclination towards trying cigarette smoking. Additionally, nicotine exposure via e-cigarettes, even at lower levels, may sensitise adolescents to its effects. If adolescents begin to experience mild physiological effects from nicotine they may be inclined to shift to cigarettes in order to get a bigger 'kick'. This hypothesis may help to account for the high prevalence of dual use observed in adolescent samples.[1 40]

Some aspects of the present study could be noted as possible limitations. The measure of e-cigarette use was relatively simple, not covering the many types of products that are now available,[1 2] and we measured cigarette smoking but not other forms of tobacco use. As in most longitudinal studies, there was attrition from the baseline sample, but we demonstrated that findings were similar for complete-case and full-information analyses that included variables related to attrition. There was some misclassification in reports of smoking, which is typical for studies of adolescent substance use,[35–37] but measurement error is compensated by having a large sample. It should be noted that there are several types of influences that potentially contribute to e-cigarette use and onset of smoking (eg, marketing, family attitudes and use). In the present research, we controlled for a number of variables correlated with e-cigarette use that index disposition to smoke cigarettes (eg, rebelliousness, parental support), and found that the effect of e-cigarettes for onset of smoking was significant in controlling for these predisposing factors. Further studies may include other types of covariates so as to ascertain unique effects of e-cigarette use for patterns of adoption. Note that the rate of cigarette smoking was relatively low in this population, and the majority of T1 e-cigarette ever-users did not transition to cigarette smoking over a 1-year period. Still, we were able to detect a significant effect of e-cigarette use for increasing the likelihood of onset of smoking, and we think this has public health implications.

What this paper adds

- ► E-cigarette use is known to be associated concurrently with cigarette smoking, but the temporal relation between these two behaviours had not been clear. Evidence from longitudinal research is needed to determine whether e-cigarette use precedes the onset of cigarette smoking.
- ► We followed a sample of high school students over a 1-year interval, and found that among initial non-smokers, those who used e-cigarettes were more likely to initiate cigarette smoking. This suggests that e-cigarette use in adolescence has behavioural costs, and this should be considered for policy formulation.

Disclaimer The content is solely the responsibility of the authors and does not necessarily reflect the views of the National Institutes of Health.

Competing interests None declared.

Ethics approval The study was approved by the Institutional Review Boards for University of Hawaii and Hawaii Department of Education.

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Data sharing statement Data will be made available to qualified researchers when the study is completed. Data will be posted on a website and requests to use the data will be reviewed by a committee of three co-investigators.

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Teens who use e-cigarettes more likely to try the real thing a year later

But regular smoking linked only to higher levels of e-cigarette use to start with, findings show

Teens who use e-cigarettes are more likely to try the real thing a year later than those who don't vape, indicates research published online in the journal **Tobacco Control.**

But subsequent regular smoking is linked only to higher levels of e-cigarette use at the outset, the findings show.

Nevertheless, the study indicates that it may be beneficial to restrict teens' access to e-cigarettes, conclude the researchers, who carried out their study in light of the ongoing heated debate about the public health benefits of e-cigarettes and their potential impact on teen smoking prevalence.

In a bid to find out if vaping among teens is linked to a heightened risk of taking up smoking subsequently, or if it might help teen smokers to quit, the researchers quizzed 2,338 teens at seven high schools in 2013, and then again a year later, about their vaping and smoking activities.

In 2013, the teens, all of whom resided in Hawaii, were 9th and 10th graders, with an average age of just under 15 years.

They were asked in depth about the frequency of their e-cigarette and tobacco use, from never; through a few times a year; right up to daily, at both time points.

Factors known to influence uptake of smoking, such as home environment, parental educational attainment, and degree of rebelliousness were also assessed by the survey.

The results showed that those teens who had used e-cigarettes in 2013 were almost three times more likely to have started smoking a year later than those who had not vaped at the time of the first survey.

This was irrespective of other factors that influence smoking uptake.

Just under a third (31%) of the sample, overall, had used e-cigarettes by 2013, rising to just under four out of 10 (38%) by 2014. Some 15% had smoked at least one cigarette in 2013, rising to around one in five (21%) by the following year.

Most (98%) of those quizzed in the first wave of the survey had heard of e-cigarettes, and over two thirds (68%) considered them to be healthier than smoking.

Among non-users of e-cigarettes and tobacco at the study outset, one in 10 had tried e-cigarettes by the second wave, while 2% had experimented with cigarettes, and fewer than one in 20 (4%) had tried both.

Transition from non-user of either e-cigarettes or tobacco to use of both by 2014 was associated with older age, white or Native Hawaiian ethnicity, and greater rebelliousness. Teens with greater levels of family support and education were less likely to make this transition.

A supplementary analysis showed that any level of e-cigarette use in 2013 was associated with smoking once or twice, or three or four times, by 2014.

But regular smoking - defined as yearly or monthly - was only associated with higher levels of e-cigarette use in 2013.

E-cigarette use among initial smokers was not linked with a reduction over time in their smoking frequency.

This is an observational study, so no firm conclusions can be drawn about cause and effect. Nevertheless, the researchers point out that their findings echo those of other studies looking at teen smoking behaviour.

"This suggests that e-cigarette use among adolescents is not without behavioural costs," they write. "These findings should be considered for policy discussions about the availability of e-cigarettes to adolescents," they conclude.

Supplementary Table 1A

Probability of smoking onset by T2 as a function of level of e-cigarette use at T1, with odds ratios and 95% confidence intervals

Level of T1 e-cigarette use	Pr{onset}	Odds ratio	Confidence interval	p
Never	2%	1.00		
1-2 times	5%	2.58	1.24 - 5.34	.01
3-4 times	7%	3.89	1.28 - 11.77	.02
Yearly/monthly	9%	5.08	1.88 - 13.73	.001
Weekly/daily	9%	5.30	2.12 - 13.28	.0004

Note: Analysis conducted for T1 never smokers, analytic $N = 1,070$. Criterion variable is defined as categories 0 or 1 (never smoked or smoked 1-2 times) at T2 vs. category 2 (smoked 3-4 times) or higher at T2. Cells for the highest levels of use are collapsed to avoid small cell sizes. Results are adjusted for demographics, parenting, and personality variables and for clustering within school.

Supplementary Table 1B

Probability of smoking onset by T2 as a function of level of e-cigarette use at T1, with odds ratios and 95% confidence intervals

Level of T1 e-cigarette use	Pr{onset}	Odds ratio	Confidence interval	p
Never	2%	1.00		
1-2 times	2%	1.94	0.68 - 5.51	n.s.
3-4 times	2%	1.21	0.22 - 6.78	n.s.
Yearly/monthly	5%	4.37	1.79 - 10.65	.001
Weekly/daily	13%	11.41	5.76 - 22.63	<.0001

Note: Analysis conducted for T1 never smokers, analytic $N = 1,070$. Criterion variable is Defined as categories 0-2 (Never smoked to smoked 3-4 times) at T2 vs. category 3 (smoke yearly) or higher at T2. Cells for the highest levels of use are collapsed to avoid small cell sizes. Results are adjusted for demographics, parenting, and personality variables and for clustering within school.

Supplementary Table 1C

Probability of smoking onset by T2 as a function of level of e-cigarette use at T1, with odds ratios and 95% confidence intervals

Level of T1 e-cigarette use	Pr{onset}	Odds ratio	Confidence interval	p
Never	1%	1.00		
1-2 times	1%	1.88	0.22- 15.70	n.s.
3-4 times	1%	1.61	0.12 - 20.75	n.s.
Yearly/monthly	4%	7.13	1.28 - 39.73	.03
Weekly/daily	10%	17.19	7.24 - 40.79	<.0001

Note: Analysis conducted for T1 never smokers, analytic $N = 1,070$. Criterion variable is Defined as categories 0-3 (Never smoked to smoked yearly) at T2 vs. category 4 (smoke monthly) or higher at T2. Cells for the highest levels of use are collapsed to avoid small cell sizes. Results are adjusted for demographics, parenting, and personality variables and for clustering within school.

Supplemental Table 2A

Odds ratio and probability of being a T2 smoker among T1 nonsmokers as a function of alternate

definition #1, for complete-case analysis and full-information analysis

T1 e-cig definition	For complete-case analysis			
	Prob. of {T2 Smoker}[A]	Odds ratio	Confidence interval	p
Non-regular user T1[A]	2%	1.00		
Regular user T1[A]	8%	3.60	1.59 - 8.16	.002

T1 e-cig definition	For full-information analysis			
	Prob. of {T2 Smoker}[A]	Odds ratio	Confidence interval	p
Non-regular user at T1[A]	3%	1.00		
Regular user at T1[A]	9%	3.45	2.09 - 5.69	<.0001

Note: Regression model includes T1 e-cigarette use, age, gender, ethnicity, parental education, parental support, and rebelliousness. [A] Defined as first two scale points (never smoked or smoked 1-2 times) vs. upper 5 scale points (smoked 3-4 times or more often).

Supplemental Table 2B

Odds ratio and probability of being a T2 smoker among T1 nonsmokers as a function of alternate

definition #2, for complete-case analysis and full-information analysis

	For complete-case analysis			
	Prob. of	Odds	Confidence	
T1 e-cig definition	{T2 Smoker}	ratio	interval	*p*
Non-regular user T1[B]	1%	1.00		
Regular user T1[B]	7%	6.01	3.16 - 11.42	<.0001

	For full-information analysis			
	Prob. of	Odds	Confidence	
T1 e-cig definition	{T2 Smoker}	ratio	interval	*p*
Non-regular user at T1[B]	1%	1.00		
Regular user at T1[B]	7%	6.36	3.10 - 13.08	<.0001

Note: Regression model includes T1 e-cigarette use, gender, ethnicity, parental education,

parental support, and rebelliousness. [B] Defined as first three scale points (never smoked, smoked

1-2 times, smoked 3-4 times) vs. upper 4 scale points (smoke yearly, monthly, or daily) .