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Journal

Tobacco Control

ISSN

0964-4563

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Publication Date

2026-10-20

DOI

10.1136/tc-2025-060044

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High-nicotine e-cigarettes and nicotine dependence among United States young and older adults, 2017–2022

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► Additional supplemental material is published online only. To view, please visit the journal online (<https://doi.org/10.1136/tc-2025-060044>).

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Received 16 January 2026
Accepted 30 August 2026



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To cite: Pierce JP, Strong DR, Ping S, et al. *Tob Control* Epub ahead of print: [please include Day Month Year]. doi:10.1136/tc-2025-060044

ABSTRACT

Background United States (US) e-cigarette sales surged from 2017 to 2022, following the introduction and marketing of high-nicotine e-cigarettes.

Methods The US Population Assessment of Tobacco and Health (PATH) Study re-interviewed a large nationally representative sample at regular intervals. Those who vaped (3000–4000 per survey) were queried on the nicotine strength of their usual e-cigarette. Study outcomes included nicotine dependence and vaping abstinence in 2022.

Results In 2022, those who vaped high-nicotine (4+%) e-cigarettes were more likely to vape daily (AOR=1.78, 95% CI: 1.30 to 2.43). Vaping high-nicotine e-cigarettes increased from minimal levels in each age group in 2017 to significant differences across age in 2022: 18–24 years=49.2%, 25–34 years=32.8%, 35–54 years=17.6% and 55+ years=4.5%. In 2017, nicotine dependence among 18–24-year-olds who vaped exclusively was much lower than among those who smoked exclusively; however, this difference had disappeared by 2022. Vaping high- (vs lower-) nicotine e-cigarettes in 2019 was associated with (1) an increase of 0.3 SD units of nicotine dependence within each age group by 2022 and (2) significantly lower odds of vaping abstinence in 2022 (AOR=0.69, 95% CI: 0.48 to 0.99, p=0.043). Among those who used the same e-cigarette brands, particularly Vuse and JUUL, 18–24-year-olds chose a high-nicotine option 2.2 times as often as 25+ year-old adults, suggesting a potential marketing effect.

Conclusions Vaping high-nicotine e-cigarettes surged between 2017 and 2022, particularly in 18–24-year-olds. Among 18–24-year-olds this was associated with increased daily vaping and a large increase in nicotine dependence. The US Food and Drug Administration's assessment of benefits versus harms of vaping high-nicotine e-cigarettes needs to be reassessed.

BACKGROUND

United States (US) e-cigarette sales were relatively steady at 6–7 million units/month between 2014 and late 2017.¹ The 2015 introduction of innovative nicotine-salt technology, along with flavours, by JUUL Labs allowed a very-high-nicotine e-cigarette (5%) to be palatable to a wide range of consumers.² A 3% nicotine content e-cigarette, labelled as moderately-high-nicotine strength, was added in 2018.³ Between 2017 and 2021, US e-cigarette

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ After 2017, there was a surge in vaping high-nicotine e-cigarettes, particularly among young adults.

WHAT THIS STUDY ADDS

⇒ From 2017 to 2022, prevalence of high-nicotine (4+%) e-cigarettes increased to 49% among 18–24-year-olds who vaped daily. This was significantly higher than the 4.5% among 55+ year-olds who vaped daily.
⇒ Population-level nicotine dependence from exclusive e-cigarette vaping increased markedly among young but not older adults.
⇒ Among those who vaped the same brand, young adults were significantly more likely than older adults to vape high-nicotine e-cigarettes, suggesting a possible effect of targeted marketing.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The Food and Drug Administration should review its marketing approvals for high-nicotine e-cigarettes to address the evidence of addiction liability in those who do not smoke. Public health interventions to prevent initiation should highlight the addictiveness of high-nicotine products.

sales surged three-fold, to over 20 million units/month. This level was maintained through 2024.⁴ With a successful marketing campaign that influenced adolescents,⁵ JUUL quickly captured a majority of this market share, and this was associated with a large increase in daily vaping among 14–17-year-olds.⁶ Competing manufacturers rapidly adopted nicotine-salt technology and high-nicotine e-cigarettes.⁷ Between 2019 and 2023, vaping prevalence among US 21–24-year-olds increased significantly from 10.1% to 15.5%, much higher than among older age groups.⁸ Between 2017 and 2022, at a time when other countries had regulated the nicotine of e-cigarettes to <2% (20 mg/ml),^{9–12} the average labelled nicotine of US national retail e-cigarette products increased rapidly from 2.5% to 4.4%.³

A US national academy report on the public health consequences of e-cigarettes¹³ concluded that

while there might be a potential benefit if e-cigarettes increased smoking cessation, there was a potential harm if those who had never smoked started vaping and became nicotine-dependent. A study that recruited those who vaped and randomised them to high- or lower-nicotine content e-cigarettes demonstrated that high-nicotine products increased plasma nicotine levels, resulting in more positive ratings of subjective effects and more intense puffing behaviours, suggesting higher dependence liability.¹⁴ Higher nicotine dependence increases the probability of long-term e-cigarette use, and early evidence suggests this will lead to health consequences for both respiratory^{15 16} and cardiovascular systems.¹⁷ Nevertheless, as of 2025, the US Food and Drug Administration (FDA) had authorised marketing for both Vuse¹⁸ and JUUL¹⁹ high-nicotine e-cigarettes.

In this article, we use the nationally representative Population Assessment of Tobacco and Health (PATH) Study²⁰ to investigate whether vaping high-nicotine e-cigarettes is associated with increased nicotine dependence, particularly among young adults. A limitation of the 2017 PATH questionnaire was that the highest nicotine content e-cigarette queried was 4+%. As this was close to the average labelled nicotine content of 2022 e-cigarettes sold in the US,³ we used this cut-point to categorise who used high-nicotine e-cigarettes. Using the PATH Study, we document the proportion who vaped high-nicotine e-cigarettes by age group between 2017 and 2022. Our prespecified hypothesis is that vaping high-nicotine e-cigarettes will be associated with increases in the national age-specific nicotine dependence levels among those who vape exclusively, particularly 18–24-year-olds. Using a longitudinal design, we hypothesised that the nicotine strength of e-cigarettes that were vaped in 2019 would be associated with increased nicotine dependence in 2022. Finally, to identify whether the marketing of Vuse and JUUL e-cigarettes might have differentially targeted high-nicotine products to US youth, we compare age-specific rates of vaping high-nicotine e-cigarettes among all those who vaped the same e-cigarette brands.

METHODS

Data source

The PATH Study used a multistage, stratified, area-probability design to recruit 45 971 12+-year-olds to complete monitored self-interviews in their home starting in 2013 and to be re-interviewed in future years.²¹ The study sample was refreshed at Wave 4 (W4, 2017) and again at W7 (2022).²² We report point prevalence estimates from all available adult surveys starting with the refreshed sample at W4 (n=32 822, surveyed December 2016–January 2018, labelled 2017), W5 (n=34 309, surveyed December 2018–November 2019, labelled 2019), W6 (n=30 516 surveyed March–November 2021) and W7 (n=30 801 surveyed January 2022–April 2023, labelled 2022). We also report longitudinal follow-up of adults who vaped e-cigarettes in 2019 (when there already was high-nicotine e-cigarette vaping) through 2022 (n=2356). For this group, the median follow-up time was 39 months (range: 27 to 51 months). The Institutional Review Board at Westat Inc. oversaw written informed consent and approved the study. Our secondary data analysis met exemption criteria for human subject review. We used the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

E-cigarette vaping

After viewing pictures of e-cigarette types, respondents were asked: Do you now use electronic nicotine products every day,

some days, or not at all? Some 2377 individuals vaped e-cigarettes daily or some days in 2017, 3454 in 2019, 2932 in 2021 and 3512 in 2022. Respondents' usual e-cigarette device was reported as disposable, prefilled pod or cartridges, refillable device, mod system or other. In 2017 and 2019, 17–20% of respondents had missing data on the nicotine strength question; however, this decreased to 7.2% in both 2021 and 2022 (online supplemental eTable 1). Across surveys, a response of 'Don't know' ranged from 21.6% (2021) to 31.2% (2022). In 2017, 4+ % nicotine strength was the highest option, with 1% reporting. In later surveys, this increased to 15.3% (2019), 24.1% (2021) and 24.6% (2022). Those who vaped but did not use other nicotine or tobacco products were labelled as vaping exclusively. At W7, self-reported vaping abstinence required (1) no current use, and not even a puff in the past 30 days or (2) no use at both W6 and W7.

Cigarette smoking

On each survey, respondents who indicated that they had not smoked 100 cigarettes in their lifetime were labelled as having never smoked. Those who had smoked were asked whether they now smoked every day, some days or not at all. Those who smoked but did not use other nicotine or tobacco products were labelled as smoking exclusively.

Nicotine dependence scores

Dependence symptoms were queried separately for electronic and non-electronic products. Those who used both products received both sets of questions and we used the higher score. There were 16 items for which a normalised index score (range 0–100) was obtained with a graded response model.²³ These were validated with nicotine equivalents measured in body fluids²⁴ and predictive validity with progression in tobacco use.²⁵ For ease of interpretation, we use this normalised score for most analyses; however, we used a standardised z-score to have a comparable measure when comparing it with cigarette smoking dependence.

Sociodemographic variables

The PATH Study's detailed questions on respondent sociodemographics have been previously presented.²⁰ Given published patterns of e-cigarette vaping,^{26 27} we categorised e-cigarette use on each survey into four age categories (18–24, 25–34, 35–54, 55+ years), sex (male, female), two categories of race-ethnicity (non-Hispanic White, other) and two levels of education (no college vs any college).

Statistics

All analyses were conducted between May 2024 and June 2026 using the 'survey' package in R (version 4.3.2). Single-wave weights adjust for survey design and non-response and provide representative estimates of the US civilian, non-institutionalised population.²⁸ Variance was estimated using replicate weights with balanced repeated replications and Fay's adjustment.²⁹ For many comparisons, we use non-overlapping CIs as a conservative indicator of statistical significance; however, for key comparisons we report p values. Categorising those who did not know the nicotine strength of their e-cigarette into the lower strength category is conservative as exposure misclassification would bias towards the null.

Longitudinal analyses were conducted using PATH data from 2019 through 2022. The 4-year follow-up response rate was 56.3%, which was higher in younger than older adults and

Table 1 Characteristics of those who vaped high-nicotine (4+%) e-cigarettes: Population Assessment of Tobacco and Health (PATH) Study (2022)

2022 variables	Categories	Sample N	Percentage vaping 4+% nicotine e-cigarettes (n=981)		Relative odds of vaping high-nicotine (4+%) e-cigarettes	
			%	95% CI	AOR (95% CI)	P value
(Intercept)		3785			0.01 (0.00 to 0.02)	<0.001
Age (years)	55+	214	4.8	1.6 to 7.9	Reference	
	35–54	639	14.2	10.9 to 17.5	3.77 (1.53 to 9.32)	<0.001
	25–34	1099	24.2	21.1 to 27.2	7.86 (3.30 to 18.77)	<0.001
	18–24	1833	39.7	37.1 to 42.3	15.07 (6.41 to 35.39)	<0.001
Sex	Female	1942	20.8	18.6 to 23.0	Reference	
	Male	1840	27.7	25.0 to 30.4	1.55 (1.23 to 1.96)	<0.001
Race	Other	1603	20.2	17.6 to 22.9	Reference	
	Non-Hispanic White	2147	26.9	24.3 to 29.5	1.32 (0.95 to 1.69)	0.034
Education	≤High school	1792	23.1	20.8 to 25.5	Reference	
	Some college	1973	26.9	23.7 to 28.3	1.17 (0.95 to 1.44)	0.147
Cigarette smoking	Never 100 cigarettes	603	30.6	27.4 to 33.8	Reference	
	Formerly smoked	1068	27.5	24.0 to 30.9	1.14 (0.83 to 1.57)	0.574
	Non-daily	1797	23.1	18.6 to 27.6	0.92 (0.61 to 1.37)	0.159
	Daily	592	11.1	8.7 to 13.6	0.50 (0.32 to 0.76)	<0.001
E-cigarette vaping	Non-daily	1797	15.1	13.0 to 17.2	Reference	
	Daily	1988	32.0	29.4 to 34.7	1.71 (1.30 to 2.27)	<0.001
E-cigarette device	Other	3014	22.1	20.3 to 23.9	Reference	
	Cartridge	250	39.0	30.7 to 47.3	1.68 (1.11 to 2.53)	0.015
	Disposable	521	33.3	28.4 to 38.2	1.71 (1.31 to 2.23)	<0.001
E-cigarette flavour	None of the below	961	14.2	9.6 to 18.9	Reference	
	Fruit (f)/candy (c)	2350	23.7	21.6 to 25.7	0.93 (0.64 to 1.35)	0.702
	Menthol (f or c)	474	37.9	33.1 to 42.6	1.99 (1.29 to 3.05)	0.002
Nicotine dependence*	Continuous				1.01 (1.01 to 1.02)	<0.001

Values in bold type denote statistical significance.

*NDS from all tobacco products. NDS is a continuous variable scaled 0–100 with an IQR: 25th=15.6, 50th=46.9, 75th=68.8.

AOR, adjusted odds ratio; NDS, Nicotine Dependence Score.

females than males but not related to education, race/ethnicity or baseline smoking or vaping characteristics (online supplemental eTable 2). The published all-waves longitudinal weights adjust for this dropout and for the within-person correlation across waves. These account for age (four levels), sex, race/ethnicity (four levels), census region (four levels), education (four levels) and tobacco use status at W4 (2017).³⁰ Multivariable regression models with survey weights were used to assess (1) loss to follow-up in 2022 and (2) characteristics of high-nicotine e-cigarette vaping in 2022. Additionally, 2019 covariates were regressed on the 2022 Nicotine Dependence Score (NDS). Our main regression analysis modelled nicotine dependence using age and study wave as predictors (Model 1), added nicotine strength of vaped e-cigarettes (Model 2) and finally interaction terms (Model 3). For 2022 vaping abstinence, we fit a logistic model of e-cigarette abstinence in 2022 among those who vaped in 2019, using 2019 sociodemographic and vaping characteristics as predictors.

RESULTS

Characteristics of high-nicotine e-cigarettes vaping in 2022

Among those who vaped in 2022, the odds of vaping high-nicotine e-cigarettes were strongly associated with age, with odds for 18–24-year-olds 15 times higher than among 55+ year-olds (adjusted OR (AOR)=15.07, 95% CI: 6.41 to 35.39, $p<0.001$) and over 70% higher among those who vaped daily compared with non-daily (AOR=1.71; 95% CI: 1.30 to 2.27, $p<0.001$) (table 1). The odds for males were 55% higher than for females ($p<0.001$), and the odds among those who also smoked

cigarettes daily were much lower than for those who had never smoked 100 cigarettes (AOR=0.50, 95% CI: 0.32 to 0.76, $p<0.001$). These odds were also linearly related to the individual's NDS ($p<0.001$). We also considered which 2019 covariates were associated with daily vaping in 2022 (online supplemental eTable 3). Daily vaping was higher among both 18–24-year-olds (AOR=2.14) and 25–34-year-olds (AOR=1.81) than among 55+ year-olds. It was higher in those who had quit smoking in 2019 than in those who had never smoked (AOR=3.41). Those who vaped high-nicotine e-cigarettes in 2019 had higher odds of vaping daily in 2022, although this effect was attenuated by daily vaping in 2019.

Age-by-year trends in vaping and using high-nicotine e-cigarettes

Between 2017 and 2022, the proportion of the US 18–24-year-old population who vaped increased significantly by 80%, from 10.3% to 18.6%, and the proportion of those who vaped daily increased two-fold (26.3% to 55.5%) (online supplemental eTable 4). In 2017, <4% of those who vaped, regardless of age or frequency of use, vaped high-nicotine e-cigarettes (figure 1). Among 18–24-year-olds who vaped daily, there was a rapid rise in use of high-nicotine e-cigarettes from 3.1% (2017) to 40.1% (95% CI: 37.0% to 43.2%) in 2019 to 49.2% (95% CI: 45.0% to 53.4%) in 2022. Among those who vaped daily in 2022, vaping high-nicotine e-cigarettes was significantly lower with each older age group of 25–34-year-olds=32.8% (95% CI: 28.1 to 37.5), 35–54-year-olds=17.6% (95% CI: 12.9 to 22.0) and 55+ year-olds=4.5% (95% CI: 0.5% to 8.5%). A similar

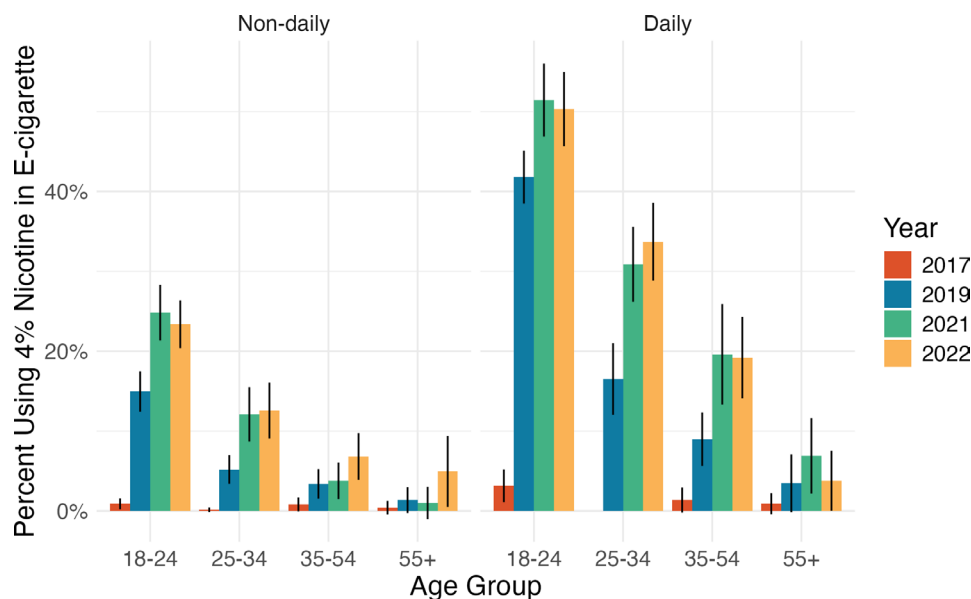


Figure 1 The percentage of United States adults who vaped e-cigarettes with 4% nicotine concentration in each of four age groups and by daily or non-daily vaping status: Population Assessment of Tobacco and Health (PATH) Study Wave 4 (2017) to Wave 7 (2022).

but lower pattern was observed among those who did not vape daily, with 2022 vaping of high-nicotine e-cigarettes among 18–24-year-olds at 22.1% (95% CI: 19.2% to 25.0%) but only 12.5% for 25–34-year-olds, 7.5% for 35–54-year-olds and 4.1% for 55+ year-olds.

2017–2022 trends in age-specific NDS between those who exclusively vaped or smoked

Among those who smoked exclusively, there was no significant change in NDS for any age group (figure 2, online supplemental eTable 5). Among 18–24-year-olds who vaped exclusively, the 2017 NDS was -0.40 SD units (SDU), which was very much lower than the $+0.20$ score for those who exclusively smoked cigarettes (non-overlapping CIs). However, there was a striking increase in this NDS score for those who vaped exclusively such that in 2022 their score ($+0.20$) was equivalent to that of those who smoked exclusively in 2017. For both 25–34-year-olds and those aged 35+ years who vaped exclusively, the CIs for their

NDS over time overlapped for each year, and the CIs for their 2022 NDS overlapped with those of those individuals who smoked exclusively.

In the first regression model of 2022 NDS among those who vaped exclusively, NDS varied significantly by age group (18–24 years, 25–34 years, 35+ years), but was significantly different only in two study years: 2021 and 2022 (Model 1 in table 2). Model 2 added the effect of vaping high-nicotine strength e-cigarettes, which significantly increased the NDS by 0.32 (95% CI: 0.26 to 0.38, $p < 0.001$) SDU. Model 3 added interaction effects by age and time period, but these did not change the effect size of e-cigarette nicotine strength. The NDS for the 18–24-year age group was significantly lower than the two older age groups in both 2021 (W6) and 2022 (W7). The effect of vaping high-nicotine strength e-cigarettes on NDS did not vary across age ($F = 1.971486$ on 2 and 85 degrees of freedom, $p = 0.146$) as shown in online supplemental eFigure 1.

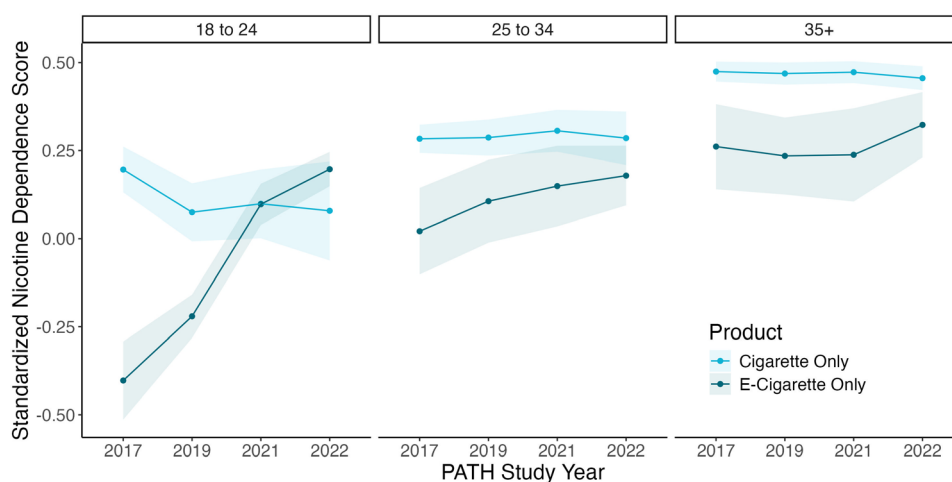


Figure 2 Changes in United States population-level nicotine dependence (normalised) in three age groups among those who smoked cigarettes without vaping e-cigarettes compared with those who vaped e-cigarettes without smoking cigarettes from 2017 to 2022. PATH, Population Assessment of Tobacco and Health.

Table 2 Regression models of nicotine dependence* among those who vape e-cigarettes without smoking cigarettes

Predictors	Model 1			Model 2			Model 3		
	Estimate	95% CI	P value	Estimate	95% CI	P value	Estimate	95% CI	P value
(Intercept)	-0.14	-0.21 to -0.07	<0.001	-0.1	-0.18 to -0.03	0.008	-0.29	-0.42 to -0.16	<0.001
Age group (25–34 years)	0.12	0.05 to 0.18	0.001	0.15	0.08 to 0.22	<0.001	0.37	0.18 to 0.56	<0.001
Age group (35+ years)	0.27	0.18 to 0.36	<0.001	0.34	0.25 to 0.43	<0.001	0.61	0.42 to 0.79	<0.001
2019 (W5)	0.02	-0.04 to 0.09	0.465	-0.06	-0.13 to 0.02	0.15	0.02	-0.13 to 0.18	0.751
2021 (W6)	0.18	0.10 to 0.26	<0.001	0.05	-0.03 to 0.14	0.217	0.27	0.13 to 0.41	<0.001
2022 (W7)	0.37	0.30 to 0.44	<0.001	0.22	0.14 to 0.30	<0.001	0.48	0.34 to 0.62	<0.001
High vs low e-cigarette nicotine strength†				0.32	0.26 to 0.38	<0.001	0.31	0.25 to 0.37	<0.001
Age group (25–34 years) × W5							-0.01	-0.25 to 0.22	0.918
Age group (35+ years) × W5							-0.07	-0.27 to 0.12	0.469
Age group (25–34 years) × W6							-0.25	-0.46 to -0.05	0.017
Age group (35+ years) × W6							-0.34	-0.54 to -0.15	0.001
Age group (25–34 years) × W7							-0.35	-0.58 to -0.11	0.004
Age group (35+ years) × W7							-0.4	-0.60 to -0.20	<0.001
Observations	6022			5591			5591		
Adjusted R ²	0.05			0.073			0.082		

Model 1=main effects of age and study time. Model 2=main effects of age, study time and e-cigarette nicotine concentration. Model 3=main effects+age x wave interactions. Values in bold type denote statistical significance.

*Nicotine dependence scale uses normalised scores so that estimates are in SD units.

†High (4+%) versus low (<4%) nicotine strength in e-cigarette vaped.

W, Wave.

The mean difference in nicotine dependence between those who smoked cigarettes and those who vaped e-cigarettes varied by age group and survey year [$F(6,76)=7.0$, $p<0.001$]. The relatively higher nicotine dependence for those using cigarettes compared with those vaping e-cigarettes across all age groups was significant only in 2017 and 2019 and not in later years (online supplemental eTable 6). By 2021 and 2022, differences in nicotine dependence between those who smoked cigarettes and those who vaped e-cigarettes occurred only for those in the 35+ years age group.

Nicotine strength of e-cigarettes in 2019 and vaping abstinence by 2022

Among those who vaped e-cigarettes in 2019, 40.9% (95% CI: 38.5% to 43.2%) were abstinent by 2022. Also, 18–24-year-olds were significantly less likely than those of each older age group to be abstinent in 2022. There were no significant differences by sex, race-ethnicity, education or plans to quit (table 3). Vaping higher-nicotine e-cigarettes in 2019 was associated with significantly less abstinence (AOR=0.69, 95% CI: 0.48 to 0.99, $p=0.043$) as was having smoked previously (AOR=0.61, 95% CI: 0.38 to 0.96, $p=0.033$).

Age differences in selection of higher-nicotine e-cigarette options within brand

In 2022, 5.2 million US 18–24-year-olds vaped e-cigarettes, which represented 29.4% of all adults who vaped (table 4). Across all e-cigarette brands vaped, 37.4% (95% CI: 37.2 to 42.7) of 18–24-year-olds reported vaping a high-nicotine e-cigarette, which was 2.2 times higher than for older adults (17.0%, 95% CI: 15.2% to 19.1%). Each of the six most popular brands vaped by 18–24-year-olds had a similar proportion of older adults who vaped them. Within each of these brands, purchasers could choose either high- or low-nicotine e-cigarettes. The high-nicotine option was chosen by a significantly higher proportion of 18–24-year-olds than 25+ year-olds for Vuse (63.3% vs

38.6%, $p<0.001$), JUUL (66.3% vs 31.9%, $p<0.001$) and Puff Bar (45.6% vs 15.7%, $p=0.003$).

DISCUSSION

In this study, the surge in US e-cigarette sales between late 2017 and 2021 was associated with an 80% increase in the proportion of 18–24-year-olds who started to vape and a doubling of the proportion of these who vaped daily, confirming a previous analysis.⁶ These increases were associated with a dramatic increase in the proportion of 18–24-year-olds who vaped high-nicotine strength e-cigarettes from 3% to 49%. A similar dramatic increase was seen for e-cigarette nicotine dependence that was specific to 18–24-year-olds, from a very low level in 2017 to a 2022 level that was equivalent to that of the 2017 18–24-year-olds who smoked cigarettes exclusively.

Regardless of age, nicotine dependence levels among those who vaped high-nicotine strength e-cigarettes were one-third of a SD unit higher than those who vaped lower-nicotine strength e-cigarettes. The surge in nicotine dependence among 18–24-year-olds was associated with both the large increase in daily vaping and the much higher proportion of these young adults who vaped using high-nicotine e-cigarettes (from 3.1% in 2017 to 49.2% in 2022). Those who vaped daily had 56% higher odds of vaping high-nicotine e-cigarettes than those who did not have a daily dependence. Young adults who vaped high-nicotine e-cigarettes in 2019 had a significant 31% lower odds than those who vaped lower-nicotine e-cigarettes of being abstinent from vaping 4 years later.

These findings support the concerns expressed in the 2016 Surgeon General's report³¹ that the US may be at the start of another epidemic of long-term nicotine dependence with associated adverse health consequences. This US vaping surge started after the US had made major progress in reducing the prevalence of cigarette smoking,³² particularly among youth.³³ The US Food and Drug Administration (FDA), which has the authority to regulate both cigarettes and e-cigarettes,³⁴ made no mention of e-cigarettes in its

Table 3 Logistic regression of 2022 vaping abstinence by 2019 sociodemographic and vaping characteristics

2019 (Wave 5) covariates	Subcategories	Population* (n)	Logistic regressions of 2019 covariates with vaping abstinence in 2022			
			Estimate % (95% CI)	AOR	95% CI	P value
(Intercept)		2356	40.9 (38.5 to 43.2)	1.41	0.96 to 2.09	0.082
2019 NDS†	Continuous			0.99	0.98 to 1.00	<0.001
Age (years)	18–24	1108	41.3 (37.8 to 44.8)	Reference		
	25–34	570	46.9 (42.3 to 51.5)	1.55	1.06 to 2.25	<0.001
	35–54	486	54.7 (50.2 to 59.2)	2.45	1.68 to 3.57	<0.001
	55+	192	49.6 (40.2 to 59.1)	2.32	1.51 to 3.59	<0.001
Sex	Male	1212	47.1 (43.5 to 50.6)	Reference		
	Female	1143	48.1 (44.5 to 51.7)	0.90	0.70 to 1.15	0.385
Race-ethnicity	Other race	907	54.6 (50.6 to 58.6)	Reference		
	Non-Hispanic White	1436	44.1 (41.5 to 46.6)	0.91	0.75 to 1.11	0.355
Education	≤High school	1067	46.3 (43.0 to 49.7)	Reference		
	Some college	1279	48.4 (45.6 to 51.2)	1.09	0.89 to 1.33	0.400
E-cigarette nicotine (%)	<4	2013	50.3 (48.1 to 52.4)	Reference		
	4+	343	28.9 (23.6 to 34.3)	0.69	0.48 to 0.99	0.043
Vaping frequency	Non-daily	1463	60.5 (57.6 to 63.4)	Reference		
	Daily	893	29.0 (25.7 to 32.4)	0.38	0.30 to 0.49	<0.001
Plan to quit e-products‡	No	1348	53.9 (54.2 to 60.2)	Reference		
	Yes	1008	39.3 (35.8 to 42.9)	1.06	0.83 to 1.36	0.629
Cigarette smoking status	Never smoked	312	54.5 (47.6 to 61.5)	Reference		
	Formerly smoked	475	35.8 (30.6 to 40.9)	0.61	0.38 to 0.96	0.033
	Currently non-daily	382	43.7 (38.2 to 49.1)	0.79	0.49 to 1.27	0.335
	Current daily	617	53.7 (49.2 to 58.2)	1.26	0.79 to 2.01	0.338

Values in bold type denote statistical significance.

*Population sample size.

†NDS from all tobacco products. NDS is a continuous variable with an IQR: 25th=15.6 (abstinence=50.1%), 50th=46.9 (abstinence=43.7%), 75th=68.8 (abstinence=39.3%).

‡sup id="9074ca90-9204-46f6-8e99-09dbc56403d1">&Plan to quit e-products for good.

AOR, adjusted odds ratio; NDS, Nicotine Dependence Score.

current proposal to regulate nicotine strength in tobacco products to non-addictive levels.³⁵ The present data suggest that this was a serious oversight.

Using 4+ % to represent high-nicotine strength e-cigarettes enabled us to include 2017 data (as it was the highest option in that survey). It had the added advantage of being close to the national average nicotine strength reported for retail e-cigarettes sold in 2022.³ Using this criterion resulted in 25% of 2022 respondents who vaped being

categorised as using high-nicotine e-cigarettes. Using an e-cigarette with a nicotine strength higher than this criterion was associated with a one-third of a SD increase in nicotine dependence compared with lower-nicotine strength e-cigarettes, providing face validity for using it as a cut-point. Given that those who use high-nicotine strength e-cigarettes are much more likely to consume many more e-cigarettes (as they are more likely to vape daily), high-nicotine e-cigarettes will account for much more than 25% of national sales.

Table 4 High-nicotine strength e-cigarette choices by young and older adults from among the six most popular e-cigarette brands for young adults in 2022.

	US population who vaped and used this brand				Percentage of those who chose this brand who vaped a high-nicotine strength option (4+%) e-cigarette				
	18–24-year-olds		25+–year-olds		18–24-year-olds		25+–year-olds		Difference*
	N	%	N	%	%	95% CI	%	95% CI	
Most popular e-cigarette brands for US 18–24-year-olds in 2022									
Hyde	436 466	8.3	627 137	5.0	41.2	33.0 to 49.9	29.8	18.8 to 43.9	0.095
Vuse	402 350	7.7	767 631	6.1	63.3	54.4 to 71.5	38.6	29.2 to 49.0	<0.001
JUUL	282 526	5.4	606 372	4.8	66.3	56.1 to 75.2	31.9	19.6 to 47.2	<0.001
Puff Bar	255 074	4.9	380 064	3.0	45.6	32.7 to 59.0	15.7	5.3 to 38.1	0.003
Smok	102 348	2.0	239 765	1.9	30.5	14.9 to 52.4	12.2	3.9 to 32.5	0.104
Blu	66 200	1.3	228 835	1.8	17.1	4.4 to 48.1	5.5	1.2 to 22.1	0.274
Other named brand†	1 538 628	29.4	3 997 277	31.9	42.6	36.9 to 48.5	20.6	17.1 to 24.5	<0.001
No named brand	2 145 414	41.0	5 727 045	45.5	29.3	25.8 to 33.1	8.5	6.4 to 11.1	<0.001
Total	5 229 006	100	12 574 126	100	37.4	37.2 to 42.7	17.0	15.2 to 19.1	<0.001

Values in bold type denote statistical significance.

*Difference between percentage of 18–24-year-olds versus 25+–year-olds vaping high-nicotine strength e-cigarettes.

†There were an estimated 269 different e-cigarette brands sold in the US in 2022.¹

US, United States.

An important question is why young people are so much more likely to use high-nicotine e-cigarettes than older adults. Most popular e-cigarette brands nominated by participants had purchasers of both high- and low-nicotine strength options. There were two standout brands (Vuse and JUUL) for which two-thirds of 18–24-year-olds, but only one-third of 25+ year-olds, reported vaping the high-nicotine option. These are also two of the brands with FDA authorisation to market their products to the US population.^{18 19} Both have been heavily marketed using paid influencers on social media.^{5 36–38} It has been estimated that 30–40% of advertising revenue generated from three major social media platforms is attributable to young people.³⁹ In addition, tobacco marketing has been determined to be a causative factor in increasing the likelihood of tobacco initiation.^{40–42}

US Congress required the FDA to use a public health standard when considering new tobacco products such as e-cigarettes.⁴³ To address this standard, the FDA evaluates the following two questions⁴⁴: Will those who smoke switch away from cigarettes to the new tobacco product? and Will any of those who do not use tobacco initiate with the new product? In providing marketing authorisation for both Vuse¹⁸ and JUUL,¹⁹ the FDA noted that there would be a benefit to adults who switched completely from cigarettes to e-cigarettes, as claimed by the manufacturers, and this outweighed the risks for young people becoming nicotine-dependent from vaping these products. This article demonstrates that among those who vape either JUUL or Vuse e-cigarette brands, 18–24-year-old adults have more than twice the odds of 25+ year-old adults to vape a high-nicotine strength option. This coincided with 18–24-year-old adults becoming much more nicotine-dependent. Such an effect would be expected if young adults were more receptive to industry marketing of these products,^{41 45} particularly on social media.⁴⁶ We demonstrated that young adults have had a dramatic increase in e-cigarette nicotine dependence. Also, high-nicotine products are associated with lower discontinuance of vaping, which will result in higher health complications to both the respiratory^{15 16} and cardiovascular systems.¹⁷ It will be important for a future analysis to identify the increase in nicotine dependence explained by the increase in high-nicotine vaping.

The surge in the initiation of vaping e-cigarettes among adolescents occurred across countries,^{47 48} some of which had a policy limiting the nicotine strength of retail e-cigarettes.⁹ But initiating vaping is only an early step to becoming nicotine-dependent. Unfortunately, most studies have not measured nicotine dependence, so it is unclear whether these countries have seen what we report here for the US, namely that nicotine dependence from e-cigarettes among young adults has increased substantially such that it is now equivalent to what was previously achieved from cigarette smoking. The nicotine strength of the vaped e-cigarette is only one of the factors that could influence nicotine intake; others include an individual's ability to modify their e-cigarette device⁴⁹ and, increasingly, co-use with nicotine pouches.⁵⁰ A comprehensive strategy to reduce nicotine dependence in youth will need to focus on de-normalising vaping, as was done for cigarette smoking.⁵¹

Strengths and limitations

A strength of this study is the use of the nationally representative PATH Study, which enables both cross-sectional and longitudinal estimates of population tobacco usage patterns. Thus, there is strong external validity to the results. A limitation is that the nicotine strength of e-cigarettes was not collected from adolescents in these PATH Study waves, and there is clear evidence that

vaping usually starts in adolescence.³¹ Further, a high proportion of respondents did not know the nicotine strength of their e-cigarette. Coding them as vaping <4% is conservative, as this would bias the finding towards the null. A limitation of all observational studies is that they are not randomised controlled trials, which are the gold standard for making causal inferences.⁵² However, ethical concerns rule out randomising those who had never used tobacco to high-nicotine e-cigarettes in such a trial. Future studies are needed using longitudinal data with ongoing waves of the PATH Study to identify whether the increased nicotine dependence in young adults identified in this study is associated with lifelong nicotine dependency and significant health consequences.

CONCLUSIONS

Between 2017 and 2022, US young adults were much more likely to vape high-nicotine strength e-cigarettes than older adults and to vape daily. There was a rapid increase in nicotine dependence that was specific to 18–24-year-olds who vaped, and dependence rose to the level equivalent to the 2017 levels of 18–24-year-olds who smoked cigarettes. Although the health consequences of vaping are expected to be less than cigarette smoking, they will likely still be substantial. These results suggest that there is an urgent need to reassess whether high-nicotine e-cigarettes meet the public health standard required by US Congress⁴³ for the US FDA to authorise their marketing.

Contributors JPP, DRS and KM are responsible for the overall content and are the guarantors of the article. All three authors had full access to all the study data, and take responsibility for their integrity and the accuracy of the data analysis. All information and materials in this article are original. JPP, DRS and KM conceptualised and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript. SBM, JPP and DRT acquired funding for the study. DRS and SP undertook the analyses for this study. SBM, DRT, MDS, JC, NEQ and BQD had input into the study conceptualisation and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work. No other individuals made substantial contributions to the article. These data have not been previously presented in any public venue.

Funding This project was supported by the Tobacco-Related Disease Research Program (TRDRP) of the University of California, Office of the President (T31IR-1584 and T32IR-4988). The funding body had no role in the design and/or conduct of the study; collection, management, analysis and interpretation of the data; and preparation, review or approval of the manuscript. Also, they were not involved in the decision to submit the manuscript for publication. The content is solely the responsibility of the authors and does not necessarily represent the official views of TRDRP.

Competing interests None.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. <https://doi.org/10.3886/ICPSR36498.v23>, <https://doi.org/10.3886/ICPSR37519.v14>.

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