E-cigarette consumption among youth who vape in Canada, England, New Zealand and the USA: Exploring methods to quantify consumption amounts and differences by product attributes using population-level surveys

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ABSTRACT

Significance Despite the popularity of vaping among young people, data on e-liquid consumption remain limited. The current study explores methods to quantify e-liquid consumption among youth who currently vape in four countries.

Methods Data were analysed from the 2023 International Tobacco Control Policy Evaluation Project Youth Surveys, conducted online with national samples in Canada, England, New Zealand and the USA, among 2916 youth aged 16–19 who vaped in the past 30 days. The volume of e-liquid consumed in the past 30 days was estimated from device-specific measures. Linear regression models examined differences in total e-liquid consumption by (1) country, age, sex-at-birth, exclusive versus dual vaping/smoking and device type; (2) four vaping dependence variables (frequency of strong urges, perceived addiction, days vaped, E-cigarette Dependence Scale (EDS) score) and (3) flavour.

Results Across countries, total e-liquid consumption reported in the past 30 days was a median of 9.7 mL and a mean of 22.4 mL. Compared with the USA, e-liquid consumption was greater in Canada (β=4.6, p=0.048) and England (β=4.8, p=0.027). Using multiple device types was associated with greater e-liquid consumption (eg, three device types vs only pods/cartridges: β=54.6, p<0.001). All four dependence indicators were positively associated with consumption, including urges to vape, perceived addiction, days vaped and EDS (all p<0.001). Youth who vaped fruit flavours reported the greatest e-liquid consumption (β=9.1, p=0.001), with some evidence of higher consumption levels for sweet/drinks/other flavours (β=4.3, p=0.093).

Conclusions The findings suggest substantial e-liquid consumption among youth who vape in all four countries.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Despite e-cigarettes being the most popular nicotine product among young people, few studies have attempted to quantify e-liquid consumption.

WHAT THIS STUDY ADDS

⇒ This study reports an exploratory methodology for quantifying estimates of e-liquid consumption among youth using population-level survey data and indicates substantial levels of use.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Quantitative consumption data can inform estimates of nicotine intake and aerosol exposure and differences by product attributes in population-level surveys. Understanding e-liquid consumption is crucial for addressing the public health implications of youth vaping.

BACKGROUND

Electronic cigarettes (e-cigarettes) are the most commonly used nicotine product among young people.[1 2] Prevalence of vaping among young people has rapidly evolved over the past decade, characterised by notable increases in frequent vaping among youth, with more recent decreases in the USA, but not other countries.[3 4] Approximately 8% of high school youth in the USA (aged ~14 to 18) in 2023/24 reported using e-cigarettes in the past 30 days while 2% vaped daily.[5 6] In Canada, 12% of grade 10 to 12 students (aged ~14 to 18) in 2021/2022 reported vaping daily.[1] In 2024, 14% of 16–17 years and 17% of 18 years in the UK reported 'current' e-cigarette use.[7] In New Zealand (NZ), approximately 11% and 27% of youth aged 15–17 and 18–24, respectively, reported daily vaping in 2023/2024.[8] Increases in daily vaping have been linked to greater dependence, likely attributed to the increasing prominence of nicotine salt e-cigarette liquids (e-liquids), which are often available in higher nicotine concentrations and enhance nicotine delivery.[9–13]

Frequency of vaping is often used as a 'proxy' for vaping consumption.[14 15] However, measures of frequency based solely on the number of days vaping are imprecise measures of consumption and exposure to e-cigarettes, as there is wide variation in daily use. Moreover, there have been notable changes in these patterns over time.[10 16] Accordingly, several studies among youth have examined more detailed measures of e-cigarette consumption using measures such as the number of puffs,

millilitres of e-liquid and e-cigarette products consumed over a period of time.[16–24] Although some studies have used 'objective' methods to assess puffing behaviour in laboratory settings,[18 19 24] most studies on young people have used self-reported measures of puffing.[16 17 20–22] For example, one study of youth who vape found evidence of an association between cravings to vape and puffs per month,[16] while other studies suggest that youth who vape take more puffs when they vape e-cigarettes with sweet flavours such as fruit.[21 22]

The reliability and validity of current measures of vaping consumption are limited.[25] Self-reported puff measures have been reported to overestimate puffs when compared with observed measures.[26] Given the episodic and variable nature of vaping patterns, people may find it difficult to recall their puffing behaviour over a specific period. The volume and length of puffs may also vary, limiting the validity of comparisons of consumption across individuals or different products.[23 26] Some studies have also quantified use using self-reported number of cartridges/pods/disposables consumed daily (or, less often, weekly), a method reportedly preferred by youth.[17 26–28] Reporting consumption by the number of cartridges/pods/disposables may be easier because of the cues associated with purchasing in these units and replacing cartridges/pods. However, 'per day' use measures may be less relevant for non-daily vaping and may even be difficult to report for daily vaping, given that even frequent consumers may use only a fraction of a product per day.[26]

Overall, there is limited evidence on e-cigarette consumption among young people, including potential differences by product attributes, such as flavour and device type. Measuring e-liquid consumption offers a potential method to estimate e-cigarette consumption across varying product types and behaviours. Population-level estimates of consumption can enhance our understanding of patterns of use and exposure to nicotine and toxic constituents in vaping aerosol, evaluate the impact of regulatory measures such as nicotine limits, and assess the impact of changes in product design, such as disposable e-cigarettes.[29 30] Using population-based surveys, the current study explored methods to quantify e-cigarette consumption among youth who vape in four countries. The study had two specific objectives: (1) to examine whether e-cigarette consumption amounts were associated with e-cigarette dependence measures and (2) to examine whether e-cigarette consumption differed by product type and flavour.

METHODS

Sample

Data were from Wave 7 of the International Tobacco Control Policy Evaluation Project Youth Tobacco and Vaping Survey, conducted online between 2 August 2023 and 18 September 2023, in Canada, England, NZ and the USA (N=13721). National samples of youth aged 16–19 were recruited from the Nielsen Consumer Insights Global Panel in Canada, England and the USA, and through consumer panels in NZ, either directly or through their parents. All potential respondents provided informed consent. Respondents received remuneration per their panel's usual incentive structure.

The current analysis included a subsample of 2916 youth from all four countries who vaped at least a few puffs from a disposable vape, prefilled pod/cartridge, or e-liquid bottle/tank device within the past 30 days. A full description of the study methods is available in the Wave 7 Technical Report.[31]

Measures

Full measures are outlined in the online supplemental file 1.

Independent variables

Sociodemographics: Variables included sex (sex-at-birth; inferred from current gender where not stated), age (years) and country (Canada, England, NZ, USA).

Past 30-day vaping and smoking: Past 30-day e-cigarette and cigarette use were assessed using validated survey measures. Past 30-day vaping and past 30-day smoking was characterized as dual-use.

The following measures were asked of those who vaped in the past 30 days.

Strong Urges to Vape: Respondents were asked, "In the past 30 days, how often did you have a strong urge to use an e-cigarette/vape?" (Several times a day; every day or most days; at least once a week; less than once a week; never; don't know; refused). 'Refused' responses (0.1% (4)) were excluded.

Number of days vaped: Respondents were asked: In the past 30 days, on how many days did you use an e-cigarette/vape?", with open-ended numeric responses, categorized as '0–9 days', '10–19 days', '20–30 days' and 'don't know'.

Perceived addiction to vaping: Respondents were asked: "Do you consider yourself addicted to using e-cigarettes/vaping?" (Not at all; yes, a little addicted; yes, very addicted; don't know; Refused). 'Refused' responses (0.3% (9)) were excluded.

E-cigarette Dependence Scale (EDS): Respondents completed the 4-item EDS scale, which is a shortened version of the 22-item PROMIS scale that measures e-cigarette dependence.[14] An average score was calculated for each respondent (range 0–4), with higher scores indicating greater dependence. 'Refused' responses were excluded (item 1=0.2% (7); item 2=0.3% (10); item 3=0.2% (6); item 4=0.2% (7)) and total 0.5% (16)).

Usual vaping flavour(s): Respondents who reported ever using more than one flavour (from a list of 12) were asked, "In the last 30 days, which of these flavours did you use most often?" with a checklist of the flavours they reported ever using (multiple selections permitted). Respondents who reported vaping in the past 30 days and ever using only one flavour were coded as using that flavour most often. Flavours were analysed as five non-mutually exclusive dummy variables: tobacco (tobacco; mix of tobacco and menthol), fruit, menthol/mint (mint; menthol; mix of tobacco and menthol), sweets/drinks/other (candy, chocolate, desserts or sweets; clove or other spice; coffee; non-alcoholic drink; alcoholic drink; other) and unflavoured. Flavour variables were coded as 'selected' versus 'not selected' (including 'don't know' and 'refused' responses). Youth who did not select any of the flavour categories were excluded (n=39).

Current vaping device type: Respondents who indicated ever trying more than one e-cigarette type were asked: "Which of the following TYPES of e-cigarettes/ vaping devices do you currently use MOST OFTEN?" and shown a response option (with image) for each of the types selected in the previous item for 'ever' use (disposable, prefilled pod/cartridge, e-liquid bottle/tank), 'don't know' or 'refused'. Respondents who reported ever using only one type were coded as using that type most often. For each device type, responses were coded as 'selected' versus not; respondents could select more than one current device type, so the variables for device type were not mutually exclusive.

Dependent variables

Respondents were asked to report e-cigarette consumption in the past 30 days using questions tailored to the device type(s)

they reported using. Respondents who used more than one device type were asked about each device type separately. Briefly, respondents were asked, "About how many [disposable vapes / cartridges or pods /bottles of e-liquid/juice] did you use up in the past 30 days?" and "About how much liquid is in the [disposable vape/cartridges or pods/e-liquid bottles] you use most often?" For disposable vapes, participants provided a numeric response in either millilitres or puffs. For cartridges/pods and e-liquid bottles, participants selected from categorical volume responses. Online supplemental file 1 includes the full question wording, response options and exclusion numbers and percentages for 'don't know' and 'refused' responses.

Total e-liquid consumed in past 30 days (mL): To determine how much e-liquid was consumed in the past 30 days for each device type, the number of products used was multiplied by the volume of e-liquid reported in the product used most often, for each of the device types reported. For respondents who reported using more than one device type in the past 30 days, the total e-liquid consumed across all types was calculated by summing the total e-liquid consumed for each device type. If respondents had missing data on any of the three e-cigarette types (disposables, prefilled pods/cartridges or e-liquid bottles/tanks), the total measure was treated as missing, and they were excluded from analyses of this measure only.

For volume response categories presented as ranges (eg, '1.0–1.5 mL'), the median value of the category was assigned. Maximum values for open-ended responses on product number and volume were based on a retail scan of the top four usual brands in each country and supplemented with qualitative information from vaping forums. For disposable e-liquid volume, minimum values were determined by the retail scan. For each device type, open-ended responses exceeding the maximum (for all volume items) or below the minimum value (for disposable e-liquid volume only) were replaced with the median of that category. Non-numeric responses (eg, 'a lot') were also assigned the median of the open-ended category.

To estimate the e-liquid volume of disposable products, self-reported puff amounts were converted to millilitres using a puff-to-mL ratio derived from manufacturer product labels from a retail scan (eg, 'Puff Bar 8000 puffs'). In general, as the number of puffs in devices increased, so did the number of puffs per millilitre. Generally, the ratio was 250 puffs/mL in disposable vapes with less than 600 puffs, 300 puffs/mL in vapes with 600–999 puffs, 400 puffs/mL in vapes with 1000–5000 puffs and 500 puffs/mL in vapes with more than 5000 puffs.

Analysis

Poststratification sample weights were calculated for each country using population estimates for sociodemographic variables; wave 1 estimates for student status (student vs not) and academic grades in Canada, England and the USA; and, calibration to the trend over time for smoking in the last 30 days indicated by the National Youth Tobacco Survey in the USA and the Canadian Student Tobacco, Alcohol and Drugs Survey in Canada. Respondents were classified into sex-by-age-by-region groups in Canada and England, sex-by-age-by-region-by-race groups in the USA, and sex-by-ethnicity groups for each year of age in NZ.[31] Weights were rescaled to the analytic unweighted sample size of respondents within each country.

Linear regression models examined total e-liquid consumption across all e-cigarette types used in the past 30 days in relation to potential predictor variables. Models were built in three steps: Step 1 included variables for country, age, sex-at-birth, exclusive vaping vs dual-use and device type. In step 2, indicators of vaping dependence (ie, urges, perceived addiction, number of days vaped and EDS scores) were added to the step 1 model; each dependence indicator was added separately to avoid collinearity. In step 3, five dummy variables for e-liquid flavour were added to the step 1 model. All statistical analyses were conducted using SAS V.9.4. 'Don't know' and 'refused' responses were excluded on a case-wise basis.

Sensitivity analyses

Steps 1–3 above were repeated in models stratified by device type (ie, disposables, pods/cartridges and e-liquid bottles/tanks). Exploratory analyses compared self-reported and 'objective' manufacturer-reported e-liquid volumes of Elf Bar cartridge/pod and disposable e-cigarette products—the most commonly reported brand among youth—for a subset of respondents (see online supplemental file 1).

RESULTS

Table 1 presents sample characteristics by country and across all countries. Briefly, participants mostly reported exclusive vaping (70.0%) in the past 30 days, used disposable vapes most often (74.1%) and vaped fruit flavours most often (82.5%).

E-liquid consumption

Table 2 shows the mean and median number of products consumed and the total volume of e-liquid consumed in the past 30 days, by device type (see online supplemental figure S1 for visualization). Across all countries and device types, youth who vaped in the past 30 days consumed a median of 9.7 mL and a mean of 22.4 mL of e-liquid in the past 30 days.

Table 3 presents results from the adjusted regression model of total e-liquid consumption from all e-cigarette devices used in the past 30 days (step 1). Youth who exclusively used pods/cartridges had the lowest consumption, followed by exclusive use of disposables ($\beta=9.8$, $p<0.0001$) and exclusive use of e-liquid bottles/tanks ($\beta=30.4$, $p<0.0001$). Use of multiple devices was associated with greater e-liquid consumption, with the highest among youth who used all three device types ($\beta=54.6$, $p<0.0001$). No significant differences in e-liquid consumption were found for age, sex and exclusive vaping versus dual use.

Differences in e-liquid consumption by country and sociodemographic variables

Table 3 also shows differences in total e-liquid consumption by country, sociodemographic variables and exclusive vaping vs dual use. Compared with youth who vape in the USA, youth in Canada and England consumed more e-liquid in the past 30 days ($\beta=4.6$, $p=0.048$ and $\beta=4.8$, $p=0.027$, respectively). In stratified models by device type (ie, disposables, cartridges/pods, e-liquid bottles), youth in NZ reported greater e-liquid consumption from disposables compared with youth in the USA, while youth in England who used e-liquid bottles/tanks reported greater consumption than youth in the USA (see online supplemental table S1).

There was no evidence of any significant differences in total e-liquid consumption by age, sex-at-birth or between exclusive vaping versus dual use (see table 3). The findings from models stratified by device type were similar, except that e-liquid consumption was higher for dual-using versus exclusive vaping among youth who used disposables ($\beta=4.5$, $p=0.013$).

Table 1 Sample characteristics of youth who vaped at least a few puffs in the past 30 days, overall and by country, weighted % (n)

	Canada (n=646)	England (n=1194)	New Zealand (n=320)	USA (n=756)	Total (n=2916)
Age, mean years (SE)	17.8 (0.04)	17.6 (0.04)	17.7 (0.08)	17.7 (0.06)	17.7 (0.02)
Sex-at-birth					
Female	51.5% (333)	55.0% (657)	56.8% (182)	56.7% (429)	1599 (54.9%)
Male	48.5% (313)	45.0% (537)	43.2% (138)	43.3% (327)	1317 (45.1%)
Past 30-day exclusive/dual use status					
Exclusive vaping	74.7% (483)	57.4% (685)	65.3% (209)	88.0% (665)	70.0% (2042)
Dual use (vaping and smoking)	25.3% (163)	42.6% (509)	34.7% (111)	12.0% (91)	30.0% (874)
Frequency of vaping*					
1–9 days	30.5% (196)	31.8% (379)	21.2% (68)	27.0% (204)	29.1% (846)
10–19 days	10.8% (69)	11.7% (139)	6.8% (22)	10.6% (80)	10.7% (310)
20–30 days	46.9% (302)	40.2% (479)	57.6% (183)	48.0% (362)	45.6% (1326)
Don't know	11.9% (76)	16.4% (195)	14.4% (46)	14.3% (108)	14.6% (425)
Frequency of strong urges to vape					
Never	16.5% (107)	17.6% (209)	9.4% (30)	15.7% (119)	16.0% (465)
Less than once a week	9.8% (63)	8.9% (106)	10.4% (33)	11.6% (88)	10.0% (290)
At least once a week	17.6% (114)	18.4% (220)	17.0% (54)	15.4% (116)	17.3% (504)
Every day or most days	23.0% (149)	24.6% (293)	21.1% (68)	19.1% (144)	22.4% (653)
Several times a day	31.3% (202)	28.0% (333)	40.8% (130)	34.8% (263)	31.9% (928)
Don't know	1.9% (12)	2.6% (30)	1.3% (4)	3.5% (26)	2.5% (81)
Perceived addiction to vaping					
Not at all	33.6% (217)	32.0% (381)	21.0% (67)	34.2% (258)	31.7% (319)
A little addicted	39.5% (255)	43.5% (517)	42.6% (136)	39.6% (299)	41.5% (1207)
Very addicted	23.8% (154)	21.3% (254)	34.6% (110)	23.1% (174)	23.8% (691)
Don't know	3.1% (20)	3.2% (38)	1.8% (6)	3.1% (23)	3.0% (87)
Total EDS score†, mean (SE)	6.1 (0.2)	6.1 (0.1)	7.2 (0.3)	5.9 (0.2)	6.1 (0.1)
Current vaping device type‡					
Disposables	61.0% (394)	85.0% (1014)	67.0% (214)	71.1% (538)	74.1% (2161)
Pods/Cartridges	42.3% (273)	13.1% (157)	31.6% (101)	36.5% (276)	27.7% (807)
Refillable tanks	17.8% (115)	13.3% (159)	22.0% (70)	11.8% (89)	14.9% (434)
Current flavours‡					
Tobacco/menthol	7.6% (48)	6.6% (78)	11.5% (36)	8.1% (60)	7.7% (223)
Mint/menthol/tobacco menthol	17.1% (109)	8.4% (100)	22.5% (70)	29.8% (221)	17.4% (500)
Fruit	82.4% (527)	86.6% (1,023)	77.9% (577)	77.6% (243)	82.5% (2370)
Sweet/drinks/other	14.9% (95)	18.3% (216)	21.8% (68)	14.4% (107)	16.9% (486)
Unflavoured	0.8% (5)	0.3% (4)	0.5% (1)	0.6% (5)	0.5% (15)

*Of the past 30 days.
†E-Cigarette Dependence Scale (EDS).
‡Categories are not mutually exclusive.

Differences in total e-liquid consumption by indicators of dependence

All four indicators of dependence were associated with greater e-liquid consumption (see figure 1, online supplemental tables S2 to S5). For example, youth reporting strong urges to vape e-cigarettes several times a day (β=22.7, p<0.0001), every day or most days (β=15.5, p<0.0001), and at least once a week (β=7.4, p=0.001) reported greater e-liquid consumption compared with those reporting never experiencing strong urges to vape (see online supplemental table S2). Similarly, youth who perceived themselves as very (β=21.4, p<0.0001) or a little (β=12.1, p<0.0001) addicted to e-cigarettes reported greater overall e-liquid consumption compared with youth who did not perceive themselves as addicted to e-cigarettes at all. In addition, youth who vaped on 20–30 (β=22.4, p<0.0001) or 10–19 (β=8.9, p=0.001) of the past 30 days reported greater e-liquid consumption compared with youth who vaped on 1–9 days. Lastly, e-cigarette consumption was positively associated with EDS scores (β=8.6, p<0.0001).

In models stratified by device type, a similar 'dose-response' pattern was observed for each of the four indicators of dependence, for disposables, pods/cartridges and e-liquid bottles/tanks, respectively (see online supplemental table S6 to S9).

Differences in e-liquid consumption by flavour

Table 4 shows estimates from the adjusted regression model that included e-liquid flavour variables. Youth who vaped fruit flavours reported the greatest e-liquid consumption (β=9.1, p=0.001), with modest evidence of higher consumption for sweet/drinks/other flavours (β=4.3, p=0.093). No differences were observed for other flavour categories (see online supplemental figure S2 for visualisation).

In models stratified by device type, the pattern of results was similar: fruit flavours were associated with the highest e-liquid consumption for disposables (β=7.8, p=0.005) and, to a lesser extent, for e-liquid bottles/tanks (β=11.6, p=0.093), but not pods/cartridges. Sweet/drinks/other flavours were associated with

Table 2 Estimates of number of products and total e-liquid consumption (mL) in the past 30 days, weighted (unadjusted)

	Canada			England			New Zealand			USA			Total		
	Mean	Median	n	Mean	Median	n	Mean	Median	n	Mean	Median	n	Mean	Median	n
Number of products used in the past 30 days															
Disposables vapes	2.0 (1.1)	0.9 (0.1)	389	2.9 (0.1)	1.4 (0.1)	1002	2.5 (0.2)	1.3 (0.2)	211	2.0 (0.2)	1.0 (0.1)	526	2.5 (0.1)	1.1 (0.1)	2127
Pods/cartridges	3.1 (0.2)	1.5 (90.2)	247	2.4 (0.3)	1.3 (0.2)	143	2.5 (0.4)	1.0 (0.2)	88	2.3 (0.2)	0.9 (0.1)	254	2.6 (0.1)	1.1 (0.1)	7331
E-liquid bottles	1.4 (0.2)	0.8 (0.1)	104	2.4 (0.3)	1.1 (0.2)	145	0.9 (0.1)	0.5 (0.1)	67	0.8 (0.1)	0.3 (0.1)	83	1.6 (0.1)	0.7 (0.1)	398
Total e-liquid consumption (mL) in the past 30 days															
Disposable vapes	19.2 (2.0)	8.5 (1.1)	205	19.5 (1.3)	8.7 (0.5)	577	22.5 (2.0)	17.2 (2.3)	122	15.6 (1.7)	8.3 (1.5)	260	18.9 (0.8)	9.6 (0.6)	1164
Pods/cartridges	11.1 (1.2)	5.3 (0.9)	158	8.4 (1.8)	3.3 (0.4)	119	11.7 (2.6)	3.2 (1.4)	65	8.4 (1.1)	2.1 (0.5)	162	9.7 (0.9)	3.6 (0.4)	503
E-liquid bottles	43.5 (4.9)	27.6 (4.3)	91	48.1 (4.9)	27.9 (3.8)	134	31.4 (4.1)	26.4 (5.2)	63	30.0 (5.5)	12.6 (2.8)	66	40.6 (2.7)	26.5 (2.9)	354
Across all products	23.3 (1.8)	9.9 (1.1)	426	23.9 (1.5)	9.3 (0.5)	781	25.0 (2.2)	17.7 (2.7)	219	17.2 (1.6)	7.2 (1.2)	430	22.4 (0.9	9.7 (0.5)	1842

Mean (SE), median (SE).

Table 3 Linear regression (step 1) of e-liquid consumption in the past 30 days across all e-cigarette products, by sociodemographic and e-cigarette use variables, n=1842

	E-liquid consumption across all products (mL)*		
	Beta	95% CI	P value
Country			
USA	ref	ref	ref
Canada	4.6	0.05 to 9.11	0.048
England	4.8	0.55 to 8.95	0.027
New Zealand	4.2	−1.10 to 9.45	0.121
Age	−0.7	−2.33 to 1.02	0.444
Sex-at-birth			
Male	ref	ref	ref
Female	−0.8	−4.14 to 2.48	0.624
Past 30-day exclusive/dual use status			
Exclusive vaping	ref	ref	ref
Dual use (vaping and smoking)	2.1	−1.30 to 5.53	0.225
Device type			
Pod only	ref	ref	ref
Disposable only	9.8	6.85 to 12.70	<0.0001
Tank/e-liquid bottle only	30.4	23.70 to 37.08	<0.0001
Disposable+pod	10.0	4.75 to 15.30	0.0002
Disposable+tank/e-liquid bottle	39.3	27.76 to 50.74	<0.0001
Pod+tank/e-liquid bottle	31.9	13.89 to 49.97	0.0005
Disposable+pod+tank/e-liquid bottle	54.6	34.82 to 74.36	<0.0001

*Linear regression modelling the amount of e-liquid (mL) consumed across all products with age (years), sex, country, past 30-day exclusive vaping/dual use status and device type as predictors (model step 1).

greater consumption for disposables only (β=6.3, p=0.021). For pods/cartridges, mint/menthol/mix of tobacco and menthol was associated with highest consumption (β=5.6, p=0.026, see online supplemental table S10).

DISCUSSION

The current study provides quantitative estimates of youth e-liquid consumption from vaping using self-reported data from population-level surveys. The findings suggest substantial levels of past 30-day e-liquid consumption: youth who vaped reported consuming a median of nearly 10 mL of e-liquid and a mean of 22 mL of e-liquid in the past 30 days. The discrepancy between the median and mean indicates the wide range of intakes and the positively skewed distribution of consumption. These estimates exceed those previously reported by PATH study participants in 2018/2019, in which 12–17 years were estimated to take a median of approximately 50 vaping puffs per month.[16] Lower estimates in the PATH study may reflect the younger age of the subsample and methodological challenges with the PATH measures, as well as possible changes in consumption since the study was conducted.[16] Adult studies also report high consumption: several studies have found that adults consume approximately 1.5 cartridges/pods/refills per day, though these estimates are derived from lab-based studies and may not be representative of the broader profile of people who vape.[17 27 28]

E-liquid consumption was similar across three of the four countries, with lower levels in the USA. Notably, the USA is the only country among the four studied without a regulatory limit on the nicotine concentration in vaping products. While nicotine concentrations were not directly assessed in the current study,

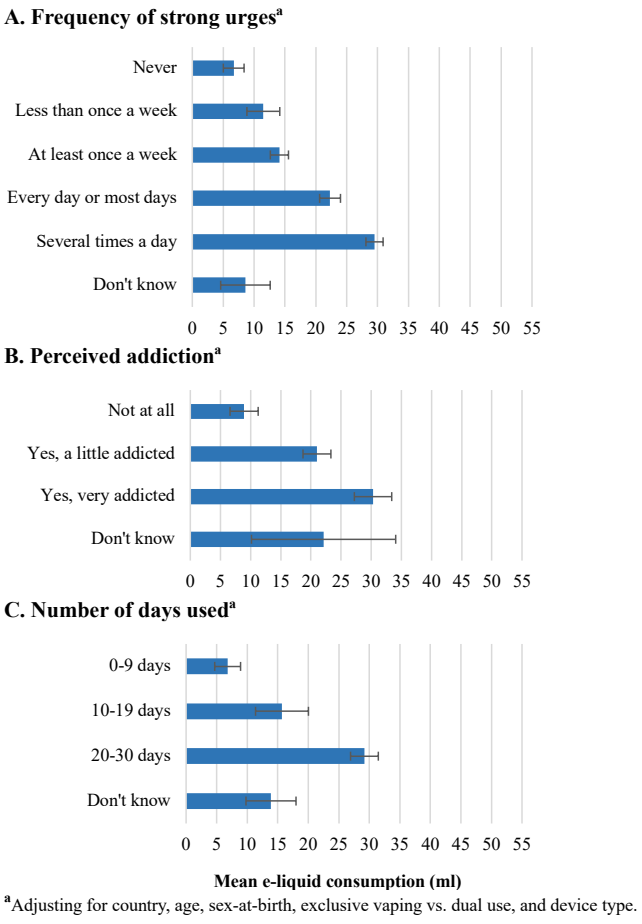

Figure 1 Mean e-liquid consumption (mL) among youth aged 16–19 who vaped at least a few puffs in the past 30 days by indicators of dependence, weighted (adjusted).

market-based data indicate much higher nicotine concentrations in the USA. As of 2022, more than 80% of e-cigarette sales were products with ≥50 mg/mL of nicotine, levels that are commercially sold only with nicotine salt formulations.[32 33] By comparison, in Canada, a market scan in 2021 indicated an average nicotine content of 17.9 mg/mL in vaping products.[34] We are unaware of similar market estimates in the UK or NZ, where nicotine levels are also capped at 20 mg/mL.[9]

Lower self-reported consumption of e-liquid among youth who vape in the USA may reflect a type of population-level compensatory behaviour—a well-established phenomenon at the individual level in which consumers adjust their use behaviour to titrate nicotine intake to their desired level.[35] Given the higher nicotine concentrations available in vaping products in the USA, youth may vape fewer puffs to achieve similar nicotine exposure. This represents a potentially important, but speculative, hypothesis that warrants additional study.

Regardless of country-level differences, these findings are consistent with biomarker data indicating that youth vaping is associated with considerable nicotine exposure.[36] Based on the typical nicotine concentrations—~18 mg/mL in Canada and ~50 mg/mL in the USA—median nicotine exposure among youth who vape may range from 180 mg to 500 mg per month. As with smoking, individual consumption varies widely, and other factors that are not addressed in the current study, such as depth of inhalation, will affect nicotine intake.[37] Prior research on adults who vape found that the self-reported number of products/cartridges used over the past 30 days was strongly associated with biomarkers of nicotine intake.[28] Measuring consumption by volume and product amounts (eg, number of pods) may be a more reliable indicator of intake than self-reported puffing amounts, given that various factors can determine the size and duration of puffs (eg, nicotine 'flux').[37] Future research should examine the correspondence between different self-reported measures for estimating consumption, including efforts to cross-validate with biomarkers of exposure. Studies should also examine how evolving products—such as nicotine salt e-liquids, which have been associated with higher consumption levels and greater nicotine intake—impact consumption.[36–39]

E-liquid consumption was associated with greater dependence, as measured by frequency of strong urges, perceived addiction, number of days of e-cigarette use in the past month and scores on the EDS. Prior research on adults who smoke and vape reports evidence of a positive association between the average level of e-cigarette consumption and scores from the Penn State Electronic Cigarette Dependence Index (PS-ECDI) and E-cigarette Fagerström Test of Cigarette Dependence (e-FTCD).[40] Like the 4-item EDS used in the current study, the PS-ECDI and e-FTCD are validated measures of e-cigarette dependence and measure primary dependence motives, such as cravings.[40 41] Relative to

Table 4 Linear regression (step 3) of e-liquid consumption in the past 30 days across all e-cigarette products, by sociodemographic, e-cigarette use and current flavour variables, n=1820

	E-liquid consumption across all products in mL*		
	Beta	**95% CI**	**P level**
Country			
USA	ref	ref	ref
Canada	4.1	−0.59 to 8.83	0.086
England	3.7	−0.68 to 8.17	0.097
New Zealand	3.8	−1.54 to 9.21	0.162
Age	−0.8	−2.52 to 0.92	0.362
Sex-at-birth			
Male	ref	ref	ref
Female	−1.3	−4.61 to 2.11	0.465
Past 30-day exclusive /dual use status			
Exclusive vaping	ref	ref	ref
Dual using (vaping and smoking)	3.1	−0.47 to 6.75	0.088
Current flavours			
Tobacco/menthol	−2.0	−8.84 to 4.81	0.563
Else			
Mint/menthol/mix of tobacco and menthol	3.7	−1.25 to 8.75	0.1420
Else			
Fruit	9.1	3.94 to 14.25	0.001
Else			
Sweet/drinks/other	4.3	−0.73 to 9.40	0.093
Else			
Unflavoured	−2.3	−16.28 to 11.78	0.753
Device type			
Pod only	ref	ref	ref
Disposable only	9.0	6.03 to 11.97	<0.0001
Tank/ e-liquid bottle only	30.5	23.82 to 37.19	<0.0001
Disposable+pod	8.4	2.97 to 13.82	0.002
Disposable+tank/e-liquid bottle	39.7	27.89 to 51.59	<0.0001
Pod+tank/e-liquid bottle	30.3	11.55 to 49.11	0.002
Disposable+pod+tank/e-liquid bottle	52.3	31.64 to 72.94	<0.0001

*Linear regression modelling the amount of e-liquid (mL) consumed across all products with current flavours, age (years), sex, country, past 30-day exclusive vaping/dual use status and device type as predictors (model step 3).

conventional cigarettes, vaping devices are easier to conceal and can be used more discreetly throughout the day, which may increase the likelihood of more frequent use and dependence among young people.[42] Data from the PATH study previously reported that consumption measured in 'puffs per month' was associated with cravings and frequency of use.[16]

E-liquid consumption was greater among youth who used e-liquid bottles/tanks than those who exclusively used disposables or pods, likely due to the nature of the self-reported measure, since e-liquid bottles typically have larger volumes than disposables and pods. Previous research has found inconsistent findings on patterns of use and intake based on device type, which likely reflects different temporal trends in the popularity of device types, self-selection and differential rates of adoption of pods/cartridges and disposables, and compensatory behaviour.[35]

E-liquid consumption also differed by flavours: consumption was higher among youth who vaped fruit flavours, with possible higher consumption for vaping sweet/drinks/other flavours. Previous research has demonstrated that flavours play an important role in the appeal of vaping products, particularly among young people.[43 44] The current study suggests that fruit and other sweet flavours are not only more appealing to youth but may also be associated with greater consumption.[21 22] The effect size of fruit and sweet/drinks/other flavours was greatest for disposables, which have increased in popularity in recent years among youth and, to a lesser extent, among adults who vape.[29 30] Youth PATH Study participants (n=200) who vaped fruit flavours measured at moderately higher point estimates for cotinine, a marker of nicotine intake; however, differences were not statistically significant.[45] Future research should examine how flavours may interact with the nicotine profile of e-liquids to influence consumption.

Limitations

This study has several limitations. First, the direction of causality for associations cannot be determined due to the cross-sectional design. Second, the estimates may not be nationally representative as the study sample was recruited through non-probability sampling; however, poststratification weights were used to enhance the representativeness of the analytical samples. This limitation likely has little effect on analyses conducted among those who vaped in the past 30 days. Third, the findings are not generalizable to all youth, as analyses were limited to youth who reported vaping in the past 30 days. Lastly, the use of self-reported data introduces recall and measurement bias. Self-reported data used to estimate e-liquid consumption are unavoidably less accurate than direct physiological measurements of vaping consumption. In the current study, approximately 45% of people who used disposable devices reported not knowing the volume of e-liquid in their product, versus one-third for pods/cartridges and 14% of people who used 'refillable' tank systems. A supplemental analysis comparing self-reported product data (eg, the amount of e-liquid or puffs in their usual brand) of a popular e-cigarette brand with objective data sourced directly from manufacturer websites showed high agreement (see online supplemental file 1). Nevertheless, not all respondents can recall this information and efforts to mitigate non-response, including imputation of median values for responses outside of a 'valid' range, may introduce measurement bias. Overall, while the methods to estimate vaping consumption from self-reported data are encouraging, there is a need for further validation using biomarker data and 'objectively' verified product information. More generally, the findings also highlight the need for standardized labelling practices of vaping products, including for nicotine content and product volume, such as labelling the number of puffs in a product.[46]

CONCLUSIONS

This study highlights substantial levels of e-cigarette consumption and potentially considerable nicotine exposure among youth who vape. The findings suggest that patterns of consumption vary across countries, with notable differences between device types and flavour preferences. Additionally, the association between higher e-liquid consumption and increased dependence underscores the potential risks of vaping addiction for youth. The findings emphasise the need to refine methods for estimating vaping consumption using self-reported measures and to validate these findings against biomarkers of exposure.

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analysis and drafted the manuscript with regular major input from coauthors. JLR, EVT, RE, RO'C and AH contributed to the interpretation of the data and critically revised the manuscript. All coauthors approved the final version. DH is the guarantor of the work.

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