Prevalence of vaping and smoking among adolescents in Canada, England, and the United States: repeat national cross sectional surveys

David Hammond,1 Jessica L Reid,1 Vicki L Rynard,1 Geoffrey T Fong,2,3 K Michael Cummings,6 Ann McNeill,5 Sara Hitchman,5 James F Thrasher,6 Maciej L Goniewicz,7 Maansi Bansal-Travers,7 Richard O’Connor,7 David Levy,8 Ron Borland,9 Christine M White1

ABSTRACT

OBJECTIVE
To examine differences in vaping and smoking prevalence among adolescents in Canada, England, and the United States.

DESIGN
Repeat cross sectional surveys.

SETTING
Online surveys in Canada, England, and the US.

PARTICIPANTS
National samples of 16 to 19 year olds in 2017 and 2018, recruited from commercial panels in Canada (n=7891), England (n=7897), and the US (n=8140).

MAIN OUTCOME MEASURES
Prevalence of vaping and smoking was assessed for use ever, in the past 30 days, in the past week, and on 15 days or more in the past month. Use of JUUL (a nicotine salt based electronic cigarette with high nicotine concentration) and usual vaping brands were also assessed. Logistic regression models examined differences in vaping and smoking between countries and over time.

RESULTS
The prevalence of vaping in the past 30 days, in the past week, and on 15 days or more in the past month increased in Canada and the US between 2017 and 2018 (P<0.001 for all), including among non-smokers and experimental smokers, with no changes in England. Smoking prevalence increased in Canada (P<0.001 for all measures), with modest increases in England, and no changes in the US. The percentage of ever vapers who reported more frequent vaping increased in Canada and the US (P<0.01 for all), but not in England. The use of JUUL increased in all countries, particularly the US and Canada—for example, the proportion of current vapers in the US citing JUUL as their usual brand increased threefold between 2017 and 2018.

CONCLUSIONS
Between 2017 and 2018, among 16 to 19 year olds the prevalence of vaping increased in Canada and the US, as did smoking in Canada, with little change in England. The rapidly evolving vaping market and emergence of nicotine salt based products warrant close monitoring.

Introduction
Vaping most likely represents a less harmful mode of nicotine delivery compared with inhalation of smoke from combustible cigarettes.1 Although the number and levels of toxicants are lower in aerosol from electronic cigarettes than from tobacco smoke, long term exposure to e-cigarette vapor might cause nicotine dependence and increase the risk of respiratory and cardiovascular health effects.1 In addition, though the use of e-cigarettes might assist established smokers in quitting smoking,2 there are widespread concerns that vaping could undermine reductions in smoking among young people.1 A robust association has been found between smoking and vaping, including in prospective cohort studies, showing that young people who vape have an increased risk of subsequent smoking, and vice versa.3 5 The extent to which these associations are causal remains unclear, as common risk factors could account for a substantial proportion of the association; however, it is also plausible that exposure to nicotine in one product might increase use of the other product.1 3 6

Regulatory frameworks for vaping products continue to evolve as countries seek a balance between preventing vaping among non-smokers without discouraging current smokers from switching to vaping.2 In May 2018, Canada implemented more permissive vaping policies as part of the Tobacco and Vaping Products Act.7 Previously, e-cigarettes containing nicotine could not be sold or advertised in Canada without premarket approval. Although no products were approved for

WHAT IS ALREADY KNOWN ON THIS TOPIC
Vaping among adolescent has increased over the past five years in Canada, England, and the US; however, frequent vaping has been rare, particularly among non-smokers
A new generation of nicotine salt vaping devices has emerged, such as JUUL, with high nicotine concentrations in North America; the impact of the market transition to nicotine salt products is largely unknown
In 2018, Canada also introduced a more permissive regulatory framework, which increased marketing and access to vaping products

WHAT THIS STUDY ADDS
The prevalence and frequency of vaping among US and Canadian adolescents increased between 2017 and 2018, along with increases in smoking among Canadian adolescents
Fewer changes were observed among adolescents in England, possibly as a result of greater marketing restrictions and maximum nicotine limits under the European Tobacco Product Directive
The findings suggest that vaping among young people might be changing in North American markets, in parallel with the rise of JUUL and the rapid emergence of nicotine salt vaping products

For numbered affiliations see end of the article.
Correspondence to: D Hammond
dhammond@uwaterloo.ca (or @davidhammondphd on Twitter;
ORCID 0000-0001-8197-6010)
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1 Department of Public Health Sciences, University of Waterloo, Waterloo, Canada
2 School of Public Health Sciences, University of Waterloo, Waterloo, Canada
3 Centre for Research in Public Health and Development, London School of Economics, London, UK
4 School of Public Health, University of Alabama at Birmingham, Birmingham, Alabama, USA
5 Department of Psychology and Centre for Tobacco Control Research and Education, University of Toronto, Toronto, Ontario, Canada
6 Health Economics and Outcomes Research, University of British Columbia, Vancouver, BC, Canada
7 Department of Population, Environment and Public Health, Uppsala University, Uppsala, Sweden
8 Department of Community and Family Medicine, University of Virginia, Charlottesville, Virginia, USA
9 Department of Sociology, University of Waterloo, Waterloo, Canada

Cardiopulmonary and cardiovascular health effects may be less severe with e-cigarette use compared to smoking.1 7 8 It remains unknown whether exposure to nicotine salts via vaping has a different effect than exposure to nicotine from smoking or other nicotine delivery methods.8

References
2 Leventhal ML, Brownson RC, Greenslade E, et al. The role of e-cigarettes in smoking cessation among young adults and published studies on their efficacy as a smoking cessation tool. JMIR Public Health Surveill 2018;4(1):e42.
legal sale, e-cigarettes containing nicotine were widely available in vape shops and online, in addition to non-nicotine e-cigarettes from traditional retail outlets. In May 2018, e-cigarettes containing nicotine became legally available for sale, which increased retail access, including for major international brands such as JUUL and Vype. The new act also permits greater advertising and promotion of vaping products, including mass media advertisements and point-of-sale displays, unless prohibited at the provincial level. Overall, the vaping market in Canada experienced rapid change, bringing it closer to the less restrictive regulatory settings in countries such as England and the US. In England, e-cigarettes can enter the market either as medicines or as consumer products. Currently, all e-cigarettes are sold as consumer products and can also be recommended through local stop smoking services. E-cigarettes sold in England are subject to the European Tobacco Product Directive, which requires health warnings, restricts certain forms of marketing, and imposes a nicotine limit of 20 mg/mL of e-liquid, in addition to codes of practice that restrict more egregious marketing practices. In the US, manufacturers are prohibited from making misleading health or cessation claims, although e-cigarettes are subject to fewer restrictions on advertising and promotion than in England. All three countries prohibit the sale of e-cigarettes to minors.

Relatively little evidence exists on the impact of different regulatory approaches on vaping prevalence. Among adults, preliminary evidence suggests that more restrictive measures might be associated with lower prevalence of vaping, although there are notable exceptions, possibly as a result of low compliance with regulations in many restrictive markets. One study of middle school and high school students examined differences between South Korea and the US and found lower rates of both vaping and smoking in South Korea, whereas the National Youth Tobacco Survey reported an increase of 0.5% in 2018, for a past 30 day smoking prevalence of 8.1% among high school students. The reason for the discrepancy between surveys is unclear, given that both are nationally representative school based surveys conducted in the first half of the calendar year. Fewer data exist on smoking and vaping among adolescents in England. Non-probability samples suggest that ever vaping has increased among 17 and 18 year olds, from 2015 (21.7%) to 2018 (28.2%), as has weekly vaping (0.8% in 2015, 2.9% in 2018). The same non-probability samples suggest that smoking has decreased over the past decade in England: “regular” smoking among 17 and 18 year olds declined from 8.3% in 2015 to 7.2% in 2018.

The vaping market in North America has evolved rapidly over the past two years owing to the growth of JUUL e-cigarettes and similar products. JUUL uses benzoic acid and nicotine salt technology to deliver higher concentrations of nicotine than conventional e-cigarettes; indeed, the nicotine concentration in the standard version of JUUL is more than 50 mg/mL, compared with typical levels of 3-24 mg/mL for other e-cigarettes. JUUL was introduced to the US market in 2015, with the largest growth occurring in 2018, such that JUUL now accounts for about half the e-cigarette market. JUUL became available for sale in England in July 2018 (although with the nicotine level capped at 20 mg/mL), and in Canada in September 2018. One of the central questions surrounding JUUL is the extent to which use among young people has contributed to its growth. News reports and social media analyses suggest that both the marketing and discreet product design of JUUL are particularly appealing to young people, whereas several cross sectional surveys suggest increasing levels of awareness and use. Overall, there is a need to examine whether vaping among adolescents might be shifting in response to changes in the design of vaping products and the emergence of nicotine salt based technology.

In the current study, we compared changes between 2017 and 2018 in the prevalence of vaping and cigarette smoking among 16 to 19 year olds in Canada, England, and the US. This age group captures a substantial proportion of both vaping and smoking initiation in all three countries. In particular, we examined whether changes to the Canadian vaping market, as a result of the new regulatory framework in 2018, were associated with changes in the prevalence of smoking or vaping.
Although no major regulatory changes for vaping were implemented in the US or England over the same period, the US product market underwent considerable change after the emergence of JUUL. Because of the combination of regulatory changes and introduction of JUUL in Canada, we hypothesized that the greatest increases in vaping would occur in Canada, followed by the US (with the highest penetration of JUUL), with the least change in England.

**Methods**

**Data source**

Data are from the first two waves of the International Tobacco Control Policy Evaluation Project (ITC) Youth Tobacco and Vaping Survey, conducted in Canada, England, and the US. Online surveys were conducted in July to August 2017 (wave 1) and August to September 2018 (wave 2). The same methods and recruitment protocols were used in all three countries. Respondents were recruited from the Nielsen Consumer Insights Global Panel, which maintains panels in Canada, England, and the US, as well as their partners’ panels. The Nielsen panel is recruited using both probability and non-probability sampling methods in each country. Nielsen selected random samples from the online panels in each country. We identified target sample sizes of 4500 for each country at each wave, based on sample size calculations to detect an absolute change of about 2% in vaping and smoking prevalence across waves. Eligible respondents included adolescents aged 16 through 19 at the time of recruitment. Respondents were recruited either directly or through their parents. Email invitations (with a unique link) were sent to a random sample of panelists (after targeting for age criteria); panelists known to be ineligible were not invited. Nielsen also contacted panelists known to be parents; those who confirmed they had one or more children aged 16–19 living in their household were asked for permission for their son or daughter to complete the survey (if more than one, specifically the one whose birthday was next). After eligibility screening, we provided potential respondents with information about the study and asked them to provide consent to participate. A restriction on small screen size was applied to ensure that images presented in the survey could be viewed with a minimum amount of scrolling or distortion.

The current analyses are based on the repeat cross sectional samples of the ITC Youth Tobacco and Vaping Survey. A total of 13,468 respondents completed the wave 1 survey and 13,423 respondents completed the wave 2 survey. Overall, 724 participants (n=382 at wave 1; n=342 at wave 2) were excluded from the sample based on data integrity checks. We also excluded participants from the analyses based on missing or incomplete data on variables required for calculating weights or determining smoking or vaping status. The analytic sample included 12,128 participants recruited at wave 1 and 11,800 newly recruited participants at wave 2. A full description of the study methods can be found in the technical report.24

**Measures**

Respondents were asked if they had ever tried an e-cigarette/vaped, the number of days they had used an e-cigarette/vaped in their lifetime, and the last time they had used an e-cigarette/vaped (analyzed as ever, past 30 day, and past week vaping). Parallel questions were asked for cigarette smoking, and used to derive ever, past 30 day, and past week smoking. In addition, respondents were classified as never smokers, experimental smokers (smoked fewer than 100 cigarettes in lifetime), current smokers (smoked at least 100 cigarettes in lifetime and smoked in past 30 days), or former smokers (smoked at least 100 cigarettes in lifetime but had not smoked in past 30 days). Participants who had vaped in the past 30 days were asked the number of days that they had vaped in the past 30 days. Race/ethnicity was assessed using adapted census questions in each country. To allow for cross country comparisons, we recoded the country specific measures into white (only) or other (including any other race/ethnicity and not stated). We also assessed alcohol and cannabis use in the past 12 months.

Participants who had vaped in the past 30 days were asked to report the specific brand of e-cigarette/vaping device they “currently use most often,” using country specific pre-coded checklists, including options for writing in an “Other,” “I don't have a usual brand,” “Don't know,” and “Refused.” In 2018, we asked respondents who vaped in the past year to report any (other) brands used in the past 12 months using the same pre-coded checklist. In addition, all participants were shown an image of JUUL and asked if they had ever used the product. The full survey is available in the technical report.24

**Statistical analysis**

We constructed post-stratification sample weights for each country, based on age, sex, geographic region, and race/ethnicity (US only), and rescaled to the sample size in each country (see technical report 24 for details). To examine changes in prevalence of smoking and vaping between waves, we estimated logistic regression models, adjusting for age (grouped as 16–17 and 18–19 years), sex, and race/ethnicity (white versus other). We examined differences between countries by testing the two way interaction between country and wave. Unless stated otherwise, we report weighted estimates, adjusted odds ratios, and 99% confidence intervals. Respondents with missing data on outcome measures or covariates were excluded from models on a case-wise basis; sample sizes for all analyses are reported in the tables. Analyses were conducted using SAS 9.4.

**Patient and public involvement**

No patients were involved in setting the research question or the outcome measures, nor were they involved in developing plans for recruitment, design, or implementation of the study. No patients were asked to advise on interpretation or writing up of results. The
Results

Table 1 presents the characteristics of respondents in each country. No differences were observed within countries between 2017 and 2018, with the exception of Canada, where fewer respondents identified only as white (adjusted odds ratio 0.63, 99% confidence interval 0.56 to 0.72; P<0.001), and cannabis use in the past 12 months increased (1.33, 1.15 to 1.54; P<0.001).

Prevalence of vaping and smoking

Table 2 presents changes in the prevalence of vaping and smoking across the three countries. Prevalence of all vaping and smoking measures increased between 2017 and 2018 in Canada. No changes were observed for vaping in England, with modest increases in smoking in the past week and 15 days or more in the past month. In the US, the prevalence of vaping in the past 30 days, past week, and 15 days or more in the past month increased, with no changes in smoking behavior. For smoking and vaping ever, in the past 30 days, and in the past week, changes between 2017 and 2018 were significantly different by country and were greatest in Canada (P<0.001 for all).

Changes in vaping prevalence by smoking status

Table 3 shows changes in vaping by smoking status from 2017 to 2018. In Canada, vaping increased among never smokers and experimental smokers, for all measures except 15 days or more in the past month. In the US, vaping increased among never smokers and experimental smokers, for all measures except ever vaping. No changes in vaping were observed by smoking status in England, or among current smokers in any country.

Ratio of ever to more frequent use

Table 4 shows the percentage of ever vapers who reported more recent vaping. In Canada and the US, the percentage of ever vapers who reported vaping in the past 30 days, the past week, and vaping 15 days or more in the past month increased in 2018, compared with 2017. No changes were observed in England. In 2018, ever smokers in Canada were more likely to report smoking 15 days or more in the past month compared with 2017, with no changes observed in the US.

Comparing differences between countries in 2018, ever vapers in the US were most likely, and ever vapers in England were least likely, to report vaping in the past 30 days, past week, and 15 days or more in the past month, except the US was not significantly different from Canada (P=0.014) for vaping in the past week (table 4). For example, 15.6% of ever vapers in the US also reported vaping on 15 days or more in the past month, compared with 6.8% in England (adjusted odds ratio 2.58, 99% confidence interval 1.71 to 3.90; P<0.001). Ever smokers in Canada reported significantly higher percentages than ever smokers in the US of smoking in the past 30 days, past week, and on 15 days or more in the past month (table 4).

In 2018, the ratio of ever use to more recent use tended to be greater for smoking than vaping in Canada and England but greater for vaping than smoking in the US, with the notable exception that similar percentages of ever vapers and ever smokers used on 15 days or more in the past month in the US.

Usual vaping brand and use of JUUL

Table 5 shows the vaping brands used most often by those who had vaped in the past 30 days in 2017 and 2018. In the US, the proportion of past 30 day vapers who reported JUUL as their usual brand increased from 9.4% in 2017 to 28.1% in 2018 (adjusted odds ratio 3.79, 99% confidence interval 2.28 to 6.31; P<0.001). In 2017, no one who had vaped in the past 30 days in Canada or England reported JUUL as their usual brand; in 2018, this increased to 10.3% of past 30-day vapers in Canada and 3.3% in England. In 2018, when asked about brands used in the past 12 months, 41.4% of past year vapers in the US indicated they had used JUUL, compared with 17.7% in Canada and 6.1% in England.

In 2018, 15.8% of respondents in the US reported they had ever tried JUUL, significantly more than in Canada (7.0%; adjusted odds ratio 2.51, 99% confidence interval 2.04 to 3.09; P<0.001) and England (2.2%; 8.55, 6.05 to 12.09; P<0.001).

Discussion

This study found increases in the prevalence of vaping among adolescents aged 16-19 years in the US and

Table 1 | Sample characteristics (weighted), by survey wave and country. Values are percentages (numbers) unless stated otherwise

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Canada 2017 (n=4038)</th>
<th>2018 (n=3853)</th>
<th>England 2017 (n=3995)</th>
<th>2018 (n=3902)</th>
<th>US 2017 (n=4095)</th>
<th>2018 (n=4045)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD) age (years)</td>
<td>17.6 (1.05)</td>
<td>17.5 (1.08)</td>
<td>17.5 (1.02)</td>
<td>17.6 (1.05)</td>
<td>17.5 (1.08)</td>
<td>17.5 (1.07)</td>
</tr>
<tr>
<td>Male</td>
<td>51.4 (2077)</td>
<td>51.5 (1984)</td>
<td>51.3 (2050)</td>
<td>51.3 (2003)</td>
<td>51.1 (2094)</td>
<td>51.1 (2068)</td>
</tr>
<tr>
<td>White only race/ethnicity*</td>
<td>58.4 (2358)</td>
<td>47.1 (1816)</td>
<td>79.4 (3172)</td>
<td>77.0 (3005)</td>
<td>73.4 (3006)</td>
<td>73.4 (2970)</td>
</tr>
<tr>
<td>Alcohol use (any) in past 12 monthsth</td>
<td>61.6 (2415)</td>
<td>59.9 (2227)</td>
<td>76.1 (2974)</td>
<td>74.8 (2852)</td>
<td>41.5 (1659)</td>
<td>38.8 (1529)</td>
</tr>
<tr>
<td>Cannabis use (any) in past 12 months†</td>
<td>22.5 (892)</td>
<td>26.8 (1009)</td>
<td>18.1 (708)</td>
<td>17.5 (673)</td>
<td>21.2 (851)</td>
<td>22.5 (894)</td>
</tr>
</tbody>
</table>

*Wording of Canadian source question changed slightly, from response option "White" in 2017 to "European" in 2018.
†Respondents missing data for alcohol use and cannabis use were removed from these calculations.
### Table 2 | Changes in prevalence of smoking and vaping between 2017 and 2018 among adolescents aged 16-19 years, by country. Values are weighted percentages (numbers) unless stated otherwise

<table>
<thead>
<tr>
<th>Vaping and smoking measures</th>
<th>Canada</th>
<th>England</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
<td>2017</td>
</tr>
<tr>
<td></td>
<td>(n=4038)</td>
<td>(n=3853)</td>
<td>(n=3995)</td>
</tr>
<tr>
<td>Vaping</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever</td>
<td>29.3</td>
<td>37.0</td>
<td>37</td>
</tr>
<tr>
<td>(1182)</td>
<td>(1425)</td>
<td>(1348)</td>
<td>(1276)</td>
</tr>
<tr>
<td>Past 30 days</td>
<td>8.4</td>
<td>14.6</td>
<td>8.2</td>
</tr>
<tr>
<td>(340)</td>
<td>(562)</td>
<td>(347)</td>
<td>(346)</td>
</tr>
<tr>
<td>Past week</td>
<td>5.2</td>
<td>9.3</td>
<td>4.6</td>
</tr>
<tr>
<td>(208)</td>
<td>(357)</td>
<td>(184)</td>
<td>(178)</td>
</tr>
<tr>
<td>≥15 days in past 30 days</td>
<td>2.1</td>
<td>3.6</td>
<td>1.86</td>
</tr>
<tr>
<td>(85)</td>
<td>(139)</td>
<td>(123)</td>
<td>(87)</td>
</tr>
<tr>
<td>Cigarette smoking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever</td>
<td>31.9</td>
<td>36.6</td>
<td>32.3</td>
</tr>
<tr>
<td>(1288)</td>
<td>(1412)</td>
<td>(1415)</td>
<td>(1322)</td>
</tr>
<tr>
<td>Past 30 days</td>
<td>10.7</td>
<td>15.5</td>
<td>15.6</td>
</tr>
<tr>
<td>(431)</td>
<td>(599)</td>
<td>(622)</td>
<td>(641)</td>
</tr>
<tr>
<td>Past week</td>
<td>7.6</td>
<td>11.9</td>
<td>9.8</td>
</tr>
<tr>
<td>(308)</td>
<td>(460)</td>
<td>(391)</td>
<td>(441)</td>
</tr>
<tr>
<td>≥15 days in past 30 days</td>
<td>4.8</td>
<td>7.4</td>
<td>5.0</td>
</tr>
<tr>
<td>(196)</td>
<td>(286)</td>
<td>(200)</td>
<td>(248)</td>
</tr>
</tbody>
</table>

*Change from 2017 to 2018, in logistic regression models within country, adjusting for age, sex, and race/ethnicity.

Canada in 2018, to the highest levels recorded to date. For example, between 2017 and 2018, the prevalence of vaping in the past 30 days among the adolescents increased by 5 percentage points in the US and 6 percentage points in Canada. These findings are consistent with recent data from national benchmark surveys conducted in the US: the prevalence of vaping in the past 30 days increased by 8.9% in the National Youth Tobacco Survey16 and 6.8% in the Monitoring in the past 30 days increased by 8.9% in the National Youth Tobacco Survey16 and 6.8% in the Monitoring in the past 30 days increased by 8.9% in the National Youth Tobacco Survey16 and 6.8% in the Monitoring Future study,18 compared with 5.1% in the current study. No Canadian data from 2018 were available with which to compare our findings; however, the findings are consistent with media and anecdotal reports from high schools of increased vaping among young people.

Increased vaping among adolescents was observed for overall prevalence as well as for the transition ratio—the percentage of ever vapers who vaped more frequently. Indeed, in the US the percentage of ever users who reported using on 15 days or more in the past month was similar for vaping and smoking. This represents a notable departure from previous years, in which vaping among adolescents was generally characterized by infrequent, experimental use.9 16 17 In 2018, prevalence of vaping on 15 days or more in the past month increased among current vapers, from 20% in 2017 to 28% in 2018.16 We are unaware of any comparable estimates from national surveys in Canada or England.

The current findings also show the rapid rise of JUUL as a vaping brand among adolescents in 2018 in the US, as well as its emergence in Canada and England almost immediately after being introduced to these markets. The increase in JUUL use among adolescents is consistent with the increase in JUUL sales over the same period, which were almost entirely responsible for the overall growth in the US vaping market.19 The increase in past 30 day JUUL users in the US—from 1.0% in 2017 to 4.5% in 2018—accounts for more than two thirds of the overall increase in prevalence of past 30 day vaping in the US. Between 2017 and 2018, the proportion of Canadian adolescents who usually used JUUL increased from 0% to 10%, despite the device being on the market for only one month. Industry data indicate substantial increases in Canadian sales of JUUL in the four months after data collection for the current study, similar to the trajectory of US sales observed over the past year.25

Although JUUL use increased among adolescents in 2018, JUUL alone does not account for all of the increase in vaping among young people. This was particularly the case in Canada, where JUUL was only the third most popular brand at the time of the survey in September 2018. However, the nicotine salt technology popularized by JUUL has since been adopted by most other brands. Indeed, all five of the leading brands among adolescents in Canada and the US, and four of the five leading brands in England, were available for sale in 2018 with nicotine salt e-liquid options. For example, Smok—the leading brand used by young people in Canada and England in 2018—released nicotine salt versions in March of 2018. The popularity of products such as JUUL among adolescents could be due to several factors, including the modern, sleek appearance of the device and highly effective social marketing.15 The widespread adoption of JUUL’s nicotine salt delivery system, however, suggests an important role of the product technology. With conventional e-cigarettes, the high nicotine concentrations present in JUUL and similar nicotine salt products would typically produce...
Table 3 | Changes in prevalence of vaping between 2017 and 2018 among adolescents aged 16-19 years, by country and smoking status.* Values are weighted percentages (numbers) unless stated otherwise

<table>
<thead>
<tr>
<th>Vaping measures by country</th>
<th>Never smokers</th>
<th></th>
<th>Experimental smokers</th>
<th></th>
<th>Current smokers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
<td>Adjusted odds ratio (99% CI) for change*</td>
<td>P value</td>
<td>2017</td>
<td>2018</td>
</tr>
<tr>
<td>Ever</td>
<td>n=2750</td>
<td>n=2641</td>
<td>1.61 (1.30 to 1.99)</td>
<td>&lt;0.001</td>
<td>n=1011</td>
<td>n=1133</td>
</tr>
<tr>
<td>Past 30 days</td>
<td>2.3 (63)</td>
<td>5.0 (122)</td>
<td>2.35 (1.51 to 3.65)</td>
<td>&lt;0.001</td>
<td>18.2 (184)</td>
<td>28.7 (323)</td>
</tr>
<tr>
<td>Past week</td>
<td>0.8 (22)</td>
<td>2.7 (66)</td>
<td>3.68 (1.86 to 7.28)</td>
<td>&lt;0.001</td>
<td>11.0 (111)</td>
<td>18.1 (203)</td>
</tr>
<tr>
<td>≥15 days in past 30 days</td>
<td>0.2 (5)</td>
<td>0.6 (14)</td>
<td>3.86 (0.88 to 16.98)</td>
<td>0.02</td>
<td>4.5 (45)</td>
<td>6.6 (74)</td>
</tr>
<tr>
<td>England</td>
<td>n=2380</td>
<td>n=2347</td>
<td></td>
<td>1287</td>
<td>n=1250</td>
<td></td>
</tr>
<tr>
<td>Ever</td>
<td>11.9 (284)</td>
<td>11.8 (276)</td>
<td>0.97 (0.76 to 1.26)</td>
<td>0.79</td>
<td>61.2 (787)</td>
<td>59.7 (746)</td>
</tr>
<tr>
<td>Past 30 days</td>
<td>1.6 (39)</td>
<td>1.7 (39)</td>
<td>1.03 (0.53 to 2.01)</td>
<td>0.91</td>
<td>15.2 (195)</td>
<td>15.8 (197)</td>
</tr>
<tr>
<td>Past week</td>
<td>0.5 (12)</td>
<td>0.4 (9)</td>
<td>0.77 (0.20 to 2.94)</td>
<td>0.61</td>
<td>7.5 (97)</td>
<td>8.2 (102)</td>
</tr>
<tr>
<td>≥15 days in past 30 days</td>
<td>0.2 (4)</td>
<td>0.1 (1)</td>
<td>0.31 (0.02 to 5.53)</td>
<td>0.30</td>
<td>3.1 (41)</td>
<td>3.7 (47)</td>
</tr>
<tr>
<td>US</td>
<td>n=2773</td>
<td>n=2708</td>
<td></td>
<td>1102</td>
<td>n=1121</td>
<td></td>
</tr>
<tr>
<td>Ever</td>
<td>13.1 (363)</td>
<td>16.0 (432)</td>
<td>1.26 (0.99 to 1.56)</td>
<td>0.012</td>
<td>65.5 (708)</td>
<td>67.1 (752)</td>
</tr>
<tr>
<td>Past 30 days</td>
<td>2.4 (66)</td>
<td>5.9 (160)</td>
<td>2.56 (1.69 to 3.88)</td>
<td>&lt;0.001</td>
<td>24.4 (264)</td>
<td>33.6 (377)</td>
</tr>
<tr>
<td>Past week</td>
<td>1.1 (31)</td>
<td>3.0 (82)</td>
<td>2.72 (1.48 to 4.98)</td>
<td>&lt;0.001</td>
<td>13.5 (146)</td>
<td>22.7 (255)</td>
</tr>
<tr>
<td>≥15 days in past 30 days</td>
<td>0.5 (14)</td>
<td>1.5 (40)</td>
<td>3.05 (1.77 to 7.93)</td>
<td>0.003</td>
<td>6.0 (64)</td>
<td>10.5 (118)</td>
</tr>
</tbody>
</table>

*Former smokers were not analyzed, owing to small sample size.
†Change from 2017 to 2018, in logistic regression models within country and smoking status, adjusting for age, sex, and race/ethnicity.

Although JUUL and other nicotine salt e-cigarettes are available in England, they are sold with lower nicotine concentrations because of the EU limits of 20 mg/mL. For example, JUUL pods in England contain less than half the nicotine concentration of US and Canadian products. Therefore, the impact of the market transition to nicotine salt products might have been mitigated in England by lower nicotine levels,
which could explain why England did not experience the same increases in vaping among adolescents as Canada and the US. Additionally, at the time of the 2018 survey, JUUL was restricted to a limited number of retail outlets in England (although the company announced an expansion to the convenience store sector in March 2019). Lower levels of vaping in England may also reflect greater marketing restrictions for vaping products or differences in public health messaging around vaping products and reasons for use. Overall, there is a need for additional research to examine the potential impact of nicotine salt products on initiation and patterns of vaping among adolescents. Continued monitoring of recent trends in vaping behavior, including specific product types, is critical.

The increase in smoking among Canadian adolescents raises important questions about the association between vaping and smoking behavior. After several decades of steady decline, smoking among 15 to 19 year olds did not change significantly between 2015 and 2017, and no other national estimates are available for 2018. If the increase in smoking prevalence in Canada was directly related to an increase in vaping, similar increases in smoking would be expected among US adolescents, who reported a similar rise in vaping; however, no statistically significant changes in smoking were observed between 2017 and 2018 in the US. Estimates from the current study are closer to the 0.5% increase in past 30 day smoking observed in the National Youth Tobacco Survey study than the 0.8% decrease recorded in the Monitoring the Future study in 2018. The greater increase in smoking in Canada might reflect emergent trends leading up to the legalization of non-medical cannabis in October 2018. Cannabis use increased among Canadian adolescents in 2018, consistent with Canada’s benchmark survey, which also found an increase in cannabis use among adolescents in the six months before its legalization. Given that smoking is the primary mode of cannabis use, and some users mix cannabis with tobacco (although to a lesser extent in North America than in Europe), it is plausible that greater cannabis use could increase cigarette smoking. However, supplemental tests indicated that the increase in smoking and vaping prevalence in Canada remained statistically significant after adjusting for cannabis use. Therefore, without discounting the possibility of common upstream determinants, the increases in vaping and smoking in Canada from 2017 to 2018 were not directly related to increased cannabis use over the same period.

### Limitations of this study

The accuracy of prevalence estimates derived from non-probability based samples warrants consideration. Prevalence estimates from the current study were highly consistent with nationally representative benchmark surveys. For example, the prevalence of vaping in the past 30 days among US adolescents was 16.2% in 2018, which lies between the National Youth Tobacco Survey estimate of 20.8% for high school students and the Monitoring the Future study estimate of 14.2% for vaping nicotine among 8th, 10th, and 12th graders. Past 30 day prevalence of smoking in 2018 was estimated at 8.1% of high school students by the National Youth Tobacco Survey and 7.6% of 12th graders by the Monitoring the Future study compared with 12.2% among 16 to 19 year olds in the current study; our estimate is somewhat higher, but also includes older adolescents and those not in school. In Canada, no 2018 data are available for comparison; however, Canadian estimates for smoking prevalence in 2017 (10.7%) were less than 1% lower than the Canadian Community Health Survey and slightly higher than the 8% reported for 15 to 19 year olds from the Canadian Tobacco, Alcohol and Drugs Survey. Overall, the current findings are within the range of estimates provided by the largest national surveys in the US and Canada. Unfortunately, there are no nationally representative probability based surveys of adolescents in England with which to compare our findings. In addition, all three countries used the same methodology in 2017 and 2018, including sample recruitment, survey measures, and weighting procedures. To examine the possibility that the 2018 sample could have been more prone to “risky” behaviors in general, we tested differences in the prevalence of alcohol and cannabis use between 2017 and 2018. No differences were observed across years in any of the countries, with the exception that cannabis use increased among Canadian adolescents, consistent with Canada’s benchmark cannabis survey. Therefore, while we acknowledge the limitations of non-probability samples, estimates from the current study show a high level of consistency with national benchmarks, and are robust after accounting for other risk behaviors that are highly correlated.

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**Table 5 | Top five vaping brands among past 30 day vapers in 2017 and 2018, by country. Values are weighted percentages (numbers)**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Usual brand*</td>
<td>Other 9.2 (31)</td>
<td>Smok 20.8 (116)</td>
<td>Smok 10.1 (35)</td>
<td>Smok 14.3 (49)</td>
<td>Smok 16.9 (77)</td>
<td>Smok 10.7 (70)</td>
</tr>
<tr>
<td>Aspire 7.3 (25)</td>
<td>Vype 4.6 (26)</td>
<td>Vype 6.9 (24)</td>
<td>Vype 6.9 (24)</td>
<td>Other 5.8 (26)</td>
<td>Other 5.8 (26)</td>
<td></td>
</tr>
<tr>
<td>V2 6.2 (21)</td>
<td>Eleaf 3.8 (21)</td>
<td>Other 5.7 (20)</td>
<td>Other 5.7 (20)</td>
<td>Other 5.8 (26)</td>
<td>Other 5.8 (26)</td>
<td></td>
</tr>
<tr>
<td>No usual brand</td>
<td>20.9 (71)</td>
<td>18.5 (104)</td>
<td>23.5 (32)</td>
<td>18.3 (63)</td>
<td>15.2 (69)</td>
<td>10.3 (67)</td>
</tr>
<tr>
<td>Don’t know 20.8 (71)</td>
<td>11.3 (63)</td>
<td>18.0 (62)</td>
<td>8.9 (31)</td>
<td>13.6 (62)</td>
<td>5.8 (38)</td>
<td></td>
</tr>
</tbody>
</table>

*Reported among participants who vaped in past 30 days (excluding n=5 who did not answer question). Column percentages do not add to 100, as only five most popular brands are reported.
with smoking and vaping. In addition, though fewer Canadian respondents identified only as white in 2018, this difference is likely attributable to a wording change in the source race/ethnicity question wherein “White” was renamed “European”; the proportion of respondents selecting “Don’t know” or “Refused” increased (from 1.9% to 7.9%), as did “Other” responses (many of whom entered “Canadian,” which could not be assumed white), all categorized as not white (only).

Conclusions and policy implications

The findings indicate increases in vaping among adolescents in Canada and the US. The study also provides empirical support to the widely held belief that young people have contributed to the increase in use of JUUL and the larger market wide shift to nicotine salt vaping products. In contrast, few differences were observed among adolescents in England, where there are mandatory limits on the nicotine concentration of e-liquids and greater restrictions on marketing. Although changes in the product market may be the most plausible explanation for differences in vaping across the study countries, additional research is required before population level changes in vaping can be attributed to specific regulatory and market factors. The current findings should also be interpreted within the broader context of overall trends in smoking and vaping, in which the prevalence of tobacco use among adults continues to decrease. Though the impact of vaping products on smoking rates remains highly contentious, it is unfortunate that the characteristics that enhance the effectiveness of e-cigarettes as smoking cessation aids—namely, efficient nicotine delivery—also increase their potential to promote addiction among young people. Before 2018, there was relatively little evidence of regular vaping among adolescents that might be indicative of nicotine addiction; however, the emergence of JUUL and nicotine salt based products might signal a change. Given how rapidly the vaping market is evolving, it is critically important to continue monitoring vaping behavior, including specific products and more frequent use, among adolescents. Rather than fuel the debate over trade-offs between less harmful nicotine alternatives for adult smokers versus increased initiation among adolescents, the findings should direct attention to regulatory measures that more selectively target these vaping products to adult smokers. This discussion has come to the fore, as Health Canada and the US Food and Drug Administration contemplate measures to protect young people, including greater restrictions on advertising and promotion, flavors, and retail access to e-cigarettes. 30 31 Finding the optimal regulatory balance that provides smokers with reasonable access to effective products, while restricting features of such products that appeal to adolescents, represents a priority for tobacco control, and for public health more generally.

AUTHOR AFFILIATIONS

1School of Public Health and Health Systems, University of Waterloo, 200 University Ave W, Waterloo, ON, N2L 3G1, Canada

2Department of Psychology, University of Waterloo, Waterloo, ON, Canada

3Ontario Institute for Cancer Research, Toronto, ON, Canada

4Department of Psychiatry and Behavioral Sciences, Medical University of South Carolina, Charleston, SC, USA

5King’s College London, London, UK

6Department of Health Promotion, Education, and Behavior, Arnold School of Public Health, University of South Carolina, Columbia, SC, USA

7Department of Health Behavior, Roswell Park Comprehensive Cancer Center, Buffalo, New York, NY, USA

8Georgetown Lombardi Comprehensive Cancer Center, Georgetown University, Washington DC, USA

9Cancer Council Victoria, Melbourne, VIC, Australia

Contributors: DH designed the study with input from all authors. JLR and CMW helped to design the survey and had primary responsibility for the data collection. VLR led the analysis with assistance from JLH and DH. DH was the primary author; all other authors contributed to the writing of the manuscript. DH is the guarantor and attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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Ethical approval: This study was approved by the University of Waterloo research ethics committee (ORE#21847) and the King’s College London Psychiatry, Nursing and Midwifery Research Ethics Subcommittee.

Data sharing: Deidentified study data may be made available on request to researchers who submit a proposal that is approved by the principal investigator.

Transparency: The lead author (DH) affirms that this manuscript is an honest, accurate, and transparent account of the study being explained. This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.


31 U.S. Food and Drug Administration. Statement from FDA Commissioner Scott Gottlieb, M.D., on proposed new steps to protect youth by preventing access to flavored tobacco products and banning menthol in cigarettes. 2018 Nov 15. www.fda.gov/FoodEvents/PressAnnouncements/ucm625884.htm (accessed 3 Dec 2018).