E-cigarette Flavor Ban in the Netherlands Reduced Vaping Prevalence Without Increasing Smoking

Abstract

Introduction The appeal of e-cigarettes is concerning as vaping is harmful to health. Flavored e-cigarettes are particularly appealing and especially to youth. Therefore, the Dutch government implemented a ban that limits e-cigarette products to tobacco flavors and unflavored options only. **Methods** We conducted a retrospective cross-sectional online survey, nine months following the ban's implementation. A research agency with certified participant pool recruited 548 adolescents and young adults (ages 13-24), and 457 adults (25+ years), all of whom used e-cigarettes prior to the ban. **Results** As a result of the ban, 40% of respondents reduced vaping or quit, and 22% quit. These outcomes did not differ between the two age groups. Most consumers (73%) who quit vaping due to the ban did not use a substitution product. A small percentage (6%) of the overall study population reported starting cigarette smoking and attributed this initiation to the e-cigarette flavor ban. Yet, overall prevalence of cigarette, cigar(illo), and waterpipe smoking declined post-ban, by 8 percentage points (ppt), 3% ppt, and 5% ppt, respectively, indicating that more users quit than started using potential substitution products. The use of non-tobacco flavors in e-cigarettes declined by 44 ppt ± 2 ppt. Among those continuing to use banned flavors, the largest group (36%) purchased them in physical shops abroad. **Conclusion** The e-cigarette flavor ban effectively reduced e-cigarette use, potentially benefiting public health. To enhance policy impact, we recommend international adoption of similar measures or other strategies to restrict cross-border purchasing.

1. Introduction

E-cigarette use is highly prevalent and poses considerable health risks. In the Netherlands, one in five adolescents and young adults (AYA) had tried an e-cigarette at least once in 2023, 10% reported monthly use, and 2% used them daily[1]. Prevalence rates in other countries are similar, with 14% of U.S. young adults reporting e-cigarette use in 2022[2]. This widespread use of e-cigarettes is concerning as vaping may cause throat irritation, coughing, cardiovascular diseases, and serious respiratory conditions such as asthma and COPD[3–5]. Moreover, the aerosols in e-cigarettes are known to damage DNA, heightening cancer risk[6]. Most e-cigarettes contain nicotine, a highly addictive substance which disrupts brain development and therefore poses a serious health risk to young users in particular[7]. Prolonged exposure to nicotine during adolescence increases the risk of cognitive, attentional, and mood disorders[7], and may serve as gateway to cigarette smoking[8].

Because flavored e-cigarettes are particularly appealing, and especially to youth[10], several jurisdictions ban or restrict e-cigarette flavors[11]. Although flavor bans appear to reduce youth vaping[12], they are often undermined by regulatory loopholes and behavioral adaptations[13–15]. Tobacco flavors are typically exempt from e-cigarette flavor bans, as they are considered less attractive to youth[16] and may appeal to adult smokers trying to quit cigarettes[17]. However, when the states of Rhode Island, Washington and New York banned all e-cigarette flavors except for tobacco, tobacco-flavored e-cigarette sales increased markedly, suggesting a shift to unregulated flavors instead of abstinence[13]. Similarly, after the U.S. Food and Drug Administration (FDA) restricted flavored pod-based devices, many young users switched to unregulated disposable devices to maintain access to preferred flavors[18]. In addition to such circumvention effects that reduce the effectiveness of flavor bans, policies can also trigger unintended consequences that may offset or counteract intended public health gains. These include the increased use of illicit-market products [19], which may contain more toxic substances than regulated alternatives[20], and the increased use of potentially more harmful product types, such as cigarettes. Indeed, some studies suggest that while flavor bans reduce vaping, they may unintentionally increase smoking [21,22].

The Dutch government implemented an e-cigarette flavor ban that limits e-cigarette products to tobacco flavors and unflavored options only[23], aiming to discourage e-cigarette initiation and use, particularly among young people[24]. The ban came into effect 1st of January 2023, and vendors were permitted to sell remaining products until 1st of January 2024. This study aimed to assess the impact of the e-cigarette flavor ban on e-cigarette use among adolescents and adults who used e-cigarettes prior to the ban. We also investigated potential unintended outcomes that could undermine the ban's intended public health benefits, including substitution with cigarettes or other alternative products. Our results will inform policy makers about the effectiveness of the Dutch e-cigarette flavor ban.

2. Materials & Methods

In September 2024, we conducted a retrospective cross-sectional survey to assess the impact of the e-cigarette flavor ban on e-cigarette product use. Our online survey targeted AYA aged 13 - 24, and adults aged 25 and older. We aimed for at least 385 respondents per age group to ensure reliable estimates of changes in e-cigarette use prevalence (for more information see supplementary materials, section 1). All participants were residents of the Netherlands, Dutch speaking, and users of e-cigarettes on at least a monthly basis throughout 2023, the year before the ban was enacted. We commissioned the research agency Ipsos I&O to recruit the participants and disseminate the survey. Participants aged 16 and older were recruited directly from the certified Ipsos I&O research panel. Younger respondents were recruited via their parents, most of whom were members of the panel. A smaller percentage of respondents in the younger age group was recruited from an external panel by Ipsos I&O. The study was approved by the WUR Research Ethics Committee (approval number 2024-012), and conducted in accordance with the Declaration of Helsinki (2013)[25]. The analysis plan was pre-registered on Open Science Framework (under https://tinyurl.com/mr3er3fx) to ensure methodological transparency.

2.1. Measures

Participants reported general demographics (age and gender) and their postal code's first two letters. We then assessed product use behaviors before the ban (retrospectively) and after the ban (currently). Additionally, we asked all participants whether they experienced changes in their product use behavior that they attributed to the e-cigarette flavor ban. The survey was conducted in Dutch. An unofficial English translation can be found in the supplementary materials, document 2.

2.1.1. Product use characteristics

We assessed vaping characteristics before and after the ban, including how often people vaped, their preferred flavor, device type, and nicotine content. Participants rated for 15 predefined adverse health effects (e.g. coughing – see supplementary materials, document 2) whether they experienced them *never* (= 0), *seldom* (= 1), *sometimes* (= 2), *often* (= 3), or *(almost) always* (= 4) due to or after vaping. A sixteenth adverse effect could be entered as open answer option, and rated on its' frequency, if applicable. The use of related products, such as cigarettes, was also assessed, pre-ban (retrospectively) and post-ban (currently).

2.1.2. Changes in product use behavior due to the ban

We asked participants whether their e-cigarette use changed due to the flavor ban. Questions focused on changes in flavor, device and use frequency, including quitting and quit attempts. Among participants who used a related product (e.g., cigarettes) both before and after the ban, we asked whether their use had increased (e.g. whether they smoke more) due to the e-cigarette flavor ban. Participants who initiated use of a tobacco, nicotine, or related product after the ban were asked whether this initiation was prompted by the ban.

2.1.3. Post-ban purchasing behavior

For participants who continued using flavors which were legal in 2023 but are banned under the current law (*now-banned flavors*), we asked how they obtained them.

2.2. Statistical Analysis

Data was analyzed using IBM SPSS Statistics; Version 29.0.1.0 (171). P values < 0.05 were regarded significant. All proportions were calculated with their SE and 95% CI.

2.2.1. Data cleaning

The survey was completed by 1062 participants. Some participants erroneously passed the screening question (by indicating at least monthly e-cigarette use pre-ban) but later commented in an open question that they had never vaped. We therefore excluded 32 individuals who both checked *'I did not vape back then'* when asked about pre-ban flavors and answered '*yearly*' or *'never'* to the question how often they vape now. We then cleaned the data as described in the data analysis plan. This involved excluding another 25 participants because their *invalid response score* exceeded three, resulting in a final sample size of 1005. Additionally, we excluded a varying number of observations from certain variables, if a participant gave invalid or contradictory answers. This step ensured data quality but resulted in substantial variations in sample sizes between the different outcome measures. Despite these exclusions, the targeted minimum of n = 385 participants per age group was consistently achieved.

2.2.2. General demographics

We first created a binary variable *proximity to border,* indicating whether participants resided in a postal code area bordering Germany or Belgium – countries where flavored e-cigarettes can be legally purchased. We then computed frequencies, means and standard deviations of general demographic variables (age, gender, and proximity to border), stratified by age group. Differences between age groups were assessed using a two-sample t-test for age, and chi-square tests for gender and proximity to border.

2.2.3. Pre-ban product use characteristics

We created a binary indicator for the use of now-banned flavors (not preregistered), defined as the predominant use of *fruit/sweet*, *mint/menthol*, or *other non-sweet* flavors, irrespective of whether participants also used *tobacco* or *flavorless* options. Additionally, we defined dual use variables for concurrent use of e-cigarettes with (a) inhaled products (cigarettes, cigar(illo)s, HTPs, (water)pipes, weed, and vaporizers) and (b) non-inhaled products (nicotine pouches, snus, and nicotine gums/patches). Adverse health effect scores were calculated by summing the frequency ratings (0–4) of adverse health effects. Due to difficulties in classifying open responses, (e.g. whether to classify “thick throat” as throat irritation or throat pain), unlike pre-registered, we grouped related symptoms into broader categories. *Throat complaints* combined throat irritation and throat pain, while *breathing complaints* merged shortness of breath, breathing difficulty, and related symptoms. Similarly, *lung complaints* included symptoms such as chest pressure and lung pain. Differences in pre-ban characteristics between age groups were tested using a two-sample t-tests for adverse health effect scores and chi-square tests for all other variables.

2.2.4. Changes in product use behavior pre- to post ban

To evaluate the overall changes in product use from pre- to post-ban, we compared user rates before and after the ban. We created a binary variable for continued e-cigarette use post-ban, defined as using e-cigarettes at least monthly after the ban. Changes in product use prevalences pre- to post-ban were calculated using paired-sample binomial tests. For each product use variable (e.g., flavor use, nicotine use, device type), we computed pre- and post-ban prevalences and their corresponding differences, all with 95% CI. Prevalences were assessed and compared across the full study population, regardless of whether participants continued e-cigarette use after the ban. This approach captures the population-level impact of the flavor ban, including both behavior changes and quitting.

2.2.5. Changes in product use behavior due to the ban

To assess whether changes in use behaviors were attributable to the flavor ban, we calculated the proportions of behavior change outcomes that participants explicitly linked to it. These included any changes in e-cigarette flavor use, device use, or frequency of use (*behavior change because of the ban*), reductions in vaping frequency, including quitting (*vape less because of the ban*), quit attempts and quitting (*attempted to or quitted because of the ban*), and complete cessation (*quitted because of the ban*). We tested for differences in these outcomes between the age groups with a chi-square test. Additionally, we calculated the proportions of participants who reported using a previously used alternative product more often due to the flavor ban (= uses replacement), and of those who started using an alternative product due to the flavor ban(= initiated replacement). The use or initiation of flavored alternatives was also assessed with proportions.

2.2.4. Predictors and product use outcomes of flavor ban-induced quitting

To further characterize participants in which the ban had intended effects, we conducted two analyses. First, we used logistic regression models to estimate the odds of *attempting to or quitting* due to the flavor ban. *Age* and *adverse effect scores* were included as predictors, each classified into four categories based on the quartiles of their respective distributions. To balance representation of participants across predictor levels, we condensed *years of vaping* into three categories: < one year, one to two years, and ≤ three years. Additionally, we excluded 11 participants who identified as neither male nor female, because their subgroup size was insufficient for a meaningful analysis. We first tested a model that included all factors, then sequentially removed non-significant factors according to a pre-registered order. The removal order was as follows: *proximity to border*, *adverse effect score categories*, *years of vaping*, *age categories*, *poly product use pre-ban* (single use, dual use, poly use), *frequency of vaping pre-ban*, e-cigarette *nicotine use pre- ban*, *gender*, and the *exclusive use of now-banned flavors pre-ban* (preregistered as the inverse: the use of tobacco and/or flavorless options pre-ban). Additionally, to examine whether participants in which the ban had its intended effects was also more likely to experience unintended effects, we conducted a non-preregistered chi-square test. Specifically, we explored whether substitution (the use or initiation of a replacement product) was more common among those who quit due to the flavor ban compared to all other participants.

2.2.6. Post-ban purchasing behavior

To assess post-ban sources of illegal flavors, we calculated the proportion of participants reporting each source, analyzed by age group and overall.

3. Results

3.1. General demographics and pre-ban product use characteristics

The final sample consisted of 548 AYA (mean age ± SD: 19 ± 3; 31.9% male, 66.8% female) and 457 adults (mean age ± SD: 41 ± 14; 47.0% male; 52.1% female). Table S1 in the supplementary materials shows demographic and pre-ban product use characteristics by age group.

3.2. Changes in product use behavior pre- to post ban

Changes in product use behavior pre- to post ban are shown in Table 1. Overall e-cigarette use declined by 51.5% across age groups. (Almost) daily use decreased by 10.4 percentage points (ppt) (a 36.4% reduction relative to pre-ban prevalence), weekly use by 15.2 ppt (51.4% reduction), and monthly use by 25.9 ppt (61.9% reduction). The use of *now-banned* flavors decreased by 44.1 ppt, indicating that pre-ban consumers of now-banned flavors either quitted e-cigarette use or changed flavor. Use of unflavored e-cigarettes increased slightly—from 1.7% to 3.5%—but only among AYA. Tobacco flavor use remained stable among AYA and declined slightly among adults (from 22.0% to 18.8%). The use of disposable e-cigarette devices declined, as did the use of refillable e-cigarettes with commercially available e-liquids, while the use of refillable e-cigarettes with self-mixed e-liquids remained stable. Related product use did not increase following the ban: cigarette use declined by 7.7 percentage points and waterpipe use by 4.9 percentage points. Cigar(illo) use declined by 3.7 percentage points among adults, while remaining stable among AYA. Prevalence of nicotine pouch/snus use, heated tobacco products (HTPs), and other nicotine products remained constant.

Table 1: Product use prevalences pre-ban and post-ban per age group and pooled across age groups, with differences in proportions pre-to post ban with 95% Confidence interval and p-value

	Age group	Pre ban (Percentage ± SE)	Post ban (Percentage ± SE)	p -value	Difference ± SE; (95% CI)
E-cigarette use	AYA	100%	229/494 = 46.4% ± 3.3%	**0.001**	53.6% ± 2.2% (49.2% - 57.8%)
	Adults	100%	210/412 = 51.0% ± 3.4%	**0.001**	49.0% ± 2.5% (44.0% - 53.7%)
	Whole population	100%	439/906 = 48.5% ± 2.4%	**0.001**	51.5% ± 1.7% (48.2% - 54.7%)
Frequency of vaping	**(Almost) Daily**				
	AYA	108/494 = 21.9% ± 4.0%	63/494 = 12.8% ± 4.2%	**<0.001**	9.1% ± 1.4% (6.2% - 11.9%)
	Adults	151/412 = 36.7% ± 3.9%	102/412 = 24.8% ± 4.3%	**<0.001**	11.9% ± 1.9% (8.1% - 15.6%)
	Whole population	259/906 = 28.6% ± 2.8%	165/906 = 18.2% ± 3.0%	**<0.001**	10.4% ± 1.2% (8.1% - 12.6%)
	Weekly				
	AYA	154/494 = 31.2% ± 3.7%	68/494 = 13.8% ± 4.2%	**<0.001**	17.4% ± 2.1% (13.3% - 21.4%)
	Adults	114/412 = 27.7% ± 4.2%	62/412 = 15.0% ± 4.5%	**<0.001**	12.6% ± 2.1% (8.5% - 16.6%)
	Whole population	268/906 = 29.6% ± 2.8%	130/906 = 14.3% ± 3.1%	**<0.001**	15.2% ± 1.5% (12.3% - 18.1%)
	Monthly				
	AYA	232/494 = 47.0% ± 3.3%	98/494 = 19.8% ± 4.0%	**<0.001**	27.1% ± 2.5% (22.0% - 32.0%)

	Adults	147/412 = 35.7% ± 4.0%	46/412 = 11.2% ± 4.6%	**<0.001**	24.5% ± 2.5% (19.6% - 29.2%)
	Whole population	379/906 = 41.8% ± 2.5%	144/906 = 15.9% ± 3.0%	**<0.001**	25.9% ± 1.8% (22.4% - 29.4%)
	Yearly				
	AYA	0/494 = 0.0% ± NA	82/494 = 16.6% ± 4.1%	**<0.001**	-16.6% ± 1.7% (-19.8% - -13.2%)
	Adults	0/412 = 0.0% ± NA	44/412 = 10.7% ± 4.7%	**<0.001**	-10.7% ± 1.5% (-13.6% - -7.6%)
	Whole population	0/906 = 0.0% ± NA	126/906 = 13.9% ± 3.1%	**<0.001**	-13.9% ± 1.1% (-16.1% - -11.6%)
	Never				
	AYA	0/494 = 0.0% ± NA	183/494 = 37.0% ± 3.6%	**<0.001**	-37.0% ± 2.2% (-41.2% - -32.6%)
	Adults	0/412 = 0.0% ± NA	158/412 = 38.3% ± 3.9%	**<0.001**	-38.3% ± 2.4% (-42.9% - -33.5%)
	Whole population	0/906 = 0.0% ± NA	341/906 = 37.6% ± 2.6%	**<0.001**	-37.6% ± 1.6% (-40.7% - -34.4%)
Flavor use*	**Tobacco**				
	AYA	32/517 = 6.2% ± 4.3%	33/517 = 6.4% ± 4.3%	1.00	-0.2% ± 1.0% (-2.3% - 1.9%)
	Adults	94/415 = 22.7% ± 4.3%	78/415 = 18.8% ± 4.4%	**0.011**	3.9% ± 1.4% (1.0% - 6.7%)
	Whole population	126/932 = 13.5% ± 3.0%	111/932 = 11.9% ± 3.1%	0.082	1.6% ± 0.9% (-0.1% - 3.3%)
	Fruit/ Sweet				
	AYA	478/517 = 92.5% ± 1.2%	234/517 = 45.3% ± 3.3%	**<0.001**	47.2% ± 2.3% (42.6% - 51.5%)
	Adults	280/415 = 67.5% ± 2.8%	127/415 = 30.6% ± 4.1%	**<0.001**	36.9% ± 2.4% (31.9% - 41.5%)
	Whole population	758/932 = 81.3% ± 1.4%	361/932 = 38.7% ± 2.6%	**<0.001**	42.6% ± 1.7% (39.2% - 45.8%)
	Mint/ Menthol				
	AYA	81/517 = 15.7% ± 4.0%	57/517 = 11.0% ± 4.1%	**<0.001**	4.6% ± 1.4% (1.9% - 7.4%)
	Adults	128/415 = 30.8% ± 4.1%	55/415 = 13.3% ± 4.6%	**<0.001**	17.6% ± 2.0% (13.5% - 21.5%)
	Whole population	209/932 = 22.4% ± 2.9%	112/932 = 12.0% ± 3.1%	**<0.001**	10.4% ± 1.2% (8.0% - 12.8%)
	Other, non-sweet				
	AYA	11/517 = 2.1% ± 4.4%	13/517 = 2.5% ± 4.3%	0.791	-0.4% ± 0.7% (-1.8% - 1.1%)
	Adults	16/415 = 3.9% ± 4.8%	13/415 = 3.1% ± 4.8%	0.549	0.7% ± 0.8% (-0.9% - 2.3%)
	Whole population	27/932 = 2.9% ± 3.2%	26/932 = 2.8% ± 3.2%	1.000	0.1% ± 0.5% (-1.0% - 1.2%)
	Unflavored				
	AYA	9/517 = 1.7% ± 4.4%	18/517 = 3.5% ± 4.3%	**0.035**	-1.7% ± 0.7% (-3.2% - -0.2%)
	Adults	15/415 = 3.6% ± 4.8%	13/415 = 3.1% ± 4.8%	0.791	0.5% ± 0.9% (-1.3% - 2.3%)
	Whole population	24/932 = 2.6% ± 3.2%	31/932 = 3.3% ± 3.2%	0.265	-0.8% ± 0.6% (-1.9% - 0.4%)
	Now banned				
	AYA	500/517 = 96.7% ± 0.8%	265/517 = 51.3% ± 3.1%	**<0.001**	45.5% ± 2.2% (40.9% - 49.6%)
	Adults	351/415 = 84.6% ± 1.9%	175/415 = 42.2% ± 3.7%	**<0.001**	42.4% ± 2.4% (37.4% - 47.0%)
	Whole population	851/932 = 91.3% ± 1.0%	440/932 = 47.2% ± 2.4%	**<0.001**	44.1% ± 1.6% (40.8% - 47.2%)
E-cigarette device*	**Disposables**				
	AYA	397/531 = 74.8% ± 2.2%	214/531 = 40.3% ± 3.4%	**<0.001**	34.5% ± 2.3% (29.8% - 38.8%)
	Adults	219/444 = 49.3% ± 3.4%	108/444 = 24.3% ± 4.1%	**<0.001**	25.0% ± 2.1% (20.7% - 29.1%)
	Whole population	616/975 = 63.2% ± 1.9%	322/975 = 33.0% ± 2.6%	**<0.001**	30.2% ± 1.6% (27.0% - 33.3%)
	Refillable with commercially available e-liquids				
	AYA	137/531 = 25.8% ± 3.7%	91/531 = 17.1% ± 4.0%	**<0.001**	8.7% ± 1.6% (5.5% - 11.8%)
	Adults	206/444 = 46.4% ± 3.5%	123/444 = 27.7% ± 4.0%	**<0.001**	18.7% ± 2.1% (14.4% - 22.8%)
	Whole population	343/975 = 35.2% ± 2.6%	214/975 = 21.9% ± 2.8%	**<0.001**	13.2% ± 1.3% (10.6% - 15.8%)
	Refillable with self-mixed e-liquids				
	AYA	14/531 = 2.6% ± 4.3%	18/531 = 3.4% ± 4.3%	0.503	-0.8% ± 0.8% (-2.4% - 0.9%)
	Adults	53/444 = 11.9% ± 4.5%	51/444 = 11.5% ± 4.5%	0.864	0.5% ± 1.3% (-2.2% - 3.0%)

	Whole population	67/975 = 6.9% ± 3.1%	69/975 = 7.1% ± 3.1%	0.892	-0.2% ± 0.8% (-1.7% - 1.3%)
E-cigarette nicotine content*	**With nicotine**				
	AYA	356/548 = 65.0 % ± 2.5%	208/548 = 38.0 % ± 3.4%	**<0.001**	27.0% ± 2.0% (23.0% - 30.8%)
	Adults	342/457 = 74.8% ± 2.3%	215/457 = 47.0% ± 3.4%	**<0.001**	27.8% ± 2.2% (23.3% ± 32.0%)
	Whole sample	698/1005 = 69.5% ± 1.7%	423/1005 = 42.1% ± 2.4%	**<0.001**	27.4% ± 1.5% (24.4% - 30.2%)
	Without nicotine				
	AYA	90/ 548 = 16.4% ± 3.9%	61/548 = 11.1% ± 4.0%	**<0.001**	5.3% ± 1.4% (2.5% - 8.1%)
	Adults	86/457 = 18.8% ± 4.2%	48/457 = 10.5% ± 4.4%	**<0.001**	8.3% ± 1.6% (5.1% - 11.4%)
	Whole sample	176/ 1005 = 17.5% ± 2.9%	109/1005 = 10.8% ± 3.0%	**<0.001**	6.7% ± 1.1% (4.6% - 8.7%)
	Unknown nicotine content				
	AYA	121/548 = 22.1% ± 3.8%	75/548 = 13.7% ± 4.0%	**<0.001**	8.4% ± 1.4% (5.5% - 11.2%)
	Adults	50/457 = 10.9% ± 4.4%	30/457 = 6.6% ± 4.5%	**0.002**	4.4% ± 1.3% (1.7% - 7.0%)
	Whole sample	171/1005 = 17.0% ± 2.9%	105/1005 = 10.4% ± 3.0%	**< 0.001**	6.6% ± 1.0% (4.6% - 8.5%)
Related product use*	**Nicotine pouches/ snus**				
	AYA	45 /548 = 8.2% ± 4.1%	39/548 = 7.1% ± 4.1%	0.526	1.1% ± 1.4% (-1.7% - 3.9%)
	Adults	9/456 = 2.0% ± 4.6%	12/456 = 2.6% ± 4.6%	0.629	-0.7% ± 0.9% (-2.5% - 1.2%)
	Whole sample	54/ 1004 = 5.4% ± 3.1%	51/1004 = 5.1% ± 3.1%	0.822	0.3% ± 0.9% (-1.4 – 2.0%)
	Cigarettes				
	AYA	230/548 = 42.0% ± 3.3%	191/548 = 34.9% ± 3.4%	**0.002**	7.1% ± 2.3% (2.7% - 11.5%)
	Adults	229/457 = 50.1 % ± 3.3%	191/457 = 41.8 % ± 3.6%	**0.002**	8.3% ± 2.6% (3.2% - 13.3%)
	Whole sample	459/1005 = 45.7% ± 2.3%	382/1005 = 38.0% ± 2.5%	**< 0.001**	7.7% ± 1.7% (4.3% - 11.0%)
	Cigar(illo)s				
	AYA	48/548 = 8.8% ± 4.1%	40/548 = 7.3% ± 4.1%	0.350	1.5% ± 1.4% (-1.2% – 4.1%)
	Adults	52/457 = 11.4% ± 4.4%	35/457 = 7.7% ± 4.5%	**0.036**	3.7% ± 1.7% (0.4% - 7.0%)
	Whole sample	100/1005 = 10.0% ± 3.0%	75/1005 = 7.5% ± 3.0%	**0.025**	2.5% ± 1.1% (0.4% - 4.6%)
	Heated Tobacco Products				
	AYA	21/548 = 3.8 % ± 4.2%	14/548 = 2.6 % ± 4.2%	0.281	1.3% ± 1.0% (-0.7% - 3.3%)
	Adults	18/457 = 3.9 % ± 4.6%	16/457 = 3.5 % ± 4.6%	0.845	0.4% ± 1.1% (-1.8% - 2.7%)
	Whole sample	39/1005 = 3.9% ± 3.1%	30/1005 = 3.0% ± 3.1	0.289	0.9% ± 0.8% (-0.6% - 2.4%)
	Waterpipe				
	AYA	80/548 = 14.6% ± 3.9%	59/548 = 10.8% ± 4.0%	**0.024**	3.8% ± 1.6% (0.6% - 7.0%)
	Adults	56/457 = 12.3% ± 4.4%	28/457 = 6.1 % ± 4.5%	**< 0.001**	6.1% ± 1.5% (3.1% - 9.1%)
	Whole sample	136/1005 = 13.5% ± 2.9%	87/1005 = 8.7% ± 3.0%	**< 0.001**	4.9% ± 1.1 (2.7% - 7.1%)
	Other				
	AYA	19/548 = 3.5% ± 4.2%	21/548 = 3.8% ± 4.2%	0.851	-0.4% ± 1.0% (-2.3% - 1.6%)
	Adults	14/457 = 3.1% ± 4.6%	12/457 = 2.6 % ± 4.6%	0.727	0.4% ± 0.6% (-0.8% - 1.7%)
	Whole sample	33/1005 = 3.3% ± 3.1%	33/1005 = 3.3% ± 3.1%	1.000	0.0% ± 0.6% (-1.2% - 1.2%)
Dual use	**E-cigarettes & inhaled products**				
	AYA	281/548 = 51.3% ± 3.0%	110/548 = 20.1% ± 3.8%	**<0.001**	31.2% ± 2.4% (26.4 – 35.8%)
	Adults	261/457 = 57.1 % ± 3.1%	95/457 = 20.8% ± 4.2%	**<0.001**	36.3% ± 2.6% (31.1% - 41.3%)
	Whole sample	542/1005 = 53.9% ± 2.1%	205/1005 = 20.4% ± 2.8%	**<0.001**	33.5% ± 1.8% (30.0% - 36.9%)
	E-cigarettes & non-inhaled products				
	AYA	45/548 = 8.2 % ± 4.1%	21/548 = 3.8% ± 4.2%	**0.002**	4.4% ± 1.4% (1.7% - 7.0%)
	Adults	9/457 = 2.0 % ± 4.6%	6/457 = 1.3 % ± 4.6%	0.581	0.7% ± 0.8% (-0.9% - 2.3%)
	Whole sample	54/1005 = 5.4% ± 3.1%	27/ 1005 = 2.7% ± 3.1%	**0.002**	2.7% ± 0.8% (1.1% - 4.3%)

*multiple answers were possible

3.3. Changes in product use behavior due to the ban

Among the n = 866 participants with consistent data for this outcome measure, 53.0% reported a change in their e-cigarette use in response to the flavor ban. These changes included adjustments in flavor use (6.4%), device use (7.4%), or vaping frequency. Reductions in vaping frequency, including quitting, were attributed to the ban by 39.5% of participants. Quitting was attempted by 32.8% of participants, and 22.4% quit successfully because of the ban. None of these outcome measures differed between the two age groups (see supplementary materials, Table S 1). Due to the e-cigarette flavor ban, 10.8% of all N = 1005 respondents reported an increased use of previously used alternative products, predominantly cigarettes. Additionally, 9.1% initiated use of alternative products as substitutes for e-cigarettes, with 5.5% starting to smoke cigarettes. A total of 6.5% of respondents reported using a flavored replacement product. Table 2 shows more information on outcome measures.

Table 2: Behavior change outcomes attributed to the flavor ban by age group and pooled across age groups. Chi-square tests for differences between age group were not significant. n = 866 unless indicated otherwise.

Outcome measure	Proportion ± SE	95% Confidence Interval
Behavior change*		
Adolescence and young adults (AYA)	54.1% ± 2.3%	49.6% - 58.5%
Adults	51.7% ± 2.5%	46.7% – 56.6%
Whole Sample	**53.0% ± 1.7%**	**49.7% – 56.3%**
Flavor change		
AYA	6.0% ± 1.1%	4.2% - 8.6%
Adults	6.8% ± 1.3%	4.6% - 9.7%
Whole sample	**6.4% ± 0.8%**	**4.9% - 8.2%**
Device change		
AYA	7.5% ± 1.2%	5.4% - 10.2%
Adults	7.3% ± 1.3%	5.0% - 10.3%
Whole sample	**7.4% ± 0.9%**	**5.8% – 9.3%**
Vape less (includes quitting)		
AYA	40.5% ± 2.2%	36.2% – 45.0%
Adults	38.2% ± 2.5%	33.5% – 43.1%
Whole Sample	**39.5% ± 1.7%**	**36.3% – 42.8%**
Attempted to or quitted		
AYA	30.9% ± 2.1%	27.0% - 35.2%
Adults	35.1% ± 2.4%	30.6% - 40.0%
Whole Sample	**32.8% ± 1.6%**	**29.8% – 36.0%**
Quit		
AYA	20.0% ± 1.8%	16.6% - 23.8%
Adults	25.5% ± 2.2%	21.4% - 30.0%
Whole Sample	**22.4% ± 1.4%**	**19.7% – 25.3%**

Uses or initiated replacement**	19.1% ± 1.2%	16.8% – 21.7%
Uses replacement	10.8% ± 1.0%	9.1% – 12.9%
• Cigarettes	10.0% ± 0.9%	8.2% – 12.0%
• Cigar(illo)s	0.4% ± 0.2%	0.1% – 1.1%
• HTPs	0.2% ± 0.1%	0.0% – 0.8%
• Snus/ nicotine pouches	0.2% ± 0.1%	0.0% – 0.8%
• Waterpipe	0.3% ± 0.2%	0.1% – 0.9%
• Other	0.4% ± 0.2%	0.1% – 1.1%
Initiated replacement	9.1% ± 0.9%	7.4% – 11.0%
• Cigarettes	5.5% ± 0.7%	4.2% – 7.1%
• Cigar(illo)s	1.5% ± 0.4%	0.9% – 2.5%
• HTPs	0.7% ± 0.3%	0.3% – 1.5%
• Snus/ nicotine pouches	1.6% ± 0.4%	1.0% – 2.6%
• Waterpipe	1.4% ± 0.4%	0.8% – 2.3%
• Other	0.5% ± 0.2%	0.2% – 1.2%
Uses or initiated flavored replacement	6.5% ± 0.8%	5.1% – 8.2%

* Behavior change includes any changes in flavor, device, or frequency of use

**Participants who attributed an increased use of previously used alternative products to the e-cigarette flavor ban (= *uses replacement),* and/or those who started using new alternative products as substitutes for e-cigarettes (= *initiated replacement*). N = 1005 (pooled across age groups)

2.2.5. Predictors and product use outcomes of flavor ban-induced quitting

Participants aged 25 to 34 were 1.8 times more likely to attempt to quit or successfully quit vaping due to the flavor ban compared to those aged 13 to 19 (see Table 3). Participants who reported frequent adverse health effects (scores ≥30) were 2.2 times more likely to attempt to quit or quit vaping because of the flavor ban compared to those with lower scores (0 - 16). In contrast, individuals who had vaped for longer periods (1 - 2 years, or 3 years or more) were less likely to attempt to quit or quit compared to those who vaped for less than a year, with odds ratios of 0.7 and 0.5, respectively. Exploratory analysis further revealed that most consumers who quit vaping due to the ban did not use substitution (73.2% ± 3.2%; 95% CI: 66.5% - 79.0%), however, they were 1.8 times more likely to use a substitute compared to those who did not quit vaping due to the flavor ban ($\chi^2 = 9.74$; $p = 0.003$).

Table 3: Predictors of attempting to quit or quitting vaping due to the flavor ban

Predictor Variables	Odds Ratio	95% CI of Odds Ratio	p-value
Age			
13 – 19 years (reference)	1		

20 – 24 years	1.4	0.9 – 2.1	0.102
25 – 34 years	1.8	1.2 – 2.8	**0.004**
35+ years	1.5	0.9 – 2.3	0.103
Years of vaping			
Less than 1 year (reference)	1		
1 – 2 years	0.7	0.5 – 1.0	**0.022**
3 years or more	0.5	0.4 – 0.8	**0.003**
Adverse effect score			
0 – 16 (reference)	1		
17 – 20	1.0	0.7 – 1.5	0.994
21 – 29	1.4	0.9 – 2.1	0.139
30+	2.2	1.5 – 3.4	**< 0.001**

3.4. Post-ban purchasing behaviors

The use of *now-banned* flavors sharply declined by 44.1 ppt. However, 47.2% of the initial sample still reported using a banned flavor after the ban. Among those who continued using banned flavors, the largest group (35.6%) purchased them in physical shops abroad, primarily in Germany or Belgium, the two countries that share a land border with the Netherlands. The second-largest group (30.9%) obtained banned flavors through someone they know, while a third (27.8%) reported using their personal stock purchased before the ban came into effect. Other sources included webshops (20.1%), social media (13.3%), and physical shops in the Netherlands (12.1%). Additionally, 5.1% reported using flavor accessories, and 3.8% mentioned other sources, such as using friends' vapes instead of buying their own, or purchasing products from dealers at schoolyards or festivals. Table 4 provides detailed information on flavor sources after the ban, both by age group and pooled across groups.

Table 4: Sources of banned flavors after the ban, per age group and across age groups (adolescence and young adults (AYA) 13 – 24 years; and adults (25+ years). N is everyone reporting continued use of banned flavors after the flavor ban. Proportions are given with their associated standard error and 95% confidence interval. Multiple answers were possible.

Place of purchase	AYA (13 – 24 years; N = 281)	Adults (25+ years; N= 191)	Whole population (N = 475)
Physical shop abroad	30.2% ± 2.7% (25.2% – 35.9%)	43.5% ± 3.5% (36.6% – 50.5%)	35.6% ± 2.2% (31.4% – 40.0%)
Germany	43/278= 15.5% ± 2.2%	44/188 = 23.4% ± 3.1%	18.7% ± 1.8% (15.4% – 22.5%)
Belgium	26/278 = 9.4% ± 1.7%	29/187 = 15.5% ± 2.6%	11.8% ± 1.5% (9.2% – 15.1%)
Other	26/278 = 9.4% ± 1.7%	19/ 187 = 10.2% ± 2.2%	9.7% ± 1.4% (7.3% – 12.7%)
Via someone I know	38.8% ± 2.9% (33.3% – 44.6%)	19.4% ± 2.9% (14.4% – 25.6%)	30.9% ± 2.1% (26.9% – 35.2%)
Home stock from before the ban	21.7% ± 2.5% (17.3% – 26.9%)	36.6% ± 3.5% (30.1% – 43.7%)	27.8% ± 2.1% (23.9% – 32.0%)
Webshop	18.1 % ± 2.3% (14.1% – 23.1%)	23.0 % ± 3.0% (17.6% – 29.5%)	20.1% ± 1.8% (16.7% – 24.0%)
Dutch webshop	6.0 % ± 1.4%	3.1 % ± 1.3%	4.9% ± 1.0% (3.2% – 7.2%)
European, non–Dutch webshop	8.9% ± 1.7%	13.1% ± 2.4%	10.6% ± 1.4% (8.1% – 13.7%)
Non–European webshop	2.1% ± 0.9%	2.1 % ± 1.0%	2.1 ± 0.7% (1.1% – 3.9%)

Unknown	2.1% ± 0.9%	6.3% ± 1.8%	3.8% ± 0.9% (2.4 – 6.0%)
Social Media	19.2% ± 2.4% (15.0% – 24.2%)	4.7 % ± 1.5% (2.4% – 8.8%)	13.3% ± 1.6% (10.6% – 16.6%)
Physical shop in the Netherlands	12.8% ± 2.0% (9.4% – 17.3%)	11% ± 2.3% (7.2% – 16.3%)	12.1% ± 1.5% (9.4% – 15.3%)
I add flavor with an accessory	2.5% ± 0.9% (1.1% – 5.2%)	8.9% ± 2.1% (5.6% – 13.9%)	5.1% ± 1.0% (3.4 – 7.5%)
Other	3.2% ± 1.1% (1.6% – 6.1%)	4.7% ± 1.5% (2.4% – 8.8%)	3.8% ± 0.9% (2.4% – 6.0%)

Discussion

We conducted a cross-sectional retrospective survey among 548 AYA and 457 adults who used e-cigarettes at least monthly before the Dutch e-cigarette flavor ban came into effect (January 2024). The aim was to assess the ban's impact on vaping behavior and product substitution. Our findings revealed that over 50% of respondents quit vaping following the ban, with 22.4% attributing their cessation directly to the ban. In total, 39.5% reported vaping less because of the ban. Chi-square tests showed no significant differences in behavior change between AYA and adults, suggesting that the ban was similarly effective across both age groups. However, logistic regression analyses identified that participants aged 25–34 were more likely to attempt to quit or successfully quit vaping due to the flavor ban compared to those aged 13–19, indicating that this age group may be particularly responsive to flavor regulations. Likewise, those who only recently started vaping were more inclined to attempt to quit or quit in response to the flavor ban compared to those with a longer history of vaping. Finally, individuals who experienced adverse health effects from vaping were more likely to (attempt to) quit, suggesting that the ban may serve as a catalyst for those already inclined to quit for other reasons. Notably, most participants who quit due to the ban did not use a substitution product, indicating a potential positive impact on their health.

Circumvention effects

E-cigarette use adaptations that could undermine the flavor ban's effectiveness were limited: only a small proportion of participants switched e-cigarette flavors (6.4%) or devices (7.4%) due to the ban. Among AYA, use of unflavored e-cigarettes increased slightly, while the use of flavor accessories was very low, and no increase in self-mixing of e-liquids was observed. These findings suggest that unflavored e-cigarettes may appeal to a small fraction of AYA users. Notably, there was no shift toward tobacco flavors; in fact, their use declined slightly among adults, indicating that currently permitted tobacco flavors may be less appealing than those available pre-ban.

Substitution effects

There were no major shifts to potentially more harmful product types. A minority of pre-ban smokers increased their cigarette consumption: 10.0% of participants reported smoking more due to the ban. In addition, 9.1% of respondents initiated replacement products, with 5.5% starting to smoke cigarettes. While this outcome is concerning on the individual level, it did not translate into a population-wide increase in alternative product use prevalence: in our sample, use of these products either declined (e.g. from 45.7% to 38% for cigarettes) or remained stable (e.g. for HTPs). National data from the Dutch adult population support this pattern, showing a decrease in smoking

prevalence from 19.0% in 2023 to 18.2% in 2024, which is consistent with the ongoing downward trend observed in previous years[26]. This indicates that the flavor ban did not disrupt or reverse the decline in smoking.

Rather than triggering a shift toward combustible tobacco, as some U.S. studies have reported[21,22], the Dutch policy appears to have largely avoided such unintended consequences. These contrasting outcomes may reflect key differences in how flavor bans are structured and implemented in the U.S. and the Netherlands. In the U.S., flavor restrictions are often introduced at state or local levels, resulting in patchwork regulations and policy loopholes[27]. For example, federal guidance has exempted disposable e-cigarettes from restrictions on flavored cartridges[28], and some states have continued to allow menthol-flavored products or granted exemptions for specific retailers[27]. In contrast, the Netherlands adopted a nationally uniform and comprehensive ban on all non-tobacco e-cigarette flavors, regardless of device type or point of sale. Furthermore, Dutch law strictly defines tobacco-flavored e-liquids to combinations of 16 allowed flavorings [28]. Together, these differences in regulatory design likely shaped consumer behavior: while many U.S. users turned to permitted alternatives, such as disposables, menthol, or cigarettes, Dutch consumers were less likely to substitute and more likely to quit nicotine altogether.

Policy implications

To further reduce substitution effects, limiting access to flavored alternatives through product-wide and well-enforced flavor bans may be effective. In our study, 6.5% of participants used a flavored replacement product, representing 33.9% of all those who used any replacement. These flavored products may have been legally available (e.g., for waterpipe tobacco), illegally obtained (e.g., flavored cigarettes), or self-made using banned flavor accessories. Whether restricting access to flavored alternatives reduces substitution requires further investigation.

To strengthen the impact of the flavor ban, measures to limit cross-border purchases—such as stricter regulations on the importation of flavored e-cigarette products—should be considered. Physical shops abroad were a major source of banned e-cigarette flavors, indicating that cross-border purchasing undermines the effectiveness of national flavor bans. Importantly, the effectiveness of flavor bans could be further enhanced through broader international adoption of similar regulations. As more countries implement comparable restrictions, opportunities for cross-border sales would diminish, reducing access for Dutch residents and potentially lowering vaping rates in neighboring regions as well. Interestingly, 27.8% of all respondents who continued using now-banned flavors still possessed a personal stock of flavored products from before the ban was implemented. These consumers may adapt their behavior once their stock is depleted, suggesting a potential delay in the full impact of the flavor ban.

Strengths and Limitations

Major strengths of this study include preregistration, rigorous data cleaning, and the use of a largely verified participant panel, which helped reduce response bias and enhance the validity of findings. Another strength is the direct assessment of self-reported behavioral responses to the ban, offering more relevant insights into product use than studies relying on indirect indicators such as product availability or sales data. Although self-reported data are prone to social desirability bias, this concern is likely limited in our study: over 90% of respondents used flavored e-cigarettes pre-ban, making it detrimental to their own interest to overstate positive outcomes of a policy that restricts their access. Moreover, 47% openly reported continued use of banned flavors post-ban—despite their illicit status—further suggesting low susceptibility to such bias.

A key limitation is that pre-ban behavior was assessed retrospectively, potentially introducing recall bias. To mitigate this, we used broad, easily memorable frequency categories (daily, weekly, monthly). Another limitation is that purchasing behavior was assessed only after the ban, preventing us from evaluating whether illicit purchasing increased as a result of the policy.

Recommendations for further research

Future research should assess changes in illegal purchasing from pre- to post-ban. In addition, research should compare initiation rates and motivations for e-cigarette uptake among young non-users before and after the introduction of flavor regulations. Like most flavor bans, the Dutch policy primarily aims to prevent the initiation of e-cigarette use among young non-users. This aligns with the World Health Organization's recommendation to regulate nicotine products to reduce their uptake among minors and other vulnerable user groups[29]. While our study included minors, all participants had already initiated e-cigarette use prior to the implementation of the ban. Consequently, we did not assess the policy's effectiveness in preventing initiation. The full impact of the flavor ban therefore remains uncertain and may be even more substantial than what we have currently documented.

Conclusion

We conclude that the Dutch e-cigarette flavor ban effectively reduced vaping among both youth and adult e-cigarette users, without prompting widespread substitution with potentially more harmful products, such as cigarettes. These findings are consistent with prior research showing that comprehensive flavor bans can reduce overall product use. To enhance policy effectiveness, we recommend international adoption of similar measures or other strategies to restrict cross-border purchasing.

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