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Original Article

Both Nonsmoking Youth and Smoking Adults Like Sweet and Minty E-liquid Flavors More Than Tobacco Flavor

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Abstract

Smokers may reduce their health risk by switching to electronic cigarette (e-cigarette) use. As e-cigarettes are not harmless, concerns exist about e-cigarette use by nonsmokers and youth. E-liquids are available in many different flavors that increase sensory appeal. Flavor preferences may differ between user groups, which could open doors for product regulation. We investigated which e-liquid flavors are attractive to specific user groups by comparing liking between adolescent nonsmokers ($n = 41$; mean age 16.9 ± 0.8), young adult nonsmokers ($n = 42$; mean age 22.7 ± 1.7), and adult smokers ($n = 56$; mean age 39.7 ± 11.1). Participants smelled tobacco- ($n = 6$) and nontobacco ($n = 24$)-flavored e-liquids and rated liking on a 9-point labeled hedonic scale, and familiarity, overall intensity, perceived sweetness, perceived bitterness, and irritation of the odors on a 100-unit Visual Analog Scale. Mean liking ranged from 2.3 (whiskey) to 6.7 (peppermint). Within all groups, the typically sweet and minty flavors (e.g., wine gum, watermelon, peppermint, menthol) were liked significantly more than the tobacco-flavored e-liquids. The set of tobacco-flavored e-liquids was significantly, but slightly, less disliked by adult smokers (3.9 ± 0.2) than adolescent (3.1 ± 0.3) and young adult (3.4 ± 0.3) nonsmokers ($P < 0.001$). No between-group differences were observed for sweet and minty flavors. Liking correlated significantly positively with odor sweetness ($R = 0.49$) and familiarity ($R = 0.48$) and negatively with odor bitterness ($R = –0.58$), irritation ($R = –0.47$), and overall intensity ($R = –0.27$). Thus, sweet- and minty-flavored e-liquids are liked equally by young nonsmokers and adult smokers, and more than tobacco flavors. Banning all flavors except tobacco will likely reduce e-cigarette appeal; potentially more for young nonsmokers than adult smokers.

Key words: consumer research, electronic cigarettes, flavors, hedonics, liking, smell

Introduction

Sensory appeal, in particular taste and smell, is generally recognized as one of the most important motives for food choice (Rozin and Fallon 1980; Steptoe et al. 1995). Other industries, such as the tobacco industry, also use flavorings to increase sensory appeal of their products. For example, tobacco industry documents reveal that menthol is commonly added to cigarettes for its cooling, smoothing, and anesthetic effects, enhancing smoking behavior and nicotine

dependence (Ferris Wayne and Connolly 2004; Megerdichian et al. 2007).

E-cigarettes vaporize e-liquids that typically contain nicotine and are available in hundreds of different flavors (Havermans et al. 2019). E-liquid flavor categories include fruit, candy, tobacco, alcohol, dessert, and more (Krusemann et al. 2019). Although e-cigarettes may attract smokers who aim to switch toward an alternative product in order to reduce their health risks (Goniewicz et al. 2014; Schmidt 2020), the availability of appealing flavors also raises interest in e-cigarettes among adolescents and young adults who do not smoke (Ambrose et al. 2015; Kong et al. 2015; Bold et al. 2016; Hilton et al. 2016). However, as e-cigarette emissions contain toxic compounds and may facilitate nicotine dependence (Goniewicz et al. 2014; Schmidt 2020), they are not harmless to health. Research also suggests that for adolescents and young adults, e-cigarettes may serve as a gateway product toward future initiation of cigarette smoking (Soneji et al. 2017). This makes regulation of e-cigarettes in order to reduce appeal and use among youth currently an important topic of debate (Foley 2019).

Although most e-cigarette users prefer and/or use e-liquids with a fruit or sweet flavor as well as traditional flavors such as tobacco (Dawkins et al. 2013; Farsalinos et al. 2013; Shiplo et al. 2015; Tackett et al. 2015; Wang et al. 2015; Berg 2016; Goldenson et al. 2016; Kim et al. 2016; Chen and Zeng 2017; Harrell et al. 2017; Huang et al. 2017; Yingst et al. 2017), flavor preferences seem to differ between (potential) user groups (Zare et al. 2018; Romijnders et al. 2019). That is, young e-cigarette users typically report a preference for sweet flavors (e.g., candy, dessert, and vanilla), while adults seem to be more attracted to non-sweet flavors (e.g., tobacco and menthol/mint) (Krishnan-Sarin et al. 2015; Harrell et al. 2017; Morean et al. 2018). Also, smokers are more interested in trying tobacco- and menthol-flavored e-cigarettes than (young) nonsmokers (Shiffman et al. 2015; Shiplo et al. 2015; Czoli et al. 2016; Romijnders et al. 2019), who are particularly interested in fruit and sweet flavors (Czoli et al. 2016; Ford et al. 2016; Pepper et al. 2016; Romijnders et al. 2019). Most of these findings about e-liquid flavor preferences come from studies using surveys to collect data. Survey research is based on respondents' mental representation and memory of how they perceive a particular flavor, and is therefore an indirect approach to investigating flavor liking. Sensory research is a more direct approach as it allows respondents to actually taste or smell a sample when assessing its flavor. However, the amount of sensory research performed as an approach to investigating attractiveness of e-liquid flavors is limited. A few vaping studies showed that flavorings producing sweet or cooling sensations positively correlate with liking of e-cigarettes, while perceived bitterness and harshness/irritation negatively correlate with liking (Kim et al. 2016; Mead et al. 2019; Pullicin et al. 2020). Moreover, recent studies showed that appeal for e-cigarettes with fruit and menthol was higher than for tobacco-flavored e-cigarettes among current, former, as well as never smokers (Leventhal et al. 2019), and that particularly green apple (fruit) flavor was liked by youth e-cigarette users (Jackson et al. 2020). Furthermore, olfaction (nose open) was found to contribute to liking and perceived sweetness of e-cigarette flavors more than taste (nose closed) (Rosbrook et al. 2017), and, in line with this, we previously showed that orthonasal smelling could be used as alternative to vaping when assessing sensory liking of e-liquid flavors (Krusemann et al. 2020).

To build on this, the current study compares liking of various e-liquid flavors between groups differing in age and smoking status. To the best of our knowledge, this is the first sensory study worldwide to investigate liking of flavors in e-cigarettes in people under the legal age of purchasing e-cigarettes who are also inexperienced vapers. This group is particularly relevant from a regulatory perspective: if, for example, flavors that attract current adult smokers but not youth and nonsmokers were to be identified, this information could support regulators in their decisions on whether and how to decrease e-cigarette appeal for youth and nonsmokers. Therefore, the current study aims to determine which flavors are attractive to specific user groups by investigating the hedonic assessment of e-liquids with various tobacco and nontobacco flavors, among adolescent nonsmokers, young adult nonsmokers, and adult smokers by smelling. Familiarity, and perceived sweetness, perceived bitterness, overall intensity, and irritation of the e-liquid odors will be investigated as well, as these attributes are known to influence liking (Kim et al. 2016).

Materials and methods

Participants

Participants were recruited in and around the cities Ede and Utrecht (the Netherlands) by Essensor BV, a company specialized in sensory market research that uses large recruitment databases and targeted search methods (i.e., via email, social media, word-of-mouth, WhatsApp, and by phone) to recruit representative participants. Inclusion criteria, assessed using a self-report questionnaire, were: being an adolescent nonsmoker (aged 16–18), young adult nonsmoker (aged 20–25), or adult smoker (aged 20–55); having ever heard of the e-cigarette prior to this study; being healthy; and having a good proficiency of the Dutch language. Nonsmokers were defined as reporting to have smoked less than 100 tobacco cigarettes in their lifetime and reporting to currently not smoke cigars, pipe, or marihuana. Smokers were defined as reporting to have smoked more than 100 tobacco cigarettes in their lifetime (excluding cigars, pipe, or marihuana) and currently smoking tobacco cigarettes on a daily basis or more than once per week. Participants were not required to have ever used e-cigarettes. Exclusion criteria were: being pregnant or lactating; having self-reported olfactory deficiencies; being employed or performing thesis research at the Division of Human Nutrition and Health of Wageningen University; and participating in other medical-scientific research.

The study was originally powered for $n = 56$ per group. Sample size was determined using data from our previous sensory study where the absolute difference in mean scores for liking of e-liquid flavors ($n = 25$; assessed by means of smelling) between user groups (smokers and nonsmokers) ranged from 0.2 to 11 on a 100-unit Visual Analog Scale (VAS) (Krusemann et al. 2020). We calculated that 56 participants are needed per group in order to identify significant differences between the group means of at least 15/100 points, which corresponds to 1.35 points on a 9-point hedonic scale, with more than 90% power and a significance level of at $P < 0.05$ after applying a correction for multiple testing.

Participants who completed the study received a financial compensation. All participants provided written informed consent prior to the first test session. The study was registered in the Dutch Trial Register (ID: NL8333) and complies with the Declaration of Helsinki for Medical Research involving Human Subjects. The study was approved by the Medical Ethical Committee of Wageningen University (METC 19/27; NL72171.081.19).

E-liquid products

Thirty commercial e-liquids, from 14 different brands, were purchased from 10 different online shops. The e-liquids' base consisted

of various propylene glycol (PG) to vegetable glycerin (VG) ratios, and, for ethical reasons since adolescents and nonsmokers were included, containing 0 mg/mL nicotine. E-liquid flavor selection was based on the different categories of the e-liquid flavor wheel (Krusemann et al. 2019). The e-liquids' odors were evaluated by the research team during a preliminary experiment to ensure inclusion of odor qualities that were distinct and that matched the e-liquid flavor name. We selected six e-liquids from the tobacco category to ensure a strong representation of this traditional category, one unflavored e-liquid as a blank sample, one e-liquid from the "other flavors" category, and two e-liquids from the remaining nontobacco categories of the e-liquid flavor wheel to optimize flavor variety. See Table 1 for an overview of the products included.

Sample preparation

Several e-liquid drops were dissolved in 1 mL demineralized water and put in a 60 mL brown glass vial. The number of drops per e-liquid is shown in Table 1 (final column) and was based on a pilot experiment in order to standardize odor intensity. In this experiment, 10 participants assessed overall odor intensity of various dilutions on a 100-unit VAS (left anchor: "not intense at all"; right anchor: "very intense"), until the mean intensity was between 50 and 75 (i.e., not too weak nor too strong). Vials were filled with e-liquid on the same day or 1 day before a test session and labeled with a random three-digit code. A new set of samples was prepared for each participant to standardize overall sample intensity. E-liquids were stored at room temperature in their original package.

Experimental procedure

The test sessions took place at two different locations (Ede and Utrecht, Essensor BV, the Netherlands). Experiments took place in sensory booths equipped with a computer; water and tissues were provided. The room was accommodated with a controlled high capacity ventilation system. Participants were asked to refrain from using scented crèmes, deodorant, and perfumes on test days and to eat or drink nothing other than water (including chewing gum, using toothpaste, and smoking) at least 1 h prior to their test visit. For each participant, two test sessions of 1 h each were scheduled on two consecutive days during which they assessed the 30 e-liquids in total in balanced order on liking, familiarity, perceived sweetness, perceived bitterness, overall intensity, and irritation of the odors.

EyeQuestion software V.4.11.68 (Logic8 BV) was used for data collection. Participants were allowed to smell the samples as often as needed to answer all questions. Each product was firstly assessed on liking ("imagine you are using an e-cigarette, how much do you like the odor of this e-liquid?") using a 9-point labeled hedonic scale. This was followed by familiarity ("how familiar are you with this odor?"), perceived sweetness, perceived bitterness, and overall intensity ("how sweet/bitter/intense do you perceive this e-liquid's odor?"), and irritation ("to what extent do you perceive an irritating

Table 1. E-liquid products ($n = 30$) used in this study, including their flavor category and dilution factor

	Flavor category	Flavor	No. of drops diluted in 1 mL demi-water
1	Tobacco	American blend	15
2	Tobacco	Cigar	5
3	Tobacco	Tobacco_a	5
4	Tobacco	Tobacco_b	10
5	Tobacco	Tobacco_c	3
6	Tobacco	Oriental	12
7	Menthol/mint	Peppermint	5
8	Menthol/mint	Menthol	3
9	Nuts	Hazelnut	3
10	Nuts	Peanut	1
11	Spices	Anise	5
12	Spices	Clove	5
13	Coffee/tea	Jasmine tea	10
14	Coffee/tea	Espresso	10
15	Alcohol	Whiskey	5
16	Alcohol	Mojito	5
17	Other beverages	Energy drink	10
18	Other beverages	Cola	5
19	Fruit (berries)	Raspberry	10
20	Fruit (citrus)	Citrus fruits	5
21	Fruit (tropical)	Pineapple	3
22	Fruit (other)	Watermelon	5
23	Dessert	Syrup waffle	2
24	Dessert	Cheesecake	2
25	Candy	Bubblegum	10
26	Candy	Wine gum	1 (in 10 mL)
27	Other sweets	Caramel	10
28	Other sweets	Vanilla	10
29	Other flavors	Lavender	3
30	Unflavored	PG/VG base only	1

PG, propylene glycol; VG, vegetable glycerin.

a, b, and c for products 3, 4, and 5 represent three different e-liquid products that were all marketed as having an (unspecified) tobacco flavor.

feeling in your nose due to this e-liquid's odor?") using 100-unit VASs (left anchor "not at all"; right anchor "very much"). It should be noted that sweetness and bitterness per se were not assessed, as participants did not taste the samples. Instead, with these ratings, we aimed to measure perceived sweetness and bitterness of the odors due to learned associations. To prevent olfactory adaptation, a 1-min break was set between each sample during which participants were instructed to smell their own clothing and rinse their mouth with water.

After assessment of the final sample, participants answered closed questions about their educational level, intention to start vaping, history of e-cigarette use (including flavor and nicotine level of most recent e-cigarette and reason for use). This was followed by a question about their interest in trying specific e-cigarette flavors (check all that apply). Participants reported how often they eat/drink/use (8-point category scale from never to daily) and how much they like (9-point labeled hedonic scale) products with the flavors included in this study. The group of smokers answered additional questions about smoking history and quit intention, and filled out the Fagerström Test for Nicotine Dependence (FTND) (Heatherton et al. 1991).

Data analysis

R statistical software V.4.0.2 (including "stringr" and "psych" packages) was used for data analysis. Of the 141 participants included in the study, 139 completed the experiment and those were used for analysis. Results were compared between user groups and between flavors.

Panel characteristics

Means and percentages of the answers to each survey item were calculated, for the whole group and for the three separate user groups. Some answer options were combined and recoded into a different answer category; these can be found in Supplementary Appendix Table A1.

Between-group comparisons

For each attribute (liking, familiarity, perceived sweetness, perceived bitterness, overall intensity, and irritation of the odors), a one-way ANOVA was performed to determine differences in the assessment of individual e-liquids and across all e-liquids (n = 30) between the following user groups: adolescent nonsmokers and young adult nonsmokers (both separately and combined into one group of nonsmokers), and adult smokers. Liking was also compared between these user groups for four sets of products with similar flavors (excluding the unflavored e-liquid). Categorization of these four product groups was based on similarities in the type of flavor (flavor category) and in sweetness ratings (see Supplementary Appendix Table A4 for sweetness data): tobacco flavors (n = 6; American blend, cigar, oriental, tobacco_a, b, c), minty flavors (n = 2; menthol, peppermint), other non-sweet flavors (n = 5; whiskey, espresso, clove, peanut, hazelnut), and sweet flavors (n = 16; the remaining products, which were those with the highest sweetness ratings). Product, user group, and gender were included as covariates in the ANOVA model. When P values were significant, post-hoc t-tests were performed to test differences between groups. A Benjamini–Hochberg false discovery rate correction was applied to the P values in order to corrected for multiple testing (Benjamini and Hochberg 1995); adjusted P values of ≤0.05 were considered significant.

Between-product comparisons

Mean ratings and standard error over the means were calculated for each product, in total and per user group. For each outcome, ratings were compared for each combination of two e-liquids, using paired t-tests to account for participants' repeated (paired) measurements. This was done for each user group separately. A Benjamini–Hochberg false discovery rate correction was applied (Benjamini and Hochberg 1995); adjusted P values of ≤0.05 were considered significant.

Correlations

Pearson correlations between liking, familiarity, perceived sweetness, perceived bitterness, overall intensity, and irritation of the odors were calculated using ratings across all products. This was done across all users and for the individual user groups. Significances of the differences in the correlations between individual user groups were tested using the r.test function in R ("psych" package). In addition, per attribute, for the total sample and for each user group separately, Pearson correlations were calculated between sensory e-liquid ratings and self-reported ratings for (1) general use and (2) liking of other (often food) products with the same flavors as those of the e-liquids included in this study. Corresponding P values were corrected for multiple testing using the Benjamini–Hochberg false discovery rate correction (Benjamini and Hochberg 1995).

Results

Panel characteristics

The final sample consisted of 41 adolescent nonsmokers (61% female; mean age 16.9 ± 0.8), 42 young adult nonsmokers (86% female; mean age 22.7 ± 1.7), and 56 adult smokers (57% female; mean age 39.7 ± 11.1). Although more than half of the participants (58%) reported to have ever or regularly used an e-cigarette, most people within all groups had no intention to start vaping. Of the ever or regular e-cigarette users, most vaped fruit or menthol/mint flavor in the e-cigarette they most recently used. For adult smokers, this was mostly menthol/mint flavor, followed by tobacco flavor. All panel characteristics are shown in Table 2.

Between-group comparisons

The group of tobacco-flavored e-liquids was significantly less disliked by adult smokers (mean ± SE: 3.9 ± 0.2) than adolescent nonsmokers (3.1 ± 0.3; $P < 0.001$) and young adult nonsmokers (3.4 ± 0.3; $P < 0.001$), both separately and combined ($P < 0.001$). The tobacco-flavored e-liquids were also significantly less disliked by young adult than adolescent nonsmokers ($P = 0.009$). Similarly, the group of other non-sweet flavors was significantly less disliked by adult smokers (mean ± SE: 3.7 ± 0.3) compared with adolescent nonsmokers (3.2 ± 0.3; $P < 0.001$), and compared with the combined group of young adult (3.4 ± 0.3) and adolescent nonsmokers ($P = 0.002$). Liking of both the sets of menthol/mint-flavored e-liquids and sweet e-liquids did not significantly differ between the user groups.

As regards to individual e-liquids, liking ratings for 28 of the 30 products did not significantly differ between adolescent nonsmokers, young adult nonsmokers, and adult smokers (Figure 1). One e-liquid from the tobacco category (American blend) was less disliked by adult smokers (mean ± SE: 4.9 ± 0.2) compared with young adult (3.8 ± 0.3) and adolescent nonsmokers (3.5 ± 0.3), both separately and combined ($P < 0.001$). Another tobacco-flavored e-liquid (Oriental flavor), was less disliked by adult smokers (mean ± SE:

Table 2. Characteristics of the panelists included in this study

		Total sample (n = 139)	Adolescent nonsmokers (n = 41)	Young adult nonsmokers (n = 42)	Adult smokers (n = 56)
Mean age ± SD		27.8 ± 12.3	16.9 ± 0.8	22.7 ± 1.7	39.7 ± 11.1
Gender (%)	Women	67	61	86	57
	Men	33	39	14	43
Education level (%)	Low	24	51	5	20
	Middle	49	49	40	55
	High	27	0	55	25
History of e-cigarette use (%)	Never	42	54	64	16
	Ever	43	41	36	50
	Regularly	15	5	0	34
Most recent flavor (% of ever/regular users in that group)	Fruit	28	63	27	15
	Menthol/mint	27	32	33	23
	Other sweets (vanilla or chocolate)	12	0	20	15
	Tobacco	11	0	0	19
	Unflavored	7	5	0	11
	Candy	4	0	7	4
	Nuts	2	0	0	4
	Other beverages	2	0	7	2
	Spices	2	0	0	4
	Coffee/tea	1	0	0	2
	Don't know	1	0	7	0
	Dessert	0	0	0	0
	Alcohol	0	0	0	0
Most recent nicotine level (% of ever/regular users in that group)	No nicotine	9	21	20	0
	1–8 mg/mL	22	26	13	23
	9–20 mg/mL	12	0	0	21
	>20 mg/mL	0	0	0	0
	Don't know	57	53	67	55
Reason for e-cigarette use (% of ever/regular users in that group)	Curiosity	67	79	80	57
	Health reasons	4	0	0	6
	To quit smoking	16	0	0	28
	Friends use it too	12	21	20	6
	Other ("it smelled nice")	1	0	0	2
Interest in e-cigarette flavor (n; check all that apply)	Fruit	97	35	28	34
	Menthol/mint	92	31	26	35
	Candy	62	23	17	22
	Other sweets (vanilla or chocolate)	51	11	17	23
	Spices	36	7	12	17
	Tobacco	32	2	5	25
	Other beverages	32	15	9	8
	Dessert	29	8	10	11
	Alcohol	27	9	10	8
	Coffee/tea	24	5	8	11
	Nuts	18	2	8	8
Intention to start vaping (%)	No intention	59	76	79	32
	Low intention	14	2	5	29
	High intention	4	0	0	11
	Don't know	23	22	17	29
Intention to quit smoking[a] (%)	No intention				18
	Low intention				42
	High intention				33
	Don't know				7
Smoking duration[a] (%)	<1 year				0
	1–5 years				9
	5–10 years				9
	>10 years				82
Number of cigarettes per day[a] (%)	1–10 (less than half a package)				42
	11–19 (more than half a package)				38
	20 (1 package)				5
	21–25 (more than a package)				11
	I have not smoked regularly				4
Cigarette flavor most often used[a] (%)	Tobacco				95
	Menthol				5
	Other				0
Ever use of cigarettes with menthol or other flavor[a] (n; check all that apply)	No				7
	Menthol				43
	Flavor other than menthol				12
Nicotine dependence[a] (Heatherton et al. 1991) (%)	Low dependence				40
	Low to moderate dependence				33
	Moderate dependence				27
	High dependence				0

Percentages may not add up to 100 due to rounding; interest in e-cigarette flavor was asked after product assessment and may thus have been influenced thereby.
[a]Only applicable to the group of adult smokers (n = 55); missing data for one participant.

4.3 ± 0.3) and young adult nonsmokers (4.3 ± 0.3) than adolescent nonsmokers (3.0 ± 0.2) ($P < 0.001$ for both). Neither familiarity, overall intensity, perceived sweetness, perceived bitterness, nor irritation of the odors differed significantly between the groups for any of the individual products ($P > 0.05$). Mean liking ratings for all (groups of) products are shown in Supplementary Appendix Table A2.

Between-product comparisons

Across all users, mean liking ratings ranged from 2.3 (whiskey) to 6.7 (peppermint) on a 9-point hedonic scale (Figure 1, Supplementary Appendix Table A2). All user groups generally liked menthol/mint- and sweet-flavored e-liquids more than tobacco and other non-sweet e-liquids. Specifically, for all three user groups, liking ratings for e-liquids with peppermint, wine gum, menthol, bubblegum, anise, watermelon, citrus fruits, raspberry, mojito, cola, energy drink, vanilla, and jasmine tea flavors were significantly higher than liking ratings of the six tobacco-flavored e-liquids, clove, hazelnut, peanut, and whiskey ($P \leq 0.05$). Mean ratings for the menthol/mint and most sweet e-liquid flavors typically ranged between 5.4 (pineapple; across-group average) and 6.7 (peppermint), which corresponds to "Neither Like nor Dislike" (5 points) and "Like" (7 points). Mean ratings for e-liquids with a tobacco or non-sweet flavor typically ranged between 2.3 (whiskey) and 4.3 (espresso), which corresponds to "Dislike Very Much" (2 points) and "Dislike Slightly" (4 points).

Across all users, mean familiarity ratings ranged from 20.4 (unflavored) to 83.8 (peppermint) on a VAS from 0 to 100 (Supplementary Appendix Table A3). Participants were particularly familiar with the minty e-liquid odors (mean ratings above 72.2 for all user groups). Specifically, e-liquids flavored as peppermint, menthol, and anise were rated as significantly more familiar (78.6 on average) than all 15 e-liquids (half of the total sample) with the lowest mean familiarity ratings (39.3 on average) within all user groups ($P \leq 0.05$).

Mean ratings for perceived sweetness of the odors ranged from 22.5 (unflavored) to 79.6 (energy drink) across all users (Supplementary Appendix Table A4). Sweetness ratings differed significantly between the e-liquids. Within all user groups, e-liquids flavored as energy drink, wine gum, bubblegum, watermelon, raspberry, citrus fruits, pineapple, and anise were perceived as significantly more sweet (71.5 on average) than all 15 e-liquids (half of the total sample) with the lowest sweetness ratings (34.3 on average) ($P \leq 0.05$).

Mean ratings for perceived bitterness of the odors ranged from 12.8 (wine gum) to 64.7 (whiskey) across all users. Bitterness differed between the e-liquids, in such a way that whiskey, tobacco ($n = 6$), espresso, peanut, clove, and hazelnut flavored e-liquids were rated as significantly more bitter (52.9 on average) than all 15 e-liquids (half of the total sample) with the lowest bitterness ratings (20.9 on average) within all user groups ($P \leq 0.05$).

Excluding the unflavored e-liquid (12.7 points), mean ratings for overall odor intensity ranged from 44.5 (vanilla) to 73.0 (whiskey) across all users. Between-product differences that were found within all user groups were the following: the whiskey-flavored e-liquid was rated as significantly more intense than anise, bubblegum, wine gum, watermelon, pineapple, raspberry, American blend, vanilla, and unflavored (48.5 on average) ($P \leq 0.05$); and the unflavored e-liquid was rated as significantly less intense than all other products ($P \leq 0.05$).

Finally, mean ratings for irritation ranged from 8.6 (unflavored) to 59.7 (whiskey). The between-product differences that were found within all user groups concerned the whiskey-flavored e-liquid, which was rated as significantly more irritating than the 15 e-liquids (half of the total sample) with the lowest irritation ratings (25.7 on average) ($P \leq 0.05$).

Correlations between attributes

Liking significantly positively correlated with perceived sweetness ($R = 0.49$) and familiarity ($R = 0.48$), and negatively with perceived bitterness ($R = -0.58$), overall intensity ($R = -0.27$), and irritation ($R = -0.47$) of the odors (see Table 3 for all correlation coefficients). The correlation coefficient between liking and perceived sweetness was

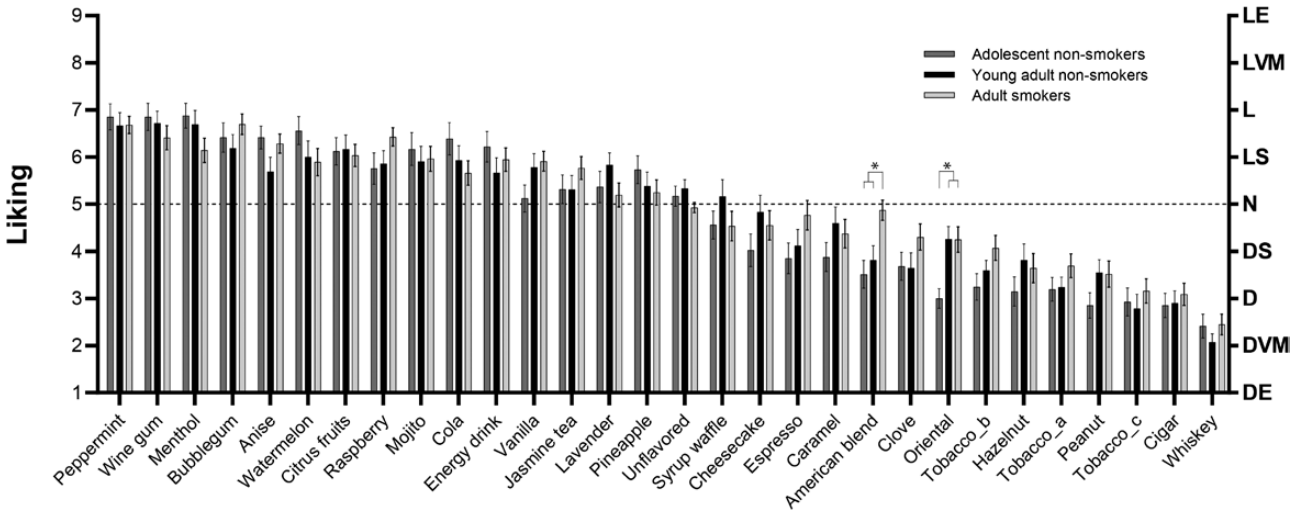

Figure 1. Mean liking ratings for individual e-liquids ($n = 30$), assessed by adolescent nonsmokers, young adult nonsmokers, and adult smokers. Products were ranked from highest to lowest mean liking score across all users ($n = 139$). The letters on the right *y* axis represent the categories of the 9-point hedonic scale: DE, dislike extremely; DVM, dislike very much; D, dislike; DS, dislike slightly; N, neither like nor dislike; LS, like slightly; L, like; LVM, like very much; LE, like extremely. Vertical bars represent standard errors of the mean. Significant differences between user groups are indicated with an asterisk (*). The same data are presented in Supplementary Appendix Table A2.

significantly stronger for adolescent nonsmokers (R = 0.58) compared with young adult nonsmokers (R = 0.44; P < 0.001) and adult smokers (R = 0.46; P < 0.001). Similarly, the correlation coefficient between liking and perceived bitterness was significantly stronger for adolescent nonsmokers (R = –0.64) than young adult nonsmokers (R = –0.57; P = 0.006) and adult smokers (R = –0.55; P < 0.001).

Correlations between sensory assessment and general product use/liking

Across all users, sensory ratings of e-liquid flavors (all attributes) did not correlate significantly with participants' self-reported frequency of eating, drinking, or using a product with the same flavor for any of the attributes (P > 0.05) (Table 4). This was also the case for the separate group of adult smokers. Within both groups of young nonsmokers, correlations between-product use and both liking and familiarity of the associated e-liquid odors were significant and positive, but weak (R < 0.30).

Across all users, sensory assessment of e-liquid flavors correlated significantly weakly positively for liking (R = 0.32), familiarity (R = 0.22), and perceived sweetness (R = 0.24), and significantly weakly negatively for perceived bitterness (R = –0.25), with how much the participants reported to like products with that particular flavor in daily life (according to survey questions) (Table 4). This means that the smell of e-liquids with the same flavor as a product they like in daily life were rated higher on sensory liking, familiarity, and perceived sweetness, and lower on perceived bitterness than those e-liquids with the same flavor as a product they dislike in daily life. Similar correlations were found for the groups of adolescent and young adult nonsmokers separately, but not for adult smokers.

Discussion

The present study aimed to investigate which e-liquid flavors appeal to adolescent nonsmokers, young adult nonsmokers, and adult smokers, as the relative effect of e-cigarette use on health differs between these groups. We found that the smell of sweet and minty e-liquid flavors was liked equally by all groups, and clearly more than tobacco flavors. Furthermore, the smell of tobacco-flavored e-liquids was less disliked by adult smokers than by adolescent and young adult nonsmokers, although differences in mean ratings were small.

Liking of minty and sweet e-liquid flavors

Not surprisingly, liking ratings for e-liquids with a minty and sweet flavor label were relatively high. Sweet tastes are universally liked, as people have an innate preference for sweet taste (Steiner 1979). The high ratings for perceived sweetness of the e-liquid odors may be explained by learned associations with sweet-tasting products, since there was a significant positive correlation between perceived sweetness and familiarity. Similarly, previous vaping studies found that liking of e-liquid flavors significantly positively correlated with sweetness and coolness (Kim et al. 2016; Mead et al. 2019). Similar results were found within our data: the e-liquids with peppermint and menthol flavors received the highest ratings for familiarity and e-liquids with sweet flavor labels were rated highest on perceived sweetness of the odor, and we found strong positive associations between liking and familiarity, and between liking and perceived sweetness, respectively. The fact that we used nicotine-free e-liquids and found similar results compared with previous studies using nicotine-containing e-liquids (Kim et al. 2016; Mead et al. 2019) may imply that (sweet and minty) flavors also independently of nicotine contribute to reward from e-cigarettes.

A review from Hoffman and colleagues about general flavor preferences showed that preference for sweet taste is highest in children and decreases with age (Hoffman et al. 2016). Therefore, in our study, we expected that the group of adolescents would like the smell of e-liquids with a sweet flavor label more than the group of young adults and adults. Although the correlation between liking and perceived sweetness was significantly stronger among adolescents, we found no significant differences between the user groups in their liking ratings for the typically sweet e-liquids. A reason for this may be that we included adolescents from 16 years old and not children of a younger age. As particularly children have a strong preference for sweet flavors in comparison with adults (Zandstra and de Graaf 1998; Hoffman et al. 2016), there may be a difference between children and adults in liking of sweet e-liquid flavors. Further research on this topic with children between 12 and 16 years old would be interesting to determine whether liking of sweet e-liquid flavors is even higher in this group. As the prevalence of e-cigarette use in this age group is concerningly high (Stevens et al. 2018; Cullen et al. 2019), sensory research in children, although ethically challenging, could provide additional support for regulation of (sweet) e-liquid flavors. This could reduce e-cigarette attractiveness, use, and thus health risks among young people who would otherwise not smoke.

Disliking of tobacco-flavored and other non-sweet e-liquids

Non-sweet e-liquid flavors, such as whiskey, tobacco, clove, and espresso were disliked the most within all user groups. These types of odors received the highest ratings for perceived bitterness and irritation, which, since people have an innate aversion to the taste of bitter (Steiner 1979), may support the existence of learned associations between bitterness and odors. This is consistent with the negative correlation between liking and perceived bitterness, which was even stronger in adolescents than both groups of young adults and adults, and between liking and irritation that we found in this study across

Table 3. Pearson correlation coefficients (R) between the attributes, across all users (n = 139) and products (n = 30)

	Liking	Familiarity	Sweetness	Bitterness	Intensity	Irritation
Liking	n.a.					
Familiarity	0.48*	n.a.				
Sweetness	0.49*	0.40*	n.a.			
Bitterness	–0.58*	–0.27*	–0.46*	n.a.		
Intensity	–0.28*	0.16*	0.02	0.30*	n.a.	
Irritation	–0.47*	–0.15*	–0.25*	0.52*	0.44*	n.a.

*Significant correlations with $P \leq 0.05$ after correcting for multiple testing.

Table 4. Pearson correlation coefficients (*R*) between frequency of eating, drinking, or using a product with a particular flavor in daily life and sensory assessment of e-liquid flavors with the same flavor label

Correlations (*R*)		Total sample	Adolescent nonsmokers	Young adult nonsmokers	Adult smokers
How often do you eat/drink/ use a product with flavor X?	Liking of e-liquid flavor X	0.15	0.30*	0.27*	–0.03
	Familiarity of e-liquid flavor X	0.06	0.24*	0.22*	–0.11
	Sweetness of e-liquid flavor X	0.05	0.26*	0.16	–0.13
	Bitterness of e-liquid flavor X	–0.06	–0.23*	–0.18	0.08
	Intensity of e-liquid flavor X	–0.02	0.01	0.04	–0.09
	Irritation of e-liquid flavor X	–0.03	–0.08	–0.02	–0.04
How much do you like a product with flavor X?	Liking of e-liquid flavor X	0.32*	0.38*	0.40*	0.18
	Familiarity of e-liquid flavor X	0.22*	0.33*	0.33*	0.05
	Sweetness of e-liquid flavor X	0.24*	0.38*	0.31*	0.08
	Bitterness of e-liquid flavor X	–0.25*	–0.33*	–0.34*	–0.12
	Intensity of e-liquid flavor X	–0.06	–0.03	–0.05	–0.10
	Irritation of e-liquid flavor X	–0.14	–0.15	–0.16	–0.15

*Significant correlations with $P \leq 0.05$ after correcting for multiple testing.

all flavors. Previous vaping studies found that liking negatively correlated with bitterness and harshness/irritation, and suggested these sensory effects to be most likely caused by nicotine (Kim et al. 2016; Mead et al. 2019; Pullicin et al. 2020). In the current study, nicotine-free e-liquids were used and similar results were found, which supports the use of smelling as an approach to hedonically assess e-liquid flavors (Krusemann et al. 2020). It should be noted that, besides disliking potentially being caused by learned associations between bitter-tasting products and their associated odor, it may have been the case that participants have used bitterness as a proxy for disliking: both disliking and perceived bitterness were associated with unfamiliarity, high irritation, and high overall odor intensities. If this would be true, our bitterness data may have been confounded and should therefore be treated with appropriate caution.

We found significant differences in liking of tobacco-flavored e-liquids between the user groups. Tobacco-flavored e-liquids were less disliked by adult smokers than by adolescent and young adult nonsmokers, even though differences in mean ratings were small. These between-group differences are in line with previous findings that smokers are more interested in trying an e-liquid with tobacco flavor as compared with (young) nonsmokers (Krishnan-Sarin et al. 2015; Shiffman et al. 2015; Shiplo et al. 2015; Czoli et al. 2016; Litt et al. 2016; Romijnders et al. 2019). Similarly, in the current study, smokers reported far more often to be interested in trying a tobacco-flavored e-liquid than the groups of nonsmokers (see Table 2). For these reasons, and due to their learned associations between tobacco flavor and perceived consequences of nicotine consumption (Benowitz 2010), we expected the group of smokers to actually like tobacco-flavored e-liquids. However, their mean hedonic ratings for these products' flavors ranged from "Dislike" (cigar) to "Neither Like nor Dislike" (American blend). In addition, even though they reported to be interested in trying tobacco flavors more often than the other groups, smokers were more interested in other flavors (fruit and menthol/mint). In line with this, the literature showed that also nontobacco flavors, such as sweet flavors, considerably appeal to (young) adult smokers (Krishnan-Sarin et al. 2015; Shiffman et al. 2015; Shiplo et al. 2015; Leventhal et al. 2019), and that fruit and other sweet flavors are actually most popular among e-cigarette users (who are often former smokers) (Shiplo et al. 2015; Tackett et al. 2015; Wang et al. 2015; Berg 2016; Goldenson et al. 2016; Chen and Zeng 2017; Harrell et al. 2017; Huang et al. 2017). Thus, it can be questioned whether (former) smokers actually like the tobacco-flavored e-liquids that are currently available on the market. In fact, since current and former smokers often seem to transition from using tobacco to using sweet e-cigarette flavors over time (Farsalinos et al. 2013; Russell et al. 2018; Romijnders et al. 2019), it is possible that they used tobacco flavors at initiation primarily because they expected that vaping those flavors would simulate the smoking experience best, while vaping tobacco flavors may actually not sufficiently represent smoking a regular cigarette in terms of flavor and/or other sensory aspects. Further research is needed to find a likeable tobacco flavor for e-cigarettes to facilitate smoking cessation in countries where other flavors than tobacco are not allowed.

Flavor perception in e-liquids versus other products

Participants were not informed about the flavor quality (i.e., flavor name) of the e-liquids when performing the sensory test, which causes their familiarity and liking ratings to be solely based on the e-liquids' odors. Sensory ratings for odor familiarity did not correlate with how often participants reported to eat, drink, or use a (often food) product with that flavor in daily life according to the survey questions. In addition, the correlation between participants' sensory assessment of flavor liking by means of smelling the e-liquids and their answers to the survey question how much they like another (food) product with the same flavor was weak. This collectively implies that perception may differ between flavors in e-liquids and the same flavor in another (food) product, and that people may not per se like the same flavors in e-liquids as they like in food. A reason for this may be that the flavor name of e-liquids does not always represent the "real" flavor as we know from another (food) product. For example, an e-liquid labeled as having banana flavor may taste more like banana candy; in this case, we would ask how much participants like and how often they eat banana (and not banana candy). This is similar to our hypothesis that tobacco-flavored e-liquids may not represent the flavor of a real cigarette. Moreover, there is not just one e-liquid labeled as having, for example, a strawberry flavor, but there are multiple strawberry-flavored e-liquids available (Havermans et al. 2019) that each have different chemical flavor compositions (Aszyk et al. 2018). These products may thus be perceived as more or less similar to the actual fruit and may be liked differently. Taken together, more research is needed to better understand the relation between flavor perception and liking in e-cigarettes compared with

other products such as food, and how this differs between user groups (e.g., smokers, nonsmokers, youth, adults).

Implications

By far, sweet and minty e-liquid flavors were liked more than tobacco flavors in all groups. It should be noted that our study took place in an experimental setting, where participants smelled e-liquids blinded in booths according to a standardized approach. The magnitude of differences found in this study may differ from a real-life context, where e-liquid flavors are vaped unblinded according to the user's preferences. Nevertheless, our results show that if countries would decide to ban all e-liquid flavors except tobacco, this will likely reduce attractiveness of e-cigarettes for all user groups. This may reduce and prevent further e-cigarette use and associated health risks among young nonsmokers, thereby improving public health.

In countries where the e-liquid market is or will be limited to tobacco flavors, it should be taken into account that manufacturers may add or continue to add sweeteners to tobacco-flavored e-liquids in order to improve palatability. This will not only increase attractiveness of e-cigarettes among smokers, but also among young nonsmokers, and should therefore be carefully addressed in legislation. On the other hand, it is unknown whether (non-sweetened) tobacco flavors would be sufficiently attractive for smokers to permanently switch toward e-cigarette use, thereby improving their health. As smoking cessation and expected health benefits are still the most important reasons for smokers to start using e-cigarettes (Romijnders et al. 2018), they might continue doing so even if they somewhat dislike the e-liquid flavors available on the market. Another possibility is that this would cause former smokers to quit using e-cigarettes, which would further improve their health (unless they start smoking again). Future research on the effect of banning all e-liquid flavors except tobacco on (former) smokers is needed.

Strengths and limitations

Worldwide, this study was the first sensory study on e-liquid flavors that included adolescent nonsmokers, thereby contributing to a better understanding of e-liquid flavor liking in this, from a public health point of view, highly interesting user group. Furthermore, we tested overall odor intensity in pilot experiments to maximize its consistency, as sensory intensity is known to influence liking (Moskowitz 1981). This resulted in mean ratings for overall odor intensity across all users ranging from 44.5 to 73.0 on a 100 unit scale, which is not too weak nor too strong. It should be noted, however, that odor intensities on individual level may have varied from the mean.

Some limitations of this study should be noted. Firstly, we had difficulties recruiting participants due to the COVID-19 outbreak, hence, the aimed sample size was not met for the groups of adolescent and young adult nonsmokers. However, based on our initial sample size calculations, the power value associated with the final sample size was >75% for both groups, which we considered acceptable. Moreover, the between-group comparisons resulted in similar outcomes when analyzing the groups separately and combined into one group of nonsmokers (n = 83). Secondly, we used nicotine-free e-liquids and an orthonasal smelling approach. Although we previously found a strong correlation (R = 0.84) between orthonasal smelling and vaping in hedonic assessment of nicotine-free e-liquid flavors (Krusemann et al. 2019), the role of nicotine in (dis)liking of e-liquid flavors through its taste and chemesthetic sensations was not covered in this study for ethical reasons, as we included nicotine-naïve individuals (nonsmokers) and individuals under legal age for e-cigarette use (adolescents).

Conclusions

We found that e-liquids with sweet and minty flavors were liked equally, and both clearly more than tobacco flavors, by all groups of potential e-cigarette users (i.e., adolescent nonsmokers, young adult nonsmokers, and adult smokers). Tobacco-flavored e-liquids were slightly less disliked by adult smokers than by the two groups of young nonsmokers. Furthermore, in general, sweet and familiar flavors positively influence liking of e-cigarettes, while flavors with high levels of perceived bitterness, irritation, and a strong overall intensity negatively impact the liking of e-cigarettes. These results suggest that if regulators decide to ban all e-liquid flavors except tobacco, this will likely reduce e-cigarette appeal for all user groups; potentially more for young nonsmokers than adult smokers. Finally, discrepancies between sensory liking and familiarity of e-liquid flavors, and liking and use of other products with the same flavor in daily life imply that perception of e-liquid flavors may not always be the same as perception of other products with the same flavor name (e.g., foods or tobacco cigarettes).

Supplementary material

Supplementary material can be found at *Chemical Senses* online.

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Conflict of interest

L.v.T. is employed by and W.V. is the owner of Essensor BV. Essensor BV was paid by Wageningen University to execute the practical aspect of this study. None of the authors have any financial or nonfinancial relationships with the tobacco nor e-cigarette industry.

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