Both non-smoking youth and smoking adults like sweet and minty e-liquid flavors more than tobacco flavor

Erna JZ Krüsemann, MSc. 1,2*; Loes van Tiel, MSc. 3; Jeroen LA Pennings, PhD 1; Wim Vaessen, PhD 3; Kees de Graaf, Prof 2; Reinskje Talhout, PhD 1; Sanne Boesveldt, PhD 2

1 National Institute for Public Health and the Environment (RIVM), Centre for Health Protection, P.O. Box 1 3720 BA Bilthoven, The Netherlands
2 Wageningen University & Research, Division of Human Nutrition and Health (Bode 62), P.O. Box 17 6700 AA Wageningen, The Netherlands
3 Essensor, Rubensstraat 215-A, 6717 VE Ede, The Netherlands

*Correspondence to be sent to: Erna JZ Krüsemann, Centre for Health Protection, National Institute for Public Health and the Environment (RIVM), P.O. Box 1 3720 BA Bilthoven, The Netherlands, erna.krusemann@rivm.nl
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 non-smokers 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 non-smokers (n=41; mean age 16.9±0.8), young adult non-smokers (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 non-tobacco (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) non-smokers (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 non-smokers and adult smokers, and more than tobacco flavors. Banning all flavors except tobacco will likely reduce e-cigarette appeal; potentially more for young non-smokers than adult smokers.

**Keywords:** flavors, electronic cigarettes, liking, hedonics, smell, consumer research
Introduction

Sensory appeal, in particular taste and smell, is generally recognized as one of the most important motives for food choice (Rozin & 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 & 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 towards 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; Bold et al., 2016; Hilton et al., 2016; Kong et al., 2015). 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 towards 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 (Berg, 2016; Chen & Zeng, 2017; Dawkins et al., 2013; Farsalinos et al., 2013; Goldenson et al., 2016; Harrell et al., 2017; Huang et al., 2017; Kim et al., 2016; Shiplo et al., 2015a; Tackett et al., 2015; Wang et al., 2015; Yingst et al., 2017),
flavor preferences seem to differ between (potential) user groups (Romijnders et al., 2019; Zare et al., 2018). 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) (Harrell et al., 2017; Krishnan-Sarin et al., 2015; Morean et al., 2018). Also, smokers are more interested in trying tobacco and menthol flavored e-cigarettes than (young) non-smokers (Czoli et al., 2016; Romijnders et al., 2019; Shiffman et al., 2015; Shiplo et al., 2015a), 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 non-smokers were to be identified, this information could support regulators in their decisions on whether and how to decrease e-cigarette appeal for youth and non-smokers. 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 non-tobacco flavors, among adolescent non-smokers, young adult non-smokers, 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 non-smoker (aged 16-18), young adult non-smoker (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. Non-smokers 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 non-smokers) 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 non-smokers were
included, contained 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 6 e-liquids from the tobacco category to ensure a strong representation of this traditional category, 1 unflavored e-liquid as a blank sample, one e-liquid from the “other flavors” category, and two e-liquids from the remaining non-tobacco 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 one day before a test session, and labelled 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 tooth paste, and smoking) at least 1 hour prior to their test visit. For each participant, two test sessions of 1 hour 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 feeling in your nose due to this e-liquid’s odor?”) using 100-unit Visual Analog Scales (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 one-minute 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 Dependency (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 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 non-smokers and young adult non-smokers (both separately and combined into one group of non-smokers), and adult smokers. Liking was also compared between these user groups for 4 sets of products with similar flavors (excluding the unflavored e-liquid). Categorization of these 4 product groups was based on similarities in the type of flavor (flavor category) and in sweetness ratings (see 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 & 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 & 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 & Hochberg, 1995).
Results

Panel characteristics

The final sample consisted of 41 adolescent non-smokers (61% female; mean age 16.9±0.8), 42 young adult non-smokers (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.

[insert Table 2 here]

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 non-smokers (3.1 ± 0.3; p < 0.001) and young adult non-smokers (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 non-smokers (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 to adolescent non-smokers (3.2 ± 0.3; p < 0.001), and compared to the combined group of young adult (3.4 ± 0.3) and adolescent non-smokers (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 non-smokers, young adult non-smokers, 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 to young adult (3.8 ± 0.3) and
adolescent non-smokers (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: 4.3 ± 0.3) and young adult non-smokers (4.3 ± 0.3) than adolescent non-smokers (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 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 and 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 6 tobacco-flavored e-liquids, clove, hazelnut, peanut, and whisky (p ≤ 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 (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 total sample) with the lowest mean familiarity ratings (39.3 on average) within all user groups (p ≤ 0.05).

Mean ratings for perceived sweetness of the odors ranged from 22.5 (unflavored) to 79.6 (energy drink) across all users (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 total sample) with the lowest sweetness ratings (34.3 on average) (p ≤ 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 total sample) with the lowest bitterness ratings (20.9 on average) within all user groups (p ≤ 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 ≤ 0.05); and the unflavored e-liquid was rated as significantly less intense than all other products (p ≤ 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 total sample) with the lowest irritation ratings (25.7 on average) (p ≤ 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 significantly stronger for adolescent non-smokers (R = 0.58) compared to young adult non-smokers (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 non-smokers (R = -0.64) than young adult non-smokers (R = -0.57; p = 0.006) and adult smokers (R = -0.55; p < 0.001).

[insert Table 3 here]

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 non-smokers, 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 non-smokers separately, but not for adult smokers.

[insert Table 4 here]

**Discussion**

The present study aimed to investigate which e-liquid flavors appeal to adolescent non-smokers, young adult non-smokers, 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 non-smokers, 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 to 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 to adults (Hoffman et al., 2016; Zandstra & de Graaf, 1998), 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 (Cullen et al., 2019; Stevens et al., 2018), 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 type 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 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 non-smokers, 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 to (young) non-smokers (Czoli et al., 2016; Krishnan-Sarin et al., 2015; Litt et al., 2016; Romijnders et al., 2019; Shiffman et al., 2015; Shiplo et al., 2015a). Similarly, in the current study, smokers reported far more often to be interested in trying a tobacco-flavored e-liquid than the groups of non-smokers (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, literature showed that also non-tobacco flavors, such as sweet flavors, considerably appeal to (young) adult smokers (Krishnan-Sarin et al., 2015; Leventhal et al., 2019; Shiffman et al., 2015; Shiplo et al., 2015b), and that fruit and other sweet flavors are actually most popular among e-cigarette users (who are often former smokers) (Berg, 2016; Chen & Zeng, 2017; Goldenson et al., 2016; Harrell et al., 2017; Huang et al., 2017; Shiplo et al., 2015a; Tackett et al., 2015; Wang et al., 2015). 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; Romijnders et al., 2019; Russell et al., 2018), 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 vs. 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 to other products such as food, and how this differs between user groups (e.g., smokers, non-smokers, 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 non-smokers, 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 non-smokers, 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 towards 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 non-smokers, 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 non-smokers. 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
non-smokers (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 (non-smokers) 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 non-
smokers, young adult non-smokers, and adult smokers). Tobacco-flavored e-liquids were
slightly less disliked by adult smokers than by the two groups of young non-smokers.
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 non-smokers 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).
Conflict of interests

LvT is employed by and WV is 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 non-financial relationships with the tobacco nor e-cigarette industry.

Funding

This work was supported by the Dutch Ministry of Health, Welfare and Sport under project number 5.7.1.

Acknowledgements

The authors would like to thank the volunteers for participating in this study. Furthermore, we owe huge thanks to Erika Bloemert for helping us with participant recruitment and Kitty van Rooij for her efforts regarding data collection. Finally, Wiebe Dam is gratefully acknowledged for his contribution to the practical aspect of this study, including pilot experiments, participant recruitment, and data collection.
References

Ambrose, B. K., Day, H. R., Rostron, B., Conway, K. P., Borek, N., Hyland, A., & Villanti, A. C. (2015). Flavored Tobacco Product Use Among US Youth Aged 12-17 Years, 2013-2014. *JAMA, 314*(17), 1871-1873. https://doi.org/10.1001/jama.2015.13802

Aszyk, J., Kubica, P., Wozniak, M. K., Namiesnik, J., Wasik, A., & Kot-Wasik, A. (2018). Evaluation of flavour profiles in e-cigarette refill solutions using gas chromatography-tandem mass spectrometry. *Journal of chromatography. A, 1547*, 86-98. https://doi.org/10.1016/j.chroma.2018.03.009

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society. Series B (Methodological), 57*(1), 289-300. http://www.jstor.org/stable/2346101

Benowitz, N. L. (2010). Nicotine addiction. *N Engl J Med, 362*(24), 2295-2303. https://doi.org/10.1056/NEJMra0809890

Berg, C. J. (2016). Preferred flavors and reasons for e-cigarette use and discontinued use among never, current, and former smokers [JOUR]. *International journal of public health, 61*(2), 225-236. https://doi.org/http://dx.doi.org/10.1007/s00038-015-0764-x

Bold, K. W., Kong, G., Cavallo, D. A., Camenga, D. R., & Krishnan-Sarin, S. (2016). Reasons for Trying E-cigarettes and Risk of Continued Use. *Pediatrics, 138*(3). https://doi.org/10.1542/peds.2016-0895

Chen, Z., & Zeng, D. D. (2017). Mining online e-liquid reviews for opinion polarities about e-liquid features. *BMC public health, 17*(1), 633. https://doi.org/10.1186/s12889-017-4533-z

Cullen, K. A., Gentzke, A. S., Sawdey, M. D., Chang, J. T., Anic, G. M., Wang, T. W., Creamer, M. R., Jamal, A., Ambrose, B. K., & King, B. A. (2019). e-Cigarette Use Among Youth in the United States, 2019. *JAMA*. https://doi.org/10.1001/jama.2019.18387 %J JAMA
Czoli, C. D., Goniewicz, M., Islam, T., Kotnowski, K., & Hammond, D. (2016). Consumer preferences for electronic cigarettes: results from a discrete choice experiment. *Tob Control, 25*(e1), e30-36. https://doi.org/10.1136/tobaccocontrol-2015-052422

Dawkins, L., Turner, J., Roberts, A., & Soar, K. (2013). 'Vaping' profiles and preferences: an online survey of electronic cigarette users. *Addiction, 108*(6), 1115-1125. https://doi.org/10.1111/add.12150

Farsalinos, K. E., Romagna, G., Tsiapras, D., Kyrzopoulos, S., Spyrou, A., & Voudris, V. (2013). Impact of flavour variability on electronic cigarette use experience: An internet survey [JOUR]. *International Journal of Environmental Research and Public Health, 10*(12), 7272-7282. https://doi.org/http://dx.doi.org/10.3390/ijerph10127272

Ferris Wayne, G., & Connolly, G. N. (2004). Application, function, and effects of menthol in cigarettes: a survey of tobacco industry documents. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco, 6* Suppl 1, S43-54. https://doi.org/10.1080/14622203310001649513

Foley, A. M. (2019). A review of the e-cigarette debate. *J Vasc Nurs, 37*(2), 153-155. https://doi.org/10.1016/j.jvn.2019.05.005

Ford, A., MacKintosh, A. M., Bauld, L., Moodie, C., & Hastings, G. (2016). Adolescents' responses to the promotion and flavouring of e-cigarettes. *Int J Public Health, 61*(2), 215-224. https://doi.org/10.1007/s00038-015-0769-5

Goldenson, N. I., Kirkpatrick, M. G., Barrington-Trimis, J. L., Pang, R. D., McBeth, J. F., Pentz, M. A., Samet, J. M., & Leventhal, A. M. (2016). Effects of sweet flavorings and nicotine on the appeal and sensory properties of e-cigarettes among young adult vapers: Application of a novel methodology [JOUR]. *Drug and Alcohol Dependence, 168*, 176-180. https://doi.org/http://dx.doi.org/10.1016/j.drugalcdep.2016.09.014

Goniewicz, M. L., Knysz, J., Gawron, M., Kosmider, L., Sobczak, A., Kurek, J., Prokopowicz, A., Jablonska-Czapla, M., Rosik-Dulewska, C., Havel, C., Jacob, P., 3rd, & Benowitz, N. (2014).
Levels of selected carcinogens and toxicants in vapour from electronic cigarettes. *Tob Control*, 23(2), 133-139. [https://doi.org/10.1136/tobaccocontrol-2012-050859](https://doi.org/10.1136/tobaccocontrol-2012-050859)

Harrell, M. B., Weaver, S. R., Loukas, A., Creamer, M., Marti, C. N., Jackson, C. D., Heath, J. W., Nayak, P., Perry, C. L., Pechacek, T. F., & Eriksen, M. P. (2017). Flavored e-cigarette use: Characterizing youth, young adult, and adult users [JOUR]. *Preventive Medicine Reports*, 5, 33-40. [https://doi.org/10.1016/j.pmedr.2016.11.001](https://doi.org/10.1016/j.pmedr.2016.11.001)

Havermans, A., Krüsemann, E. J. Z., Pennings, J., de Graaf, K., Boesveldt, S., & Talhout, R. (2019). Nearly 20 000 e-liquids and 250 unique flavour descriptions: an overview of the Dutch market based on information from manufacturers. *Tob Control*, tobaccocontrol-2019-055303. [https://doi.org/10.1136/tobaccocontrol-2019-055303](https://doi.org/10.1136/tobaccocontrol-2019-055303)

Heatherton, T. F., Kozlowski, L. T., Frecker, R. C., & Fagerstrom, K. O. (1991). The Fagerstrom Test for Nicotine Dependence: a revision of the Fagerstrom Tolerance Questionnaire. *Br J Addict, 86*(9), 1119-1127. [https://doi.org/10.1111/j.1360-0443.1991.tb01879.x](https://doi.org/10.1111/j.1360-0443.1991.tb01879.x)

Hilton, S., Weishaar, H., Sweeting, H., Trevisan, F., & Katikireddi, S. V. (2016). E-cigarettes, a safer alternative for teenagers? A UK focus group study of teenagers' views. *BMJ Open*, 6(11), e013271. [https://doi.org/10.1136/bmjopen-2016-013271](https://doi.org/10.1136/bmjopen-2016-013271)

Hoffman, A. C., Salgado, R. V., Dresler, C., Faller, R. W., & Bartlett, C. (2016). Flavour preferences in youth versus adults: a review. *Tob Control, 25*(Suppl 2), ii32-ii39. [https://doi.org/10.1136/tobaccocontrol-2016-053192](https://doi.org/10.1136/tobaccocontrol-2016-053192)

Huang, L. L., Baker, H. M., Meernik, C., Ranney, L. M., Richardson, A., & Goldstein, A. O. (2017). Impact of non-menthol flavours in tobacco products on perceptions and use among youth, young adults and adults: a systematic review. *Tob Control, 26*(6), 709-719. [https://doi.org/10.1136/tobaccocontrol-2016-053196](https://doi.org/10.1136/tobaccocontrol-2016-053196)

Jackson, A., Green, B., Erythropel, H. C., Kong, G., Cavallo, D. A., Eid, T., Gueorguieva, R., Buta, E., O'Malley, S. S., & Krishnan-Sarin, S. (2020). Influence of menthol and green apple e-liquids containing different nicotine concentrations among youth e-cigarette users. *Exp Clin Psychopharmacol*. [https://doi.org/10.1037/pha0000368](https://doi.org/10.1037/pha0000368)
Kim, H., Lim, J., Buehler, S. S., Brinkman, M. C., Johnson, N. M., Wilson, L., Cross, K. S., & Clark, P. I. (2016). Role of sweet and other flavours in liking and disliking of electronic cigarettes. *Tob Control*, 25(Suppl 2), ii55-ii61. https://doi.org/10.1136/tobaccocontrol-2016-053221

Kong, G., Morean, M. E., Cavallo, D. A., Camenga, D. R., & Krishnan-Sarin, S. (2015). Reasons for Electronic Cigarette Experimentation and Discontinuation Among Adolescents and Young Adults. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco*, 17(7), 847-854. https://doi.org/10.1093/ntr/ntu257

Krishnan-Sarin, S., Morean, M. E., Camenga, D. R., Cavallo, D. A., & Kong, G. (2015). E-cigarette use among high school and middle school adolescents in Connecticut [JOUR]. *Nicotine and Tobacco Research*, 17(7), 810-818. https://doi.org/http://dx.doi.org/10.1093/ntr/ntu243

Krusemann, E. J. Z., Boesveldt, S., de Graaf, K., & Talhout, R. (2019). An E-Liquid Flavor Wheel: A Shared Vocabulary Based on Systematically Reviewing E-Liquid Flavor Classifications in Literature. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco*, 21(10), 1310-1319. https://doi.org/10.1093/ntr/nty101

Krusemann, E. J. Z., Wenng, F. M., Pennings, J. L. A., de Graaf, K., Talhout, R., & Boesveldt, S. (2020). Sensory Evaluation of E-Liquid Flavors by Smelling and Vaping Yields Similar Results. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco*, 22(5), 798-805. https://doi.org/10.1093/ntr/ntz155

Leventhal, A. M., Goldenson, N. I., Barrington-Trimis, J. L., Pang, R. D., & Kirkpatrick, M. G. (2019). Effects of non-tobacco flavors and nicotine on e-cigarette product appeal among young adult never, former, and current smokers. *Drug Alcohol Depend*, 203, 99-106. https://doi.org/10.1016/j.drugalcdep.2019.05.020

Litt, M. D., Duffy, V., & Oncken, C. (2016). Cigarette smoking and electronic cigarette vaping patterns as a function of e-cigarette flavourings. *Tob Control*, 25(Suppl 2), ii67-ii72. https://doi.org/10.1136/tobaccocontrol-2016-053223
Mead, E. L., Duffy, V., Oncken, C., & Litt, M. D. (2019). E-cigarette palatability in smokers as a function of flavorings, nicotine content and propylthiouracil (PROP) taster phenotype. *Addict Behav, 91*, 37-44. [https://doi.org/10.1016/j.addbeh.2018.11.014](https://doi.org/10.1016/j.addbeh.2018.11.014)

Megerdichian, C. L., Rees, V. W., Wayne, G. F., & Connolly, G. N. (2007). Internal tobacco industry research on olfactory and trigeminal nerve response to nicotine and other smoke components. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco, 9*(11), 1119-1129. [https://doi.org/10.1080/14622200701648458](https://doi.org/10.1080/14622200701648458)

Morean, M. E., Butler, E. R., Bold, K. W., Kong, G., Camenga, D. R., Cavallo, D. A., Simon, P., O’Malley, S. S., & Krishnan-Sarin, S. (2018). Preferring more e-cigarette flavors is associated with e-cigarette use frequency among adolescents but not adults. *PLoS ONE, 13*(1), e0189015. [https://doi.org/10.1371/journal.pone.0189015](https://doi.org/10.1371/journal.pone.0189015)

Moskowitz, H. R. (1981). Sensory intensity versus hedonic functions; classical psychophysical approaches. *Journal of Food Quality, 5*, 109-137.

Pepper, J. K., Ribisl, K. M., & Brewer, N. T. (2016). Adolescents’ interest in trying flavoured e-cigarettes. *Tob Control, 25*(Suppl 2), ii62-ii66. [https://doi.org/10.1136/tobaccocontrol-2016-053174](https://doi.org/10.1136/tobaccocontrol-2016-053174)

Pullicin, A. J., Kim, H., Brinkman, M. C., Buehler, S. S., Clark, P. I., & Lim, J. (2020). Impacts of Nicotine and Flavoring on the Sensory Perception of E-Cigarette Aerosol. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco, 22*(5), 806-813. [https://doi.org/10.1093/ntr/ntz058](https://doi.org/10.1093/ntr/ntz058)

Romijn, K., van Osch, L., de Vries, H., & Talhout, R. (2018). Perceptions and Reasons Regarding E-Cigarette Use among Users and Non-Users: A Narrative Literature Review. *Int J Environ Res Public Health, 15*(6). [https://doi.org/10.3390/ijerph15061190](https://doi.org/10.3390/ijerph15061190)

Romijn, K. A., Krusemann, E. J., Boesveldt, S., Graaf, K., Vries, H., & Talhout, R. (2019). E-Liquid Flavor Preferences and Individual Factors Related to Vaping: A Survey among Dutch Never-Users, Smokers, Dual Users, and Exclusive Vapers. *Int J Environ Res Public Health, 16*(23). [https://doi.org/10.3390/ijerph16234661](https://doi.org/10.3390/ijerph16234661)
Rosbrook, K., Erythropel, H. C., DeWinter, T. M., Falinski, M., O'Malley, S., Krishnan-Sarin, S., Anastas, P. T., Zimmerman, J. B., & Green, B. G. (2017). The effect of sucralose on flavor sweetness in electronic cigarettes varies between delivery devices. *PLoS ONE, 12*(10), e0185334. https://doi.org/10.1371/journal.pone.0185334

Rozin, P., & Fallon, A. (1980). The psychological categorization of foods and non-foods: A preliminary taxonomy of food rejections. *Appetite, 1*(3), 193-201. https://doi.org/10.1016/s0195-6663(80)80027-4

Russell, C., McKeganey, N., Dickson, T., & Nides, M. (2018). Changing patterns of first e-cigarette flavor used and current flavors used by 20,836 adult frequent e-cigarette users in the USA. *Harm Reduct J, 15*(1), 33. https://doi.org/10.1186/s12954-018-0238-6

Schmidt, S. (2020). Vaper, Beware: The Unique Toxicological Profile of Electronic Cigarettes. *Environ Health Perspect, 128*(5), 52001. https://doi.org/10.1289/EHP6628

Shiffman, S., Sembower, M. A., Pillitteri, J. L., Gerlach, K. K., & Gitchell, J. G. (2015). The Impact of Flavor Descriptors on Nonsmoking Teens' and Adult Smokers' Interest in Electronic Cigarettes [JOUR]. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco, 17*(10), 1255-1262. https://doi.org/10.1093/ntr/ntu333

Shiplo, S., Czoli, C. D., & Hammond, D. (2015a). E-cigarette use in Canada: Prevalence and patterns of use in a regulated market [JOUR]. *BMJ Open, 5*(8). https://doi.org/http://dx.doi.org/10.1136/bmjopen-2015-007971

Shiplo, S., Czoli, C. D., & Hammond, D. (2015b). E-cigarette use in Canada: prevalence and patterns of use in a regulated market. *BMJ Open, 5*(8), e007971. https://doi.org/10.1136/bmjopen-2015-007971

Soneji, S., Barrington-Trimis, J. L., Wills, T. A., Leventhal, A. M., Unger, J. B., Gibson, L. A., Yang, J., Primack, B. A., Andrews, J. A., Miech, R. A., Spindle, T. R., Dick, D. M., Eissenberg, T., Hornik, R. C., Dang, R., & Sargent, J. D. (2017). Association Between Initial Use of e-Cigarettes and Subsequent Cigarette Smoking Among Adolescents and Young Adults: A
Systematic Review and Meta-analysis. *JAMA Pediatr, 171*(8), 788-797.

https://doi.org/10.1001/jamapediatrics.2017.1488

Steiner, J. E. (1979). Human Facial Expressions in Response to Taste and Smell Stimulation. In H. W. Reese & L. P. Lipsitt (Eds.), *Advances in Child Development and Behavior* (Vol. 13, pp. 257-295). JAI. https://doi.org/https://doi.org/10.1016/S0065-2407(08)60349-3

Steptoe, A., Pollard, T. M., & Wardle, J. (1995). Development of a measure of the motives underlying the selection of food: the food choice questionnaire. *Appetite, 25*(3), 267-284.

https://doi.org/10.1006/appe.1995.0061

Stevens, G., van Dorsselaer, S., Boer, M., de Roos, S., Duinhof, E., ter Bogt, T., van den Huijden, R., Kuyper, L., Visser, D., Vollebergh, W., & de Loose, M. (2018). *HBSC 2017: Gezondheid en welzijn van jongeren in Nederland.* https://hbsc-nederland.nl/wp-content/uploads/2018/09/Rapport-HBSC-2017.pdf

Tackett, A. P., Lechner, W. V., Meier, E., Grant, D. M., Driskill, L. M., Tahirkheli, N. N., & Wagener, T. L. (2015). Biochemically verified smoking cessation and vaping beliefs among vape store customers. *Addiction, 110*(5), 868-874. https://doi.org/10.1111/add.12878

Wang, L., Zhan, Y., Li, Q., Zeng, D. D., Leischow, S. J., & Okamoto, J. (2015). An Examination of Electronic Cigarette Content on Social Media: Analysis of E-Cigarette Flavor Content on Reddit [JOUR]. *Int J Environ Res Public Health, 12*(11), 14916-14935.

https://doi.org/10.3390/ijerph121114916

Yingst, J. M., Veldheer, S., Hammett, E., Hrabovsky, S., & Foulds, J. (2017). A Method for Classifying User-Reported Electronic Cigarette Liquid Flavors. *Nicotine & tobacco research: official journal of the Society for Research on Nicotine and Tobacco, 19*(11), 1381-1385.

https://doi.org/10.1093/ntr/ntw383

Zandstra, E. H., & de Graaf, C. (1998). Sensory perception and pleasantness of orange beverages from childhood to old age. *Food quality and preference, 9*(1-2), 5-12.

https://doi.org/10.1016/s0950-3293(97)00015-3
Zare, S., Nemati, M., & Zheng, Y. (2018). A systematic review of consumer preference for e-cigarette attributes: Flavor, nicotine strength, and type. *PLoS ONE, 13*(3), e0194145. https://doi.org/10.1371/journal.pone.0194145
Figure legends

Figure 1: Mean liking ratings for individual e-liquids (n=30), assessed by adolescent non-smokers, young adult non-smokers, 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 Appendix Table A2.
Table 1: E-liquid products (n = 30) used in this study, including their flavor category and dilution factor.

| Flavor category       | Flavor            | # 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                                 |

NB: a, b, and c for product 3, 4, and 5 represent three different e-liquid products that were all marketed as having an (unspecified) tobacco flavor; PG = propylene glycol; VG = vegetable glycerin.
Table 2: Characteristics of the panelists included in this study.

|                                | Total sample (n = 139) | Adolescent non-smokers (n = 41) | Young adult non-smokers (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 (%)**      |                        |                                 |                                 |                        |
| 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 (%)** |                    |                                 |                                 |                        |
| 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 (%)** |                    |                                 |                                 |                        |
| 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* (%)** |         |   |   |   |
| No intention                 | 18      |    |    |    |
| Low intention                | 42      |    |    |    |
| High intention               | 33      |    |    |    |
| Don’t know                   | 7       |    |    |    |
| **Smoking duration* (%)**    |         |   |   |   |
| < 1 year                     | 0       |    |    |    |
| 1–5 years                    | 9       |    |    |    |
| 5–10 years                   | 9       |    |    |    |
| > 10 years                   | 82      |    |    |    |
| **Number of cigarettes per day* (%)** |         |   |   |   |
| 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* (%)** |         |   |   |   |
| Tobacco                      | 95      |    |    |    |
| Menthol                      | 5       |    |    |    |
| Other                        | 0       |    |    |    |
| **Ever use of cigarettes with menthol or other flavor* (n; check all that apply)** | |   |   |   |
| No                           | 7       |    |    |    |
| Menthol                      | 43      |    |    |    |
| Flavor other than menthol    | 12      |    |    |    |
| **Nicotine dependence* (%)** |         |   |   |   |
| Low dependence               | 40      |    |    |    |
| Low to moderate dependence   | 33      |    |    |    |
| Moderate dependence          | 27      |    |    |    |
| High dependence              | 0       |    |    |    |

General note: 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.

* Only applicable to the group of adult smokers (n = 55); missing data for 1 participant.
Table 3: Pearson correlation coefficients ($R$) between the attributes, across all users ($n = 139$) and products ($n = 30$). As expected, all correlations were significant, except sweetness vs. intensity.

|        | Liking | Familiarity | Sweetness | Bitterness | Intensity | Irritation |
|--------|--------|-------------|-----------|------------|-----------|------------|
| Liking | n.a.   | 0.48*       | n.a.      | 0.40*      | n.a.      | 0.47*      |
| Familiarity | 0.49* | 0.40*       | n.a.      | 0.27*      | 0.30*     | 0.44*      |
| Sweetness   | 0.58* | –           | 0.40*     | –          | 0.30*     | 0.52*      |
| Bitterness  | –     | 0.28*       | 0.16*     | 0.02       | 0.25*     | n.a.       |
| Intensity   | –     | –           | n.a.      | 0.02       | n.a.      | n.a.       |
| Irritation  | –     | –           | –         | 0.25*      | n.a.      | 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 non-smokers | Young adult non-smokers | 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.
