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Combinations of electronic nicotine delivery system device and liquid characteristics among U.S. adults

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A B S T R A C T

Introduction: The combination of electronic nicotine delivery systems (ENDS) device and liquid characteristics affect user nicotine and toxicant exposure, however population-level national survey studies have not reported device and liquid features jointly nor in detail. We examined combinations of characteristics of devices and liquids used by adult ENDS users.

Methods: U.S. adults (21+) using ENDS at least five days/week (n = 1,179) completed an online survey in 2020 and uploaded photos of their most used device and liquid. Device/liquid combinations were analyzed to determine and describe the most common pairings. Data were weighted to the U.S. population of adult daily ENDS users.

Results: Five device/liquid combinations accounted for 87 % of those reported. The most prevalent combination, reported by 36.2 %, was re-useable devices with adjustable settings and a tank refilled with a free-base nicotine liquid with a median nicotine concentration of 5.2 mg/mL. The second most frequent combination – re-usable devices with no adjustable settings and a nicotine salt liquid in a disposable pod or cartridge – was reported by 22.8 % and the median nicotine concentration was 49.4 mg/mL. Wattage, voltage and resistance varied across device/liquid combination. Overall, 66.5 % refilled their device's tank or pod and 64.2 % had the ability to manipulate device characteristics (power, airflow, and/or coil).

Conclusions: Analyzing ENDS device/liquid combinations rather than each separately can allow researchers to better evaluate relationships between use and key outcomes, such as quitting cigarettes and abuse liability. Additional research may reveal whether certain combinations are more effective at helping smokers quit and which device/liquid combinations should remain on the market.

1. Introduction

The electronic nicotine delivery systems (ENDS) market is highly heterogeneous with many combinations of devices and liquids available. (O'Connor et al., 2022 Mar; Ozga et al., 2022 Feb 14) That the market is changing rapidly adds to the challenges of understanding product use and impact. Based on the U.S. nationally representative 2020 National Health Interview Survey, 3.7 % of adults (9.1 million) currently use ENDS, with ENDS use prevalence highest among adults aged 18–24 (9.4 %). (Cornelius et al., 2022 Mar 18).

The amount of nicotine and non-nicotine toxicants that an ENDS device/liquid combination can deliver has implications for how effective it can be to help people stop using cigarettes, for dependence (abuse liability), and for potential health effects. (Gades et al., 2022; Hoetger et al., 2021 Oct 14) A device's power characteristics (wattage: a function of battery voltage and heating coil resistance), nicotine concentration of the liquid, and nicotine form (salt or free-base) all influence the amount of nicotine delivered to the user. (Shihadeh and Eissenberg, 2015 Feb; El Hourani et al., 2022; Wagener et al., 2017 Mar; Leventhal et al., 2021 Jan 4; Talih et al., 2021; Talih et al., 2020 Oct 1; Hiler et al., 2020 Oct) Which products are being used and by whom has implications for understanding how ENDS use benefits or harms individual and public health.

A number of nationally representative studies have reported survey data on broad types of ENDS devices used, but because the ENDS market changes rapidly and published studies report data from prior to 2020,

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they are not presented here. Briefly, the ENDS marketplace in the U.S. was originally categorized by "generation", (Ozga et al., 2022 Feb 14) with the most popular device type first being disposable devices that looked like cigarettes, followed by re-useable devices with a more tubular shape that resembled a pen. The third generation were re-usable devices that were modifiable and adjustable. The fourth generation were devices that used replaceable or refillable pods and cartridges. The ENDS marketplace has continued to evolve at a fast rate, with increasingly blurred lines between classic definitions.

Based on our own analyses of wave 5 (12/2018–11/2019) of the nationally representative Population Assessment of Tobacco and Health (PATH) study, using the PATH response options, among adult ENDS users who used ENDS > 20 days/month, 42.8 % used devices with a replaceable, prefilled cartridge (e.g., JUUL), 37.0 % used devices with a refillable tank, 10.4 % used a "mod" (modifiable) system, 8.2 % used a disposable device, and 1.6 % used other ENDS types. (Inter-University Consortium, xxxx).

Further, recent U.S. store sales scanner data from August 2019-May 2020, found that 80.2 % of total ENDS sales were prefilled cartridge products and 19.8 % were disposable products, (Ali et al., 2020 Sep 18) though vape shops and sales from websites, which represented about half of 2019 ENDS sales in the U.S., were not included. Scanner and survey data measure different constructs, potentially increasing uncertainty about the products being used. This uncertainty is increased further because there are gaps in the literature due to ambiguous device type categories, examining device and liquid data independently rather than together, low level of detail collected about the devices and liquids used, representativeness of the sample, and the timeliness of data. Further, concerns have been raised about the validity of self-report regarding device and liquid information. (Rudy et al., 2017 Oct).

To address this uncertainty and gaps in the current literature, the aim of this paper is to examine the range of devices and liquids – examined jointly rather than separately – used by frequent (5+ days/week) adult ENDS users from the U.S. in 2020. This paper reports more detail about device and liquid characteristics than has been reported previously for a sample that is weighted to be representative of U.S. adult daily ENDS users. We addressed ambiguity in device categories by collecting, coding and reporting a range of characteristics of devices and liquids, rather than asking respondents to select from a pre-determined list of device categories. Further, we responded to challenges with validity of self-report by asking participants to upload photos of their most used device and liquid for that device, which were then coded for a range of characteristics.

2. Methods

The target population for the VAPER (Vaping and Patterns of E-cigarette Use Research) study was adult ENDS users living in the U.S. who used ENDS at least 5 days/week. Participants were recruited for an online survey using social media ads for three weeks in four cities before transitioning to a Craigslist-focused strategy. Craigslist ads were posted on two boards (gigs and jobs) in 125 locations across the U.S. at varying frequencies (e.g, twice weekly, weekly, monthly). U.S. census population estimates for cities and states were used to identify Craigslist catchment areas covering well-populated areas; posting frequency depended on the rate of displacement of our ads by more recently posted ads in each catchment area. Ads linked to a study landing page that included a simple welcome message, followed by a description of the study. Potential participants were asked to provide consent online; those who consented were routed to a registration page to collect identifying data, such as name, date of birth, cell phone number, email, and mailing address. To be eligible for the survey, ENDS users had to be at least 21 years old, use ENDS at least 5 days/week, and provide personal identifying information. The survey was hosted in REDCap. Participants submitted photos of their most used device and liquid. The Virginia Commonwealth University Institutional Review Board (IRB) approved the study (HM20015004), with the Johns Hopkins Bloomberg School of Public Health IRB relying on the VCU IRB as the IRB of record (IRB9277).

7,875 people were screened for age and ENDS use frequency (Fig. 1); 3,586 were not invited to take the survey because of ineligibility due to being too young (n = 363), using ENDS fewer than five days/week (n = 2,691), or both (n = 365); further, 161 did not answer the age or ENDS use question, and 6 did not complete the screening questionnaire. Of those invited to take the full survey (n = 4,289), 2,813 completed it. A range of security and data integrity measures were employed to maximize data quality; we excluded 1,634 surveys for the following reasons: multiple screening questionnaire attempts (n = 162); identity authentication failure (including not providing additional verification information if their provided mailing address did not match the information in the third party personal record service, n = 765); invalid mailing address (mailing address not in the U.S., not residential, or a PO Box, n = 13); suspected bots or professional survey takers (e.g., repeat answers to open-ended questions, especially those that were obscure; mailed incentives returned to us by USPS, n = 71); inconsistent responses for date of birth and age (n = 38); time to completion under 5 min (n = 24); inaccurate responses to two attention checking questions (n = 64); submission of unusable photos (including photos from the internet, n = 464); exclusion for miscellaneous reasons (n = 3); and, reporting of nicotine concentration as 0 mg/ml (n = 30). The final sample size was 1,179.

Respondents were asked about their most used device including questions about device characteristics such as re-usable vs disposable, refillability, uses a tank or pod/cartridge, and has settings that allow one to modify the power or airflow or has a coil that can be modified. The device categories were developed by our team. Our review of the literature found existing approaches to be disparate and outdated for the current marketplace, which is evolving at a fast rate with increasingly blurred lines between classic definitions (e.g., generations 1–4). These definitions are often reliant on shape, which can be subjective. Therefore, we determined it was more appropriate to devise a more future-proofed categorization system with discrete categories based on more objective device attributes. This focus on objective attributes allowed us to develop survey skip logic that could be tailored to user experiences with a range of devices. Respondents were also asked about their most used ENDS liquid for their most used device, including the concentration of nicotine and whether it contains nicotine salts (i.e., protonated nicotine).

The relevant questions for this analysis are provided in Appendix A. Respondents self-reported their state of residence; states were categorized into four regions based on the US Census Bureau's designation (https://www2.census.gov/geo/pdfs/maps-data/maps/reference/us_regdiv.pdf). We defined participants who smoke cigarettes as those who reported smoking a cigarette in the past 30 days.

To code the submitted photos for device and liquid characteristics, we searched the internet for any identifying text or markings on the device and liquid container and visually compared the submitted photo with the search results to identify the brand, model (for devices), and flavor (for liquids). In addition to coding information directly from submitted photos (e.g., nicotine concentration written on the liquid bottle), the brand and model/flavor determined from the internet search were used to identify and search the internet for device (e.g., wattage, voltage, resistance) and liquid (e.g., nicotine form and concentration) characteristics. When device or liquid characteristics were not available from the coded photos or websites searched, we used self-report data where possible. Procedures for obtaining device wattage, voltage and resistance are described in Appendix B. Device and liquid photo coding were conducted by LC and JH to ensure reliability of at least 90 %. If issues/questions arose about a specific record, the coders reviewed the record, discussed, and agreed on a strategy for coding. Upon completion of coding, JH reviewed all records for accuracy.

For nicotine concentration, we converted percentages to mg/mL by

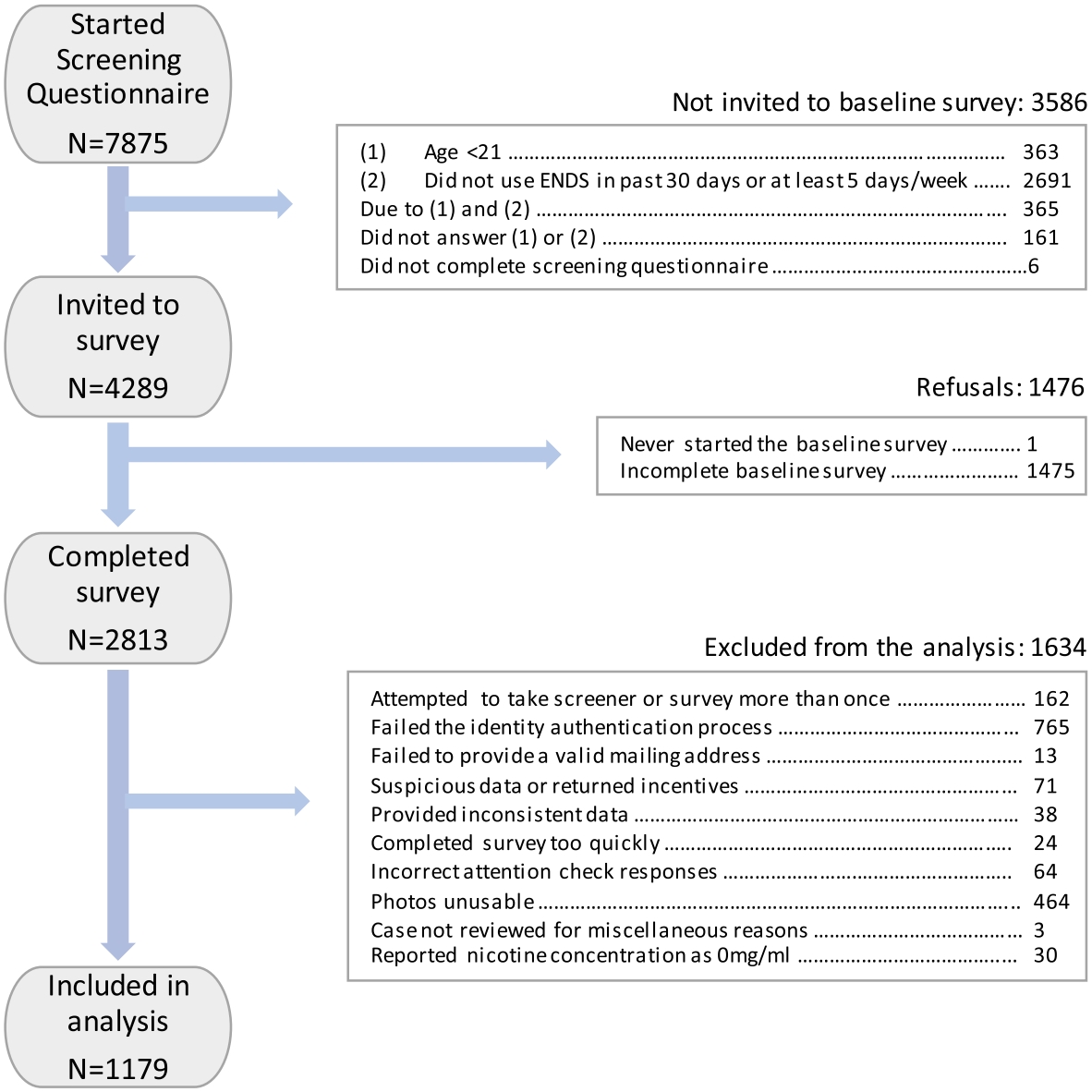

Fig. 1. VAPER wave 1 respondent flowchart.

multiplying by 10; however, if the liquid brand/model was JUUL, NJOY Ace or NJOY Daily we recorded the value known from other sources (e.g., if self-reported mg/mL was 50 for JUUL, it was recoded to 59 (About, 2022). Nicotine concentration was treated as missing if the self-reported value was over 100 mg/mL (n = 7).

We conducted the analyses by starting with broad device type: reusable or disposable. Next, we classified devices based on the dimensions of refillability, device liquid container, and setting adjustability. To determine device/liquid combinations, we then assessed the nicotine formulation of the liquid used with the participants' most used device.

Reusable devices: We first stratified by whether the participant used a liquid in a pre-filled pod/cartridge, a refillable pod/cartridge, or a refillable tank, then by whether the respondent's device had settings that allowed them to modify the power, airflow, or coil (categorized as adjustable if any were adjustable), and then by the liquid nicotine form (salt vs free-base). Within each stratum, we calculated the mean, median and range of liquid nicotine concentration and device wattage, voltage, and resistance.

Disposable devices: Because by definition these devices are not refillable nor have a tank or use a pod/cartridge, we stratified by whether the respondent's device had settings that allowed them to modify the power, airflow, or coil, then by liquid nicotine form. Within each stratum, we calculated the mean, median and range of liquid nicotine concentration and device wattage, output voltage and resistance.

To ensure the sample was representative of the population of interest, we used the post-stratification weighting method (Royal, 2019; Biemer et al., 2008) based on data from the 2019 Tobacco Use Supplement to the Current Population Survey (TUS-CPS). The distribution of participants' sociodemographic characteristics in general mirrored that of daily ENDS users in the 2019 TUS-CPS. Those who were White men<35 years old, and White women 35 years and older, had similar distribution in gender and race as their counterparts in 2019 TUS-CPS; post-stratification weights for these subgroups were between 1.24 and 0.97. However, for those aged 35 and older, the sample had proportionally fewer White men (15 % vs 27 %), and proportionally more non-White women younger than 35 (8 % vs 3 %); the largest post-stratification weight for these age/gender/race groups was 1.78. We used the gender/age/race post-stratification weight to conduct the

descriptive and inferential statistical analyses. Percentages presented are weighted; n's presented are weighted but scaled to the actual sample size.

To ensure statistical tests were based on the actual sample size, we report p values using the Rao-Scott Chi-square test, (Lipsitz et al., 2015 Sep) that first performs the Chi-Square test with the weighted sample and then adjusts the results with a design correction.

3. Results

3.1. Sample characteristics

Participants were predominantly from the South (42.0 %) and West (29.1 %) regions; 18.8 % were from the Midwest and 10.1 % from the Northeast (Table 1). Most (80.0 %) were under 45 years old, and 56.6 % self-identified as male. Most participants reported a single race (93.2 %), the vast majority of whom were White (87.9 %), 1.8 % were Black or African American, 1.1 % were Asian or Asian American, <1 % were American Indian or Alaska Native (0.4 %) and Native Hawaiian or Pacific Islander (0.2 %), and 1.8 % were "other". About 9 % reported being Hispanic, Latino or of Spanish origin. Seventy percent reported having an annual household income less than $60,000, and 46.5 % reported an income less than $40,000. Forty percent reported using cigarettes within the last month and 29.1 % reported smoking cigarettes at least one day per week in a typical week.

Table 1
Socio-demographic characteristics of participants, VAPER cohort 1 wave 1 baseline survey, 2020.

Socio-Demographic Characteristics	All Participants (N = 1179)		Smoked Cigarettes in Past 30 Days: No (n = 705)		Yes (n = 474)	
	n	%	n	%	n	%
Geographic Location (p = 0.16)						
Midwest	222	18.8 %	131	18.6 %	91	19.1 %
Northeast	119	10.1 %	74	10.5 %	45	9.5 %
South	495	42.0 %	312	44.3 %	183	38.7 %
West	343	29.1 %	188	26.6 %	155	32.6 %
Age (p = 0.20)						
21–24	153	13.0 %	92	13.0 %	61	12.9 %
25–29	199	16.9 %	110	15.7 %	89	18.8 %
30–44	591	50.2 %	367	52.0 %	225	47.4 %
45–54	154	13.0 %	96	13.6 %	58	12.2 %
55–69	82	7.0 %	41	5.7 %	42	8.8 %
Gender (p = 0.51)						
Male	668	56.6 %	407	57.7 %	260	55.0 %
Female	494	41.9 %	289	41.0 %	204	43.2 %
Other*	10	0.8 %	4	0.6 %	6	1.3 %
Prefer not to answer	8	0.7 %	5	0.7 %	3	0.6 %
Race (p = 0.15)						
Single race**	1099	93.2 %	664	94.1 %	435	91.8 %
American Indian or Alaska Native	4	0.4 %	2	0.3 %	2	0.5 %
Asian or Asian American	13	1.1 %	8	1.1 %	5	1.0 %
Black or African American	21	1.8 %	12	1.7 %	9	1.9 %
Native Hawaiian or Pacific Islander	3	0.2 %	0	0.0 %	3	0.6 %
White	1037	87.9 %	627	89.0 %	409	86.3 %
Other	22	1.8 %	15	2.1 %	7	1.4 %
Multi race	65	5.5 %	33	4.7 %	32	6.7 %
Prefer not to answer	15	1.3 %	8	1.2 %	7	1.5 %
Hispanic, Latino, or of Spanish origin (p = 0.72)						
Yes	101	8.6 %	57	8.1 %	44	9.3 %
No	1067	90.5 %	642	91.0 %	425	89.8 %
Prefer not to answer	11	0.9 %	7	1.0 %	4	0.9 %
Annual Household Income (p < 0.001)						
$0 - $39,999	548	46.5 %	283	40.2 %	265	55.9 %
$40,000 - $59,999	278	23.6 %	188	26.6 %	90	19.1 %
$60,000 - $99,999	212	18.0 %	135	19.1 %	78	16.4 %
$100,000 +	114	9.7 %	88	12.5 %	26	5.4 %
Prefer not to answer	27	2.3 %	12	1.6 %	15	3.2 %

Notes: The numbers of participants reported in the table are weighted sample numbers scaled to the unweighted sample size. P-values were determined using Rao-Scott Chi-square tests.

3.2. Device/liquid combinations

The majority of participants (91.9 %) used reusable devices with a rechargeable battery (n = 1,083). There were five predominant device type/liquid combinations (Fig. 2, right-hand column). (1) Just over a third (36.2 %) of the sample used reusable devices that have adjustable settings, refilling their device tank with a free-base nicotine liquid. (2) The next most common device/liquid combination (22.8 %) was reusable devices without adjustable settings with a nicotine salt liquid in a disposable pod/cartridge. The third and fourth most common device/liquid combinations were reusable devices having adjustable settings with refillable pods/cartridges and (3) a nicotine salt liquid (12.6 % of the sample); and (4) a free-base liquid (8.1 % of the sample). (5) Disposable devices with no adjustable settings and a nicotine salt liquid were used by 7.1 %. Table 2 presents nicotine concentration, wattage, voltage and resistance by device characteristics and nicotine formulation. Appendix C presents the frequency of liquid flavors for the most common device/liquid combinations. Below, the most common device/liquid combinations are described in more detail.

Reusable devices with refillable tanks (n = 487): 41.3 % of participants used reusable devices with refillable tanks; all but one had adjustable settings (Fig. 2, middle column). Among them, a vast majority of participants (n = 427, 87.7 %) used a free-base liquid with a median nicotine concentration of 5.2 mg/mL (range 1–90 mg/mL); this combination was relatively more prevalent for those aged 30–44, for males, and for people who did not smoke cigarettes (Table 3). Median wattage, voltage, and resistance for this group were 63.6 W, 3.5 V and 0.2 O, respectively.

Reusable device with disposable pod/cartridge (n = 298): One quarter (25.3 %) of all participants used reusable devices with disposable pods/cartridges of which 94.6 % (n = 283) used devices without adjustable settings. Among participants who used reusable devices with disposable pods/cartridges and without adjustable settings, 95 % (n = 269) used a nicotine salt liquid with a median nicotine concentration of 49.4 mg/mL (range 5–60 mg/mL); this combination was used relatively more by those aged 21–29 or 45–54 and by those who smoke cigarettes. Median wattage, voltage, and resistance for this group were 9.4 W, 3.9 V, 1.5 O, respectively.

Reusable devices with refillable pod/cartridges (n = 274): Nearly-one quarter of participants (23.2 %) used reusable devices with refillable pods/cartridges of which 93.4 % used devices with adjustable settings. Among participants who used refillable pod/cartridges with adjustable settings, 60.8 % (n = 149) refilled their pods/cartridges with a nicotine salt liquid with a median nicotine concentration of 34.3 mg/mL (range 3–59 mg/mL); 39.2 % (n = 96) refilled with a free-base liquid with a median nicotine concentration of 4.1 mg/mL (range 3–50 mg/mL). Reusable devices with adjustable settings with a refillable pod/cartridge filled with a nicotine salt liquid were used by 12.6 % of the sample, used relatively more among young adults aged 21–24 followed by those aged 25–29. Reusable devices with adjustable settings with a refillable pod/cartridge filled with a free-base nicotine liquid were used relatively more by those aged 45–54. Median wattage, voltage, and resistance for the group using a nicotine salt liquid were 15.1 W, 3.7 V, and 1 O, respectively, and for the group using a free-base liquid were 16.6 W, 3.5 V, and 0.6 O, respectively.

Disposable devices (n = 96): Disposable devices were used by 8.1 % of this sample of frequent ENDS users of which 86.5 % used disposable devices without adjustable settings. Participants using disposable devices without adjustable settings all used a nicotine salt liquid with a

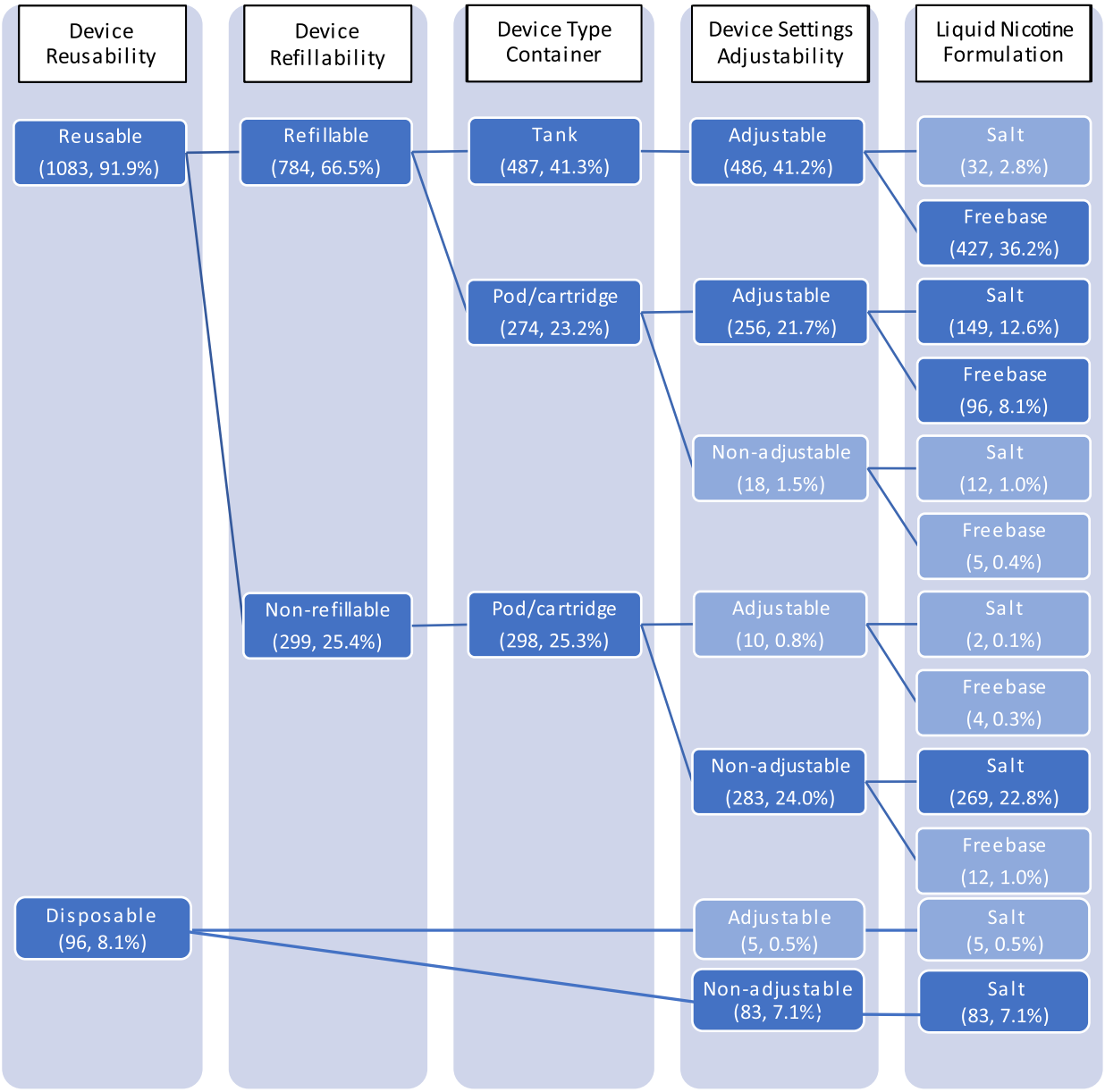

Fig. 2. Combinations of device characteristics and nicotine formulation, VAPER wave 1, 2020. Notes: The darker shaded boxes show the most common combinations. All percentages use 1,179 as the denominator. Weights based on gender, age and race groups were applied to the calculations of the counts and percentages using the post-stratification weighting method with TUS-CPS 2019 data and therefore they are representative of the population of adult (21 +) frequent e-cigarette users (using at least 5 days per week) living in the United States. The total % and n for each column may not add to 100 % and 1179 respectively due to missing data along the hierarchy (left to right) or rounding after applying weights. Missing data for device type container and device settings adjustability were due to photo submissions and self-reported device brand/model having quality control issues and an absence of information about these variables in online sources. Device settings adjustability also has missing data due to the exclusion of self-reported responses about device settings adjustability from participants who reported device refillability and reusability that were different than what their photo indicated. Missing data for liquid nicotine formulation were due to quality control issues with photos and self-reported liquid brand/flavor, absence of information about these variables in online sources, and participants indicating they did not know. Overall, 1100 observations in the sample have device type container, device settings adjustability, and liquid nicotine formulation information. The one respondent who reported using a reusable device with a refillable tank, but withOUT adjustable settings, is omitted from the figure.

median nicotine concentration of 42.5 mg/mL (range 3–60 mg/mL); this combination was used relatively more by those aged 21–24, females, people of Hispanic, Latino or Spanish origin, and those who smoke cigarettes. The median wattage, voltage and resistance were 9.4 W, 4.0 V, and 1.6 O, respectively.

3.3. Differences by sociodemographic characteristics

Table 3 shows the distribution of socio-demographic characteristics of participants across the five most common device/liquid combinations. The most popular combination in the Midwest, South and West regions was reusable devices with adjustable settings and tanks refilled with a free-base nicotine liquid (Table 3). The second most common combination in the Midwest was reusable devices without adjustable settings used with a nicotine salt liquid from a disposable pod/cartridge; this was the most popular device type/liquid combination in the Northeast. Reusable devices with adjustable settings and tanks refilled with a free-base liquid was the most popular device type/liquid combination across age groups 25 and older. Among the 21–24 year old age group, the most popular combination, used by 26.7 % of

Table 2
Nicotine concentration, wattage, voltage and resistance by device characteristics and nicotine formulation, VAPER wave 1, 2020.

Device Type	Device Settings Adjustability*	Nicotine Formulation	n¥	Nicotine Concentration (mg/mL)				Wattage				Voltage				Resistance			
				n	Mean	Median	(Min, Max)	n	Mean	Median	(Min, Max)	n	Mean	Median	(Min, Max)	n	Mean	Median	(Min, Max)
Refillable Tank	Adjustable	Salt	32	32	32.5	31.9	(3.0, 50.0)	28	34.7	20.2	(10.5, 95.2)	29	3.1	2.9	(2.0, 5.2)	30	0.4	0.4	(0.1, 1.6)
		Freebase	427	417	6.4	5.2	(1.0, 90.0)	369	62.0	63.6	(5.6, 220.0)	381	3.8	3.5	(<0.1, 37.5)	392	0.3	0.2	(0.1, 2.8)
Refillable Pod/ Cart	Adjustable	Salt	149	146	38.4	34.3	(3.0, 59.0)	129	17.1	15.1	(3.0, 65.0)	133	3.5	3.7	(1.9, 4.1)	137	0.9	1.0	(0.2, 1.5)
		Freebase	96	93	8.0	4.1	(3.0, 50.0)	83	22.4	16.6	(7.0, 80.0)	85	3.4	3.5	(1.5, 5.2)	88	0.7	0.6	(0.2, 1.4)
	Non-adjustable	Salt	12	12	39.9	34.7	(25.0, 50.0)	10	11.9	12.9	(7.4, 14.0)	11	4.1	4.0	(3.9, 4.2)	11	1.4	1.2	(1.2, 2.0)
		Freebase	5	5	18.7	8.2	(3.0, 50.0)	4	11.6	11.3	(7.2, 14.0)	5	4.0	3.9	(3.4, 4.2)	5	1.4	1.2	(1.2, 2.0)
Disposable Pod/ Cart	Adjustable	Salt	2	1	31.4	30.2	(30.0, 32.5)	1	6.0	6.0	(6.0, 6.0)	2	3.2	2.9	(2.6, 3.7)	1	1.1	1.1	(1.1, 1.1)
		Freebase	4	4	48.4	28.9	(3.0, 80.0)	4	30.0	30.0	(30.0, 30.0)	–	–	–	–	–	–	–	–
	Non-adjustable	Salt	269	262	46.6	49.4	(5.0, 60.0)	232	12.4	9.4	(6.3, 16.6)	240	4.0	3.9	(3.7, 4.2)	247	1.4	1.5	(1.0, 2.6)
		Freebase	12	12	16.5	14.8	(1.0, 40.0)	11	10.8	10.0	(10.0, 16.2)	11	3.9	3.8	(3.7, 4.2)	11	1.6	1.5	(1.1, 2.6)
Disposable	Adjustable	Salt	5	5	50.0	50.0	(50.0, 50.0)	5	14.4	14.4	(14.4, 14.4)	5	4.1	4.1	(4.1, 4.1)	5	1.2	1.2	(1.2, 1.2)
	Non-adjustable	Salt	83	83	48.8	42.5	(3.0, 60.0)	71	9.5	9.4	(7.7, 11.0)	74	4.0	4.0	(3.9, 4.1)	76	1.7	1.6	(1.4, 2.2)

¥: the n's in this column are for those for whom we had data on reusability, refillability, device type container, device settings adjustability, and liquid nicotine formulation. When we report n's in the manuscript they may be higher if liquid nicotine formulation is not taken into account. We did not have valid nicotine formulation data for 5.4% of the sample; we did not have valid nicotine concentration data for 1.8% of the sample.
*Settings refer to watt/volt (or power), coil, and airflow; adjustable if any of them is adjustable.
"-" in the table above refer to non-zero weighted ns but datapoints for corresponding statistics were not present in the sample.

Note.

1. Weights based on gender, age and race groups were applied to the calculation of the statistics using the post-stratification weighting method with TUS-CPS 2019 data and therefore they are representative of the population of adult (21 +) frequent e-cigarette users (using at least 5 days per week) living in the United States.
2. Missing data for device type and device settings adjustability were due to photo submissions and self-reported device brand/model having quality control issues and an absence of information about these variables in online sources. Device settings adjustability also has missing data due to the exclusion of self-reported responses about device settings adjustability from participants who reported device refillability and reusability that were different than what their photo indicated. Missing data for nicotine formulation and concentration were due to quality control issues with photos and self-reported liquid brand/flavor, absence of information about these variables in online sources, and participants indicating they did not know. Overall, 1100 observations in the sample have device type, device settings adjustability, and liquid nicotine formulation information; minor discrepancies in the n's were caused by rounding after applying weights.
3. For device wattage, voltage, and resistance, if a value of wattage/voltage/resistance was not available, we first attempted to fill the missing value through a power calculator utilizing Ohm's law via the two other available wattage/voltage/resistance/current values. If more than two wattage/voltage/resistance/current values were missing or the power calculator-generated value was considered an outlier, we calculated the midpoint of the device minimum and maximum wattage/voltage/resistance if both minimum and maximum values were available. Furthermore, we purchased ENDS devices participants used that, after conducting all the attempts above, still had high numbers of missing wattage/voltage/resistance values and measured the voltage and resistance values of these devices using a multimeter to minimize the amount of missing data. Finally, we attempted to fill the remaining missing wattage/voltage/resistance values by re-utilizing the power calculator via any available pair of wattage/voltage/resistance/current values, including those generated through all the aforementioned attempts.

Table 3
Socio-demographic characteristics of participants, by the most common device/liquid combinations, VAPER cohort 1 wave 1 baseline Survey, 2020.

Socio-Demographic Characteristics	Reusable device, adjustable settings, refillable tank, freebase	Reusable device, no settings, disposable pod/cart, salt	Reusable device, adjustable settings, refillable pod/cart, salt	Reusable device, adjustable settings, refillable pod/cart, freebase	Disposable device, no settings, salt	Others
	(n = 427; 36.2 %)	(n = 269; 22.8 %)	(n = 149; 12.6 %)	(n = 96; 8.1 %)	(n = 83; 7.1 %)	(n = 156; 13.2 %)
	% (n)	% (n)	% (n)	% (n)	% (n)	% (n)
Geographic Location (p = 0.01)						
Midwest	29.4 % (65)	27.5 % (61)	12.2 % (27)	8.1 % (18)	8.3 % (18)	14.4 % (32)
Northeast	26.8 % (32)	37.2 % (44)	13.2 % (16)	2.8 % (3)	5.8 % (7)	14.1 % (17)
South	39.0 % (193)	21.0 % (104)	11.8 % (59)	8.6 % (43)	6.2 % (31)	13.3 % (66)
West	39.8 % (136)	17.2 % (59)	13.9 % (48)	9.2 % (32)	7.9 % (27)	11.9 % (41)
Age (p < 0.001)						
21–24	23.0 % (35)	26.7 % (41)	22.4 % (34)	3.3 % (5)	13.4 % (21)	11.1 % (17)
25–29	32.3 % (64)	28.0 % (56)	16.0 % (32)	7.4 % (15)	8.2 % (16)	8.1 % (16)
30–44	42.2 % (250)	18.8 % (111)	11.5 % (68)	8.8 % (52)	6.0 % (36)	12.8 % (76)
45–54	32.9 % (51)	27.8 % (43)	6.7 % (10)	11.3 % (17)	4.6 % (7)	16.7 % (26)
55–69	33.2 % (27)	22.3 % (18)	5.7 % (5)	7.9 % (6)	4.5 % (4)	26.3 % (22)
Gender (p = 0.10)						
Male	38.9 % (259)	21.8 % (145)	13.5 % (90)	7.5 % (50)	6.0 % (40)	12.3 % (82)
Female	32.3 % (159)	24.5 % (121)	11.3 % (56)	8.8 % (43)	8.8 % (43)	14.3 % (71)
Other	60.0 % (6)	20.0 % (2)	10.0 % (1)	0.0 % (0)	0.0 % (0)	10.0 % (1)
Prefer not to answer	25.0 % (2)	0.0 % (0)	25.0 % (2)	25.0 % (2)	0.0 % (0)	25.0 % (2)
Race (p = 0.12)						
Single race**	36.3 % (398)	22.8 % (250)	12.4 % (137)	8.2 % (91)	6.7 % (74)	13.5 % (148)
Am Indian/ Alaska Native	42.2 % (2)	27.1 % (1)	0 % (0)	11.6 % (1)	0 % (0)	19.0 % (1)
Asian or Asian American	18.3 % (2)	19.9 % (2)	21.0 % (3)	18.3 % (2)	6.6 % (1)	15.9 % (2)
Black or African American	39.9 % (8)	21.6 % (4)	8.7 % (2)	6.3 % (1)	16.1 % (3)	7.3 % (2)
N Hawaiian/ Pac Islander	47.0 % (1)	17.6 % (1)	0 % (0)	0 % (0)	0 % (0)	35.5 % (1)
White	36.3 % (376)	23.1 % (239)	12.6 % (130)	8.2 % (85)	6.4 % (66)	13.4 % (139)
Other	39.7 % (9)	10.9 % (2)	8.3 % (2)	4.5 % (1)	17.5 % (4)	19.1 % (4)
Multi race	33.6 % (22)	24.5 % (16)	17.3 % (11)	5.1 % (3)	12.5 % (8)	6.9 % (5)
Prefer not to answer	42.9 % (7)	14.1 % (2)	6.6 % (1)	11.8 % (2)	6.3 % (1)	18.2 % (3)
Hispanic, Latino, or of Spanish origin (p = 0.04)						
Yes	34.4 % (35)	21.0 % (21)	9.8 % (10)	8.8 % (9)	14.0 % (14)	12.1 % (12)
No	36.3 % (388)	23.1 % (247)	13.0 % (138)	7.9 % (84)	6.4 % (69)	13.3 % (142)
Prefer not to answer	41.0 % (4)	7.7 % (1)	6.2 % (1)	27.0 % (3)	4.5 % (1)	13.6 % (1)
Annual Household Income (p = 0.32)						
$0 - $39,999	33.9 % (186)	22.7 % (124)	12.3 % (67)	7.9 % (43)	8.1 % (44)	15.2 % (83)
$40,000 - $59,999	38.5 % (107)	23.6 % (65)	10.2 % (28)	8.8 % (24)	5.3 % (15)	13.7 % (38)
$60,000 - $99,999	37.7 % (80)	23.1 % (49)	17.0 % (36)	6.2 % (13)	8.4 % (18)	7.6 % (16)
$100,000 +	35.0 % (40)	22.4 % (26)	14.2 % (16)	9.2 % (11)	4.8 % (5)	14.3 % (16)
Prefer not to answer	52.3 % (14)	15.3 % (4)	4.3 % (1)	15.7 % (4)	3.7 % (1)	8.7 % (2)

(*continued on next page*)

Table 3 (*continued*)

Socio-Demographic Characteristics	Reusable device, adjustable settings, refillable tank, freebase	Reusable device, no settings, disposable pod/cart, salt	Reusable device, adjustable settings, refillable pod/cart, salt	Reusable device, adjustable settings, refillable pod/cart, freebase	Disposable device, no settings, salt	Others
	(n = 427; 36.2 %)	(n = 269; 22.8 %)	(n = 149; 12.6 %)	(n = 96; 8.1 %)	(n = 83; 7.1 %)	(n = 156; 13.2 %)
	% (n)	% (n)	% (n)	% (n)	% (n)	% (n)
Smoked cigarettes in past 30 days (p < 0.001)						
No	42.0 % (296)	19.4 % (137)	12.9 % (91)	9.3 % (65)	5.7 % (40)	10.8 % (76)
Yes	27.6 % (131)	27.8 % (132)	12.2 % (58)	6.4 % (30)	9.1 % (43)	16.9 % (80)

Note: The numbers of participants reported in the table were weighted sample numbers scaled to the unweighted sample size. Due to rounding up of the rescaled numbers, the column totals add to 1,180 instead of the effective sample size of 1,179.
P-values were determined using Rao-Scott Chi-square tests. The Rao-Scott Chi-square test was not computed for gender by device type because at least one table cell has 0 frequency (i.e., reported gender as other or prefer not to answer); we tested the difference using the records with gender as male or female.

respondents in that age group, was reusable devices without adjustable settings with disposable pods/cartridges containing a nicotine salt liquid. Both men and women used reusable devices with adjustable settings and a tank that are refilled with a free-base nicotine liquid, with men (38.9 %) using it somewhat more than women (32.3 %). Those who did not smoke cigarettes in the past 30 days used reusable devices with adjustable settings and tanks refilled with a free-base nicotine liquid (used by 42.0 %); those who smoked cigarettes in the past 30 days equally used this combination (27.6 %) and reusable devices without adjustable settings used with a nicotine salt liquid from a disposable pod/cartridge (27.8 %).

4. Discussion

A majority of participants refilled their device's tank or pod (66.5 %) and had the ability to manipulate device characteristics (power, airflow and/or coil) (64.2 %). Further, there is much heterogeneity in the combinations of device and liquids used by frequent adult ENDS users in the U.S. In addition, *within* these device/liquid combinations, there is also substantial variability in device performance specifications (wattage, voltage, resistance) as well as nicotine concentration of the liquid. The immense diversity of performance characteristics of devices and liquids used by frequent ENDS users and the fact that a majority of frequent ENDS users in this nationally representative sample were able to manipulate device specifications and customize their liquids make if very challenging for the FDA to regulate users' exposure to nicotine and toxicants. However, despite this heterogeneity, five device/liquid combinations accounted for 87 % of the combinations used by this sample.

The most prevalent combination, used by 36.2 % of the sample, was tank-like devices used with a relative low nicotine concentration free-base liquid and a relatively a high wattage compared to other device types. This is concerning given that more toxicants are produced when a higher power is used. (Hoetger et al., 2021 Oct 14) It is also worth noting that those who smoked cigarettes in the past 30 days were less likely to use tank-like devices and more likely to use pod-type devices with a nicotine salt liquid (that have a relatively high nicotine concentration), compared to those who did not currently smoke cigarettes. This may be because people who are currently smoking cigarettes are looking for an easy way to obtain high doses of nicotine in a more simple and discreet manner; further, JUUL was starting to market their devices to adult smokers as cigarette replacements, encouraging them to "Make the Switch" (https://tobacco.stanford.edu/pods/juul/switch/). That young adults were more likely than older adults to use devices with nicotine salt liquids (that have a relatively high nicotine concentration), raises concerns about abuse liability among this group and the possibility that they will maintain dependence and long-term use of these or other nicotine or tobacco products.

This is the first study to report this granular level of detail on combinations of device and liquid types used among a national sample of adult frequent ENDS users. We used unambiguous device categories, classifying devices based on the dimensions of reusability, refillability, device liquid container, and setting adjustability; and, we determined the nicotine formulation (salt vs free-base) of the liquid used with this device. By prioritizing data coded from user-submitted photos of their most used device and liquid, we had more accurate data than what would be obtained by self-report alone. (Crespi et al., xxxx) Further, we paired the device and liquid data rather than looking at them separately, providing a more holistic description of the products adult frequent ENDS users are choosing. Because all these features influence nicotine and non-nicotine toxicant delivery, (Benowitz et al., 2021 Aug; Talih et al., 2017; Blank et al., 2020 Nov; El-Hellani et al., 2018 Jan 5) this level of granularity likely is essential in future studies attempting to examine the influence of ENDS use on concurrent cigarette smoking, nicotine/tobacco dependence, and/or health effects of ENDS use.

Some limitations of this study should be noted. First, our sample had proportionally more frequent ENDS users with an income of less than $60,000 compared to the TUS-CPS (73 % vs 52 %; post-stratification weight: 0.71); there were also proportionally fewer respondents from the Northeast region of the U.S. (11 % vs 17 %) and from the Midwest (18 % vs 28 %) and proportionally more from the South (41 % vs 36 %) and West (31 % vs 20 %), with post-stratification weights ranging from 0.64 to 1.56. However, other sociodemographic characteristics were similar to the frequent ENDS users in the TUS-CPS and the percentages reported in this paper are weighted, so they likely represent a good approximation of device/liquid combinations at the national level. Second, while we were able to minimize the extent of missing data by incorporating both participant-uploaded photos as well as self-report data, we did have some missing data, particularly for wattage (12.8 %), voltage (10.2 %), resistance (7.5 %), nicotine formulation (4.5 %) and nicotine concentration (2.4 %). Third, to keep the survey length to a reasonable amount of time for respondents in order to maximize response rates, we only asked details about participants' most used device in the past week; future research could examine in more depth the range of devices used by frequent ENDS users. Fourth, we did not collect data on smoking histories, and we are not able to say how many of the 30 people who reported using 0 mg/mL of nicotine (and were excluded from these analyses) had smoked cigarettes in the past. It may be that some people continue to use e-cigarettes for reasons such as giving them something to do with their hands, or replacing some social aspects of smoking; future research could gain a better understanding of the demographics of people who report using 0 mg/mL nicotine and reasons for using 0 mg/ml nicotine. Fifth, this study did not conduct topography assessments so we are not able to comment on how participants used their devices (e.g., number, frequency and volume of puffs over a

defined period of time); puff topography introduces further variability with regard to nicotine and non-nicotine toxicant exposure, and thus is relevant to understanding ENDS influence on concurrent cigarette use, dependence, and health outcomes. (Hiler et al., 2020 Oct; Hiler et al., 2017 Oct).

There are also several strengths of this study. Data are from a recent, national sample that overall had a socio-demographic distribution of frequent ENDS users very close to that of the 2019 TUS-CPS. In addition, the data presented here are weighted to match the socio-demographic distribution of daily adult ENDS users in the 2019 TUS-CPS. We employed a range of security and data integrity measures to maximize data quality. Participants uploaded photos of their most used device and liquid, which were coded for the characteristics we report here, thus improving confidence in data that users are not accurate at reporting. (El Hourani et al., 2022; Talih et al., 2020 Oct 1) Further, the details collected and reported about devices and liquids are more comprehensive than have been reported previously for a national sample of frequent ENDS users. Analyzing ENDS device/liquid combinations together rather than separately can allow future research to better evaluate relationships between use and outcomes such as quitting cigarettes and harms. The ECtra study in the UK has started to do this, finding that those starting with a low nicotine concentration and/or a cigalike device have a greater risk of relapse to cigarette smoking. (Gentry et al., 2020).

One of the challenges in ENDS research is comparing the distribution of device types across studies. This is due to inconsistent definitions and categories used. (O'Connor et al., 2022 Mar) Further, categorization of devices based on "generations" (Ozga et al., 2022 Feb 14) or other broad categories ignores key variability that influences important constructs such as nicotine delivery. There are also rapid changes to features of devices sold in the market (e.g., emergence of disposables that are rechargeable such as Hyde recharge devices). Our results demonstrating substantial variability within device type indicate that the same device type can be operating at very different wattages and with very different nicotine concentrations, in addition to the variability introduced by how people set their adjustable settings such as airflow. (Eversole et al., 2020 Nov) Each of these factors can affect ENDS' ability to support smoking cessation, as well as influence abuse liability and health effects.

We encourage discussion in the field regarding the value of categorizing devices across various key characteristics, such as reusability, refillability, settings adjustability, and container type, as was presented here; further, it could be useful to describe nicotine liquids stratified by nicotine formulation. (Pennings et al., 2022) Using consistent definitions will aid cross-study and cross-national comparisons as well as evaluations of related policies. Cox et al., 2020, Gaiha et al., 2022.

5. Conclusion

This study presents, for the first time, a high level of granular detail about the devices and accompanying liquids used by a U.S. national sample of frequent adult ENDS users in 2020, drawing on photos of their products (device and liquid) as well as their survey responses. A majority of daily adult ENDS users in the U.S. have control over their device and liquid characteristics. Because nicotine and toxicant delivery of an ENDS device and liquid combination depends on both device and liquid characteristics, analyzing ENDS device/liquid combinations can improve evaluations of the relationships between use and key outcomes, such as quitting cigarettes and abuse liability. Additional research may reveal whether certain combinations are used for different reasons, are more effective at helping smokers quit, and which device/liquid combinations should remain on the market.

CRediT authorship contribution statement

Joanna E. Cohen: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Jeffrey J. Hardesty:** Conceptualization, Methodology, Investigation, Data curation, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Qinghua Nian:** Methodology, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Elizabeth Crespi:** Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Supervision. **Joshua K. Sinamo:** Methodology, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Ryan D. Kennedy:** Conceptualization, Methodology, Writing – review & editing. **Kevin Welding:** Conceptualization, Methodology, Writing – review & editing. **Bekir Kaplan:** Writing – review & editing. **Eric Soule:** Methodology, Writing – review & editing. **Thomas Eissenberg:** Conceptualization, Writing – review & editing, Funding acquisition. **Alison B. Breland:** Conceptualization, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This work was supported by NIDA and the FDA Center for Tobacco Products (CTP) under award number U54DA036105. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH or the Food and Drug Administration.

Appendix A. Relevant VAPER survey questions

The way in which nicotine formulation and concentration questions were asked depended on each participant's response to the previous questions. For example, for nicotine formulation, participants who reported using a disposable device would then be asked about whether their device's ENDS liquid contains salt (i.e., "Does the device's e-liquid contain nicotine salts?") instead of whether their ENDS liquid contain salt (i.e., "Does the e-liquid contain nicotine salts?") for participants reporting using a non-disposable device.

Variable	Question	Response
Demographics Related Questions		
Age (VAR NAME: age_screen)	How old are you?	Single choice, required 1 < 18 2 18-20 3 21-24 4 25-29 5 30-34 6 35-39 7 40-44 8 45-49

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Variable	Question	Response
		9 50-54 10 55-59 11 60-64 12 65-69 13 70+
Gender (VAR NAME: gender_bq)	Are you...?	Single choice, required 1 Male 2 Female 3 Other 4 Prefer not to answer
Race Type (VAR NAME: race_bq2)	Which best applies to your race?	Single choice, required 1 Single race 2 Multi race 3 Prefer not to answer
Single Race (VAR NAME: race_bq3)Show the field ONLY if: [race_bq2] = '1'	What race do you consider yourself to be?	Single choice, required 1 American Indian or Alaska Native 2 Asian or Asian American 3 Black or African American 4 Native Hawaiian or Pacific Islander 5 White 6 Other
Income (VAR NAME: income_bq)	What is your best estimate of the total annual household income from all sources, before taxes, in 2019?	Single choice, required 1 $0 - $19,999 2 $20,000 - $39,999 3 $40,000 - $59,999 4 $60,000 - $79,999 5 $80,000 - $99,999 6 $100,000 - $119,999 7 $120,000 - $139,999 8 $140,000 - $159,999 9 $160,000 - $179,999 10 $180,000 - $199,999 11 $200,000+ 12 Prefer not to answer
Relevant Vaping and Smoking Behavior Related Questions		
Past 30-days E-cigarette Use (VAR NAME: ecig_past30days_screen)	Have you used an e-cigarette or vaping device to vape e-liquids with or without nicotine in the past 30 days?	Single choice, required1Yes0No
Number of Days Vaping E-cigarette in a Typical Week (VAR NAME: ecig_typicalweek_screen)Show the field ONLY if: [ecig_past30days_screen] = '1'	How many days in a typical week do you use an e-cigarette or vaping device to vape e-liquids with or without nicotine?	Single choice, required 1 I do not use an e-cigarette or vaping device to vape e-liquids with or without nicotine in a typical week 2 1 day 3 2 days 4 3 days 5 4 days 6 5 days 7 6 days 8 7 days
Past 30-days Cigarette Use (VAR NAME: cig_past30days_screen)	Have you smoked a cigarette in the past 30 days?	Single choice, required1 Yes0 No
Number of Days Smoking Cigarette in a Typical Week (VAR NAME: cig_typicalweek_screen)Show the field ONLY if: [cig_past30days_screen] = '1'	How many days in a typical week do you smoke cigarettes?	Single choice, required 1 I do not smoke cigarette in a typical week 2 1 day 3 2 days 4 3 days 5 4 days 6 5 days 7 6 days 8 7 days
Relevant Characteristics of ENDS and Liquid Related Questions		
E-cigarette Device Brand and Model (VAR NAME: ecig_brandmodel_bq)	What is the brand AND model of the device (e.g., JUUL, Vaporesso Luxe, Voopoo Drag 2, etc.)?	Open-ended, required
E-cigarette Device Reusability (VAR NAME: device_reuse_dispose_bq)	Is the device...	Multiple choice, required 1 Re-usable (i.e., you recharge the device when the battery life is low or at 0%) 2 Disposable (i.e., you discard entire device when the battery life is low or at 0%)
E-cigarette Device Modifiable Settings (VAR NAME: device_modifiable_settings_bq)Show the field ONLY if: [device_reuse_dispose_bq] = '1'	Does the device have SETTINGS that allow you to modify power or vapor volume?	Single choice, required 1 Yes 2 No
E-cigarette Device Display (VAR NAME: device_display_bq)Show the field ONLY if: [device_reuse_dispose_bq] = '1'	Does the device have a VISUAL DISPLAY that allows you to see the wattage or other vape settings?	Single choice, required 1 Yes 2 No
		Single choice, required1 Yes2 No3 Don't know

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(*continued*)

Variable	Question	Response
E-cigarette Modifiable Tank (VAR: modifiable_tank_bq)Show the field ONLY if:[device_reuse_dispose_bq] = '1'	Can you modify or replace the device's tank or coil [TANK]?	
E-cigarette Modifiable Coil (VAR NAME: modifiable_coil_bq)Show the field ONLY if:[device_reuse_dispose_bq] = '1'	Can you modify or replace the device's tank or coil [COIL]?	Single choice; required1 Yes2 No3 Don't know
E-cigarette Pod/Cartridge Type (VAR NAME: podcart_type_bq)Show the field ONLY if: [device_reuse_dispose_bq] = '1'	When the device runs out of e-liquid, do you TYPICALLY...	Single choice; required 1 Discard the empty cartridge or pod and replace with a new and unused cartridge or pod prefilled with e-liquid 2 Refill the empty tank/cartridge/pod with e-liquid from a larger container(s) of e-liquid
Liquid Type (VAR NAME: rr_liquid_type_bq)Show the field ONLY if: [podcart_type_bq] = '2'	Is your most used e-liquid a...	Single choice; required 1 Customized flavor blend – mixed yourself 2 Customized flavor blend – mixed for you by someone else 3 Non-customized flavor
Nicotine Concentration (1) [For participants reported using disposable pod/cartridge device] (VAR NAME: rd_liq_nicotine_bq)Show the field ONLY if: [podcart_type_bq] = '1'	Do you know how much nicotine is in the e-liquid?	Single choice; required 1 Yes, I know the mg of nicotine 2 Yes, I know the % of nicotine 3 No
Nicotine Concentration (2) [For participants reported using refillable-reusable device with non-custom liquid] (VAR NAME: rr_nc_liq_nicotine_bq) Show the field ONLY if: [rr_liquid_type_bq] = '3'	Do you know how much nicotine is in the e-liquid?	Single choice; required 1 Yes, I know the mg of nicotine 2 Yes, I know the % of nicotine 3 No
Nicotine Concentration (3) [For participants reported using disposable device] (VAR NAME: d_liq_nicotine_bq)Show the field ONLY if: [device_reuse_dispose_bq] = '2'	Do you know how much nicotine is in the device's e-liquid	Single choice; required 1 Yes, I know the mg of nicotine 2 Yes, I know the % of nicotine 3 No
Nicotine Concentration (4) [For participants reported using refillable-reusable device with custom liquid] (VAR NAME: rr_csm_nicotine_bq)Show the field ONLY if: [rr_liquid_type_bq] = '1' or [rr_liquid_type_bq] = '2'	Do you know how much nicotine is in the flavor blend?	Single choice; required 1 Yes, I know the mg of nicotine 2 Yes, I know the % of nicotine 3 No
Nicotine Concentration – Specify in mg Show the field ONLY if: [rd_liq_nicotine_bq] = '1' OR[rr_liq_nicotine_bq] = '1' OR[d_liq_nicotine_bq] = '1' OR[rr_csm_liq_nicotine_bq] = '1'	Please specify:	Open-ended; (integer; min=0); required
Nicotine Concentration – Specify in %Show the field ONLY if: [rd_liq_nicotine_bq] = '2' OR[rr_liq_nicotine_bq] = '2' OR[d_liq_nicotine_bq] = '2' OR[rr_csm_liq_nicotine_bq] = '2'	Please specify:	Open-ended; (integer; min=0, max=100); required
Nicotine Formulation (1)[For participants reported using disposable pod/cartridge device] (VAR NAME: rd_liq_salts_bq)Show the field ONLY if: [podcart_type_bq] = '1'	Does the e-liquid contain nicotine salts?	Single choice; required 1 Yes 2 No 3 Don't know
Nicotine Formulation (2) [For participants reported using reusable-refillable device with non-custom liquid](VAR NAME: rr_nc_liq_salts_bq)Show the field ONLY if: [rr_liquid_type_bq] = '3'	Does the e-liquid contain nicotine salts?	Single choice; required 1 Yes 2 No 3 Don't know
Nicotine Formulation (3) [For participants reported using reusable-refillable device with custom liquid] (VAR NAME: rr_csm_liq_salts_bq)Show the field ONLY if:[rr_liquid_type_bq] = '1' or [rr_liquid_type_bq] = '2'	Does the flavor blend contain nicotine salts?	Single choice; required 1 Yes 2 No 3 Don't know
Nicotine Formulation (4) [For participants reported using disposable device] (VAR NAME: d_liq_salts_bq)Show the field ONLY if:[device_reuse_dispose_bq] = '2'	Does the device's e-liquid contain nicotine salts?	Single choice; required 1 Yes 2 No 3 Don't know
Liquid Brand [For participants reported using reusable-refillable device with non-custom liquid] (VAR NAME: rr_nc_liq_brand_bq)Show the field ONLY if: [rr_liquid_type_bq] = '3'	Do you know the brand on the e-liquid container (e.g., Naked 100, Beard Vape, Milkman, etc.)?	Single choice; required 1 Yes 2 No
Liquid Brand – Specify [For participants reported using reusable-refillable device with non-custom liquid] (VAR NAME: rr_nc_liq_brand_specify_bq) Show the field ONLY if: [rr_nc_liq_brand_bq] = '1'	Please specify the brand:	Open-ended; required

Appendix B. Procedures for obtaining device Wattage, voltage and resistance

For device wattage, voltage, and resistance, if a value of wattage/voltage/resistance was not available, we first attempted to fill the missing value through a power calculator utilizing Ohm's law via two other available wattage/voltage/resistance values. If more than two wattage/voltage/resistance/current values were missing or the previously power calculator generated value was considered an outlier, we calculated an adjusted midpoint of the device minimum and maximum wattage/voltage/resistance given both minimum and maximum values were available, based on the average user of the device type. Furthermore, we purchased ENDS devices commonly used by participants that, after conducting all the attempts mentioned previously, still had too many missing wattage/voltage/resistance values; we measured the voltage and resistance values of these devices using a multimeter to minimize the amount of missing data. Finally, we attempted to fill the remaining missing wattage/voltage/resistance values by re-utilizing the power calculator via any available pair of wattage/voltage/resistance/current values, including those generated through all the aforementioned attempts.

Appendix C. Liquid flavor, by the most common device/liquid combinations, VAPER cohort 1 wave 1 baseline Survey, 2020

	Reusable device, adjustable settings, refillable tank, freebase (n = 427; 36.2 %) % (n)	Reusable device, no settings, disposable pod/cart, salt (n = 269; 22.8 %) % (n)	Reusable device, adjustable settings, refillable pod/cart, salt (n = 149; 12.6 %) % (n)	Reusable device, adjustable settings, refillable pod/cart, freebase (n = 96; 8.1 %) % (n)	Disposable device, no settings, salt (n = 83; 7.1 %) % (n)	Others (n = 156; 13.2 %) % (n)
Liquid flavor						
Tobacco	5.2 % (22)	38.2 % (103)	5.1 % (8)	13.7 % (13)	3.3 % (3)	13.1 % (20)
Tobacco menthol or menthol	1.9 % (8)	45.8 % (123)	2.6 % (4)	6.2 % (6)	2.9 % (2)	6.2 % (10)
Mint	1.9 % (8)	8.5 % (23)	4.0 % (6)	0.0 % (0)	8.4 % (7)	4.1 % (6)
A flavor like fruit, candy, alcohol, coffee, vanilla, or others	88.0 % (376)	6.9 % (19)	85.3 % (127)	76.5 % (73)	85.4 % (71)	73.6 % (115)
No flavor	0.2 % (1)	0.0 % (0)	0.8 % (1)	0.0 % (0)	0.0 % (0)	1.1 % (2)
Missing	2.8 % (12)	0.5 % (1)	2.1 % (3)	3.5 % (3)	0.0 % (0)	2.0 % (3)

References

O'Connor, R., Schneller, L. M., Felicione, N. J., Talhout, R., Goniewicz, M. L., & Ashley, D. L. (2022 Mar). Evolution of tobacco products: Recent history and future directions. *Tob Control., 31*(2), 175–182.

Ozga, J. E., Felicione, N. J., Douglas, A., Childers, M., & Blank, M. D. (2022 Feb 14). Electronic cigarette terminology: Where does one generation end and the next begin? *Nicotine Tob Res., 24*(3), 421–424.

Cornelius, M. E., Loretan, C. G., Wang, T. W., Jamal, A., & Homa, D. M. (2022 Mar 18). Tobacco product use among adults - United States, 2020. *MMWR Morb Mortal Wkly Rep., 71*(11), 397–405.

Gades MS, Alcheva A, Riegelman AL, Hatsukami DK. The role of nicotine and flavor in the abuse potential and appeal of electronic cigarettes for adult current and former cigarette and electronic cigarette users: A systematic review. Nicotine Tob Res. 2022 Mar 19:ntac073. doi: 10.1093/ntr/ntac073. Epub ahead of print.

Hoetger, C., Bono, R. S., White, A. M., Barnes, A. J., & Cobb, C. O. (2021 Oct 14). The interaction of nicotine concentration and device power on electronic nicotine delivery system (ENDS) abuse liability among exclusive ENDS users and dual users of ENDS and combustible cigarettes. *Exp Clin Psychopharmacol.*. https://doi.org/10.1037/pha0000523

Shihadeh, A., & Eissenberg, T. (2015 Feb). Electronic cigarette effectiveness and abuse liability: Predicting and regulating nicotine flux. *Nicotine Tob Res., 17*(2), 158–162.

El Hourani, M., Shihadeh, A., Talih, S., & Eissenberg, T. (2022). CSTP Nicotine Flux Work Group. Comparison of nicotine emissions rate, 'nicotine flux', from heated, electronic and combustible tobacco products: Data, trends and recommendations for regulation. *Tob Control.* Jan 27:Tobaccocontrol-2021-056850.

Wagener, T. L., Floyd, E. L., Stepanov, I., Driskill, L. M., Frank, S. G., Meier, E., et al. (2017 Mar). Have combustible cigarettes met their match? The nicotine delivery profiles and harmful constituent exposures of second-generation and third-generation electronic cigarette users. *Tob Control., 26*(e1), e23–e28. https://doi.org/10.1136/tobaccocontrol-2016-053041

Leventhal, A. M., Madden, D. R., Peraza, N., Schiff, S. J., Lebovitz, L., Whitted, L., et al. (2021 Jan 4). Effect of exposure to e-cigarettes with salt vs free-base nicotine on the appeal and sensory experience of vaping: A randomized clinical trial. *JAMA Netw Open., 4*(1), Article e2032757. https://doi.org/10.1001/jamanetworkopen.2020.32757

Talih S, Salman R, Soule E, El-Hage R, Karam E, Karaoghlanian N, El-Hellani A, Saliba N, Shihadeh A. Electrical features, liquid composition and toxicant emissions from 'pod-mod'-like disposable electronic cigarettes. Tob Control. 2021 May 12:tobaccocontrol-2020-056362. doi: 10.1136/tobaccocontrol-2020-056362.

Talih, S., Salman, R., El-Hage, R., Karaoghlanian, N., El-Hellani, A., Saliba, N., et al. (2020 Oct 1). Effect of free-base and protonated nicotine on nicotine yield from electronic cigarettes with varying power and liquid vehicle. *Sci Rep., 10*(1), 16263. https://doi.org/10.1038/s41598-020-73385-6

Hiler, M., Karaoghlanian, N., Talih, S., Maloney, S., Breland, A., Shihadeh, A., et al. (2020 Oct). Effects of electronic cigarette heating coil resistance and liquid nicotine concentration on user nicotine delivery, heart rate, subjective effects, puff topography, and liquid consumption. *Exp Clin Psychopharmacol., 28*(5), 527–539.

Inter-University Consortium for Political and Social Research (ICPRS). National Addiction & HIV Data Archive Program. Population Assessment of Tobacco and Health (PATH) Study [United States] Public-Use Files (ICPSR 36498) https://www.icpsr.umich.edu/web/NAHDAP/studies/36498/datadocumentation.[Accessed 8 April 2022].

Ali, F. R. M., Diaz, M. C., Vallone, D., Tynan, M. A., Cordova, J., Seaman, E. L., et al. (2020 Sep 18). E-cigarette unit sales, by product and flavor type - United States, 2014–2020. *MMWR Morb Mortal Wkly Rep., 69*(37), 1313–1318.

Rudy, A. K., Leventhal, A. M., Goldenson, N. I., & Eissenberg, T. (2017 Oct). Assessing electronic cigarette effects and regulatory impact: Challenges with user self-reported device power. *Drug Alcohol Depend., 1*(179), 337–340.

Discover More About JUULpods & Flavors. https://www.juul.com/resources/What-is-JUUL-Vape-Liquid-All-JUUL-Pod-Flavors; Date accessed April 4, 2022.

Royal, K. D. (2019). Survey research methods: A guide for creating post-stratification weights to correct for sample bias. *Educ Health Prof., 2*, 48–50.

Biemer, P. P. C. L. (2008). Weighting survey data. In E. D. Leeuw, J. Hox, & D. Dillman (Eds.), *International handbook of Survey Methodology*. New York, NY: Routledge.

Lipsitz, S. R., Fitzmaurice, G. M., Sinha, D., Hevelone, N., Giovannucci, E., & Hu, J. C. (2015 Sep). Testing for independence in J×K contingency tables with complex sample survey data. *Biometrics., 71*(3), 832–840.

Crespi E, Hardesty JJ, Nian Q, Sinamo J, Welding K, Kennedy RD, Cohen JE. Agreement between self-reports and photos to assess e-cigarette device and liquid characteristics: Results from wave 1 of the longitudinal VAPER study. J Med Internet Res [in press].

Benowitz, N. L., St Helen, G., & Liakoni, E. (2021 Aug). Clinical pharmacology of electronic nicotine delivery systems (ENDS): Implications for benefits and risks in the promotion of the combusted tobacco endgame. *J Clin Pharmacol., 61*(Suppl 2), S18–S36.

Talih, S., Balhas, Z., Salman, R., El-Hage, R., Karaoghlanian, N., El-Hellani, A., et al. (2017). Transport phenomena governing nicotine emissions from electronic cigarettes: Model formulation and experimental investigation. *Aerosol Sci Technol., 51*(1), 1–11.

Blank, M. D., Pearson, J., Cobb, C. O., Felicione, N. J., Hiler, M. M., Spindle, T. R., et al. (2020 Nov). What factors reliably predict electronic cigarette nicotine delivery? *Tob Control., 29*(6), 644–651. https://doi.org/10.1136/tobaccocontrol-2019-055193

El-Hellani, A., Salman, R., El-Hage, R., Talih, S., Malek, N., Baalbaki, R., et al. (2018 Jan 5). Nicotine and carbonyl emissions from popular electronic cigarette products: Correlation to liquid composition and design characteristics. *Nicotine Tob Res., 20*(2), 215–223.

Hiler, M., Breland, A., Spindle, T., Maloney, S., Lipato, T., Karaoghlanian, N., et al. (2017 Oct). Electronic cigarette user plasma nicotine concentration, puff topography, heart rate, and subjective effects: Influence of liquid nicotine concentration and user experience. *Exp Clin Psychopharmacol., 25*(5), 380–392.

Gentry, S. V., Ward, E., Dawkins, L., et al. (2020). Reported patterns of vaping to support long-term abstinence from smoking: A cross-sectional survey of a convenience sample of vapers. *Harm Reduct J, 17*, 70.

Eversole, A., Maloney, S., Talih, S., Salman, R., Karaoghlanian, N., Lipato, T., et al. (2020 Nov). Variable voltage, tank-style ENDS do not always deliver nicotine. *Tob Regul Sci., 6*(6), 416–422.

Pennings, J. L. A., Havermans, A., Pauwels, C. G. G. M., Krüsemann, E. J. Z., Visser, W. F., & Talhout, R. (2022). Comprehensive Dutch market data analysis shows that e-liquids with nicotine salts have both higher nicotine and flavour concentrations than those with free-base nicotine. *Tob Control.*. https://doi.org/10.1136/tobaccocontrol-2021-056952

Gaiha, S. M., Lempert, L. K., McKelvey, K., & Halpern-Felsher, B. (2022 Mar). E-cigarette devices, brands, and flavors attract youth: Informing FDA's policies and priorities to close critical gaps. *Addict Behav., 126*, Article 107179. https://doi.org/10.1016/j.addbeh.2021.107179

Cox, S., Hastings, J., West, R., & Notley, C. (2020). The case for development of an E-cigarette Ontology (E-CigO) to improve quality, efficiency and clarity in the conduct and interpretation of research. *Qeios*. https://doi.org/10.32388/5YYRPJ