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Behaviour Study

Puffing topography and mouth level exposure of two closed-system Vype e-cigarettes

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ABSTRACT

E-cigarettes have the potential to reduce the harm caused by cigarette smoking; however, product likeability and product satisfaction are important in encouraging smokers to switch to less harmful products. Actual use studies play a key part in evaluating the reduced risk potential of tobacco and nicotine products. User's puffing behaviour, including puff duration and sensory effects were evaluated for two types of e-cigarette device: a coil-and-wick 'pen-type' device (Vype ePen3), and a ceramic block-and-plate 'pod-type' device (Vype ePod) with 18 mg/ml nicotine e-liquid. Puffing topography was recorded for these devices with two groups (n=52 each) of adult regular vapers (age 21-64 years) following a fixed 10 puffs protocol where subjects vaped through a special holder attached to a puffing analyser. The sensory characteristics of the aerosol were evaluated using a questionnaire. Mean puff volume was significantly greater ($p \leq 0.0001$) for ePen3 than for ePod (79.8 vs 49.4 ml), while puff duration and puff interval were similar (2.13 vs 2.29 s and 8.9 vs 10.3 s, respectively). Notably, MLE to aerosol and nicotine from ePen3 and ePod were similar (3.89 vs 4.80 mg and 0.06 vs 0.07 mg respectively) despite of very different designs of the devices. Participants reported similar overall likeability and other sensory scores for ePen3 and ePod. In summary, the puffing topography attributes support the CORESTA recommended method no. 81, (CRM81) puffing regime, used for *in vitro* and chemical analysis. The MLE to nicotine per session from both the products were lower than a typical 6 mg cigarette.

Keywords: Puffing topography, Puffing behaviour, Vype, Puff volume, Puff duration, Mouth level exposure

INTRODUCTION

Cigarette smoking is one of the leading avoidable causes of disease, including cancer, cardiovascular disease and respiratory diseases linked to the inhalation of cigarette smoke containing multiple chemicals and known toxicants.[1-3] Risk of smoking-related disease is associated with daily consumption and number of years of smoking, therefore quitting is undoubtedly the best way to both increase life expectancy and decrease the health burden of cigarettes.[4-7] Notably however, only 3%-5% of smokers who try to quit without assistance are successful, and fewer than 10% of all smokers achieve long-term abstinence; therefore, other approaches are needed.[8,9]

The idea of tobacco harm reduction by 'decreasing total morbidity and mortality, without completely eliminating tobacco and nicotine use' was conceived by the US Institute of Medicine in 2001.[10,11] Since then, public health bodies have established tobacco harm reduction policies to encourage smokers to switch to using non-combustible tobacco and nicotine products, such as nicotine replacement therapy (NRT) and electronic cigarettes (e-cigarettes), in place of conventional smoking.[7,12,13]

By producing an inhalable aerosol containing much fewer and lower concentrations of toxicants relative to cigarette smoke, e-cigarettes have strong potential to meet the criteria for tobacco harm reduction.[14] In the United

Kingdom there were an estimated 2.5 million users in 2018.[7]

In order to be useful in a tobacco harm reduction approach, however, e-cigarettes must be able to deliver nicotine efficiently and meet adult consumer's preferences, in addition to reduced toxicant emissions.[14] It is therefore important to carry out 'actual use' studies that evaluate a consumer's use behaviour, including consumption, puffing topography (i.e., puff volume, duration and interval) and mouth level exposure (MLE) to nicotine and aerosol. These parameters affect a user's actual exposure to harmful constituents and play an important role in determining the overall reduced risk potential of alternative nicotine products.[15,16]

Importantly, both user behaviour and the sensory effects of e-cigarettes vary considerably depending on the device (e.g., power setting, resistance, open pressure drop) and composition of the e-liquid (e.g., nicotine content, flavours, etc.).[17,18] It is important to obtain data covering a range of different devices and e-liquids to understand the potential contribution that a product might have in reducing tobacco-related harm. This actual use study was undertaken with the aim of understanding user puffing topography and MLE to aerosol relating to two commercially available closed-system e-cigarettes: a pen-type device with 18 mg/ml nicotine e-liquid (Vype ePen3); and a pod-type e-cigarette with 18 mg/ml nicotine and nicotine-free e-liquid (Vype ePod).

Murphy et al 2017, proposed a multi-disciplinary risk assessment framework comprising pre-clinical, clinical, and population studies to assess the risk profile of novel tobacco products.[16] This assessment framework comprises a series of verifiable studies, in 9 different stages, for comprehensive next generation product (NGP) evaluation and the substantiation of health-related claims. This study contributes to the data collected for stage 4 of the framework. Stage 4 studies include quantifying exposure beginning with puffing behaviour and mouth level exposure studies giving insight into how consumers use new products and quantifying the maximum yield possible. Furthermore, puffing behaviour studies are important for assessing if the machine puffing regimes used in laboratory-based pre-clinical measurements are reflective of consumer's actual behaviour.

METHODS

Study design

Two separate studies were conducted in Gosport, UK, in 2019, with two cohorts of e-cigarette users who had been vaping daily for more than 6 months were recruited. Their puffing topography, MLE and sensory perception was measured when using two different types of e-cigarette: a wick and coil device (Vype ePen3) with nicotine e-liquid (part one), and a ceramic block and plate pod device (Vype ePod). The first study evaluated ePen3 device with an 18 mg/ml nicotine cartridge, while the second study evaluated ePod with 0 mg/ml and 18 mg/ml nicotine e-liquids. The study protocol and Informed Consent Form were approved in accordance with the ethical principles outlined.

Study products

The two study products were Vype ePen3 (BAT) and Vype ePod (BAT), which were both commercially available in the United Kingdom at the time of the study. The description of the study products and the composition of the e-liquids used are shown in Table 1, Figure 1 and 2. The ePen3 device was used with Wild Berries e-liquid (18 mg/ml nicotine); the ePod with Mango e-liquids (0 and 18 mg/ml nicotine). The aerosol collected mass (ACM) generated using the CORESTA recommended method No. 81 (CRM81) machine puffing regime for ePen3 and ePod was 8 and 6.5 mg/puff, respectively. The CRM81 puffing regime recommends a 55 ml puff volume, 3 s puff duration and 30 s puff interval.[19] The open pressure drop was 23 and 70 mmWG, respectively, measured at a flow rate of 17.5 ml/s.

Figure 1: Vype ePen3.

Figure 2: Vype ePod.

Table 1: Study products.

Vype ePen3	Study 1
Description	Comprises a battery section with a rechargeable 650-mAh lithium battery and a non-refillable cartridge with a disposable mouthpiece. It is manually activated with a single button, has no adjustable settings, and a power output of 7.8 W. The e-liquid is aerosolised by a cotton wick and coil (NiFe, resistance 1.39 Ω). Pre-filled Vype e-liquid (2 ml) cartridge is push fitted to the battery pack. The pressure drop of the system measured at 17.5 ml/s was 23 mmWG. ACM delivery is 8.0 mg/puff[a].
E-liquid formulation	Vype Wild Berry e-liquid cartridge containing 18 mg/ml nicotine (1.77% w/w), PG[b] (54% w/w), VG[c] (33.5% w/w), water (10% w/w), benzoic acid (0.73% w/w) and berry flavourings[d].

Continued.

Vype ePod	Study 2
Description	Comprises a metallic outer case, a printed circuit board to control the device, a rechargeable lithium 350-mAh, and a non-refillable e-liquid cartridge. The device is puff-activated with a power output of 6.5 W. The e-liquid is aerosolised by a ceramic wick and a flat metal heating element (NiCr, resistance 0.8~1.4 Ω). Pre-filled Vype e-liquid (1.9 ml) cartridge is magnetically attached to the battery pack. The pressure drop of the system measured at 17.5 ml/s was 70 mmWG. ACM delivery is 6.5mg/puff[a].
E-liquid formulation	Vype mango e-liquid cartridge containing 0 mg/ml nicotine, PG (50% w/w), VG (50% w/w) and mango flavourings[d]. Vype mango e-liquid cartridge containing 18 mg/ml nicotine (1.59% w/w), PG (50% w/w), VG (47.69% w/w), benzoic acid (0.72% w/w) and mango flavourings[d].

Note: a-Data provided by BAT - derived from 5 replicates (50 puffs per replicate), using machine puffing regime 55 ml/3.0s/30 square profile, with 1s pre-puff activation for Vype ePen3; b-Propylene glycol; c-vegetable glycerol; and d-undisclosed amount of flavourings contained in the PG.

Study participants

Two groups of approximately 60 adult participants, including solus users of e-cigarettes and dual users of e-cigarettes and tobacco cigarettes were recruited by an independent market research agency (Survey Marketing Services, Newcastle, UK) in May and October 2019 in accordance with the International Code on Market Opinion and Social Research and Data Analytics.[20] The inclusion criteria were age 21-64 years, daily use of e-cigarettes, vaping for at least 6 months, and vaping e-liquid containing 12 mg/ml or higher nicotine. The exclusion criteria were women who were pregnant or breastfeeding, and persons fitted with pacemakers. All participants read and signed an informed consent form before the study and were each given a unique volunteer ID code by the agency, which was used to identify individuals throughout the study. Participants were free to withdraw from the study for any reason at any stage and were reimbursed for participation after completion of the study. They were asked to abstain from using any nicotine product for an hour prior to the study visit.

Study protocol

The same protocol was used for both studies. Participants attended the study centre for approximately 45 minutes per visit (using only one product per visit), during which time they used the study product in two separate product use sessions separated by a 20-min interval. In each session, participants were asked to take 10 puffs on the study product, vaping as they would normally, through a special holder that was attached to a Puffing Analyser (SA7) for measuring puffing topography parameters.[21] In the 20-min interval, participants completed a short sensory questionnaire. The purpose of the sensory questionnaire was to supplement the puffing topography and help explain any differences seen in the topography and MLE data.

Puffing topography

For the two types of e-cigarette devices, puff volume, puff duration, puff interval and pressure drop were recorded by a desktop puffing analyser (SA7) (Figure 3), originally developed to measure smoking topography.[21] The SA7 comprises a product holder attached to a data acquisition transmission unit (DAT unit). Two tubes on either side of a 2 mm diameter orifice within the product holder detect the change in pressure during a puff, which is proportional to the flow rate squared.[21] The product holder was previously modified for use with e-cigarettes.[22, 23] In each session, participants were asked to take 10 puffs on the study product, vaping as they would normally. The study products were weighed before and after each use to determine the device mass loss (DML), which in turn was used to estimate the mouth level exposure (MLE) to aerosol and nicotine (see below). A clean disposable plastic mouthpiece was attached to the product holder at the beginning of each session (to avoid cross-contamination between participants).

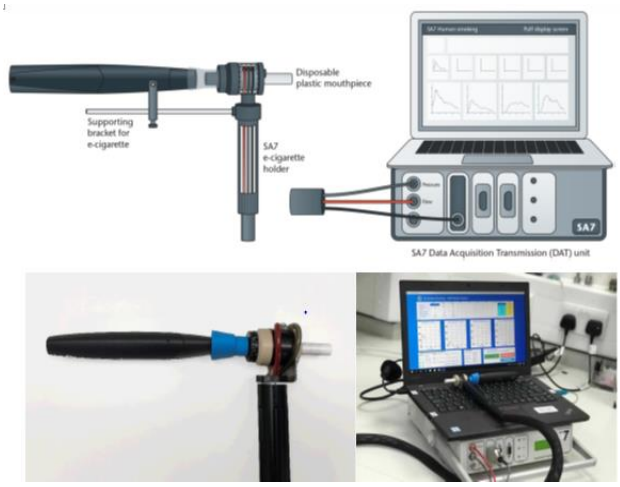

Figure 3: Illustration (top) and images (bottom) of the SA7 puffing topography device, showing the modified product holder for e-cigarettes.

MLE

Participant's MLE to aerosol collected mass (ACM) and nicotine was estimated from DML by using calibration graphs generated under different machine-puffing regimes.[23] In brief, 10 puffs of each study product were taken under eight different machine puffing regimes using a PM1 vaping machine (Borgwaldt KC, Hamburg,

Germany), with puff volumes ranging 40-120 ml and puff durations ranging 1.5-6.0 s, using a bell shaped profile and puff frequency of 30s.

For Vype ePen3, a 1-second pre-puff button activation was applied at the start of each puff. The aerosol for each puffing regime was collected onto a clean 44mmm Cambridge Filter Pad (CFP). Both the CFP and device were weighed before and after puffing to determine ACM and DML, respectively. Nicotine content in the ACM was determined by gas chromatography as described previously.[23]

For each product, DML was plotted against the corresponding ACM and nicotine yields to produce calibration graphs with the line of best fit forced through the origin. R^2 values for the calibration were 0.9820-0.9996. Participants' MLE was then estimated from the DML using the regression equations as follows:

$$MLE\ to\ ACM = DML \times slope_{ACM}$$

$$MLE\ to\ nicotine = DML \times slope_{nicotine}$$

Sensory questionnaire

After the first product use session, participants were asked to complete a sensory questionnaire comprising questions on product likeability, immediate aerosol delivery, draw effort, amount of aerosol filling the mouth, irritation, hit/kick intensity and taste. They were asked to score these sensory attributes on both a magnitude scale, ranging from 1 (low) to 5 (high), and a 'just-right' scale with options of too low, slightly too low, just right, slightly too high and too high.

Data analysis

Statistical analysis was carried out using Minitab 19 and SAS v9.4 statistical software. Puffing topography records and sensory data were compiled in a Minitab spreadsheet and mean±standard deviation (SD) values were determined. Puffing topography and MLE data were analysed for significant differences between ePen3 and ePod (18 mg/ml nicotine) using a linear mixed effects model with Product as a fixed effect and Subject as a random effect, to account for N=27 subjects being in both studies. ePod variants (0 and 18 mg/ml nicotine) were compared using a paired t-test at 5% significance level (α). Similarly, Magnitude sensory perception responses were analysed for significant differences between ePen3 and ePod (18 mg/ml nicotine) using similar linear mixed effects model and between ePod variants (0 and 18 mg/ml nicotine) using a paired t-test at the 5% significance level (α). 'Just right' sensory perception responses were analysed for significant differences from the ideal value of 3 using a one-sample t-test, where 3- 'just right'.

RESULTS

Study participants

In the first study, 60 adult vapers (30 males, 30 females; 30 solus users, 30 dual users) were recruited to use the ePen3; in the second, 58 (29 males/29 females; 30 solus users, 28 dual users) were recruited to use the ePod.

In study 1 (ePen3), 52 participants completed all topography measurements, 51 completed all sensory perception questionnaires, and 44 completed both. In Study 2 (ePod), 52 completed all topography measurements, 58 completed all sensory perception questionnaires, and 52 participants completed both (Table 2).

Puffing topography

The mean puff volume, puff duration, puff interval and pressure drop for all participants in each study are summarised in Table 3 and 4.

The pressure drop during puffing was significantly higher ($p \leq 0.0001$) for ePod compared with ePen3 (162.1 vs 97.6 mmWG) resulting in significantly lower puff volumes ($p \leq 0.0001$) for ePod than ePen3 (49.4 vs 79.8 ml). A much higher pressure drop experienced by users vaping the ePod as compared with the ePen3 may be attributed to the relatively higher open pressure drop of ePod (70 mmWG) compared with ePen3 (23 mmWG) measured at a flow rate of 17.5 ml/s.

Participants took significantly longer puff durations ($p \leq 0.0001$) for the 0 mg/ml nicotine ePod than for the 18 mg/ml nicotine ePod (2.68 s vs 2.29 s), and took significantly larger puff volumes ($p \leq 0.0001$) for the 0 mg/ml nicotine ePod compared to the 18 mg/ml nicotine ePod (58.4 ml vs 49.4 ml). Longer puff durations and larger puff volumes taken for the nicotine-free e-liquid may be attributed to participants puffing harder in order to achieve the desired satisfaction from the product due to the lack of nicotine.

Mouth level exposure

The data for MLE are summarised in Table 5 and 6.

MLE to aerosol (ACM) was similar ($p=0.1637$) for both ePen3 and ePod (3.39 mg/puff vs 4.80 mg/puff).

MLE to nicotine was also similar ($p=0.3802$) for both ePen3 and ePod (0.06 mg/puff vs 0.07 mg/puff).

As expected, the MLE to ACM was significantly higher ($p \leq .0001$) for the 0 mg/ml nicotine ePod compared with the 18 mg/ml nicotine ePod (6.02 mg/puff vs 4.80 mg/puff), whilst the MLE to nicotine was significantly lower ($p \leq 0.0001$) for the 0 mg/ml nicotine ePod compared

to the 18 mg/ml nicotine ePod (0.00 mg/puff vs 0.07 mg/puff).

Sensory questionnaire

Results from the sensory questionnaire, reported as a mean score from 1 to 5, are summarised in Table 7 and 8. The 18 mg/ml nicotine ePen3 and ePod were perceived to be similar in all of the sensory attributes evaluated (Table 7). However, the 0 mg/ml nicotine ePod was perceived to be significantly lower in aerosol delivery (p=0.0230), mouthful (p=0.0231), irritation (p=0.0002) and Hit/Kick intensity (p≤0.0001) compared with 18 mg/mL nicotine ePod (Table 8).

On the 'just right' scale (Table 9), the 0 mg/ml nicotine ePod was perceived to be 'slightly too hard' to draw and 'slightly too low' for all other attributes. The 18 mg/ml nicotine ePod was perceived to be 'slightly too hard' to draw and 'slightly too low' for mouthful and taste amount. The 18 mg/ml nicotine ePen3 by contrast was perceived to be 'just right' for most attributes and slightly higher than ideal for aerosol delivery, irritation and hit/kick intensity.

Table 2: Demographic characteristics of participants who completed puffing topography.

Characteristics	ePen group (n=52)	ePod group (n=52)
Gender		
Male	27	27
Female	25	25
Type of user		
Solus	29	26
Dual (+cigs)	23	26
Age group (years)		
21-25	10	9
26-35	13	18
36-45	9	14
46-55	9	11
56-64	3	0
Missing age data*	8	0

Note:* within the ICF boundaries of over 21 years old bracket.

Table 3: Puffing topography- Vype ePen3 18 mg/ml (study 1) vs Vype ePod 18 mg/ml (study 2). Mean±SD and p value[a].

Parameters	Mean±SD		P value
	Vype ePen3 18 mg (n=52)[b]	Vype ePod 18 mg (n=52)[c]	
Puff volume (ml)	79.8±48.9	49.4±20.6	<0.0001
Puff Duration (s)	2.13±1.00	2.29±0.99	0.5407
Puff interval (s)	8.9±4.4	10.3±6.2	0.1472
Pressure drop (mmWG)	97.6±46.2	162.1±47.5	<0.0001

Note: a-Results obtained using a mixed effects model with fixed effect of product and a random effect of subject, p values come from the comparison of the Least squares means, the threshold of statistical significance is 0.05; b- N=52 participants. 2 measures per participant (averaged); c- N=52 participants. 2 measures per participant (averaged).

Table 4: Puffing topography- Vype ePod 0 mg/ml vs 18 mg/ml nicotine (study 2). Mean±SD and p value[a].

Parameters	Mean±SD		P value
	Vype ePod 0 mg (n=52)[b]	Vype ePod 18 mg (n=52)[c]	
Puff volume (ml)	58.4±25.9	49.4±20.6	<0.0001
Puff duration (s)	2.68±1.15	2.29±0.99	<.0001
Puff interval (s)	9.4±5.5	10.3±6.2	0.1183
Pressure drop (mmWG)	168.6±54.1	162.1±47.5	0.1203

Note: a-Determined using paired t-test at 5% significance level (α); b- N=52 participants. 2 measures per participant (averaged) c- N=52 participants. 2 measures per participant (averaged).

Table 5: Mouth level exposure- Vype ePen3 18 mg/ml (study 1) vs Vype ePod 18 mg/ml (study 2). Mean±SD and p value[a].

Parameters	Mean±SD		P value
	Vype ePen3 18 mg (n=52)[b]	Vype ePod 18 mg (n=52)[c]	
MLE to ACM (mg/puff)	3.89±2.55	4.80±2.83	0.1637
MLE to nicotine (mg/puff)	0.06±0.04	0.07±0.04	0.3802

Note: a-Results obtained using a mixed effects model with fixed effect of product and a random effect of subject, p values come from the comparison of the least squares means, the threshold of statistical significance is 0.05; b N= =52 participants. 2 measures per participant (averaged); and c- N=52 participants. 2 measures per participant (averaged).

Table 6: Mouth level exposure- Vype ePod 0 mg/ml vs 18 mg/ml nicotine (study 2). Mean±SD and p value[a].

Parameters	Mean±SD		P value
	Vype ePod 0 mg (n=52)[b]	Vype ePod 18 mg (n=52)[c]	
MLE to ACM (mg/puff)	6.02±3.07	4.80±2.83	<.0001
MLE to nicotine (mg/puff)	0.00±0.00	0.07±0.04	<.0001

Note: a- Determined using paired t-test at 5% significance level (α); b N=52 participants. 2 measures per participant (averaged); and c N=52 participants. 2 measures per participant (averaged).

Table 7: Sensory magnitude scores-Vype ePen3 18 mg/ml (study 1) vs Vype ePod 18 mg/ml (study 2). Mean±SD and p value[a].

Question (magnitude scale)	Mean±SD		P value
	Vype ePen3 18 mg (n=51)	Vype ePod 18 mg (n=58)	
1. Overall likeability	3.4±1.2	3.2±1.2	0.4240
2a. Aerosol delivery	3.6±1.0	3.3±1.0	0.1693
3a. Draw effort	3.2±1.1	3.2±1.1	0.6524
4a. Mouthful	3.4±1.0	3.2±0.9	0.3136
5a. Irritation	3.1±1.3	3.0±1.2	0.5556
6a. Hit/kick intensity	3.5±1.1	3.3±1.1	0.3467
7a. Taste amount	3.0±0.8	3.0±1.1	0.9900
8. Taste likeability	3.4±1.2	3.3±1.2	0.6899

Note: a- Results obtained using a mixed effects model with fixed effect of product and a random effect of subject, p values come from the comparison of the least squares means, the threshold of statistical significance is 0.05.

Table 8: Questionnaire (magnitude scores): Vype ePod 0 mg/ml vs 18 mg/ml nicotine (study 2). Mean±SD and p value[a].

Question (magnitude scale)	Mean±SD		P value
	Vype ePod 0 mg (n=58)	Vype ePod 18 mg (n=58)	
1. Overall likeability	3.6±1.2	3.2±1.2	0.0937
2a. Aerosol delivery	3.0±1.2	3.3±1.0	0.0230
3a. Draw effort	3.4±1.1	3.2±1.1	0.2304
4a. Mouthful	2.9±1.1	3.2±0.9	0.0231
5a. Irritation	2.1±1.2	3.0±1.2	0.0002
6a. Hit/kick intensity	2.4±1.1	3.3±1.1	<.0001
7a. Taste amount	3.1±1.1	3.0±1.1	0.6084
8. Taste likeability	3.4±1.1	3.3±1.2	0.6451

Note: a- Determined using paired t-test at 5% significance level (α).

Table 9: Sensory questionnaire ('just right' scores): Mean±SD and p value[a].

Question ('just right' scale)	Vype ePod 0 mg (n=58)		Vype ePod 18 mg (n=58)		Vype ePen3 (n=51)	
	Mean±SD	P value	Mean±SD	P value	Mean±SD	P value
2b. Aerosol delivery	2.4±0.8	0.0000	2.9±0.9	0.5682	3.3±0.9	0.0293
3b. Draw effort	3.5±0.8	0.0000	3.2±0.8	0.0255	3.1±0.7	0.1805
4b. Mouthful	2.5±0.8	0.0000	2.8±0.7	0.0385	3.1±0.8	0.5950
5b. Irritation	2.5±0.8	0.0001	3.1±0.9	0.3810	3.3±0.8	0.0053

Continued.

Question ('just right' scale)	Vype ePod 0 mg (n=58)		Vype ePod 18 mg (n=58)		Vype ePen3 (n=51)	
	Mean±SD	P value	Mean±SD	P value	Mean±SD	P value
6b. Hit/kick intensity	2.3±0.9	0.0000	3.1±1.0	0.3667	3.5±1.0	0.0007
7b. Taste amount	2.4±0.8	0.0000	2.4±0.8	0.0000	3.0±0.8	1.0000

Note: Determined using a one-sample t-test at the 5% significance level (α) where the hypothesised value 3='just right.

DISCUSSION

E-cigarettes have been shown to have lower toxicant emissions in comparison to conventional cigarette smoke and thus have the potential to reduce the health risks associated with cigarette smoking.[14,24] However, exposure to both nicotine and other constituents from these devices is also affected by how the consumer uses them; therefore, it is essential to characterize consumer use behaviour such as puffing topography alongside emissions to obtain an overall estimate of the relative harm from these products.[25] Such 'real-world' e-cigarette topography data also help to inform laboratory-based emissions testing by identifying the most appropriate puffing parameters for instrumental analyses.[26] While a number of previous studies have documented the user puffing topography of e-cigarettes, devices and e-liquids are continually evolving, and the new products should be assessed to gather as much data as possible.[23,27-29] Here we have evaluated user puffing topography and sensory effects for a pen-type (Vype ePen3) and pod-type e-cigarette device (Vype ePod) with 18 mg/ml nicotine e-liquid. The ePod device was also evaluated with 0 mg/ml nicotine e-liquid. Study participants exerted lower pressure drop (PD) and generated higher puff volumes from ePen3 than ePod (97.6 vs 162.1 mmWG and 79.8 vs 49.4 ml, respectively). This may be attributed to the lower open PD of ePen3 compared with ePod (23 vs 70 mmWG at 17.5 ml/s). Despite of the difference in the puffing topography attributes between the two devices, user MLE to ACM and nicotine were observed to be similar. This was reflected in the similar overall likeability and scores for the sensory attributes evaluated. The nicotine delivery for these products were considerably lower than that delivered by a typical 6 mg 'tar' cigarette (1.3±0.5 mg/stick).[30]

Previous studies of various e-cigarettes ranging from early 'cig-a-likes' to new prototypes have reported mean puff volumes ranging from 41.2 ml for a recent prototype device with distiller plate technology and 51.0 ml for two cartomizer devices, to 101.4 ml for early tank devices.[23,27,28] The current values (ePen3, 79.8 ml; ePod, 49.4 ml) fall within this reported range. Similarly, previously reported puff durations range from 1.4 s and 2.65 s to 4.16 s, with current values (ePen3, 2.13 s; ePod, 2.29 s) falling within this range.[23,27,28]

Many factors have been reported to affect puffing topography including e-liquid flavour, which may affect mean puff duration and mean number of puffs, and nicotine content, where higher nicotine leads to shorter puff durations.[17,31-34] Similarly, in the second study, participants vaping ePod with 0 mg/ml nicotine e-liquid were observed to take longer puff duration compared to those using 18 mg/ml nicotine e-liquid (2.68 s vs 2.29 s). Consequently, generating higher puff volumes in the process. This may be explained by the participants engaged in compensatory puffing, owing to the lack of nicotine in the e-liquid.[32]

Other factors that may influence puffing topography include PG:VG ratio, where high PG content leads to shorter and smaller puffs, and device settings such as power, with higher power settings leading to shorter puff duration.[18,35] In the present study, however, PG:VG ratios of the two 18 mg/ml e-liquids were similar (ePen3 54.00:33.50 vs ePod 50.00:47.69) and the two devices had fixed power settings of 7.8W (ePen3) and 6.5W (ePod). Puffing topography also differs by level of established experience in the product user with longer puffs taken by experienced users relative to naïve product users.[33,36] A recent study showed that inexperienced e-cigarette users increased their inter-puff interval and puff duration over a 2-week trial period.[37] In the present study, these potential differences were avoided by recruiting only experienced vapers. Because sensory perception of a nicotine product and its use are key aspects in trying to encourage a smoker to switch to reduced risk products, we also assessed the participants' subjective responses (via a questionnaire) after using the products. Overall, the participants reported similar likeability and other sensory scores for the two devices with 18 mg/ml nicotine e-liquid; similar characteristics of the aerosol generated. However, the ePod device with 0 mg/ml nicotine e-liquid was perceived to be lower in aerosol delivery, mouthful, irritation, hit/kick intensity and less liked overall compared with the 18 mg/ml nicotine e-liquid, presumably due to the lack of nicotine in the ePod device.

Limitations

The study had some limitations. In the topography sessions, participants were asked to take 10 puffs from the study products and it is possible that longer puff durations and larger puff volumes may be observed during *ad libitum* as compared with fixed puffing sessions.[38] In addition, while two puffing sessions were recorded for each participant, it is possible that an e-cigarette user may show variability in puffing topography recorded at different times and in different situations.[39,40] Furthermore, the present study recorded a snapshot of use behaviour for participants trying an unfamiliar device, and puff duration and volume has been shown to increase with product use over time.[41]

CONCLUSION

Alongside aerosol emissions testing, actual use studies provide key information on the manner in which

consumers use nicotine and tobacco products and thus help to estimate the overall exposure to harm from these products, as well as providing parameters to inform laboratory-based testing. Hypothetically, the effect of increasing puffing volume on aerosol delivery would be less for e-cigarettes than for cigarettes, as it is independent of the heating of the tobacco and is principally used to condense the vapour into an aerosol. The average puff volumes observed with ePen3 and ePod (18 mg/ml nicotine) were 79.8 ml and 49.4 ml, respectively. Even though the puff volume for ePen3 was higher than the 55 ml machine puff volume recommended by CORESTA (2015), this volume is still relevant to consumers. In the two studies the mean puff duration for ePen3 and ePod (18 mg/ml nicotine) was 2.13 and 2.29 s respectively. Usually, consumers depress the activation button before puffing (for approximately 1 s), meaning that the heating coil is activated for a 1 s longer than the measured puff duration. As a result, the e-cigarette aerosolisation duration (or time when the heating coil was activated) for ePen3 was probably closer to the 3 s puff duration recommended by CORESTA (2015). The fixed puff protocol along with the confined study where users vaped through a special holder tethered to a puffing analyser may have resulted in the short puff interval compared to the 30 s puff interval recommended by CORESTA (2015). In summary, the puffing topography attributes like puff volume, puff duration and puff interval broadly support the CRM 81 machine puffing regimes (CORESTA 2015) used for in vitro and chemical analysis. Notably, MLE to aerosol and nicotine from ePen3 and ePod were similar (3.89 vs 4.80 and 0.06 vs 0.07 mg respectively) despite the very different designs of the devices. The nicotine delivery for these products were considerably lower than that delivered by a typical 6 mg 'tar' cigarette (1.3±0.5 mg/stick).

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