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The feasibility of measuring puffing behaviour in Roll-Your-Own cigarette smokers

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Abstract

Objective: Despite the increase in roll-your-own (RYO) cigarette consumption in many countries, very little is known about RYO smokers. In order to estimate the health risks inherent to RYO use, it is important to assess exposure to tobacco toxins in this group. Exposure is determined by a number of factors, including puffing behaviour, but so far this issue has not been addressed among RYO smokers. This study sought both to determine the feasibility of measuring puffing behaviour in this group, its reliability and validity, and to characterise puffing behaviour among RYO smokers compared with smokers of factory-made (FM) cigarettes.

Methods: At two visits, 24 hours apart, 131 FM and 29 RYO cigarette smokers provided saliva samples which were assayed for cotinine, a measure of nicotine intake and thus smoke exposure. Self-reported puffing behaviour of participants, as well as their demographic and smoking characteristics were also assessed. At the end of the first visit, smokers were shown how to use a portable smoking topography machine that measures puffing behaviour, the CReSSmicro, and asked to smoke all cigarettes with this machine until the second visit, when participants were asked to provide feedback on using the device.

Results: Both RYO and FM cigarette smokers reported that the CReSSmicro was easy to use; however, RYO cigarette smokers were more likely to have missing data, to reduce cigarette consumption and to indicate a change in their puffing behaviour because of the device. Machine-determined puffing behaviour was equally stable over time in both groups with similar ability to predict exposure; cotinine levels were related to machine but not self-reported puffing parameters. Overall, RYO smokers appeared to puff cigarettes less hard but for longer than FM cigarette smokers.

Conclusion: The measurement of puffing behaviour using a topography device is feasible but less practicable for RYO than FM cigarette smokers. Puffing parameters

show comparable reliability and validity for both groups of smokers and reveal some differences in smoking topography dependent on the type of cigarette smoked.

Introduction

It is well-documented that raising the price of factory made (FM) cigarettes leads to a decline in consumption;[1] increasing prices by 10% is typically associated with a 3 to 5% fall in demand.[2;3] However, while many smokers will actually stop smoking, others may delay cessation by smoking fewer cigarettes more intensely to maintain a similar nicotine intake [4] and/or by switching to cheaper (often smuggled) products,[5] which may attenuate the impact of taxation on consumption.[6] It is therefore not surprising that in tandem with recent increases in taxation, there has been a corresponding rise in the consumption of comparatively inexpensive roll-your-own (RYO) cigarettes in various countries,[7-9] which substitute FM cigarettes.

In the UK, where FM cigarettes are more highly taxed then RYO tobacco (in addition to a per unit duty, FM cigarettes are also taxed at 22 percent of the retail price [10]) RYO use is now prevalent with over a quarter of smokers hand-rolling their cigarettes [11] - having nearly doubled from just a decade ago.[12] Despite the increasing importance of this group of smokers in terms of tobacco control measures, there is a dearth of information about the impact of RYO cigarettes on health risks, attitudes and smoking behaviour.[13] What research does exist indicates that smoke from RYO cigarettes has some carcinogen levels at least as high as FM cigarettes [14;15] and that smoking RYO cigarettes causes a variety of diseases.[16;17]. There is also evidence suggesting that RYO compared with FM cigarette smokers may be at increased risk of particular forms of cancer.[18;19]

In contrast to manufactured cigarettes, RYO cigarettes are not standardised in form or shape and therefore come under even less regulatory oversight than FM cigarettes.[20] This potentially enables tobacco companies to mislead smokers more easily about RYO

tobacco content.[9] Indeed, smokers tend to think that RYO cigarettes are more ‘natural’ and therefore may confer some health benefit over FM cigarettes,[13;21] when this is not the case. Since yields from RYO as opposed to FM cigarettes depend on more factors that are under the control of the user, such as the size of the tube, packing density, the use of filters and the amount of tobacco used, RYO cigarette emissions are necessarily more varied than FM cigarette emissions [13] and standardised testing methods have been proposed.[e.g. 22] While the few studies that have estimated RYO yields find these on average to be higher than yields from FM cigarettes [23;24], these emissions strongly depend on the physical characteristics of the RYO cigarette and are thus arbitrary..

Moreover, investigations of FM cigarettes have shown that there is very little, if any, relationship between cigarette yields and intake.[25] Studies of puffing behaviour imply that smokers tend to compensate for varying nicotine yields by adjusting their puffing behaviour to obtain the desired amount of nicotine.[26] The measurement of in vivo puffing behaviour has progressed over the years owing to the development of portable, hand-held devices [27] and can provide important insights into the impact of the physical characteristics of cigarettes (such as filter ventilation) on behavioural modification and thus exposure and, ultimately, health risks.[28] Yet, there are currently no studies that have investigated the feasibility of measuring the puffing behaviour of RYO smokers to address these issues.

Our study therefore aimed to assess the feasibility of measuring puffing behaviour among RYO as compared with FM cigarette smokers, its associated reliability and validity, as well as to characterise RYO and FM smokers in terms of smoking topography.

Methods

Participants

Participants were recruited through advertisements in local newspapers, flyers, emails, or posters on public bulletin boards at or around University College London. Smokers who responded to the advertisements were screened for eligibility through a telephone interview. Participants were included if they were between 18 and 60 years of age, had smoked at least five cigarettes daily for the past year, and had been a regular smoker of one particular cigarette brand (either manufactured or roll-your-own tobacco) for more than three months. Eligible cigarette brands were selected on the basis of national sales and nicotine yield to include at least one of the most popular 'light' and 'regular' cigarette brands and one popular RYO tobacco brand. Smokers were ineligible if they had a history of lung or heart disease or if they were pregnant.

Procedure

Ethical approval was granted by the University College London Ethics Committee. Participants visited the laboratory on two occasions, 24 hours apart. At the first visit, the purpose of the study was explained and general demographic and smoking characteristics recorded including the consumption of other tobacco-related products such as marijuana, which smokers were asked to refrain from using for the duration of the study; at both visits participants also provided information about their puffing behaviour before saliva samples were collected. Smokers of RYO cigarettes were also asked to roll three cigarettes, which were then weighed, measured and averaged across the three cigarettes. At the end of the first visit participants were given the CReSSmicro® machine (Plowshare Technologies, Inc. Baltimore, Maryland), a smoking topography machine, and smoked a test cigarette through the machine. Smokers were asked to smoke all cigarettes for the intervening 24 hours using this device until they returned for

the second visit, when they would smoke a final cigarette using the machine. Participants were reimbursed £50 for their time.

Measures

Machine-determined puffing behaviour

The CReSSmicro® machine is a battery-operated, hand-held portable device (see Picture 1) that measures a full complement of smoking topography variables including puff volume, puff count, puff duration, peak flow, inter-puff interval, time, and date; it has been previously validated for use with FM cigarettes.[29] The device uses an orifice flow meter mouthpiece that produces a pressure drop related to the flow rate of smoke through the mouthpiece. Data are collected by having the participant insert a cigarette in the device and smoke the cigarette as normal. Once the participant is finished, the cigarette butt is withdrawn from the device and extinguished, as usual. Data are stored on the device and downloaded for analysis. Recorded data were checked for consistency, invalid data removed and average values of puffing parameters across all cigarettes smoked computed.

Self-reported puffing behaviour

Various self-reported measures of general puffing behaviour were obtained through questionnaire items. Inter-puff interval was assessed by asking smokers how long on average they thought they let the cigarette burn in between taking puffs. The number of puffs per cigarette was determined by asking smokers to estimate the number of puffs they take on average per cigarette. Depth of inhalation was determined by a multiple choice item. Smokers were asked if they: (1) don't inhale into the chest at all; (2) inhale only a little into the chest; (3) inhale deeply into the chest or (4) inhale into the chest as deeply as possible. Lastly, smokers were asked to indicate on a scale from 1 (not at all hard) to 10 (as hard as possible) how 'hard' or intensely they thought they smoked

cigarettes on average, bearing in mind their responses to how deeply they inhaled and how many puffs they took per cigarette.

Demographic and smoking characteristics

During the interview smokers were questioned about their smoking history, quit attempts, future quit plans, as well as general demographic information. Deprivation level was determined using the Index of Multiple Deprivation (IMD), a reliable measure of relative poverty based on post codes.[30] Body mass index (BMI) was calculated from participants' self-reported height and weight (kg/m^2). Smokers were asked to indicate their intention to quit smoking in the next month on two validated 7-point Likert-type response scales ranging from 'very unlikely' to 'very likely' and 'definitely will' to 'definitely will not'.[31] Questionnaire items were used to calculate the Heaviness of Smoking Index (HSI),[32] a short version of the Fagerström test for nicotine dependence. The HSI is derived from the time to the first cigarette (≤5 min=3 points; 6-30 min=2 points; 31-60 min=1 point; >60=0 points) and cigarettes per day (1-10=0 points; 11-20=1 point; 21-30=2 points; >31= 3 points) producing a scale from 0 to 6 with higher scores indicating greater dependence on nicotine.

Marker of smoke exposure

Saliva samples were collected using a dental roll, which participants were asked to keep in the mouth until saturated. Samples were assayed for cotinine, a major metabolite of nicotine that provides a very sensitive and specific quantitative measurement of tobacco intake using a tandem mass spectrometric method.[33]

Statistical Analysis

Statistical analysis was carried out using SPSS 14.0. Intraclass correlation coefficients (ICC) were calculated using a two-way mixed model to estimate test-retest reliability of

measures. Group differences were assessed by means of chi-square test for dichotomous data, and t-test and ANOVA for continuous variables. In addition, stepwise linear regression was conducted to predict outcome variables.

Results

Sample description

The study sample had a mean age of 31 and slightly more men than women (Table 1). Participants had been smoking for an average of 14 years, smoked nearly 14 cigarettes per day and over a third had at some point used marijuana. The majority had attempted to quit in the last year but only a tenth were inclined to agree with the statement that they were intending to stop smoking in the next month. RYO cigarette smokers were more likely to be male (Fisher's exact test, p=.007) but there were no other differences between FM and RYO cigarette smokers in terms of demographic characteristics.

Table 1: Demographic and smoking characteristics by cigarette type at baseline

	All smokers (N=160)	FM (N=131)	RYO (N=29)
Demographic data			
Mean (SD) age	31.7 (10.7)	31.4 (10.4)	33.1 (12.2)
Percent (N) male	56.3 (90)	51.1 (67)	79.3 (23)**
Mean (SD) IMD	32.0 (13.1)	32.3 (13.4)	30.4 (11.6)
Mean (SD) BMI	23.9 (4.0)	24.0 (4.1)	23.3 (3.4)
Smoking data			
Mean (SD) cigarettes per day	13.8 (5.9)	13.4 (5.7)	15.9 (6.4)
Mean (SD) length of time of smoking in years	14.3 (11.1)	14.1 (10.7)	15.6 (13.0)
Mean (SD) HSI	2.4 (1.5)	2.3 (1.4)	2.7 (1.8)
Percent (N) smoking marijuana	36.9 (59)	36.6 (48)	37.9 (11)
Percent (N) quit attempt in last year	56.3 (90)	57.3 (75)	51.7 (15)
Mean (SD) Intention to quit next month	2.8 (1.6)	2.9 (1.6)	2.5 (1.7)
Percent (N) Want to quit next month	11.3 (18)	11.5 (15)	10.3 (3)
Percent (N) Want to quit next month	11.3 (18)	11.5 (15)	10.3 (3)
Mean (SD) Salivary Cotinine (ng/ml) [#]	292 (182)	273 (130)[~]	311 (135)[$]

[#]Adjusted for age, sex, body-mass index (BMI), index of multiple deprivation (IMD), dependence (HSI);[~]N=110; [$]N=21 ; **p<.01

Due to an interaction between cigarette type and cotinine levels at visit 1 and 2 – adjusted cotinine levels increased among FM (to 311 (SD=144) ng/ml) but not among RYO (309 (SD=149) ng/ml) cigarette smokers across visits ($F(1, 150)=4.329$, $p=.039$) – only baseline cotinine levels are presented in Table 1. Although RYO smokers had somewhat higher levels of cotinine and other indicators of dependence such as consumption and HSI at baseline, these differences were not significant. Moreover, the intake of nicotine per cigarette in this sample was very similar for RYO (19.6 ng/ml per cigarette) and FM cigarette smokers (20.4 ng/ml per cigarette).

The majority of RYO smokers in this study (65.5%) rolled cigarettes with filters (which are pre-made and sold at tobacco stores) and the rest with either a roach (handmade filter using cardboard) or nothing at all (see Picture 1 for an example of each of these RYO cigarette types). There was an equal split among RYO smokers in terms of the shape of the cigarette as either being rolled tapered (48.3%) or with a constant diameter throughout (51.7%). RYO smokers were very consistent in their hand-rolling across cigarettes using an average of 511 mg tobacco (95%CI 476-548) per cigarette with a steady diameter of 5.8 mm (95%CI 5.6-6.1) and a standard length of 70.0 mm, which was determined by the paper used. This compares with a mean weight of 660 mg tobacco (95%CI 651-669) per FM cigarette with an average diameter and length of 7.5 mm (95%CI 7.5-7.6) and 85.1 mm (95%CI 84.1-86.0) respectively. Thus RYO cigarettes were on average more densely packed than FM cigarettes (0.28 vs 0.18 mg/mm^3; $t(158)=17.6$, $p<.001$).

The weight of tobacco of RYO cigarettes was correlated with cotinine levels across visits ($r=.347$ $p=.07$) and there were no significant differences in exposure between smokers of RYO cigarettes with or without filters.

Puffing behaviour

In general, smokers did not report any problems using the CReSS machine. The majority of FM (81.7%) and RYO (75.6%) cigarette smokers said that the device was easy or very easy to handle. However, the use of the CReSS machine in RYO presented some challenges, especially for smokers who used neither a filter nor a roach. For these smokers, the mouth-piece of the device needed to be adapted by placing blue-tac around the opening so as to ensure that the rolled cigarette was kept in place. For smokers who hand-rolled cigarettes with filter or roaches this was not a problem as these cigarettes stayed in place when inserted into the mouth-piece. However, for all RYO smokers the removal of the cigarette was somewhat difficult as the rolled cigarette had a smaller diameter than manufactured cigarettes, and therefore was placed deeper into the mouth-piece, which resulted in cigarettes sometime needing to be removed from the mouth-piece with the help of tweezers.

In the total sample, the majority reported that their smoking behaviour had changed a little bit when using the device (59.4%) and a fifth said it had changed their smoking a lot. RYO smokers were more likely than FM cigarette smokers to say that they had adjusted their smoking behaviour because of using the machine ($\chi^2(1)=3.9$, $p=.049$). This is reflected in a significant reduction in cigarette consumption during the study from baseline values ($t(159)=4.73$, $p<.001$), which occurred among both FM and RYO cigarette smokers but was more pronounced in the latter group; consumption was reduced by one and four cigarettes per day, respectively. As cotinine levels did not decline, indeed increased among FM cigarette smokers, this suggests that both FM and RYO cigarette smokers obtained more nicotine from each cigarette when using the device (24.8 and 22.4 ng/ml cotinine per cigarette for FM and RYO smokers, respectively).

In an open-ended question, participants were invited to specify further how their smoking had changed. Confirming the above results, nearly twice as many RYO (62%) than FM (35%) cigarette smokers said they had reduced their smoking in some form. A substantial proportion of all smokers (20%) said they had smoked fewer cigarettes and an equal proportion claimed that they had more difficulties inhaling and therefore dragged harder on each cigarette. Some smokers also commented that using the device meant that they smoked less of each cigarette. However, only FM cigarette smokers said that taste of the cigarettes changed when smoking with the machine and that they smoked more of each cigarette.

Despite these comments, in the total sample there were no significant changes in self-reported puffing assessed before and after the use of the CReSS device. However, there were differences when looking at the two groups of smokers separately; in contrast to FM cigarette smokers, smokers who hand-rolled reported a significant decrease in the puffs taken per cigarette ($t(28)=3.93$, $p<.001$) and the time spent between taking puffs ($t(28)=2.25$, $p=.032$). This is probably because they did not want to keep re-lighting the cigarette in the machine. As this change in smoking behaviour was anticipated, self-reported puffing assessed at the second visit was used in the analysis to account for adjustment in puffing thus ensuring comparability to machine-determined measures.

Table 2 ICC for CReSS measures by cigarette type

CReSS puffing parameters	Intraclass correlation coefficient (95% CI)	
	FM (124)	RYO (24)
Number of cigarette puffs	.885 (.850-.914)	.861 (.749-.932)
Interpuff interval	.772 (.702-.830)	.700 (.464-.854)
Puff duration	.933 (.912-.950)	.947 (.904-.974)
Puff volume	.924 (.897-.945)	.927 (.867-.965)
Average Puff flow	.932 (.905-.952)	.891 (.803-.947)
Peak puff flow	.934 (.901-.955)	.899 (.817-.951)

Intraclass correlation coefficients (ICC) for the various puffing parameters of the first five cigarettes smoked with the CReSS device over the 24 hours between visits showed comparable stability over time for both FM and RYO cigarette smokers (Table 2). However, there was some discrepancy in the handling of the device; more FM (94.7%) than RYO (82.8%) cigarette smokers managed to smoke at least five valid cigarettes with the CReSS device (Fisher's exact test, p=.043).

Table 3: Self-reported and machine-determined puffing behaviour by cigarette type

	All Smokers (N=160)	FM (N=131)	RYO (N=29)
Self-reported puffing at Visit 2		Mean (SD)	
Number of cigarette puffs	12.4 (6.7)	12.5 (7.0)	11.8 (4.9)
Interpuff interval in seconds	14.5 (14.3)	14.9 (15.1)	12.9 (10.1)
Inhalation strength	2.9 (0.6)	2.9 (0.6)	2.9 (0.7)
Smoking intensity	6.2 (1.7)	6.1 (1.8)	6.4 (1.6)
CReSS puffing parameters[#]			
Number of cigarette puffs	14.1 (4.6)	13.6 (4.5)	15.6 (5.6)
Interpuff interval (s)	25.1 (10.3)	25.8 (10.3)	23.0 (12.7)
Puff duration (s)	1.6 (0.5)	1.5 (0.5)	1.8 (0.6)*
Puff volume (ml)	54.6 (14.3)	54.2 (14.0)	52.7 (17.2)
Average Puff flow (ml/s)	36.8 (8.1)	37.7 (7.8)	30.9 (9.6)**
Peak puff flow (ml/s)	53.7 (14.3)	55.3 (14.0)	44.2 (17.2)**
Inhalation time per cigarette (s)	21.5 (7.1)	20.0 (6.3)	27.3 (7.8)**
Total smoke time per cigarette (s)	317 (77)	316 (77)	318 (75)
Smoke volume per cigarette (ml)	742 (244)	712 (232)	789 (286)

[#]FM has one missing case (N=130) & controlling for sex; *p<.02; **p<.001

As shown in Table 3, there were no significant group differences in self-reported puffing behaviour at the second visit. However, inhalation strength reported at baseline differed by cigarette type; FM cigarette smokers indicated that they inhaled more strongly than RYO cigarette smokers (t(158)=2.05, p=.042). Machine-determined puffing behaviour also revealed some disparities; RYO smokers had a tendency to take more puffs per cigarette and also took significantly longer puffs compared with FM cigarette smokers leading to overall greater inhalation time (number of cigarette puffs x puff duration).

Manufactured cigarette smokers, in contrast, puffed harder on cigarettes as shown by higher average and peak puff flows.

Among RYO cigarette smokers, there were some notable variations dependent on the use of filters; those who used a roach or nothing at all had a significantly higher average ($t(27)=-2.7$, $p=.013$) and peak ($t(27)=-2.9$, $p=.007$) puff flow and reported taking fewer puffs per cigarette ($t(26.636)=4.1$, $p<.001$).

In order to evaluate the validity of puffing behaviour among RYO and FM cigarette smokers, all self-reported and machine-determined puffing measures were included in a stepwise linear regression to predict exposure (see Table 4). As self-reported puffing at the second visit and machine-determined puffing since the first visit were used in the analysis, visit 2 cotinine levels were predicted to ensure correspondence between predictors (puffing) and outcome (exposure). When looking at the total sample and controlling for BMI, age, sex, nicotine dependence and deprivation, machine measures predicted cotinine levels better than self-report measures.

Table 4: Prediction of cotinine from puffing measures in FM and RYO cigarette smokers[#]

	Total sample	FM[‡]	RYO[¶]
Cotinine predictors	N=131	N=110	N=20
Self-reported puffing	R^2=.046	R^2=.04	R^2=.064
	p=.077	n.s.	n.s.
CreSS puffing parameters	R^2=.106[$]	R^2=.125[$]	R^2=.162
	p=.005	p=.005	n.s.

[#] Controlling for age, sex, dependence, body-mass-index and deprivation; [‡]Also controlling for ISO nicotine yield; [¶]Also controlling for tobacco weight; [$] One case missing

The comparison of factory-made with roll-your-own cigarettes smokers revealed only a few discrepancies. Additional predictors for FM (ISO nicotine yield) and RYO (tobacco weight) cigarette smokers were included to account for their possible influence on

exposure biomarkers. Cotinine levels were best predicted by a combination of CReSS measures in both groups. Machine and self-report measures explained a somewhat larger amount of the variance in cotinine levels among RYO than FM cigarette smokers. However, there was a reasonable agreement in the variance of cotinine levels explained by puffing parameters among FM and RYO cigarette smokers, indicative of comparable validity of these measures among the different groups. Nicotine dependence (as measured by HSI) was the strongest individual predictor of cotinine levels in both FM and RYO smokers (β=.48, $p<.001$ β=.58, $p=.005$, respectively).

Discussion

Now more than ever it is important to gain a better understanding of the smoking behaviour and characteristics of RYO cigarette smokers. This is the first study to investigate the puffing behaviour in this group of smokers and one of only very few studies looking at the use of RYO tobacco in any country. There were more male than female RYO smokers as has been found in national surveys in the UK [11] and elsewhere.[13] The RYO cigarettes that were produced by our sample had very similar physical characteristics to those of earlier studies [24;34] and the great consistency (in terms of tobacco weight and diameter) with which cigarettes were rolled implies that RYO smokers tend to make cigarettes to specifications that have become habitual and provide a desired amount of nicotine. This observation is in agreement with the positive correlation that was found between participants' cotinine levels and average tobacco weight per cigarette.

Machine-determined puffing was found to be equally stable over time for both RYO and FM cigarette smokers. Most smokers agreed that the device was easy to use; however, it appeared that RYO cigarette smokers had more problems than FM cigarette smokers handling the machine as shown by a greater reduction in cigarette consumption and greater self-reported adjustments in puffing. The finding that RYO cigarette smokers accumulated fewer valid cigarettes with the CReSS machine suggests that the device might be less practicable for this group of smokers. While there was a greater increase in cotinine levels among FM than RYO cigarettes smokers, this may have been mediated by a comparatively small reduction in smoking intensity and cigarette consumption among FM cigarette smokers when using the topography device. In addition, since RYO smokers typically consume cigarettes that are more varied in terms of their packing density, use of filter and paper, this may also have contributed to the

observed differential. Altogether, however, there was an increase in the intake per cigarette among both FM and RYO cigarette smokers while using the device.

Smokers were broadly similar in terms of self-reported puffing while using the device. At baseline, however, FM cigarette smokers reported inhaling more strongly than RYO smokers and this is confirmed by machine-determined puffing. FM cigarette smokers achieved a greater puff flow than smokers of hand-rolled cigarettes, especially those using filters, which may be indicative of the greater ease with which highly-ventilated, less densely packed, manufactured cigarettes can be smoked. It appears that RYO smokers may compensate for this by taking more and longer puffs per cigarette leading to a greater total inhalation time per cigarette. The suggested compensatory puffing is presumably motivated by a drive to obtain a stable amount of nicotine per cigarette, which is in agreement with the similarity in the intake per cigarette among RYO and FM cigarette smokers that was observed in this study.

Machine puffing measures related in a comparable manner to cotinine levels among FM and RYO smokers; although they were only predictive of cotinine levels among FM cigarette smokers, this is probably due to the smaller number of RYO cigarette smokers in this study. While self-reported puffing was not a significant predictor of cotinine among RYO and FM cigarette smokers, in the total sample it was predictive of cotinine levels only to some extent. This is in agreement with previous research showing utility for some and not other measures of self-reported puffing for estimating exposure.[35;36] The fact that in comparison with CReSS measures, self-report among RYO smokers explained less of the respective variance in cotinine levels implies that more than self-report is needed when trying to understand exposure in hand-rolled cigarette smokers.

This study has a number of limitations. The sample was restricted in size and thus not powered to detect smaller effects. This may explain why RYO cigarette smokers - despite having higher dependence and cotinine levels - were not significantly different from FM cigarette smokers on these measures as has been previously reported [9;37]. Moreover, participants were not randomly selected, which could have introduced uncontrolled confounders. Indeed, RYO smokers in our study were by comparison younger and less deprived than would be expected. However, as the main purpose of this study was to describe the feasibility of measuring puffing behaviour, it is unlikely that these differences would have unduly changed results.

Our findings suggest that the CReSS machine is feasible for use among RYO smokers yielding results with comparable stability over time to that of FM cigarette smokers. However, because of differences in the handling of the device, it may be less reliable for RYO smokers leading to greater data loss. Although the CReSS machine altered smoking behaviour to some extent, it did not seem to alter exposure among hand-rolled cigarette smokers. It did, by contast, increase exposure among smokers of factory made cigarettes; an aspect that requires more investigation. In agreement with previous research,[28] machine-determined puffing was found to predict exposure among FM cigarette smokers and a comparable level of explained variance of cotinine levels for hand-rolled cigarette smokers implies equal validity of machine-determined puffing among RYO cigarette smokers.

In conclusion, puffing parameters could be assessed with adequate reliability using the CReSS machine in most RYO smokers. The device revealed differences in how RYO and FM cigarettes were smoked. Smokers of manufactured cigarettes tended to inhale with greater speed, which was off-set by a greater inhalation time among RYO smokers.

Further research is now needed to evaluate the replicability of findings in a larger, representative sample.

What is already known on this topic

Puffing behaviour is an important determinant of exposure in cigarette smokers.

However, puffing behaviour has been assessed only in smokers of factory-made cigarettes so far.

There are currently no studies on the measurement of puffing behaviour, its reliability or validity in Roll-Your-Own cigarette smokers.

What this study adds

Puffing measures can be assessed with adequate reliability in most Roll-Your-Own cigarette smokers using a smoking topography device.

Puffing behaviour was comparably related to exposure in Roll-Your-Own and factory-made cigarette smokers.

Early indications suggest Roll-Your-Own cigarette smokers puff less hard but longer on each cigarette than smokers of factory-made cigarettes.

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Contributions of authors
LS, RW and AMc participated in the conception, analysis and interpretation of the above paper. LS and AMc carried out the study. LS wrote the manuscript and RW and AMc were involved in revisions of the original manuscript.

Conflict of Interest
RW undertakes research and consultancy for developers and manufacturers of smoking cessation treatments such as nicotine replacement products. LS has received an honorarium for a talk and travel expenses from a pharmaceutical company making smoking cessation products.

Ethics approval
This study was approved by the University College London Ethics Committee.

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