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Smoking intensity before and after introduction of the public place smoking ban in Scotland

Madeleine Ashley, Pam Saunders, Gavin Mullard, Krishna Prasad, Derek Mariner *, Justine Williamson, Audrey Richter

Group Research and Development, British American Tobacco (Investments) Ltd., Regents Park Road, Southampton SO15 8TL, UK

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ABSTRACT

A study was performed to determine whether cigarettes were smoked more intensely outside of public venues in Scotland, compared to indoors, after introduction of the public place smoking (PPS) ban. It was conducted in three waves: before the ban, immediately after and 6 months after introduction. The study included 322 regular smokers of four cigarette brand variants. Filter analysis measurements were used to estimate the human-smoked yields of tar and nicotine from cigarettes smoked predominantly inside (before the ban) or outside (after the ban) public venues. Self-reported cigarette consumption data were also collected. Numbers of cigarettes smoked indoors in public places fell dramatically after the ban. There was a corresponding rise in smoking incidence in outdoor public locations. The ban did not significantly affect the total number of cigarettes smoked by the subjects over the weekends investigated. Human-smoked yields of tar and nicotine decreased slightly after the introduction of the ban and some reductions were significant. Therefore, smoking outdoors at public venues, following the PPS ban, did not increase smoking intensity. Any changes in smoking behaviour that may have occurred had little effect on mainstream smoke exposure or cigarette consumption for those that continued to smoke.

1. Introduction

A public place smoking (PPS[1]) ban was introduced in Scotland in March 2006 as a means to protect non-smokers from exposure to environmental tobacco smoke (ETS). ETS is formed from greatly diluted sidestream smoke (generated from the burning coal of the cigarette between puffs) and exhaled mainstream smoke (Baker and Proctor, 1990). Smoking bans may have secondary consequences with a positive or negative impact on exposure and health. For example, it has been reported that people who smoke outside of their workplace smoke their cigarettes 'harder' than those smoked outside of social settings where smokers are less likely to be constrained by time or influenced by preceding smoke deprivation (Chapman et al., 1997). This observational study recorded a higher mean number of puffs per cigarette and a shorter smoking duration for workplace smokers compared to smokers in social locations. These data lead Chapman et al. (1997) to suggest that such workplace smoking bans may be detrimental to the smoker, unless there is an associated reduction in daily cigarette consumption, and so to question whether employees should be allowed breaks to smoke outside.

While observational studies can provide information on many aspects of smoking behaviour, the effects of smoking parameters, such as puff frequency, on smoke exposure levels can only be inferred. An alternative approach would be to use cigarette filter analysis which is a quantitative means of estimating a smoker's exposure to mainstream smoke constituents. It is based on the established principle that the smoke constituents remaining in the filter of a standard cigarette after use are directly proportional to the amounts of those constituents that passed through the filter (Shepperd et al., 2006). Filter analysis provides an estimate of the maximum amount of smoke inhaled by a smoker on a per cigarette basis (human-smoked (HS) yield). In many cases this may be an over estimate of actual smoke inhalation per cigarette due to mouth-spill (the amount of smoke drawn into the mouth but released before the remainder is inhaled), a parameter which is highly variable and dependent on an individual's smoking habit. Total daily exposure can be estimated by multiplying exposure per cigarette by cigarettes per day. Total exposure can potentially be more accurately assessed using measurements of biomarkers of exposure, such as nicotine plus major metabolites or 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNAL) in urine samples

* Corresponding author. Fax: +44 (0) 2380 588143.
E-mail addresses: madeleine_ashley@bat.com (M. Ashley), pam_saunders@bat.com (P. Saunders), gavin_mullard@bat.com (G. Mullard), krishna_prasad@bat.com (K. Prasad), derek_mariner@bat.com (D. Mariner), justine_williamson@bat.com (J. Williamson), audrey_richter@bat.com (A. Richter).

[1] *Abbreviations used:* PPS, public place smoking; ISO, International Organization for Standardization; NFDPM, nicotine-free dry particulate matter; MRA, market research agency.

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(Hatsukami et al., 2006). However, filter analysis has the advantage of not requiring biological sample collection. Filters can be collected by smokers during their usual everyday activities, i.e. from cigarettes smoked under normal conditions of use. Moreover, filter analysis can be used to sample subsets of daily cigarettes to compare exposure when, e.g., smoking under different external conditions or in different locations.

Methodologies for filter analysis have recently been reviewed (Pauly et al., 2009), and include digital imaging of smoke particulate matter (O'Connor et al., 2007), measurement of the solanesol content, as a marker for total smoke particulates (Watson et al., 2004; Polzin et al., 2009) and analysis of tar (Nicotine-Free Dry Particulate Matter, NFDPM) and nicotine in smoked filters (Shepperd et al., 2006; St.Charles et al., 2009). The latter technique has been shown to correlate well with the most robust measure of cigarette smoke exposure, namely the determination of nicotine and five major metabolites in 24 h urine samples (St.Charles et al., 2006; Shepperd et al., 2009; Morin et al., this issue).

We took the opportunity presented by the Scottish smoking ban to test the hypothesis that cigarettes would be smoked more intensely when smokers were required to change from indoor to outdoor locations resulting in smokers obtaining a higher yield of tar and nicotine from each cigarette smoked outdoors. We did so by performing a filter analysis study in three consecutive waves, the first shortly before the ban was introduced and the second and third, one and six months after it came into force. Regular smokers of one of four selected cigarette brand variants collected the filters from cigarettes that they had smoked at public venues. In addition we collected self-reported data on numbers of cigarettes smoked at each wave of the study to determine whether changes in HS yields of tar and nicotine per cigarette might be amplified or reduced by changes in overall cigarette consumption.

2. Materials and methods

2.1. Cigarettes

Four cigarette products, equating to one brand variant from each of four different cigarette brands, were included in the study (Table 1). They consisted of the top two King Size brand variants with the largest market share in Scotland in each of the 5–6 mg and 10 mg (International Organization for Standardization (ISO) tar yield sectors. In the EU, the maximum machine-smoked tar yield for cigarettes is 10 mg (European Parliament, 2001). Twenty thousand cigarettes per product with the same batch/pack code were obtained and stored frozen at −20 °C. This was sufficient to provide for all three consecutive waves and additional laboratory analyses. The use of a single batch of each product served to minimise effects of product variability on the analytical data. Tar and nicotine mainstream smoke yield measurements for the specific batches of purchased cigarettes were determined in the laboratories of British American Tobacco (BAT), Group R&D, Southampton using ISO methods (ISO 10362-1:1999; ISO 3308:2000a; ISO 4387:2000b; ISO 10315:2000c).

Table 1
Cigarettes, tar and nicotine yields and number of smokers in study.

Cigarette	Yield[a] (mg/cig)		Number of smokers
	Tar	Nicotine	
A	10	0.9	79
B	10	0.8	85
C	6	0.5	87
D	5	0.5	71

[a] Measured using ISO 10315:2000 (International Organization for Standardization, 2000c), 10362:1999 (International Organization for Standardization, 1999) and 4387:2000 (International Organization for Standardization, 2000a), and printed on cigarette packs.

2.2. Subject recruitment

Subjects were recruited in the field by a Market Research Agency (MRA) in the following towns and cities in Scotland: Glasgow, Paisley, Dundee, Falkirk, Grangemouth, Kilmarnock, Ayr, East Kilbride and Hamilton. The aim was to recruit groups of subjects that matched the smoker demographics (age and gender) of each product in Scotland. At least 50 smokers of each product were required to complete all three waves; therefore a minimum of 70 were recruited to allow for attrition. All subjects fulfilled the following inclusion criteria: they were aged between 21 and 64 years, regular smokers ($\geqslant$8 cigarettes per day or >20 per weekend) of one of the cigarettes included in this study, willing to participate in all three filter studies, had been smoking the product for at least 6 months, typically went to public houses, bars, clubs or restaurants at least twice a week, between Thursday and Sunday and agreed to take a filter collector with them during the survey period. All subjects were reminded of the risks of smoking before agreeing to participate and those planning to quit smoking were excluded. A stipend of £15, £35 and £50 was paid to each subject on completion of waves 1, 2 and 3 of the study, respectively.

2.3. Protocol

The filter study was conducted in 2006 as follows; wave 1: February 2006 before the ban came into force on 26th March 2006; wave 2: April 2006 just after the introduction of the ban; wave 3: October 2006, six months later. The MRA performed the fieldwork for each wave. Interviewers visited the subjects at home on a Thursday or Friday. Each subject was briefed on the survey protocol before giving their written informed consent to participate in the study. The subjects were given three packs of cigarettes, to ensure brand and batch consistency across waves, and asked to smoke them as they would normally over the following three days (Thursday to Saturday or Friday to Sunday).

The subjects were asked to collect the filters from any of the study cigarettes that were smoked inside or outside a range of public venues, specifically: public houses, bars, restaurants, clubs, cafes, sports venues, hotels, betting shops and airports. For this, they were given a purpose-designed filter collector to cut, store and protect the filter tips after smoking (Fig. 1). Each subject was given instruction on filter collector operation and storage and asked to demonstrate correct use. Each collector had an anti-tamper seal and a unique barcode denoting wave, product, pack yield and subject number.

To obtain a representative sample, each subject was instructed to collect a minimum of 20 filter tips. The subjects were also given a tally sheet to record how many cigarettes they had smoked over the 72 h period in the locations specified for filter collection.

The day after the study period an interviewer visited each subject at their home to collect the filters. The interviewer checked to confirm that the anti-tamper seals on the storage box had not been broken or removed, which would have resulted in the sample being omitted from the study. The subjects completed an Exit Questionnaire which included self-reported total cigarette consumption over the previous 72 h. In addition, the numbers of cigarettes recorded on the tally sheets were used by the interviewer to complete questions in the Exit Questionnaire relating to consumption in the study locations, and the subjects were also asked how many cigarettes they had smoked inside and outside of the home or other, unspecified outdoor locations during the same period.

All the filter collectors were logged onto a sample tracking document by subject number, product and wave and then stored in a

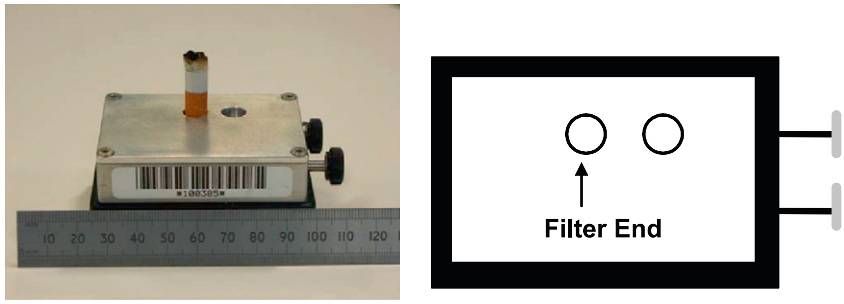

Fig. 1. Photograph and plan view diagram of the filter cutter/collector. The mouth ends of smoked cigarettes are inserted into the collector hole labelled 'Filter End'. The rear handle on the right of the photograph is then pushed in to cut a 10 mm section from the filter and the front handle is pulled out to transfer the cut filter into the integral storage box.

cool/dry environment for up to 1 week. The tips were checked and any that were incorrectly cut, damaged or heavily stained with lipstick were rejected. Individual collections of tips were also rejected in the event of poor subject compliance, e.g., insufficient filter tips (<12) or when tobacco rod or ash were present in the filter collector. The filters were put into labelled aluminium tins and frozen at −34 °C to prevent gradual evaporative loss of smoke constituents. The filters were kept frozen until all three waves of the study had been completed.

2.4. Filter analysis

All filter analysis was carried out in the BAT Regional Product Centre, Bayreuth, Germany. Filter tips were thawed shortly before extraction and analysis. For all subjects, three replicate extracts were prepared, each containing five tips selected at random. In <5% of cases four tips were used because the subject did not collect 15 tips of suitable quality. Each tip was measured using a digital calliper, the length (±0.1 mm) recorded and the mean length for each batch of five determined.

Each set of filter tips was placed in a glass flask with 20 mL of methanol containing 0.05 mg/mL *n*-heptadecane as an internal standard. This was shaken on a flat bed orbital shaker at medium speed (~160 rpm) for a minimum of 30 min. The tar content of the filters was quantified by total UV absorbance (310 nm) measurement within 24 h of preparation. The nicotine content of the tip extract was determined by gas chromatography/flame ionization detection (Agilent 6890) using a 23 m × 0.53 mm DB-Wax (1.0 μm film thickness) fused silica gas chromatography column (limit of quantitation: 0.02 mg/tip), with reference to a set of nicotine standards. The tar and nicotine contents of the extracts were corrected to tar or nicotine per 10.0 mm tip length taking into account the number of tips used for each replicate extract and their mean measured length.

2.5. Human-smoked yield estimation

Each cigarette product was calibrated by machine smoking over a wide range of potential human smoking behaviour parameters (e.g., puff volumes, durations and flows). For each smoking regime, five cigarettes were smoked onto a pre-weighed Cambridge filter pad to trap >99% of the total particulate matter present in the mainstream smoke. A 10 mm section was then accurately cut from the mouth-end of each of the five filters using a filter collector. The cut filter tips were analysed for tar and nicotine content as described above.

The Cambridge filter pad was reweighed, to obtain total particulate matter yield, and then extracted in 20 mL of propan-2-ol containing *n*-heptadecane (0.25 mg/mL) and ethanol (4.0 mg/mL) as internal standards. The extract was analysed for nicotine and water content by standard ISO gas chromatography/flame ionization detection and thermal conductivity detection methodology, respectively (International Organization for Standardization, 2000c, 1999). Tar yields (NFDPM, mg/cigarette) were calculated by subtraction of the nicotine and water yields from the total particulate matter yield. This complete procedure was repeated on a separate occasion, to provide duplicate data points for each calibration regime for each product in the study. The tip tar or nicotine data was plotted against the Cambridge filter pad tar or nicotine to generate a calibration plot for each cigarette product.

Estimated HS nicotine yield (mg/cigarette) was obtained for each extract replicate by using the measured human tip nicotine values and the linear regression equation from the nicotine calibration plot of the same cigarette product. Similarly, estimated HS tar yield data were obtained using UV absorbance per tip data and the linear regression equation from the tar calibration plot. It is important to note that the cigarettes used for calibration were of the same batch/pack code as those collected from the subjects in all three waves of the study. By this means the effects of product variability were minimised and the robustness of the HS yield estimates increased.

2.6. Data analysis

To balance the data before comparison between waves, subjects who had not completed all three waves of the study for both filter collection and completion of the questionnaires were rejected from the study. As a result, 21 out of a total of 343 subjects recruited (6.1%), were omitted from the final data analysis. Paired *t*-tests were used to compare the HS tar and nicotine yields obtained for each product for wave 1 and wave 2, wave 1 and wave 3 and wave 2 and wave 3. Analysis of Variance (ANOVA) General Linear Model was used to compare the self-reported total cigarette consumption across waves.

3. Results

3.1. Subject data

The distribution of subjects that completed all three waves, and the recruitment targets, based on consumer demographics, are shown in Table 2. The subjects generally matched the target distributions, age being within 13% and gender distribution within 7% for three products. Consumers of product C were the least well matched to the target demographics. The majority of subjects ($\geqslant$92% for each product) had been smoking their product for at least 2 years.

3.2. Cigarette consumption and smoking location

Consumption data relied on self-reporting of cigarette use recorded on the study tally sheet and exit questionnaire. The number

Table 2
Subject distribution: age and sex.

Product	% Age (years)		Gender % M/F (target)
	<30 (target)	⩾30 (target)	
A	33 (46)	67 (54)	53/47 (46/54)
B[a]	24 (34)	76 (66)	35/65 (41/59)
C	22 (49)	78 (51)	44/56 (58/42)
D	24 (15)	76 (85)	35/65 (41/59)

[a] No data for one subject.

of cigarettes smoked in the different locations, for all subjects combined, plus the total number smoked over the 72 h study period for the three waves are shown in Table 3. The number of cigarettes smoked in these locations was 66%, 57% and 46% of the total reported weekend (72 h) cigarette consumption for waves 1, 2 and 3, respectively. While this may reflect some inaccuracies in the tally sheet figures it also suggests that many cigarettes were smoked in places other than those included in the study. A statistical comparison of consumption data (number of cigarettes smoked over 72 h) using ANOVA indicated that there was no significant difference across waves ($p = 0.078$).

Indoor smoking at recreational venues fell dramatically from 94% of those recorded (calculated from the figures in Table 3 using the sum of all locations excluding home and other) before the ban to 3% and 0% after the ban while outdoor smoking incidence increased.

3.3. Estimated human-smoked tar and nicotine yields

Calibration plots for each product were derived by smoking the cigarettes over a wide range of potential human smoking behaviour parameters (e.g., puff volumes, durations and flows). The correlations between tar and nicotine in cigarette filter tips and in mainstream smoke were derived by linear regression analysis (Table 4). The regression equations were then used to estimate HS tar and nicotine yields per cigarette from filter tip measurements.

In wave 1, 94% of cigarettes smoked in the selected venues were smoked indoors; therefore, the HS yield data from a subset of these cigarettes are generally representative of indoor smoking intensity prior to the PPS ban. By comparison, in waves 2 and 3, 97% and 100% of cigarettes smoked in the same venues were smoked outdoors so in these cases the HS yield data are representative of outdoor smoking intensity following the ban. The HS tar data for each wave and statistical analysis are shown in Fig. 2A and Table 5. At the 95% confidence level, there was a significant decline in wave 2 compared with wave 1 for three of the products (A–C), and a small but non-significant reduction for the fourth product (D).

Table 4
Linear regression data for the calibration plots.

Product	Linear regression data					
	Tar estimation			Nicotine estimation		
	Slope	Intercept	R^2	Slope	Intercept	R^2
A	5.333	−0.283	0.971	5.590	0.031	0.985
B	5.615	−0.865	0.972	5.212	0.008	0.989
C	5.377	−1.102	0.960	5.099	−0.020	0.987
D	4.479	−1.207	0.955	4.533	−0.074	0.982

There was a further decline in HS tar yields in wave 3 compared with wave 2 for all products and this was significant for two products (B and D). There was a significant reduction for all products in wave 3 compared to wave 1.

The HS nicotine yield data for each wave and statistical analysis are shown in Table 6 and Fig. 2B. At the 95% confidence level, there was a significant decline in wave 2 compared with wave 1 for two of the products (A and B), and a small but non-significant decline for the other two products. No significant differences in HS nicotine were found in any product in wave 3 compared with wave 2. There was a significant reduction for three products (A–C) in wave 3 compared to wave 1.

4. Discussion

This is the first study to report the use of filter analysis as a means to quantify the effects of a PPS ban on smoking intensity. The results indicate that, for regular smokers, changing from indoor to outdoor smoking at public locations, such as bars, restaurants, sports venues and betting shops, resulted in either no change or a slight decrease in HS tar and nicotine yields per cigarette. The trend was more apparent seven months, compared to 1 month, after the ban. While this study did not investigate reasons for any reductions in HS yields, waves 2 and 3 occurred during spring and autumn months. Therefore, it is possible that cold weather may have been a contributing factor, i.e. people may have spent less time smoking and consumed less of each cigarette when smoking outside compared to inside the study locations.

Chapman et al. (1997) have reported that people who smoke outside their workplace as a result of indoor smoking bans appear to smoke more intensely; they were observed to smoke for shorter periods of time and take more puffs per cigarette. In that study, Chapman et al. observed the smoking habits of people outside of workplaces versus outside of social locations, after a PPS ban was already in place (Chapman et al., 1997). By comparison, we have measured smoke exposure on a mean HS yield per cigarette basis for the same individuals before and after a move from indoors to

Table 3
Cigarette consumption for the study period, combined data for all subjects.

Location	Wave 1			Wave 2			Wave 3		
	Inside	Outside	Total	Inside	Outside	Total	Inside	Outside	Total
Pub/bar	5652	252	5904	200	4337	4537	0	4470	4470
Club	1631	30	1661	12	956	968	0	1004	1004
Restaurant	368	114	482	0	322	322	0	553	553
Sport Venue	134	56	190	0	171	171	0	237	237
Café	503	60	563	0	538	538	0	470	470
Hotel	28	3	31	0	78	78	0	79	79
Betting Shop	249	5	254	3	284	287	0	245	245
Airport	2	0	2	0	0	0	0	22	22
Home	2639	369	3008	2430	552	2982	2399	308	2707
Other	1025	652	1677	866	1181	2047	50	1057	1107
Sum, all locations	12,231	1541	13,772	3511	8419	11,930	2449	8445	10,894
All cigarettes in 72 h			20,794			20,839			23,466

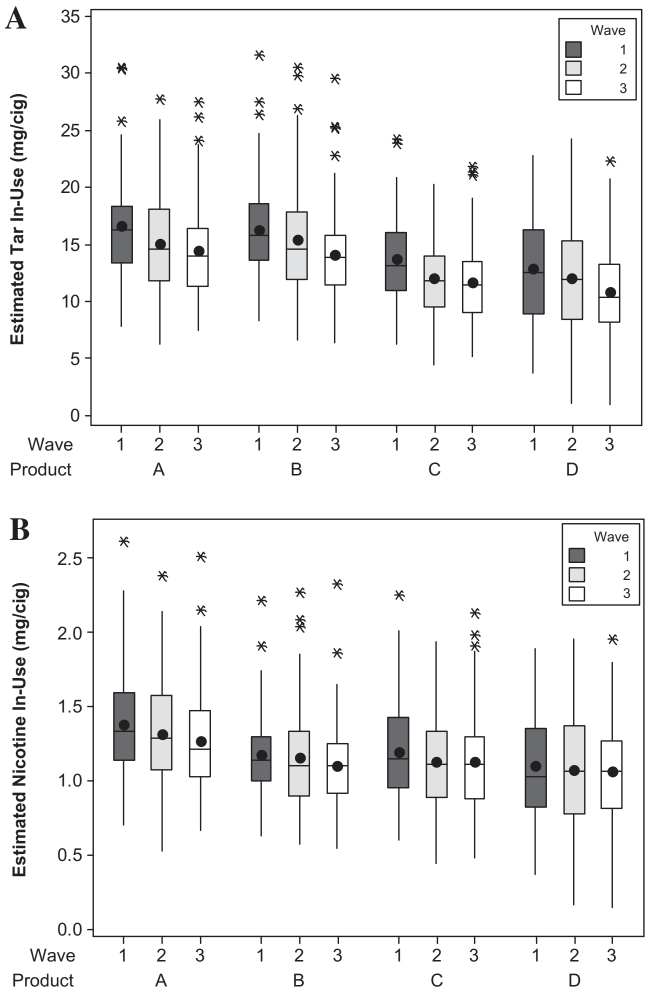

Fig. 2. Box plots for HS yield estimates of tar (A) and nicotine (B). Top, middle and bottom bars represent the 25th, 50th and 75th percentiles; black dots indicate the mean values; whiskers extend to the maximum and minimum result within 1.5 times box height; stars are outliers.

Table 5
Human smoked (HS) tar data, statistical comparison across waves.

Product	ISO tar* (mg/cig)	Wave	HS tar (mg/cig)		*p* Value paired *t*-test		
			Mean	SD	Waves 1 and 2	Waves 1 and 3	Waves 2 and 3
A	11.1	1	16.6	4.4	<0.001	<0.001	0.090
		2	15.1	4.6			
		3	14.5	4.1			
B	10.8	1	16.2	4.4	0.029	<0.001	<0.001
		2	15.4	5.0			
		3	14.1	4.3			
C	6.2	1	13.7	3.8	<0.001	<0.001	0.138
		2	12.1	3.3			
		3	11.6	3.6			
D	5.3	1	12.9	4.5	0.059	<0.001	0.001
		2	12.0	5.0			
		3	10.8	4.2			

* These tar values were determined according to ISO 4387:2000 (International Organization for Standardization, 2000b) from a laboratory sample of cigarettes from the batch of 20,000 cigarettes of each type purchased. ISO 8243:2006 (International Organization for Standardization, 2006) provides a confidence interval for tar of ±20% between a 'one point in time sample', as taken for this study, and the on-pack declared values (Table 1) which are based on a composite sample, taken over a period of time.

Table 6
Human smoked (HS) nicotine data, statistical comparison across waves.

Product	ISO nicotine (mg/cig)	Wave	HS nicotine (mg/cig)		*p* Value paired *t*-test		
			Mean	SD	Waves 1 and 2	Waves 1 and 3	Waves 2 and 3
A	0.98	1	1.38	0.34	0.022	<0.001	0.121
		2	1.32	0.38			
		3	1.27	0.34			
B	0.85	1	1.17	0.28	0.429	0.002	0.051
		2	1.15	0.34			
		3	1.10	0.30			
C	0.54	1	1.19	0.31	0.010	0.041	0.991
		2	1.13	0.30			
		3	1.13	0.35			
D	0.56	1	1.10	0.36	0.522	0.270	0.596
		2	1.08	0.41			
		3	1.06	0.35			

outdoors at selected social locations as a result of a ban being imposed. In this study, cigarettes smoked outdoors appeared to be smoked equally or less intensely than those smoked indoors. However, in this case HS yield was determined for a subset (approximately 50%) of daily cigarettes which did not include those smoked during the individuals' working hours. Whether the finding of no increase in smoking intensity can transferred to a workplace situation, where there may be pressure on the smoker to return indoors, is uncertain.

This study demonstrated good compliance with the public place smoking ban, as no cigarettes were reportedly smoked indoors at the study locations seven months after the ban. There was a corresponding increase in outdoor smoking, but total cigarette consumption was unchanged over the study period. Self-reported consumption is an imprecise measure that can be affected by bias and under-reporting (Warner, 1978), in addition, recent data suggest that self-reported cigarette consumption on recruitment to a study tends to be higher than cigarette consumption 'in the last 24 h' (Mariner et al., this issue). However, in this study design the same subjects were used in all three waves. Therefore, if one reasonably assumes that individuals consistently under or over report smoking habits, then the across wave comparisons in this case are a valid tool for assessing changes in consumption. Also, the pattern is consistent with the combined monthly sales volume figures for the selected cigarette products in Scotland compiled by ACNielsen Retail Audit which reported total sales by retailers to consumers for cigarettes A–D in Scotland in 2006 as follows: millions of cigarettes for February: 152.21; April: 153.76; October: 162.00.

In summary, smoking outdoors at public venues, as a result of the PPS ban in Scotland, did not increase smoking intensity. Any changes in smoking behaviour that may have occurred had little effect on estimated mainstream smoke exposure or cigarette consumption for those that continued to smoke. We suggest that filter analysis can provide a valuable tool for measuring changes in smoke exposure as a consequence of, e.g., environmental factors that affect smoking behaviour or differences in cigarette design.

5. Conflict of interest statement

The authors declare that there are no conflicts of interest.

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