

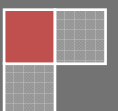
2010

# Smoking in cars

## A project report from the Scottish Centre for Indoor Air

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This report has been written by scientists at the Scottish Centre for Indoor Air, a research collaboration between the University of Aberdeen and the Institute of Occupational Medicine. Further details of our work can be found at the web address: [www.indoorair.org.uk](http://www.indoorair.org.uk)



## EXECUTIVE SUMMARY

Children's exposure to second-hand tobacco smoke (SHS) has been reduced in many settings in recent years. Smoke-free legislation in enclosed public spaces means that children are no longer exposed to SHS in restaurants, cafes and shopping malls with exposure generally only arising in outdoor spaces or within home or car settings. There is continuing debate about the need for restrictions on smoking behaviour within cars where children are present given the confined volume, restricted ability to move away from the source and the resulting high SHS exposure that may be experienced.

This study examined the level of SHS measured as PM<sub>2.5</sub> concentrations (mass of particles that measure less than 2.5 µm in diameter) during 48 car journeys carried out by 8 study participants during October 2010. Data on PM<sub>2.5</sub> levels were logged in 43 journeys (26 smoking and 17 non-smoking).

The arithmetic mean PM<sub>2.5</sub> concentration during journeys where smoking took place was 95 µg/m<sup>3</sup>, approximately 14 times higher than the mean figure of 6.8 µg/m<sup>3</sup> measured during non-smoking journeys. Peak levels across the 26 smoking journeys averaged 410 µg/m<sup>3</sup> compared to 12 µg/m<sup>3</sup> during non-smoking journeys. The highest peak PM<sub>2.5</sub> concentration of 886 µg/m<sup>3</sup> occurred during a smoking journey.

At no point in any of the non-smoking journeys did PM<sub>2.5</sub> concentrations exceed the 35 µg/m<sup>3</sup> US EPA outdoor air guidance concentration for unhealthy air. All smoking journeys exceeded this threshold at some stage of the journey with the percentage of the time when concentrations rose above 35 µg/m<sup>3</sup> ranging from 16 to 100% (mean 49%).

As expected, PM<sub>2.5</sub> concentrations were strongly linked to the rate of smoking expressed as number of cigarettes per minute. Ventilation and opening of car windows produced lower measured levels of SHS compared to poorly ventilated cars but the effect was generally only of the order of 26% (123 µg/m<sup>3</sup> in cars with little ventilation to 91 µg/m<sup>3</sup> in cars with open windows).

The results presented here are broadly similar to previously published studies of SHS intensities in cars where smoking takes place. The mean PM<sub>2.5</sub> concentration measured in smoking cars in this study was 95 µg/m<sup>3</sup> which can be compared to the level measured in bars in Scotland (246 µg/m<sup>3</sup>) and England (142 µg/m<sup>3</sup>) prior to the introduction of smoke-free legislation.

PM<sub>2.5</sub> concentrations in cars where smoking takes place are high and greatly exceed levels that are deemed to be unhealthy in outdoor air. Smoking in cars leads to exposure to SHS that is likely to be damaging to health. Measures to restrict the exposure of children to SHS should be considered at both an individual and a societal level.

## INTRODUCTION

Exposure to Second-hand tobacco Smoke (SHS) is associated with a range of child-health issues including sudden infant death, lower respiratory infection, middle ear disease, wheeze, asthma, and meningitis [1]. Children are likely to be at greater risk from SHS exposure due to their faster breathing rates, less developed immune system and their inability to move away from the source in many home and car settings. Smoke-free legislation has led to significant changes in exposure to SHS in work settings and public places including bars [2] and restaurants with no obvious displacement effect to homes [3] at a population level. The recent Royal College of Physician Tobacco Advisory group report 'Passive smoking and children' (March 2010) called on regulation to prohibit smoking in vehicles as part of a wider campaign to both reduce smoking prevalence and non-smokers' exposure to SHS [1]. There is substantial support for restrictions on smoking in cars, particularly cars carrying children [4] with some national and state-level laws already in force in Canada, USA, Australia, Cyprus and South Africa.

The confined environment and proximity of passengers to any smoking activity within a car produces high and sustained exposure levels although the information available on personal exposure concentrations is sporadic and generally based on small studies. Measurement of the airborne mass of fine particulate matter that measure less than 2.5  $\mu\text{m}$  in diameter ( $\text{PM}_{2.5}$ ) is a well established surrogate for SHS concentrations [5]. Previous studies have observed high concentrations in  $\text{PM}_{2.5}$  levels in indoor environments such as bars where smoking takes place [6]. Data from the US [7] and Canada [8] have also reported high levels of  $\text{PM}_{2.5}$  in cars of smokers. One recent report [9] carried out by the Tobacco Control Collaborating Centre (TCCC) in the UK, published details of 21 car journeys and associated measurements of  $\text{PM}_{2.5}$ . This project indicated time weighted average concentrations of  $\text{PM}_{2.5}$  of between 13 and 242  $\mu\text{g}/\text{m}^3$  (mean 88  $\mu\text{g}/\text{m}^3$ ) during car journeys where smoking took place. For comparison the US Environmental Protection Agency has a health-based guidance level for outdoor  $\text{PM}_{2.5}$  concentrations of 35  $\mu\text{g}/\text{m}^3$  averaged over a 24 hour period [10]. Figure 1 shows this health-based guidance levels used.

**Figure 1** US EPA health-based guidance levels for 24h average PM<sub>2.5</sub>

<b>PM<sub>2.5</sub> <math>\mu\text{g}/\text{m}^3</math></b>	<b>AQI</b>	<b>Advice</b>
35	Unhealthy for sensitive groups	Heart/lung disease and elderly/ children advised to reduce prolonged exertion
65	Unhealthy	Heart/lung disease/elderly/children avoid prolonged exertion; everyone reduce prolonged exertion
150	Very unhealthy	Heart/lung disease avoid all physical activity; everyone avoid prolonged exertion
250	Hazardous	Heart/lung disease remain indoors; everyone avoid physical activity

NHS Greater Glasgow & Clyde (NHSGGC) commissioned a study to examine the intensity of SHS in cars with and without smokers to inform a public education and information campaign on the dangers to children of adults smoking within cars. This report describes measurements made as part of this study.

## **AIMS**

The project had the following primary aims:

- To characterise PM<sub>2.5</sub> concentrations during car journeys where smoking takes place;
- To examine determinants of PM<sub>2.5</sub> concentrations in terms of journey time, type, cigarette consumption and use of ventilation systems;
- To compare the PM<sub>2.5</sub> concentrations measured with those from cars where smoking does not take place and with other measurements available from the scientific literature.

## **METHODS**

### **Ethics**

NHSGGC held discussions with their local ethics committee and received confirmation that ethical approval is not required for this observational project. Due to the health effects of SHS we deemed it unethical to have children involved in this study. We used life-sized dolls positioned in car seats to provide a realistic sampling position for the measuring device. Participants were asked to undertake their normal smoking behaviour within their car.

### **Study design**

The research design was broadly similar to that reported in a previous study carried out by the TCCC [9], allowing direct comparison with the previously reported data from that work.

NHSGGC staff recruited a total of 8 volunteers (6 smokers and 2 non-smokers), supplied the recruits with a study information sheet and gained written informed consent. Study recruits were asked to place a child-sized doll within a front-facing car seat in one of the rear car seats of their car during all journeys they made over a 3 day period. PM<sub>2.5</sub> was measured during each car journey using a Sidepak AM510 Personal Aerosol Monitor (TSI Inc, MN, USA)- a device that has been extensively used in the research and measurement of SHS concentrations. A short length of tubing attached the device to the nose/mouth area of the doll. The sampling arrangement is shown in figure 2.

Participants were provided with a detailed instruction sheet and a brief demonstration on how to set the device to logging mode at the start of each of their car journeys and how to switch off the instrument at the end (appendix A). A questionnaire was administered at the beginning of their participation in the study (appendix B) to gather basic demographic details. Participants were also supplied with approximately 10 1-page data collection sheets (appendix C) to gather simple information about each journey they made over the 3 day period. Participants were also asked to carry a Global Positioning System device during car journeys to collect data on location and vehicle movement. These data are not presented here but will be analysed at a later date.

Participants were asked to carry out their normal daily driving and smoking routines and not to alter how they typically behaved for the measurement period. The only request was that the smokers tried to carry out at least 1 journey where smoking did not take place. Participants were also asked to comply with any workplace policy relating to smoking and driving.

Data collection took place between 4th and 14th October 2010 and occurred at various locations within the Glasgow conurbation in the West of Scotland.

**Figure 2** Photograph of the Sidepak, car seat and child-sized doll as used in participants' cars.



The Sidepak AM510 devices had a PM<sub>2.5</sub> impactor attached and had been internally calibrated against recently serviced and calibrated devices. A calibration factor of 0.295 to correct for the density of SHS-based aerosol was applied as described elsewhere [5].

PM<sub>2.5</sub> measurements were logged at 1-minute intervals over each car journey, with each 1 minute data point being the average of 60 1-second sample measurements. On completion of the 3 day sampling period the device was retrieved and the data downloaded using Trackpro 4.1.0.1 software. Data were then transferred to the Microsoft Excel package for calculation of average and maximum values.

The Sidepak device was cleaned, the impactor re-greased and the instrument zero-calibrated before being passed to the next study participant.

## Statistical analysis

The average and maximum PM<sub>2.5</sub> concentrations were calculated for each car journey. The percentage of time (over the time period the Sidepak operated during each journey event) when the PM<sub>2.5</sub> concentration exceeded a value of 35 µg/m<sup>3</sup> was calculated for each journey. Data from each participant questionnaire and from each journey collection sheet was then entered in to an Excel worksheet and matched up with the Sidepak-derived PM<sub>2.5</sub> exposure data for each journey.

Descriptive statistics were calculated and plots of the average and maximum PM<sub>2.5</sub> levels by journey characteristics were performed. The levels for smoking and non-smoking journeys are identified on each plot using different symbols.

A t-test was carried out to investigate the difference between the levels during smoking and non-smoking journeys, where a test for equal variances determined whether to pool the variances or estimate them separately. Regression analyses were used to examine whether any of the factors had an effect on the PM<sub>2.5</sub> levels. This was done for the whole sample, as well as for the smoking journeys alone.

## RESULTS

### Study participant characteristics

Eight drivers participated in the project, 6 smokers (5 females and 1 male) and 2 female non-smokers. Three of the smokers declared that they usually smoked between 10-19 cigarettes per day and the other three smokers smoked more than 20 cigarettes per day. All smokers indicated that they smoked several times a day inside the car. The average age of the participants was 50 years, ranging from 41 to 62.

### Vehicle characteristics

Eight different vehicles were used with 7 different car models: Peugeot 307, Nissan X-trail, Ford Fiesta, Vauxhall Astra, Honda CRV, Toyota Yaris and Volkswagen Polo (2). Cars varied in age between 7 years to less than 1 year since first registration. Two of the 8 cars had a mileage less than 25,000 miles, three were between 25,001 and 50,000 miles, two between 50,001 and 76,000 and 1 had a reading in excess of 76,000. No additional information was collected on characteristics of the vehicles used.

### Journey characteristics

The project involved a total of 48 journeys between the 4<sup>th</sup> and 14<sup>th</sup> October 2010. Each participant drove between 3 and 8 journeys with the mean journey number being 6. Smoking occurred during 29 journeys, while no smoking occurred during 19 journeys. The Sidepak device captured PM<sub>2.5</sub> data in 43 of the 48 journeys with 3 smoking journeys and 2 non-smoking journeys not logged. Eleven of the non-smoking journeys were carried out by the non-smoker participants, while a further eight journeys were driven by the smoking participants.

Journey start and stop times were taken directly from the Sidepak where this data was available and from the self-report on the journey data collection sheets in the 5 cases where it was not. The smoking journeys took place between 6am and 10pm. Six journeys were in the early morning (pre 8am), 7 in the morning (between 8am - 12pm), 14 were in the afternoon (12pm-5pm) and 2 in the evening (between 5 -10pm). The average distance per journey was 6 miles, ranging from 1 to 17 miles. The average duration per journey was 27 minutes, ranging from 7 minutes to 1 hour and 10 minutes.

The non-smoking journeys took place between 8 am and 10 pm; seven occurred between 8am and 12pm, 5 between 12-5pm and a further 7 in the evening between 5-10pm. The average duration was 27 minutes, ranging from 8 minutes to 1 hour and 5 minutes and the mean travelled distance was 13.5 miles, ranging from 1 to 37 miles.

Table 1 provides details of the window positioning and ventilation system use for both smoking and non-smoking journeys. Journeys where smoking took place were much more likely to have windows open for the majority of the journey time (86%) compared to non-smoking journeys (5%). Ventilation was

more common in non-smoking journeys than smoking journeys (63% v 41% had systems on for the majority of the journey time)

**Table 1** Descriptive summary of windows positioning and ventilation conditions in smoking and non-smoking journeys.

<b>Vehicle ventilation</b>	<b>Smoking journeys</b>	<b>Non-smoking journeys</b>
<b>WINDOWS</b>		
Closed during entire of journey	1	15
Closed during most of journey	3	3
Open during most of journey	10	0
Open during entire journey	15	1
<b>VENTILATION</b>		
Off during entire of journey	16	6
Off during most of journey	1	1
On during most of journey	4	3
On during entire journey	8	9

Table 2 provides a break-down of the self-assessed driving conditions by smoking and non-smoking journey type. Approximately 86% of smoking journeys were in urban or city centre type areas compared to 63% of non-smoking journeys.

**Table 2** Descriptive summary of surrounding environment conditions.

<b>Journey type</b>	<b>Smoking journeys</b>	<b>Non-smoking journeys</b>
Mostly city centre	8	3
Mostly urban	17	9
Mostly country roads	1	3
Mostly motorway	3	4

Table 3 illustrates that self-assessed traffic conditions were similar for both smoking and non-smoking journey type. Drivers assessed traffic conditions to be 'heavy' in 24% of smoking journeys and 21% of non-smoking journeys.

**Table 3** Descriptive summary of traffic conditions.

<b>Traffic conditions</b>	<b>Smoking journeys</b>	<b>Non-smoking journeys</b>
Light	6	7
Medium	16	8
Heavy	7	4

### **Cigarettes smoked**

The number of cigarettes smoked during the journeys ranged from none to four, with no smoking taking place for 19 of the journeys. Only one cigarette was smoked for the majority of smoking journeys (n=19), with two cigarettes being smoked during 6 journeys, three smoked in 2 journeys and one journey where 4 cigarettes were smoked.

Smoking had occurred in the car in the 24 hours previous to the monitoring period in 35 of the journeys with a further 2 journeys reporting the most recent smoking event being over 4 days previously. Eleven journeys from the two non-smokers were performed in cars that had no history of smoking behaviour.

### **PM<sub>2.5</sub> concentrations**

PM<sub>2.5</sub> data were available for 43 of the 48 journeys. Table 4 shows a summary of the data collected with the average and maximum PM<sub>2.5</sub> concentrations for each journey.

**Table 4** Details of each journey.

JOURNEY ID	PARTICIPANT ID	DATE	START TIME	END TIME	JOURNEY DURATION	DISTANCE in miles	CIGARETTES SMOKED	VENTILATION	WINDOWS	ENVIRONMENT	TRAFFIC	PM <sub>2.5</sub> MEAN	PM <sub>2.5</sub> MAX
NHSG01J01	NHSG01	04/10/2010	12:40:00 *	12:50:00 *	00:10:00 *	3	1	1	4	1	1		
NHSG01J02		04/10/2010	13:25:00 *	13:35:00 *	00:10:00 *	2	1	1	4	1	2		
NHSG01J03		05/10/2010	07:45:00 *	08:00:00 *	00:15:00 *	3	1	1	4	1	2		
NHSG01J04		05/10/2010	11:25:32	11:45:32	00:20:00	3	1	1	3	1	1	93.99	434.98
NHSG01J05		05/10/2010	11:59:47	12:07:47	00:08:00	3	1	1	4	1	1	82.45	289.13
NHSG01J06		05/10/2010	13:42:37	13:51:37	00:09:00	3	1	1	4	1	2	94.98	242.01
NHSG01J07		05/10/2010	16:28:25	17:29:25	01:01:00	8	2	1	4	1	3	27.20	307.52
NHSG01J08		06/10/2010	08:51:41	09:17:41	00:26:00	4	2	1	4	1	3	72.22	376.90
NHSG02J01	NHSG02	04/10/2010	17:59:50	19:09:50	01:10:00	35	0	4	1	3	1	2.32	6.33
NHSG02J02		05/10/2010	08:50:11	09:54:11	01:04:00	37	0	1	1	3	1	3.29	9.49
NHSG02J03		05/10/2010	14:14:21	15:07:21	00:53:00	37	0	3	1	3	2	2.90	8.86
NHSG02J04		05/10/2010	15:30:20	15:48:20	00:18:00	10	0	1	1	1	3	3.96	6.96
NHSG02J05		06/10/2010	08:31:47	09:36:47	01:05:00	35	0	2	1	4	3	6.88	18.67
NHSG03J01	NHSG03	06/10/2010	15:20:35	16:05:35	00:45:00	8	0	1	1	2	2	1.87	2.58
NHSG03J02		06/10/2010	17:08:36	17:36:36	00:28:00	10	2	1	2	3	1	82.56	362.05
NHSG03J03		06/10/2010	20:48:56	21:28:56	00:40:00	11	3	1	3	2	1	100.73	807.36
NHSG03J04		07/10/2010	09:25:36	09:35:36	00:10:00	1	0	1	1	2	1	5.91	13.23
NHSG03J05		07/10/2010	18:05:36	18:12:36	00:07:00	1	1	1	2	2	1	188.40	340.76
NHSG03J06		07/10/2010	21:16:16	21:37:16	00:21:00	2	0	1	2	2	1	2.89	6.13
NHSG03J07		08/10/2010	13:31:03	13:39:03	00:08:00	1	1	1	3	2	3	142.18	420.93
NHSG03J08		08/10/2010	14:07:17	14:14:16	00:06:59	1	1	1	2	2	2	97.57	182.61
NHSG04J01	NHSG04	07/10/2010	10:01:30	10:21:30	00:20:00	4	0	3	1	2	2	3.75	6.79
NHSG04J02		07/10/2010	12:26:46	12:46:46	00:20:00	3	1	4	1	2	2	97.91	403.05
NHSG04J03		08/10/2010	09:45:00 *	09:50:00 *	00:05:00 *	2	0	4	1	2	1		
NHSG04J04		08/10/2010	10:38:00 *	10:45:00 *	00:07:00 *	2	0	4	1	2	2		
NHSG05J01	NHSG05	11/10/2010	12:39:35	12:57:35	00:18:00	5	0	1	1	2	1	7.26	9.04
NHSG05J02		11/10/2010	14:12:49	14:32:49	00:20:00	5	1	1	3	2	2	69.60	491.13
NHSG05J03		11/10/2010	16:59:37	17:15:37	00:16:00	5	1	1	3	2	3	87.33	473.38
NHSG05J04		12/10/2010	08:30:33	08:48:33	00:18:00	5	1	3	3	2	3	60.20	254.92
NHSG05J05		12/10/2010	11:43:39	12:00:39	00:17:00	8	1	3	3	2	2	67.29	298.16
NHSG05J06		12/10/2010	13:51:44	14:09:44	00:18:00	8	1	2	3	2	2	36.39	224.59
NHSG05J07		12/10/2010	16:22:10	16:57:10	00:35:00	5	1	1	3	2	3	81.59	885.45
NHSG05J08		13/10/2010	08:28:05	08:49:05	00:21:00	6	2	3	3	2	3	101.40	349.79
NHSG06J01	NHSG06	12/10/2010	07:44:53	08:27:53	00:43:00	9	3	4	4	2	2	23.31	76.17
NHSG06J02		12/10/2010	16:27:18	17:08:18	00:41:00	9	3	4	4	2	2	71.34	516.83
NHSG06J03		13/10/2010	06:59:20	07:38:20	00:39:00	9	4	3	4	2	2	97.13	656.72
NHSG07J01	NHSG07	13/10/2010	16:02:24	16:19:24	00:17:00	12	0	3	4	4	2	20.06	24.85
NHSG07J02		14/10/2010	06:39:41	07:10:41	00:31:00	17	2	4	4	4	2	78.42	419.17
NHSG07J03		14/10/2010	07:44:08	07:54:08	00:10:00	2	1	4	4	2	2	221.88	803.81
NHSG07J04		14/10/2010	16:04:19	16:20:19	00:16:00	12	1	4	4	4	2	55.26	210.39
NHSG07J05		15/10/2010	06:34:32	07:07:32	00:33:00	17	2	4	4	4	2	44.89	195.55
NHSG07J06		15/10/2010	07:42:12	07:51:12	00:09:00	2	1	4	4	2	2	285.76	642.79
NHSG08J01	NHSG08	13/10/2010	14:45:39	14:59:39	00:14:00	4	0	4	1	1	2	19.69	26.27
NHSG08J02		13/10/2010	16:55:58	17:22:58	00:27:00	11	0	4	1	1	3	13.19	21.52
NHSG08J03		14/10/2010	09:34:28	10:02:28	00:28:00	8	0	4	1	2	1	12.05	15.51
NHSG08J04		14/10/2010	10:23:56	10:39:56	00:16:00	6	0	4	1	2	2	7.75	11.39
NHSG08J05		14/10/2010	17:14:08	18:00:08	00:46:00	14	0	4	2	4	3	0.42	3.80
NHSG08J06		14/10/2010	18:54:31	19:42:31	00:48:00	25	0	4	2	4	2	0.59	5.70

\* Data collected from journey info; SidePak device data not recovered

windows: 1: closed during entire journey; 2: closed during most of journey; 3: open during most of journey; 4: open during most of journey

ventilation: 1: off during entire journey; 2: off during most of journey; 3: on during most of journey; 4: on during entire journey

environmen1: mostly city centre; 2: mostly urban; 3: mostly country roads; 4: mostly motorway

traffic conditions: 1: light; 2: medium; 3: heavy

PM<sub>2.5</sub> is expressed in micrograms per m<sup>3</sup>

Figure 3 shows the PM<sub>2.5</sub> concentrations observed during each journey for each participant, shown separately for smoking and non-smoking journeys. The dashed line indicates the US EPA 'unhealthy' guidance level for outdoor air PM<sub>2.5</sub>.

**Figure 3** Concentration of PM<sub>2.5</sub> found in car journeys by participant.

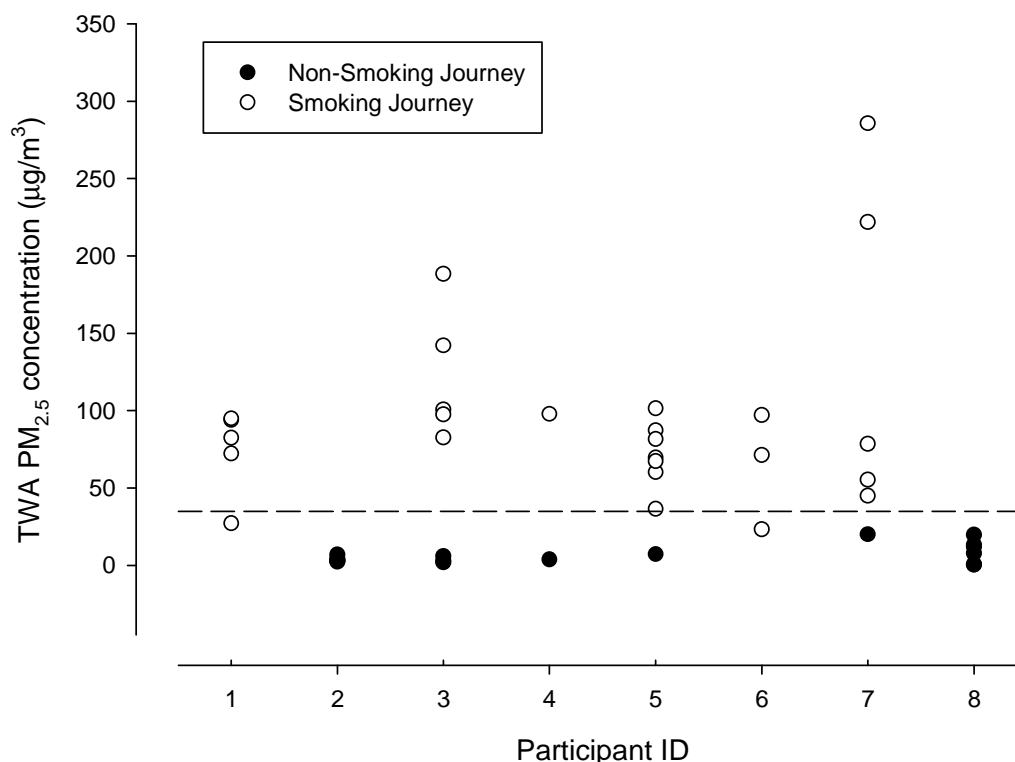


Table 5 shows the descriptive statistics of the mean and maximum PM<sub>2.5</sub> found during smoking and non-smoking journeys.

**Table 5** Descriptive statistics of the mean and maximum PM<sub>2.5</sub> concentrations found during smoking and non-smoking car journeys.

Journeys	n	AM (µg/m <sup>3</sup> )	GM (µg/m <sup>3</sup> )	Range (µg/m <sup>3</sup> )
<i>Mean</i>				
Smoking	26	94.7	81.3	(23, 286)
Non-smoking	17	6.8	4.3	(0.4, 20.1)
<i>Peak levels</i>				
Smoking	26	410.2	360.7	(76, 886)
Non-smoking	17	11.6	9.6	(2.6, 26.3)

AM = Arithmetic Mean  
GM = Geometric Mean

During non-smoking journeys PM<sub>2.5</sub> concentrations did not exceed the 35 µg/m<sup>3</sup> US EPA 'unhealthy' guidance level for outdoor air [10] at any point.

During smoking journeys PM<sub>2.5</sub> concentrations were found to breach this threshold between 16 and 100% of the duration of the journey. On average, 49% of the time during journeys where smoking took place was spent at a concentration that exceeded the US EPA 'unhealthy' guidance level. There was a significant difference in the levels of PM<sub>2.5</sub> between smoking and non-smoking journeys (P<0.001, T-test assuming unequal variances, appendix D)

Figure 4 shows a scatter plot of the PM<sub>2.5</sub> concentrations against the number of cigarettes per reported minute for each journey. There was a clear trend for higher PM<sub>2.5</sub> concentrations with increasing number of cigarettes smoked per minute. Some 55% of the variance in the log-transformed PM<sub>2.5</sub> concentrations was explained by the rate of cigarettes smoked in the car.

**Figure 4** Scatter plot of PM<sub>2.5</sub> concentration against number of cigarettes smoked per minute.

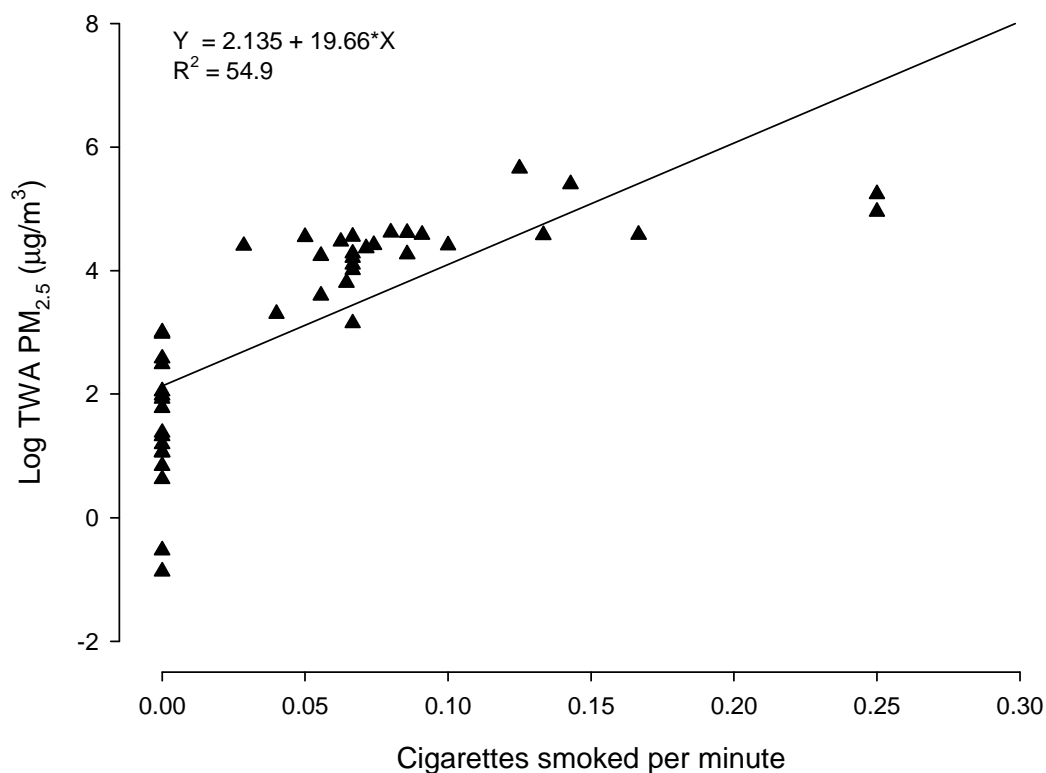
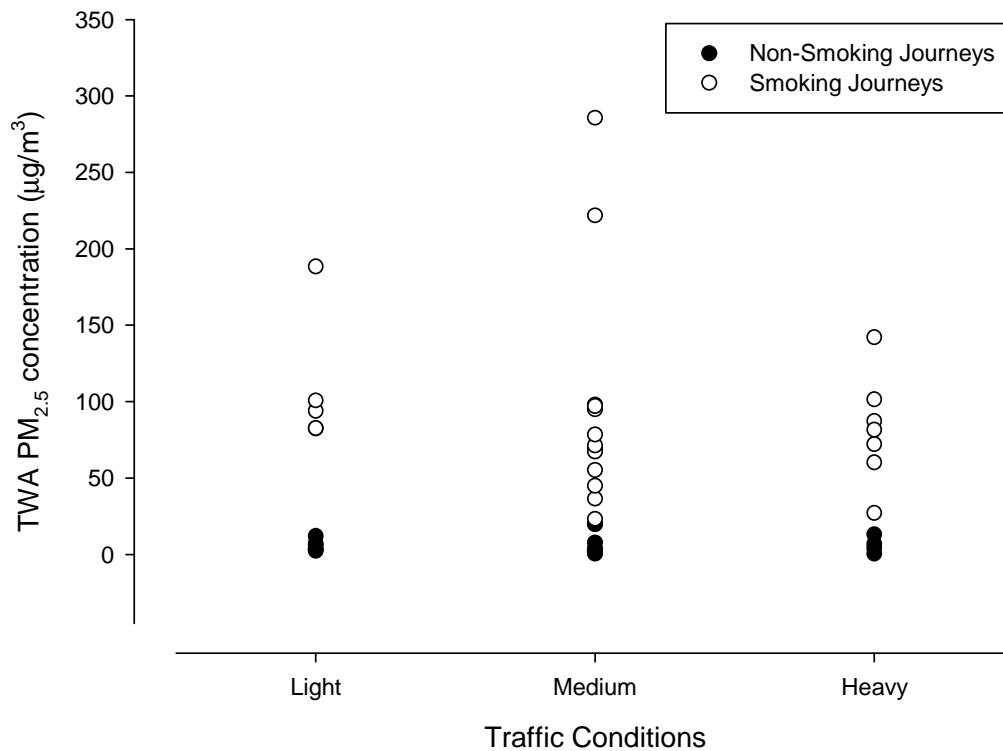


Figure 5 shows a graph of PM<sub>2.5</sub> concentrations found during each journey under different traffic conditions (as reported by the participants) during smoking and non-smoking journeys.

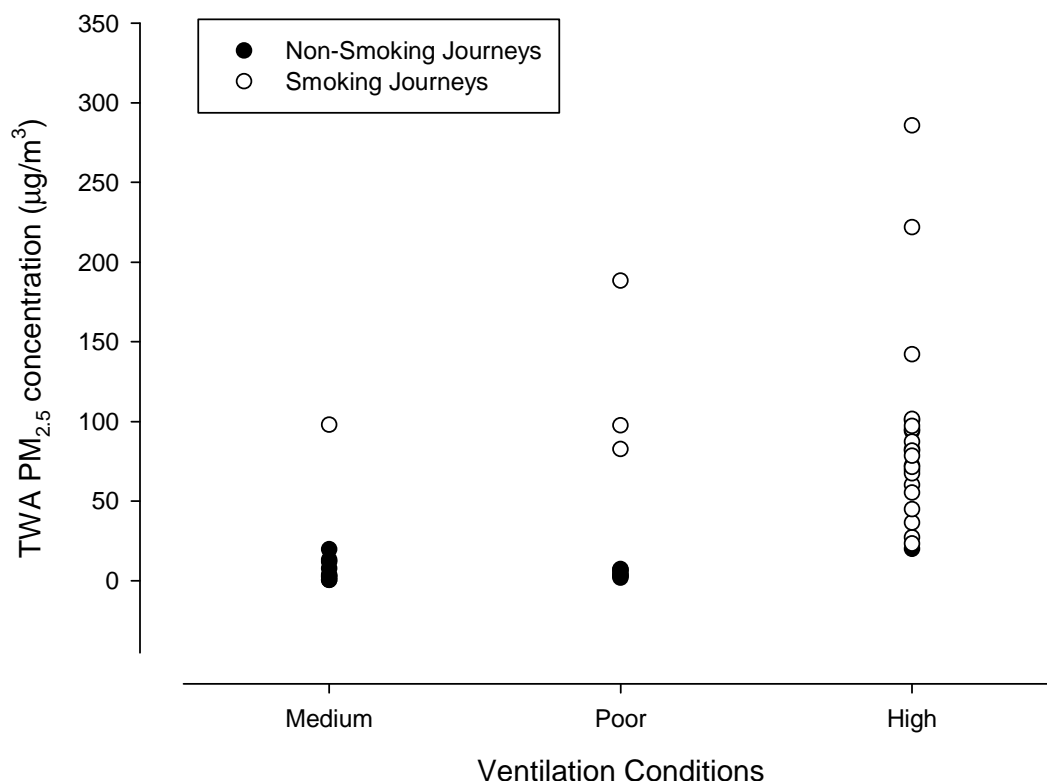


**Figure 5** PM<sub>2.5</sub> concentration observed in each journey according to the traffic conditions in smoking and non-smoking journeys.

There was no statistically significant difference in PM<sub>2.5</sub> concentrations between different traffic conditions ( $p = 0.776$ , Regression analysis, appendix D).

Figure 6 shows the PM<sub>2.5</sub> concentrations found in each journey according to the different window positioning and ventilation settings: poor ventilation refers to windows shut during most or the entire journey and ventilation system off during most or entire journey; medium ventilation refers to windows closed during most of the journey and ventilation system on during most of journey; and high ventilation refers to windows open during most or the entire journey and any ventilation setting.

**Figure 6** PM<sub>2.5</sub> concentration in each journey according to the overall ventilation conditions in the car.



PM<sub>2.5</sub> concentrations in smoking journeys appeared to be higher when the ventilation was poor (AM=123 µg/m<sup>3</sup>), compared to journeys where the ventilation was medium (AM=98 µg/m<sup>3</sup>) or high (AM=91 µg/m<sup>3</sup>), although the number of journeys for the poor and medium rated ventilation conditions are small. Regression analyses to test whether the ventilation conditions or the presence of open windows make a difference to the PM<sub>2.5</sub> levels identified both as having a significant effect (P-value <0.001, Regression analysis, appendix D). However when considering only the smoking journeys neither of these factors were significant (P=0.501 and P=0.703, respectively).

## DISCUSSION

This study investigated PM<sub>2.5</sub> concentrations as a surrogate for SHS levels during car journeys where drivers did and did not smoke. The arithmetic mean PM<sub>2.5</sub> concentrations found in cars with active smoking was 95 µg/m<sup>3</sup> which is more than double that of the US EPA 24-hour 'unhealthy' guidance value of 35 µg/m<sup>3</sup>. The values measured during smoking journeys can be compared to those reported in two studies that utilized very similar methodology. Gotz and colleagues in the UK [9] and Edwards et al in New Zealand [11] both reported PM<sub>2.5</sub> concentrations in the rear of cars with the sampling point at the position of a child's nose. Gotz et al [9] reported an arithmetic mean concentration of 88 µg/m<sup>3</sup> (range of 13 to 242 µg/m<sup>3</sup>) while the New Zealand study [11] found a PM<sub>2.5</sub> concentration of 168 µg/m<sup>3</sup> with the car window fully open.

A number of other studies have investigated PM<sub>2.5</sub> concentrations due to SHS in vehicles in the USA [7] and Canada [8]. Rees and colleagues [7] found mean concentrations of 272 µg/m<sup>3</sup> when windows were closed which is greater than that found under the poor ventilation condition of this present study. PM<sub>2.5</sub> concentrations with open windows were 51 µg/m<sup>3</sup> [7] which is lower than that reported in this present study (91 µg/m<sup>3</sup>). The Canadian study [8] measured substantially higher PM<sub>2.5</sub> concentrations of 844 µg/m<sup>3</sup> in cars with air conditioning on and 223 µg/m<sup>3</sup> in situations where the driver was holding the cigarette close to an open window.

Research carried out by Ott et al [12] found that ventilation, air conditioning, window position and car speed all influenced SHS concentrations in cars. Such factors combined with different smoking behaviours may account for the differences in PM<sub>2.5</sub> concentration across studies.

By design vehicle ventilation has numerous combinations and permutations making it difficult to assess the air exchange. Use of ventilation and windows will also vary over the duration of a journey and will depend on time of day, traffic and weather conditions. It is difficult for one study to cover all the combinations possible but by using volunteers who smoke, realistic sampling scenarios can be utilised.

While this study provides evidence that ventilation can help reduce SHS concentrations in cars the effect was generally small and the SHS concentrations present in well ventilated cars are still much greater than the US EPA 'unhealthy' guidance level.

We have used the US EPA 'unhealthy' guidance level for outdoor air as there is no indoor air exposure limit or standard for SHS expressed as PM<sub>2.5</sub> in the UK, EU or US settings. The comparison to this guidance should be done with some caution as the outdoor air guidance is based on a 24 hour time-weighted average. Clearly the exposures during car journeys we have measured are all much shorter than a 24-h averaging period but given recent work suggesting that there may be no safe level of exposure to SHS [13] we think that the use of the US EPA outdoor air standards for PM<sub>2.5</sub> is a reasonable health-based method of comparison. It is also important to

consider that children who are exposed to SHS in cars are very likely to also be exposed to SHS within their home setting and so while we do not have data here on 24-h average levels it is reasonable to assume that the time spent in the car will only be one of several micro-environments where children may be exposed to SHS and hence elevated PM<sub>2.5</sub> levels over the course of the day.

The results can also be compared to the concentrations of PM<sub>2.5</sub> that were measured in recent studies that looked at bars in Scotland and England prior to the implementation of smoke-free legislation in 2006 and 2007 respectively. The mean PM<sub>2.5</sub> concentration measured in smoking cars in this study was 95 µg/m<sup>3</sup> which is about 40% the average exposure level measured in bars in Scotland (246 µg/m<sup>3</sup>) and about two-thirds of the average level measured in bars in England (142 µg/m<sup>3</sup>) [1]. Typical PM<sub>2.5</sub> levels in bars now that smoking is prohibited are of the order of 5-20 µg/m<sup>3</sup> and similar to those measured in the non-smoking car journeys.

It is also worth comparing the levels of PM<sub>2.5</sub> measured in smoking cars to those found in large highly polluted cities. Recent concern about the effects of high PM levels on athlete and visitor health during the 2008 Beijing Olympics generated considerable media coverage. Pictures of Beijing with atmospheric PM levels similar to those measured during smoking car journeys show conditions that raised much concern in the Western media [14].

There are some limitations that should be considered when interpreting the results reported in the current study. The data set is small with less than 50 journeys in total collected from just 8 individuals over a short two week period. The selection of participants was carried out by NHS GGC and it is difficult to know how representative they are of typical smokers within the wider population. In addition, data on the duration windows were opened and ventilation systems switched on, the outside temperature, wind speed, and speed of the vehicles when driving were not recorded or analysed as part of this work. This study took place in October where ventilation in cars through the use of open windows or air conditioning is possibly more frequent than during winter months and so may under-estimate SHS concentrations that would be experienced in winter. The converse is also true in that our data may be an over-estimate of exposures in summer months. Although participants were asked to perform their normal behaviour they were also being asked to switch on/off equipment and complete data sheets at the beginning and end of each journey which will have introduced some non-typical activity and may have changed the SHS exposure that was measured.

While it is important to be aware of these weaknesses and to consider how representative the measurements made in this study are, the high level of agreement with the only previous UK study of PM levels in cars suggests that the results are broadly valid and are likely to demonstrate typical SHS exposures of children in cars in the UK.

Given the well accepted health impacts of SHS [15] it is important to consider methods to limit exposure of non-smoking car occupants and children in particular. Providing smokers and non-smokers with greater understanding of

the concentrations of SHS generated during smoking within a car coupled with information and education on the health effects of SHS must be a primary public health intervention. Stronger mandatory measures that prohibit smoking in private vehicles have already been implemented in parts of Canada and Australia and are being considered elsewhere [16]. Recent evidence suggests that there is growing support for formal Scottish or UK legislation to protect children in cars from SHS exposure [17] and if educational measures fail to reduce children's exposure to SHS then such policies may be considered at a societal level.

## CONCLUSION

The concentrations of fine particulate matter found in cars where smoking took place were high and in all cases exceeded the US EPA 24-hour outdoor air 'unhealthy' guidance value of  $35 \mu\text{g}/\text{m}^3$  for some considerable duration of the journey. Concentrations were strongly associated with the number of cigarettes smoked per time period. While slightly lower concentrations were observed when ventilation systems were used and/or windows were open, the mitigating effect was small and exposure intensities remained considerable. Exposure to  $\text{PM}_{2.5}$  at the levels reported here is likely to be harmful to respiratory health and measures to remove or reduce this exposure within the confines of vehicles should be considered both in terms of individual responsibility and via societal change.

## **ACKNOWLEDGEMENTS**

The authors of this report would like to express their thanks to the participants who took part in this study. We would also like to thank the Tobacco Control Co-ordinating Centre for the loan of the dolls and car seats and for access to their previous report on similar work in England.

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# **Appendix A**

## **Participant Brief**

## ***Thank you for agreeing to participate in our Smoking in Cars Project!***

You will find some more information about the project below.  
If you have any additional questions, please do not hesitate to contact us.

### ▪ **Purpose of the project:**

- To investigate exposure to second hand smoke from cigarettes in children travelling in cars with a smoker
- To measure the concentration of ultra-fine particle matter (PM<sub>2.5</sub>) in cars where smoking occurs.
- To compare PM<sub>2.5</sub> concentrations under different smoking and driving conditions, including different types of cars, number of cigarettes smoked, ventilation (turned on/off, windows open/closed), environmental (city centre vs. countryside roads) and traffic conditions

### ▪ **Equipment:**

You will be provided with the following equipment:

- 1 SidePak monitor with a plastic tube, 1 bag
- 1 child car seat, 1 doll
- Monitoring forms for 5+ journeys
- A small GPS pen

### ▪ **Timeframe:**

We will arrange a meeting with you to show you how to use the equipment and to answer any questions you may have. You will then have **2-3 days** to complete the monitoring before we meet with you again to collect the equipment.

### ▪ **What we ask you to do:**

- Install the car seat and doll in the back seat of your car (see instructions below)
- Put the SidePak monitor in the bag and attach the straps around the doll's neck; position the plastic tube at nose level
- Let the monitor run during **each journey you make in your car**.  
[Note that each journey should be at least **15 min long** and that one of these should be a **test journey** where you do **not** smoke].
- Complete a **monitoring form** for each journey. The form asks for the start and end time, number of cigarettes smoked, ventilation and traffic conditions. It is therefore important that you complete it directly after each journey.

- **Gift vouchers:**

When you provide us with data from your car journeys over a 2 day period and completed all of the information on the accompanying monitoring forms, NHS GGC will send you a **£20 gift voucher**.

- **General Instructions:**

- We ask you to record **one test journey** (at least 15 minutes long) where you do not smoke. This will serve as a comparison to the other journeys.
- Keep the Sidepak **monitor in a safe place** at all times. When you leave your car, you will need to take the device with you to prevent theft. At work or at home, ensure that it is stored in a place where it cannot be accessed by others (esp. children) and away from potential damage. Please also remove the doll from the car seat while you are away from the car.
- Ensure that the **monitor is firmly strapped to the doll** when you are driving. As with any heavy objects that hang around loosely in your car, the device increases your risk of injury in case of an accident.
- Note that the SidePak monitor is only recording data when the screen displays '**Data logging**'. Changing numbers on the display do not indicate that any information is being saved! Please check that the **monitor is properly recording** so that you do not lose any data. Every time you are logging a data set, the device will assign it a number (test 1, test 2, test 3, etc.). You will see these displayed on the screen.
- Keep all of your monitoring sheets in one place and remember to complete them at the end of each journey. Keep in mind that you will need to record the **start and end times**, mileage and other information that you may not remember at a later time.
- However, please do not feel that you have to smoke during any of your journeys. You are **not expected to alter your smoking behaviour** in any way for the purpose of this project.
- If you have any questions or queries or if any of the instructions do not seem clear to you, **please get in touch!** You will find our contact information on page 6.

## Installing the Equipment

### ▪ Child car seat

- Place the child car seat on the **left side** of the **back seat** in your vehicle (i.e., opposite the driver's side). Ensure it is firmly pushed against the vehicle seat. If necessary, remove the headrest of the vehicle seat.



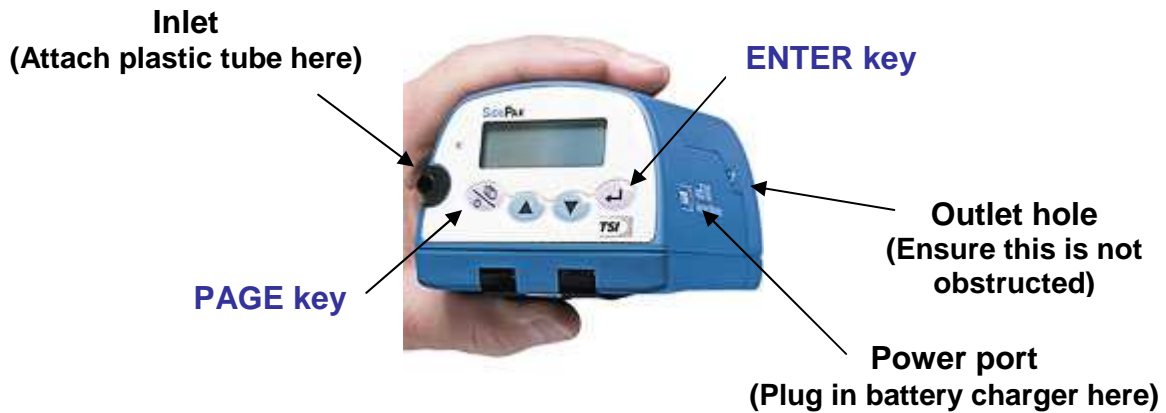
### ▪ Doll

- Sit the doll in the child car seat with the back against the backrest.
- Position the lap section of the safety belt under both armrests (as indicated by labels with red arrows on seat).
- Insert the buckle tongue in the belt buckle and pull the lap belt tight.
- Thread the shoulder belt under the armrest and then through the belt hook on the headrest.

### ▪ Sidepak monitor

- Turn the Sidepak **monitor on** as described in the next section. The plastic tube needs to be attached to the inlet of the monitor
- Place the monitor on the doll's lap. The small outlet hole on the left side of the unit should not be obstructed
- Run the tube through the doll's t-shirt and position the end of the **tube at nose level**.
- **Record the journey start time** on your monitoring form.

## Operating the SidePak Monitor



### **Before the start of each journey:**

1. Press the **PAGE key** to turn the unit on.
2. Wait 1 minute for the pump to start up and the readings to stabilise. The display will read **"SURVEY MODE"** when it is ready.
3. Press the **PAGE key** again.
4. When the display reads **"Data Log"**, press the **ENTER key**.
5. Press the down arrows until **"Run Manual"** is displayed and press the **ENTER key**.
6. Check that the screen displays **"Data Logging"**. If this is not the case, then the machine is not recording!

### **At the end of each journey:**

7. Press the **ENTER key** twice to stop data logging.
8. Press the **PAGE key** repeatedly until the display shows **"SURVEY MODE"**.
9. To turn the unit off completely, press and hold the **PAGE key** for 3 seconds.
10. Take the unit **out of your car** and keep it in a **safe place**.

## **Further Information and Assistance**

- **Contact Us:**

**From 9:30 – 17:00:**

Brenda Friel, XXXXX, Email: [Brenda.Friel@ggc.scot.nhs.uk](mailto:Brenda.Friel@ggc.scot.nhs.uk)

Andrew Apsley, XXXXX, Email: [andrew.apsley@abdn.ac.uk](mailto:andrew.apsley@abdn.ac.uk)

**Any other time:**

If you have any questions or difficulties operating the equipment outside of normal business hours, please do not hesitate to call Andrew Apsley at XXXXXXXX.

- **Who we are:**

The **Scottish Centre for Indoor Air research** (SCIA) is a collaboration between the University of Aberdeen and the Institute of Occupational Medicine in Edinburgh. One of the key aims of the SCIA is to increase our understanding of exposure to secondhand smoke in homes and cars (particularly with respect to children's exposure) and its health effects; exploring possible interventions to reduce exposure in these microenvironments. We believe that the provision of exposure data to smokers is likely to be a very effective mechanism of behavioural modification.

A guiding principle of the SCIA is to strengthen the links between research and evidence-based development of policy; one of our longer-term aims of the SCIA will be to help provide advice and guidance on health-based limit values for indoor air pollutants in much the way that this currently exists for outdoor air.

Our scientific team have published peer-reviewed scientific papers examining the effects of smoke-free legislation across the UK and are involved in a range of studies looking at methods of changing smoking behaviour.

***Thank you for your time!***

## **Appendix B**

### **Smoking in cars questionnaire**

ID:

## Smoking in cars questionnaire

### Section 1: Driver Information

1. Gender      Male                       ①                      Female                       ②

2. Age: \_\_\_\_\_

3. On average, how many cigarettes do you smoke?

- Smoke 20+ per day                       ①
- Smoke 10 -19 per day                       ②
- Smoke less than 10 per day                       ③
- Smoke less than daily                       ④

4. On average, how often do you smoke in your car?

- Several times a day                       ①
- Once a day                       ②
- Occasionally                       ③
- Do not usually smoke in my car                       ④

### Section 2: Vehicle Information

5. Make & model: \_\_\_\_\_

6. Year: \_\_\_\_\_

7. Mileage:
- 25,000 miles or less                       ①
  - 26,000 - 50,000 miles                       ②
  - 51,000 - 75,000 miles                       ③
  - 76,000 miles or more                       ④

### Section 3: Additional Comments

Do you want to tell us anything else about this project or about smoking in cars in general?

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# **Appendix C**

## **Participant journey sheet**

**JOURNEY Number**

<b>Date:</b>	<table border="1"> <tr> <td></td><td></td><td></td><td></td><td></td><td></td> </tr> <tr> <td colspan="2"><b>Day</b></td> <td colspan="2"><b>Month</b></td> <td colspan="2"><b>Year</b></td> </tr> </table>							<b>Day</b>		<b>Month</b>		<b>Year</b>		<i>Example:</i> 09/01/09
<b>Day</b>		<b>Month</b>		<b>Year</b>										
<b>Start time:</b>	<table border="1"> <tr> <td></td><td></td><td></td><td></td> </tr> <tr> <td colspan="2"><b>Hours</b></td> <td colspan="2"><b>Minutes</b></td> </tr> </table>					<b>Hours</b>		<b>Minutes</b>		<i>Example:</i> 13:42				
<b>Hours</b>		<b>Minutes</b>												
<b>End time:</b>	<table border="1"> <tr> <td></td><td></td><td></td><td></td> </tr> <tr> <td colspan="2"><b>Hours</b></td> <td colspan="2"><b>Minutes</b></td> </tr> </table>					<b>Hours</b>		<b>Minutes</b>		<i>Example:</i> 15:49				
<b>Hours</b>		<b>Minutes</b>												
<b>Distance driven:</b>	<table border="1"> <tr> <td></td><td></td><td></td><td></td> </tr> <tr> <td colspan="4"><b>Miles</b></td> </tr> </table>					<b>Miles</b>				<i>Example:</i> 0025				
<b>Miles</b>														
<b>Number of cigarettes smoked:</b>	<table border="1"> <tr> <td></td><td></td> </tr> <tr> <td colspan="2"><b>Cigarettes</b></td> </tr> </table>			<b>Cigarettes</b>		<i>Example:</i> 03								
<b>Cigarettes</b>														
<b>Time since smoking last occurred in this vehicle</b>	<table border="1"> <tr> <td></td><td></td><td></td><td></td><td></td><td></td> </tr> <tr> <td colspan="2"><b>Days</b></td> <td colspan="2"><b>Hours</b></td> <td colspan="2"><b>Minutes</b></td> </tr> </table>							<b>Days</b>		<b>Hours</b>		<b>Minutes</b>		<i>Example:</i> 00.05.00 would be 5 hrs
<b>Days</b>		<b>Hours</b>		<b>Minutes</b>										
<b>Ventilation:</b>	Off during entire journey Off during most of journey On during most of journey On during entire journey	① ② ③ ④												
<b>Windows:</b>	Closed during entire journey Closed during most of journey Open during most of journey Open during entire journey	① ② ③ ④												
<b>Environment:</b>	Mostly city centre Mostly urban Mostly country roads Mostly motorway	① ② ③ ④												
<b>Traffic:</b>	Light Medium Heavy	① ② ③												

# **Appendix D**

## **Statistical test results**

T-Test for differences in the Log TWA PM<sub>2.5</sub> between non-smoking and smoking journeys, assuming unequal variances.

Sample	Size	Mean	Standard deviation	Standard error of mean	P-Value
Non-Smoking	17	1.5	1.1	0.26	<0.001
Smoking	26	4.4	0.6	0.11	

Regression Analysis of relationship between the Log TWA PM<sub>2.5</sub> and cigarettes smoked per reported minute

	d.f.	s.s.	m.s.	v.r.	F pr.	% Variance
Regression	1	64.6	64.6	52.2	<.001	54.9
Residual	41	50.7	1.2			
Total	42	115.3	2.7			

Regression Analysis of relationship between the Log TWA PM<sub>2.5</sub> and reported traffic Conditions

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	1.5	0.73	0.26	0.776
Residual	40	113.8	2.84		
Total	42	115.3	2.74		

Regression Analysis of relationship between the Log TWA PM<sub>2.5</sub> and reported ventilation Conditions

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	57.1	28.53	19.60	<.001
Residual	40	58.2	1.46		
Total	42	115.3	2.74		

Regression Analysis of relationship between the Log TWA PM<sub>2.5</sub> and window positioning

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	3	55.0	18.32	11.84	<.001
Residual	39	60.3	1.55		
Total	42	115.3	2.74		

Regression Analysis of relationship between the Log TWA PM<sub>2.5</sub> and reported ventilation Conditions for smoking journeys only

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	0.46	0.23	0.71	0.501
Residual	23	7.48	0.33		
Total	25	7.94	0.32		

Regression Analysis of relationship between the Log TWA PM<sub>2.5</sub> and window positioning for smoking journeys only

	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	3	0.48	0.16	0.47	0.703
Residual	22	7.46	0.34		
Total	25	7.94	0.32		