UK Smoke-Free Legislation: Changes in PM$_{2.5}$ Concentrations in Bars in Scotland, England, and Wales

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Objective: Evaluate the effect of smoke-free legislation on fine particulate [particulate matter $< 2.5 \, \mu m$ in diameter (PM$_{2.5}$)] air pollution levels in bars in Scotland, England, and Wales.

Design: Air quality was measured in 106 randomly selected bars in Scotland, England, and Wales before and after the introduction of smoking restrictions.

Methods: PM$_{2.5}$ concentrations were measured covertly for 30-min periods before smoke-free legislation was introduced, again at 1–2 months post-ban (except Wales) and then at 12-months post-baseline (except Scotland). In Scotland and England, overt measurements were carried out to assess bar workers’ full-shift personal exposures to PM$_{2.5}$. Postcode data were used to determine socio-economic status of the bar location.

Results: PM$_{2.5}$ levels prior to smoke-free legislation were highest in Scotland (median 197 $\, \mu g \, m^{-3}$), followed by Wales (median 184 $\, \mu g \, m^{-3}$) and England (median 92 $\, \mu g \, m^{-3}$). All three countries experienced a substantial reduction in PM$_{2.5}$ concentrations following the introduction of the legislation with the median reduction ranging from 84 to 93%. Personal exposure reductions were also within this range. There was evidence that bars located in more deprived postcodes had higher PM$_{2.5}$ levels prior to the legislation.

Conclusions: Prior to legislation PM$_{2.5}$ concentrations within bars across the UK were much higher than the 65 $\, \mu g \, m^{-3}$ ‘unhealthy’ threshold for outdoor air quality as set by the US Environmental Protection Agency. Concentrations in Scottish and Welsh bars were, on average, two or more times greater than in English bars for which seasonal influences may be responsible. Legislation in all three countries produced improvements in indoor air quality that are consistent with other international studies.

Keywords: deprivation; hospitality sector; inhalation exposure; legislation; PM$_{2.5}$; public health; second-hand smoke

INTRODUCTION

Second-hand smoke (SHS) is a known cause of lung cancer (Hackshaw et al., 1997) and cardiovascular disease (Law et al., 1997) and can increase symptom
frequency in subjects with asthma (Eisner, 2005). The US Surgeon General’s report in 2006 qualified SHS as causal to cardiovascular disease (US Department of Health and Human Services, 2006) and there is growing evidence that exposure to SHS may also increase the risk of acute myocardial ischaemia (Otsuka et al., 2001). Recent evidence suggests that smoke-free legislation may reduce the number of hospital admissions for myocardial infarction (Pell et al., 2008). To address the World Health Organization’s Framework Convention on Tobacco Control, public health policy in many countries has moved to control exposure to SHS in social and work settings. After much debate in the UK, the Smoking, Health and Social Care Act (Scotland) of 2005 prohibited smoking in enclosed or substantially enclosed public places in Scotland from 26 March 2006. This was followed by near-identical legislation in Wales (introduced on 2 April 2007) and England (1 July 2007).

One of the driving arguments for legislation has been that non-smokers should not be required to be exposed to SHS in their place of work. Bar workers have been shown to have particularly high exposures to SHS, with non-smoking bar workers producing salivary cotinine levels some four times the level of non-smokers who live with partners who smoke, and nearly 10 times the levels of non-smokers living in non-smoking households (Jarvis, 2001). Prior to the introduction of the legislation, one analysis suggested that SHS exposure may account for the death of 54 bar workers across the UK every year (Jamrozik, 2005).

Fine particulate matter such as PM$_{2.5}$ (particulate matter $<$2.5 $\mu$m in diameter) is a good measure of SHS concentrations particularly in environments where there are no major sources of combustion (Hyland et al., 2008). We have previously reported results from our study in Scotland (Semple et al., 2007a,b), although not the findings from our studies in Wales and England. This paper presents combined results of measurements of PM$_{2.5}$ made in bars across Scotland, England, and Wales before and up to 12 months after the introduction of smoke-free legislation and examines the change in PM$_{2.5}$ levels within the hospitality industry across the UK, exploring the possible contribution of deprivation on both pre-legislative concentrations and the percentage reduction in PM$_{2.5}$ levels experienced in bars.

**METHODS**

*Study population and sampling strategy*

Air quality measurements were collected from bars in Scotland, England, and Wales as part of three separate projects designed to evaluate the effect of the introduction of legislation in each of these countries. A common protocol for air sampling was used in all three projects. The dates of the legislation changes were 26 March 2006 (Scotland), 2 April 2007 (Wales), and 1 July 2007 (England). Bars were selected randomly in each study using a database of bars generated from online business directories from selected regions and urban areas in each country. In Scotland, postcode sectors of the cities of Aberdeen, Glasgow, and Edinburgh, together with rural areas of Aberdeenshire and the Borders, were targeted to provide a broad range of socio-economic areas. In England, postcode sectors of London, Liverpool, Newcastle, Cumbria, and Northumbria were targeted, while in Wales, postcodes in a South Wales city, South Wales valley, Mid-Wales, and North Coast Towns were targeted.

*Discreet sampling of air quality in bars*

Measurement of PM$_{2.5}$ levels in pubs was carried out covertly using methods described previously (Semple et al., 2007b). We used a battery-operated aerosol monitor (TSI SidePak AM510 Personal Aerosol Monitor) fitted with an impactor in order to measure PM$_{2.5}$. The monitor was placed in a small bag with a short length of Tygon tubing attached to the inlet and left protruding to the outside. The monitor was zero calibrated each day prior to use and the airflow rate set at 1.7 l min$^{-1}$. The monitor logged PM$_{2.5}$ concentrations at 1-min intervals. The data were downloaded to a computer using TSI Trackpro software (v3.41) and concentrations were converted using a conversion factor of 0.295 to take account of the relative density of SHS particulate as previously described (Repace, 2006). Bars were visited by either one or two researchers for a period of at least 30 min. The researcher became a ‘customer’, purchased a drink, and sat or stood in a central inside area of the bar away from doors, windows, or any ventilation equipment while also avoiding positioning in the immediate vicinity of anyone who was smoking. Repeat bar visits after 1 or 2 months and 12 months after baseline were undertaken on the same day of the week and as close to the time of the original visit as possible. Whenever possible, the researchers also attempted to position themselves in the same location within the bar as the previous visit.

*Personal work-shift sampling*

Using methods fully described elsewhere (Semple et al., 2007a) a total of 13 bar workers from seven bars in England and six in Scotland were recruited to wear the PM$_{2.5}$ monitors for their work-shift.
The TSI SidePak AM510 Personal Aerosol Monitor was attached to their belt and a short length of Tygon tubing was used to sample air from their breathing zone. The monitor logged PM$_{2.5}$ concentrations at 1-min intervals. Where possible, this monitoring was repeated shortly after implementation of the smoke-free legislation. All subjects taking part in this work provided written informed consent, and for the purposes of assessing SHS exposures, these workers were all non-smokers.

**Statistical analysis**

Time-weighted average PM$_{2.5}$ concentrations were calculated using MS Excel and the data transferred to Statistical Package for Social Sciences (v15) for analysis. The postcode of each bar was used to obtain a measure of the deprivation score of the local area. For these purposes, we used the English Index of Deprivation for super output areas (2007), the Welsh Indices of Deprivation (2000), and the Scottish Index of Multiple Deprivation (2005). Each postcode was assigned a deprivation category according to these schemes with Category 1 being the least deprived and Category 10 the most deprived. Due to small numbers, these categories were combined to give five deprivation categories (1–1 & 2, 2–3 & 4, 3–5 & 6, 4–7 & 8, 5–9 & 10).

Due to the increase in variation in PM$_{2.5}$ levels with increasing means, the analysis of deprivation category was carried out on the log scale. Regression was carried out by fitting deprivation category so as to investigate the existence of both a linear trend and differences between the deprivation categories. The same was done for the change in PM$_{2.5}$ levels between phases, where the log ratio is equivalent to the difference in the logs.

**Ethics**

Ethical approval for the English and Wales data collection was obtained from the Research Ethics Committee of the Liverpool John Moore’s University and Glyndŵr University Research Ethics Committee. For the Scottish data collection, an Advisory Committee Group was established for reviewing and monitoring ethical and scientific procedures.

**RESULTS**

**Study population**

The number, location, and timing of visits to the bars in each country are summarized in Table 1. Timing of the visits was dictated by the legislation in each country. Phase 1 (P1) was carried out in the 4 months preceding the legislation; Phase 2 (P2) was carried out in the 2 months immediately post-legislation; and phase 3 (P3) was carried out approximately 12 months after the visits at phase 1. Due to funding constraints, P2 was not performed in Wales, while P3 was not carried out in Scottish bars. In Scotland and Wales, some bars were visited on more than one occasion at each phase in order to gather data during quieter mid-week and early evening times, in addition to later evening and weekend time periods. Therefore, for these countries, the number of visits is greater than the number of bars visited (Table 1). Not all bars visited at P1 or P2 were available at P3 due to logistical difficulties or due to the bars being closed.

**Discreet PM$_{2.5}$ measurements**

Levels before implementation of the ban ranged from 5 to 1005 $\mu $g m$^{-3}$ with median levels being highest in Scotland, followed by Wales and then England (Table 2). Using the US Environmental Protection Agency’s (EPA) 24-h Air Quality Index levels for outdoor air pollution (US EPA, 2009), more than four of five bars in the Scottish study had PM$_{2.5}$ concentrations above the ‘unhealthy’ (65 $\mu $g m$^{-3}$) threshold during the covert measurements; a similar proportion of bars in the Welsh study also exceeded this level, while the proportion was closer to three in five bars in the English study. Figure 1 shows a box plot of the distribution of PM$_{2.5}$ concentrations measured in each country at P1 with horizontal marker lines representing the US EPA unhealthy (65 $\mu $g m$^{-3}$) and ‘hazardous’ (250 $\mu $g m$^{-3}$) thresholds.

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**Table 1. Details of bars visited at each phase in each country**

<table>
<thead>
<tr>
<th></th>
<th>Scotland</th>
<th>England</th>
<th>Wales</th>
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<tbody>
<tr>
<td></td>
<td>P1</td>
<td>P2</td>
<td>P3</td>
</tr>
<tr>
<td>Bars visited</td>
<td>42</td>
<td>42</td>
<td>—</td>
</tr>
<tr>
<td>Total visits</td>
<td>53</td>
<td>53</td>
<td>—</td>
</tr>
<tr>
<td>Mean entry time (h and min)</td>
<td>18:07</td>
<td>17:58</td>
<td>—</td>
</tr>
</tbody>
</table>

P1 is phase 1: 2 months prior to the introduction of smoke-free legislation. P2 is phase 2: 2 months post-implementation of smoke-free legislation. P3 is phase 3: 12 months post-implementation of smoke-free legislation.
The dark horizontal line in each box represents the median value, the top and bottom of the box represent the 25th and 75th percentile levels with the lines extending to the 5th and 95th percentile of the distribution. Measurement points out-with this range are presented individually as outliers.

With the exception of 5 of 176 follow-up visits, PM$_{2.5}$ concentrations in bars were higher at P1 than at either P2 or P3 in all three countries. Three of the five exceptions had very low PM$_{2.5}$ concentrations prior to the introduction of smoke-free legislation. All three countries demonstrated substantial reductions in PM$_{2.5}$ concentrations at P2 and P3 follow-up studies (Figs 2 and 3). Using paired samples (based on day and time), the biggest median reduction was found in England between P1 and P2 (93%) but similar figures were observed in Scotland (91%) at P2 and Wales (85%), where the measure was between P1 and P3.

Table 3 provides detail of the distribution of bars included in this study by deprivation category, while Fig. 4 shows a box plot of PM$_{2.5}$ concentrations measured at P1 by deprivation category. There is evidence of a linear trend in PM$_{2.5}$ levels by deprivation category.

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**Table 2. Summary details of PM$_{2.5}$ levels measured at each phase in each country**

<table>
<thead>
<tr>
<th></th>
<th>Scotland</th>
<th>England</th>
<th>Wales</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Total visits</td>
<td>53</td>
<td>53</td>
<td>24</td>
</tr>
<tr>
<td>P2 Range of PM$_{2.5}$ concentrations (μg m$^{-3}$)</td>
<td>8–902</td>
<td>6–105</td>
<td>16–872</td>
</tr>
<tr>
<td>P3 Median (and IQR) PM$_{2.5}$ concentration (μg m$^{-3}$)</td>
<td>197 (87–350)</td>
<td>15 (8–23)</td>
<td>184 (78–327)</td>
</tr>
<tr>
<td>P1 % Above 65 μg m$^{-3}$</td>
<td>81</td>
<td>6</td>
<td>79</td>
</tr>
<tr>
<td>P2 Median % reduction from P1</td>
<td>91</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>P3 IQR</td>
<td>5</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

IQR = inter-quartile range.

*Paired samples.

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**Fig. 1.** Box plot of PM$_{2.5}$ levels measured discretely in bars in each country in a 3-month period before legislation. The 65 and 250 μg m$^{-3}$ threshold lines represent the US EPA unhealthy and hazardous levels for outdoor air concentrations of PM$_{2.5}$.
deprivation category at P1 ($F = 0.018$). However, when looking at the table of means it is clear that this trend is not convincing as Category 2 has a higher mean than both Categories 1 and 3. There is no evidence of a trend at P2 ($F = 0.73$) or P3 ($F = 0.227$) or an effect of deprivation on the levels of PM$_{2.5}$ ($F = 0.096$ and 0.133, respectively).

Figure 5 presents details of the percentage change in PM$_{2.5}$ levels from P1 at either P2 (A for Scotland and England) or P3 (B for England and Wales) subdivided by deprivation category. There is evidence of a linear trend in the change in PM$_{2.5}$ by deprivation category, from P1 to P2 ($F = 0.019$) and from P1 to P3 ($F < 0.0001$). In both cases, this suggests that more deprived areas experienced a greater percentage reduction in PM$_{2.5}$ levels post-implementation when compared to more affluent areas, although the higher P1 levels in the more deprived areas does imply that there was a greater opportunity for improvement in those pubs. There is evidence of differences in the mean change from P1 to P2 between the different deprivation categories but not for the change from P1 to P3. Deprivation category does not explain much of the variation in the change in PM$_{2.5}$. The model for the change from P1 to P2 had a geometric residual SE of 1.03, reducing to

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**Fig. 2.** Scatter plots showing PM$_{2.5}$ concentrations at pre-ban compared to 2 months post-ban in Scotland (A) and England (B).

**Fig. 3.** Scatter plots showing PM$_{2.5}$ concentrations at pre-ban compared to 1-year later in bars in England (A) and Wales (B).
When deprivation category was fitted. For the model for the change from P1 to P3, the residual reduced from 1.15 to 1.03.

**Personal PM$_{2.5}$ measurements**

Table 4 presents summary statistics of personal PM$_{2.5}$ exposures of a small sample of bar workers in Scotland and England measured at P1 and P2. The median exposure at P1 was higher in Scotland compared to England but was reduced to similar levels at 2 months post-implementation. Bar workers in both countries were experiencing considerable full-shift exposures to SHS with personal time-weighted average exposures reaching as high as 1083 $\mu$g m$^{-3}$ in one case. The median value of the percentage reduction experienced by these workers was 88% in Scotland and 84% in England, very similar to the reductions demonstrated by the 30-min spot covert measurements made in bars in these countries.

**DISCUSSION**

This paper provides the first comparison of particulate matter levels in bars across Scotland, England, and Wales before and after the introduction of comprehensive smoke-free legislation in all three countries. Using similar protocols in each of the three separate studies, we have gathered a large data set of PM$_{2.5}$ concentrations measured discreetly for at least 30 min in >300 bar visits. We also have a small number of 26 personal exposure shift samples for bar workers in Scotland and England. These data consistently demonstrate highly substantial reductions in PM$_{2.5}$, as a marker for SHS, across all three countries. The size of the reduction varies from bar to bar and by time of visit, but overall, the size of the reduction experienced in the three countries is between 84 and 91%. The median reduction in personal exposures of bar workers in both Scotland and England was also within this range.

Other studies in Ireland (Goodman et al., 2007) and New York State (Travers et al., 2004) together with a study looking at Irish-theme bars globally (Connolly et al., 2009) have shown changes in airborne concentrations of PM$_{2.5}$ after the introduction of smoke-free legislation between 80 and 95%, which are consistent with our findings.

This paper shows that, prior to smoke-free legislation, PM$_{2.5}$ concentrations in bars were frequently above the US EPA’s 24-h unhealthy threshold for outdoor air pollution of 65 $\mu$g m$^{-3}$ (US EPA, 2009), with 81% of measurements in Scotland, 63% in England, and 79% in Wales providing 30-min average concentrations above this concentration. Due to practical difficulties of performing a study of this nature discreetly and for reasons of personal safety, the timing of our measurements tended to be early evening and so it is likely that these measurements underestimate the PM$_{2.5}$ levels experienced in bars prior to smoke-free legislation at later and busier times of the evening. It is also possible that the level of compliance with the smoke-free legislation at later times in evening may be different.
From the total of 176 post-ban visits, there were only six bars that exceeded the 65-µg m\(^{-3}\) threshold after smoke-free laws were enacted. There was active smoking in two of these six with the possibility that smoking had taken place prior to sampling in the others. There were also issues of smoking at or within the doorway in several of these establishments with the potential for SHS entering the main body of the building.

Our study showed some limited evidence that pre-legislation levels of PM\(_{2.5}\) tended to be higher in bars located in more deprived postcodes, as was found in a previous study of bars in Greater Manchester (Edwards et al., 2006). Our study also indicates that, post-legislation, there tended to be greater percentage reductions in PM\(_{2.5}\) levels in bars in higher deprivation category areas compared to bars in more affluent areas. This may, in part, be due to the lower pre-ban levels in less deprived areas and the fact that these bars were closer at P1 to the baseline of ambient ‘non-SHS’ PM\(_{2.5}\) concentrations found in outdoor air. The amount of variability in the percentage reduction that was explained by the deprivation category was low however, broadly suggesting that the legislative changes were equally effective in improving air quality in bars regardless of the socio-economic conditions within the area they were located. We do acknowledge that postcode is an imperfect measure of the type of clientele who use a bar. This is particularly true of city-centre bars where the surrounding postcode may not reflect the customer base. The proportion of bars in each deprivation category was not even in all three countries and this may reflect issues as diverse as local drinking habits and planning/licensing arrangements in different parts of the UK. As a percentage, there were fewer bars in affluent areas sampled in England (12% in categories 1 and 2) compared to Scotland (23%) and Wales (25%). We also note that the methods of classifying deprivation are slightly different in Scotland, England, and Wales and that our method of

Table 4. Summary of personal PM\(_{2.5}\) exposure measurements made on bar workers

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<th>Scotland</th>
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<th>England</th>
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<tbody>
<tr>
<td></td>
<td>P1</td>
<td>P2</td>
<td>P1</td>
<td>P2</td>
</tr>
<tr>
<td>Number</td>
<td>N = 6</td>
<td>N = 6</td>
<td>N = 7</td>
<td>N = 7</td>
</tr>
<tr>
<td>Duration range (h and min)</td>
<td>5:16–6:57</td>
<td>5:11–6:39</td>
<td>3:23–7:30</td>
<td>3:11–6:22</td>
</tr>
<tr>
<td>Duration mean (h and min)</td>
<td>6:14</td>
<td>5:55</td>
<td>5:36</td>
<td>3:52</td>
</tr>
<tr>
<td>PM(_{2.5}) concentration range (µg m(^{-3}))</td>
<td>27–1083</td>
<td>8–90</td>
<td>22–640</td>
<td>7–40</td>
</tr>
<tr>
<td>Median (IQR) PM(_{2.5}) concentration (µg m(^{-3}))</td>
<td>230 (38–1074)</td>
<td>30 (14–58)</td>
<td>63 (24–243)</td>
<td>27 (10–35)</td>
</tr>
<tr>
<td>Median % reduction from P1</td>
<td>—</td>
<td>88</td>
<td>—</td>
<td>84</td>
</tr>
</tbody>
</table>

IQR = inter-quartile range.
combining deprivation scores across the three nations may fail to take account of absolute differences in socio-economic conditions between the countries. We think that any effect on our analyses arising from these subtle differences between areas in the UK is likely to be small.

Prior to the introduction of the smoke-free legislation, the concentrations of SHS in Scotland were higher than those in England (median 197 versus 92 µg m⁻³). This may be due to the timing of the P1 measurements. P1 was carried out in January and February 2006 in Scotland, whereas P1 in England was performed in the warmer months of May and June 2007. It is possible that there was a greater use of outside areas and ‘beer gardens’ by smokers during the English P1 survey resulting in lower indoor SHS levels. The P1 survey in Wales was also carried out during the winter months and results were very similar to the levels measured in Scotland. Other factors, such as differences in bar design and/or lower smoking prevalence rates in England compared to Scotland and Wales may also partially explain this finding.

The method of discreet sampling used in this study is a particular strength of this data set. Due to the high levels of interest and strong views held about smoke-free legislation in England, it was felt that overt sampling within bars may well have influenced smoking and/or ventilation use behaviours in the bars being sampled, resulting in either higher or lower SHS concentrations to those present on typical days. A full discussion of some of the issues surrounding discreet data collection in public spaces is presented in a paper by Petticrew et al. (2007).

CONCLUSIONS

There was some limited evidence that, across the three countries, bars in more deprived areas had higher pre-legislation concentrations of SHS levels compared to bars located in more affluent postcodes. While there is some evidence that bars in England had lower SHS levels compared to those in Scotland and Wales, it is difficult to determine how much of this effect was seasonal and due to increased smoking outdoors prior to the introduction of smoke-free legislation in England.

Fine particulate air pollution levels were substantial in bars across the UK prior to smoke-free legislation. There is evidence from epidemiological studies to suggest considerable respiratory (Göttschi et al., 2008) and cardiovascular (Mills et al., 2009) public health effects at outdoor PM₂.₅ concentrations much lower than those measured in bars in Scotland, England, and Wales in this study. It seems likely that the data on PM₂.₅ presented here is an underestimate of past exposures when the prevalence of smoking in the population was higher. Smoke-free legislation has produced a large reduction in PM₂.₅ levels in bars across the UK with levels reducing by >80% across all three countries. Most bars in the UK now have fine particulate matter concentrations of between 5 and 25 µg m⁻³, close to those found in outside ambient air. Our previous work on the effects of smoke-free ordinance on the health of bar workers in Scotland (Ayres et al., 2009) suggests that the improvements in air quality experienced in Scottish bars produced significant reductions in respiratory and sensory symptoms in both smoking and non-smoking bar workers. This current study demonstrates the clear effect of smoke-free legislation in producing marked reductions in fine particulate matter exposures of workers employed in bars in all deprivation categories across the UK.

FUNDING

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