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Second-hand smoke exposure in indoor and outdoor areas of cafés and restaurants: Need for extending smoking regulation outdoors? ☆

Marcela Fu [a,b,c], Esteve Fernández [a,b,c,*], Jose M. Martínez-Sánchez [a,b,1], Noemi San Emeterio [c], Nuria Quirós [a], Xisca Sureda [a,b,2], Montse Ballbè [a,b,c,d], Glòria Muñoz [e,f,g], Anna Riccobene [a,b], Francesc Centrich [e,f,g], Esteve Saltó [b,h,i], María J. López [f,g,j]

[a] Tobacco Control Unit, Cancer Prevention and Control Programme, Institut Català d'Oncologia – ICO, Av. Granvia de L'Hospitalet 199–203, L'Hospitalet de Llobregat, 08908 Barcelona, Spain
[b] Cancer Control and Prevention Group, Institut d'Investigació Biomèdica de Bellvitge – IDIBELL, Av. Granvia de L'Hospitalet 199–203, L'Hospitalet de Llobregat, 08908 Barcelona, Spain
[c] Department of Clinical Sciences, School of Medicine, Universitat de Barcelona, C. Feixa Llarga s/n, L'Hospitalet de Llobregat, 08907 Barcelona, Spain
[d] Addictions Unit, Psychiatry Department, Institute of Neurosciences, Hospital Clínic de Barcelona, C. Villarroel 170, 08036 Barcelona, Spain
[e] Chemistry Area, Agència de Salut Pública de Barcelona, Av. Drassanes, 13, 08001 Barcelona, Spain
[f] Biomedical Research Centre Network for Epidemiology and Public Health – CIBERESP, Parc de Recerca Biomèdica de Barcelona, C. Doctor Aiguader 88 Pl. 1, 08003 Barcelona, Spain
[g] Institut d'Investigació Biomèdica Sant Pau, C. Sant Antoni Maria Claret 167 – Pavelló de Sant Frederic 16 Pl. 1, 08025 Barcelona, Spain
[h] Department of Public Health, School of Medicine, Universitat de Barcelona, C. Casanova 143, 08036 Barcelona, Spain
[i] Health Plan Directorate, Ministry of Health, Generalitat de Catalunya, Trav. Les Corts, 131-159 – Pavelló Ave Maria, 08028 Barcelona, Spain
[j] Evaluation and Intervention Methods Service, Agència de Salut Pública de Barcelona, Pl. Lesseps 1, 08023 Barcelona, Spain

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ABSTRACT

Smoke-free legislation in indoor public places has concentrated smokers in the areas outside building entrances or other outdoor areas. This study assessed the drift of second-hand smoke between outdoor and indoor areas of cafés and restaurants in Barcelona, Spain, and characterized the exposure on outdoor terraces. Using a cross-sectional design, we monitored vapor-phase nicotine in indoor areas and outside entrances simultaneously ($n=47$), and on some outdoor terraces ($n=51$). We computed the median nicotine concentration and interquartile range (IQR) to describe the data and performed multivariate analysis to describe nicotine concentration and its determinants. The overall median nicotine concentration indoors was 0.65 $\mu g/m^3$ (IQR: 0.29–1.17 $\mu g/m^3$), with significant differences based on the number of smokers at the entrance ($p=0.039$). At outside entrances, the overall median nicotine concentration was 0.41 $\mu g/m^3$ (IQR: 0.21–1.17 $\mu g/m^3$). The nicotine concentrations indoors and at the corresponding outside entrances were not significantly different, and the multivariate analysis confirmed the relationship between these variables. On terraces, the overall median nicotine concentration was 0.54 $\mu g/m^3$ (IQR: 0.25–1.14 $\mu g/m^3$), but it increased to 0.60 $\mu g/m^3$ when a tobacco smell was perceived, 0.72 $\mu g/m^3$ on closed terraces, 1.24 $\mu g/m^3$ when there were >6 smokers, and 1.24 $\mu g/m^3$ when someone smoked >20 min. Multivariate analysis confirmed the outdoor terrace area, the season, the type of enclosure, and the number of smokers as the most relevant variables explaining nicotine concentration ($R^2=0.396$). These findings show that second-hand smoke exposure exists in indoor areas due to smokers smoking at the outside entrances. In addition, exposure may occur on outdoor terraces when smokers are present and the terrace is enclosed to some extent. Thus, the current Spanish law does not fully protect non-smokers from second-hand smoke and supports extending regulation to some outdoor areas.

☆In memory of our colleagues and friends Giovanni Invernizzi (1949–2013) and Manel Nebot (1957–2012), with whom we shared previous investigations on this and other tobacco control topics.

* Corresponding author at: Tobacco Control Unit, Cancer Prevention and Control Programme, Institut Català d'Oncologia, Av. Granvia de L'Hospitalet, 199-203, L'Hospitalet de Llobregat, 08908 Barcelona, Spain.
E-mail address: efernandez@iconcologia.net (E. Fernández).
[1] Present address: Biostatistics Unit, Department of Basic Sciences, Universitat Internacional de Catalunya, C. Josep Trueta s/n, Sant Cugat del Vallès, 08195 Barcelona, Spain.
[2] Present address: Social and Cardiovascular Epidemiology Research Group, School of Medicine, Universidad de Alcalá, Campus Universitario C/19, Ctra. Madrid-Barcelona, Alcalá de Henares, 28871 Madrid, Spain.

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1. Introduction

Exposure to second-hand smoke is a risk factor for many respiratory diseases in children and adults, and its inhalation causes lung cancer and coronary heart disease in non-smoking adults (US Department of Health and Human Services, 2006). A dose-response has been described for the health risks associated with this exposure, and the evidence suggests that any exposure carries some risk (US Department of Health and Human Services, 2006).

Passive exposure to tobacco smoking in indoor spaces has been extensively documented, and many countries have implemented smoke-free legislation in indoor workplaces and public places (Callinan et al., 2010). Smokers are now concentrated in the areas outside building entrances (Kennedy et al., 2012). Consequently, tobacco smoke drifting from outdoor into indoor areas has been described (Brennan et al., 2010; Edwards and Wilson, 2011; López et al., 2012; Sureda et al., 2012; van der Deen et al., 2014), indicating a need to investigate the extent to which second-hand smoke exposure in non-smoking areas is due to the outdoor smoking (Callinan et al., 2010; Sureda et al., 2013). Furthermore, passive smoking outdoors is an emerging topic that has generated debate about the adequacy of regulation in these spaces (Bloch and Shopland, 2000; Chapman, 2008; Repace, 2000; Thomson et al., 2008). Available evidence indicates notable exposure to tobacco smoke in some outdoor smoking areas and adjacent smoke-free indoor areas (Klepeis et al., 2007; Sureda et al., 2013; Sureda et al., 2012). Some studies have reported popular support regarding outdoor smoking restrictions (Gallus et al., 2012; Kennedy et al., 2012; Sureda et al., 2015), and smoking in outdoor areas is incipiently restricted in some jurisdictions (American College Health Association, 2012; Cameron et al., 2010; Lemstra et al., 2008). Few national or regional laws include banning smoking in specific outdoor areas, and those that do are focused mainly on primary and secondary schools (Martinez et al., 2014). In Spain, national law 42/2010 bans smoking in areas outside health facilities and playgrounds, with a partial ban in the outdoor areas of hospitality venues, where smoking is allowed or banned according to certain conditions of coverage and the number of walls (BOE, 2010).

All of these issues highlight the need for better assessment of outdoor smoking as a potential source of tobacco smoke exposure in established smoke-free indoor areas as well as in outdoor areas, requiring the use of highly sensitive methods. Thus, the objective of this study was to characterize the exposure to second-hand smoke in indoor and outdoor areas of cafés and restaurants by measuring airborne nicotine concentrations. More specifically, we describe the second-hand smoke drift from the outside entrances of a sample of cafés and restaurants into indoor areas and characterize the exposure to second-hand smoke on outdoor terraces of cafés and restaurants, taking into account their level of enclosure, among other variables.

2. Methods

2.1. Study design and sampling

This is a cross-sectional study using a random sample of cafés and restaurants in the city of Barcelona, Spain. We used a multistage design to obtain the sample of venues, following the same methodology as in previous investigations (Galan et al., 2014; López et al., 2013). In the first stage, we selected a random sample of census tracts in each of the 10 municipal districts, weighted by population size. In the second stage, we selected a random sample of cafés and restaurants with cafeteria service in each census tract (a total of 70 venues). We defined cafés as hospitality settings serving cafés, non-alcoholic beverages and snacks; and restaurants as hospitality venues where food and beverages were served. Fast food outlets and pubs or restaurants without a bar or cafeteria service were excluded.

2.2. Fieldwork, measurements, and analytical procedures

Five researchers involved in the fieldwork were trained together not only for the handling of the instruments, but also to collect the observational data. The air was monitored in the main indoor area and at the outside entrance of each venue simultaneously by two researchers, who then monitored the outdoor terrace. The monitoring was performed without notifying or warning the owner, employees, or patrons in order to favor spontaneous behavior, but we provided information about the investigation to the owners and employees who noticed the monitoring. This investigation did not require approval from an ethics committee because no measurements were made on humans.

The fieldwork was performed between April and December 2013 in hot and mild seasons (i.e., summer *vs.* spring and autumn) mainly, but not exclusively, on weekdays (86% of venues) and at different times of day (11% of the venues were monitored before 12:00; 66% between 12:00 and 20:00, and 23% after 20:00). The researchers behaved as normal patrons while monitoring and recording observational data in a notebook. At the end, 49 venues were monitored indoors and at outside entrance areas and on the outdoor terrace, 10 venues were monitored only indoors and at outside entrance areas, and 11 venues were monitored only on outdoor terraces. Twenty-one nicotine benchmark measurements (one for every 3–4 venues) were obtained from *a priori* outdoor smoke-free areas (without nearby smokers), at least 10 m away from any cafeteria or restaurant. These areas were *a priori* thought to be smoke-free, but we noted whether someone smoked near these points during the sampling time in order to be able to control for it if necessary.

2.2.1. Air monitoring indoors and at the outside entrances

Two trained researchers simultaneously monitored vapor-phase nicotine indoors and at the outside entrance of the venue for at least 30 min. This time was increased in increments of 5 min up to a maximum of 1 h if no smokers were present at the outside entrance. The researcher inside the venue obtained the most central table available, regardless of the venue's size, and discretely indicated to the other researcher at the outside entrance the precise moment to begin monitoring. The researchers were trained to ensure strict synchronized operation of the instruments using clocks and chronometers. When possible, the researcher at the outside entrance stood within 1 m of the entrance without limiting access to the venue, maintaining a maximum distance from the entrance of 2 m. Each researcher recorded detailed information on some contextual variables. Observational variables indoors included the visually-estimated area and height, whether ventilation was present and the type (natural, fan, and/or air conditioner), approximate distance between the observation point and the entrance, and kitchen structure (open, semi-open, closed but with the door open, or closed with the door closed). We also noted the presence of no-smoking signage and evidence of tobacco consumption (i.e., ashtrays, tobacco smell, and cigarette butts). Observational variables at outside entrances included wind direction subjectively assessed from the entrance (back to it) as no wind, lateral, frontal, or both of them, and some physical characteristics of the entrance, such as the presence of any cover, including its size and material; the presence, number, and material of walls; no-smoking signage; and evidence of tobacco consumption (i.e., ashtrays, tobacco smell, and cigarette butts). Other variables included the number of smokers within 3 m of the observation point during the entire observation period and the number of cigarettes smoked minute by minute within the observed area.

2.2.2. Air monitoring on the outdoor terraces

After indoor-entrance monitoring, the researchers sat on the outdoor terrace at the most central table available, avoiding any smoking source placed <1 m from the observation point. Vapor-phase nicotine was monitored for 30 min or up to 1 h if no smokers were present as in the indoor-entrance monitoring. Recorded variables included the visually-estimated area of the terrace, number of tables, presence and type of any cover and material (plastic, vegetation, wood, canvas, concrete, glass, and/or sunshades), and the presence of walls, including number, type (complete, incomplete and size of the opening), and material (plastic, vegetation, wood, canvas, concrete, glass). Using the information on the walls and roof we defined four levels of enclosure and recategorized them into two categories according to the definition of "outdoor area" included in the Spanish law. The law considers open any uncovered terrace or a covered terrace with up to two walls or faces and considers closed any covered terrace with more than two walls or faces; smoking is allowed only in the first case (BOE, 2010). Other variables of interest included the distance from the entrance, presence of no-smoking signage, and evidence of tobacco consumption (i.e., ashtrays, cigarette butts, tobacco smell). We also noted the number of smokers on the terrace and within 3 m of the observation point during the monitoring, as well as the number of cigarettes smoked minute by minute.

2.2.3. Air monitoring at control points

We performed 21 benchmark measurements on a geographical basis, with an approximate ratio of 1control for every 3–4 venues. Control points had to be in the vicinity of the venue but at least 10 m from it and away from any source of tobacco smoke. We recorded the distance from the venue, the number of smokers within a 3 m radius of the observation point or that passed by this point during the monitoring, and the number of cigarettes smoked minute by minute.

2.2.4. Vapor-phase nicotine monitoring

We measured vapor-phase nicotine with an active sampling method (Hammond et al., 1987), using a filter cassette containing a 37-mm Teflon-coated glass fiber filter treated with sodium bisulfate. We used a Tygon tube to connect the cassette to an air sampling pump (Sidekick 224–52MTX; SKC Limited, UK) that drew air at 3 L/min. The pumps were calibrated before each monitoring day using a Defender 510-M Calibrator (Bios International Corp, USA). We used two instrumentation kits for simultaneous monitoring indoors and at entrance areas. All instrumentation was carried discretely in a bag with the filter cassette protruding from it and caring for not bending or obstructing the tube. Indoors the bag was put on a table or seat at least 1 m from any wall with the cassette facing the center of the venue. At outside entrances, the researcher wore the bag while standing, with the cassette opposite the body. On outdoor terraces, the bag was placed on a chair or the table, as appropriate. After the samples were taken, the filters were stored and sent to the Laboratory of the Public Health Agency of Barcelona, where nicotine was desorbed from the filter and analyzed by gas chromatography/mass spectrometry to determine the nanograms of nicotine on the filter. We estimated the time-weighted average nicotine concentration (in $\mu g/m^3$) by dividing the amount of the extracted nicotine by the volume of air sampled. The limit of quantification was 5 ng/filter, equivalent to 0.06 $\mu g/m^3$ of nicotine per 30 min of exposure. For those samples below the limit of quantification, we assigned half this value.

2.3. Statistical analysis

For the data analysis we selected only the venues at which a smoker was present at the outside entrance or on the outdoor terrace during the corresponding monitoring period. We had some missing data due to technical problems during the fieldwork or laboratory analyses; from all 70 venues we had data available from 47 indoor areas, 49 outside entrances, 51 terraces, and 18 control points. The different settings were analyzed separately. We determined the medians, interquartile ranges (IQR), and minimum-maximum nicotine concentration (in $\mu g/m^3$) for each location. We compared nicotine concentrations within strata of some potential explanatory variables by using the Kruskal-Wallis test for independent samples. We also computed the Spearman's rho correlation between the nicotine concentrations indoors and at the outside entrance. In addition, we described the distribution of the nicotine concentration at all locations using box-plots and the Wilcoxon signed ranks test for paired comparisons of median concentrations (indoors *vs.* outside entrances) and the Mann-Whitney U test for independent comparisons (control point *vs.* indoors or outside entrances, and open *vs.* closed terraces). We performed multiple linear regression models to assess the relationship between indoor and outdoor nicotine concentrations in cafés and restaurants and to characterize the determinants of the nicotine concentration on the terraces. Given the skewed distribution of nicotine concentration, we used log transformed values. The final models fulfilled the assumptions for linear regression (normality, homoscedasticity, multicollinearity, error specification, outliers, and self-correlation).

3. Results

3.1. Measurements indoors and at the outside entrances

All of the indoor nicotine samples had quantifiable levels. The overall median nicotine concentration indoors (n=47) was 0.65 $\mu g/m^3$ (IQR: 0.29, 1.17 $\mu g/m^3$). Significant differences were found in the nicotine concentrations based on the number of smokers at the outside entrance, varying from 0.46 $\mu g/m^3$ (IQR: 0.25, 0.65 $\mu g/m^3$) when 3–5 smokers were present to 1.13 $\mu g/m^3$ (IQR: 0.81, 1.81 $\mu g/m^3$) when >5 smokers were present (Table 1). No differences were found in the nicotine concentration according to the minutes someone smoked at the entrance or other physical variables of the indoor area, including area, volume, distance to the entrance, or if the door was open or closed (Table 1). The results did not differ when the data were stratified according to door status (open or closed), as shown in Table 2.

The overall median nicotine concentration at outside entrances (n=49) was 0.41 $\mu g/m^3$ (IQR: 0.21, 1.17 $\mu g/m^3$; no samples were below the limit of quantification). No significant differences were observed when considering the structural (presence of roof, walls) and other contextual variables (number of smokers, number of minutes someone smoked, or tobacco smell; Table 3).

The nicotine concentration data distribution was more dispersed and skewed at the entrances than indoors (Fig. 1(A)). The median nicotine concentration was higher indoors than at the entrance (0.65 *vs.* 0.41 $\mu g/m^3$), though this difference was not statistically significant. Both measurements were correlated (Spearman's rho=0.520; $p<0.001$). Nicotine concentrations were significantly higher at both locations than at the control points (median <0.06 $\mu g/m^3$; IQR: <0.06, 0.16 $\mu g/m^3$; maximum value: 0.66 $\mu g/m^3$; Fig. 1(A)), among which 10 samples were below the limit of quantification.

We fitted multivariate models to assess the hypothesis of smoke drifting from outdoors to indoors, controlling for the

Table 1
Median and interquartile range (IQR) of vapor-phase nicotine concentration inside 47 cafés and restaurants in Barcelona, Spain, 2013.

	Nicotine (μg/m³)			
	n	Median (IQR)	Min, max	*P*-value[a]
Total	47	0.65 (0.29, 1.17)	0.08, 3.47	
Area indoors				0.594
≤ 40 m²	22	0.83 (0.29, 1.56)	0.08, 3.47	
> 40 m²	25	0.51 (0.36, 0.98)	0.10, 1.79	
Volume indoors				0.542
≤ 90 m³	15	0.85 (0.31, 1.60)	0.08, 3.47	
91–150 m³	17	0.48 (0.25, 0.98)	0.10, 1.63	
> 150 m³	15	0.51 (0.36, 1.56)	0.10, 1.79	
Distance to the entrance				0.550
≤ 5 m	30	0.76 (0.31, 1.03)	0.08, 3.47	
> 5 m	17	0.48 (0.29, 1.17)	0.10, 1.79	
Door status				0.158
Closed	4	0.39 (0.25, 0.53)	0.10, 0.67	
Open	43	0.81 (0.29, 1.28)	0.08, 3.47	
No. of smokers at the entrance				0.039
1–2	21	0.65 (0.29, 1.17)	0.08, 1.79	
3–5	14	0.46 (0.25, 0.65)	0.10, 1.03	
> 5	12	1.13 (0.81, 1.81)	0.10, 3.47	
Minutes someone smoked at the entrance				0.139
1–10	19	0.39 (0.21, 0.97)	0.08, 1.79	
11–20	19	0.95 (0.43, 1.63)	0.10, 3.47	
21–30	9	0.67 (0.25, 0.98)	0.10, 2.99	

[a] Kruskal-Wallis test.

Table 3
Median and interquartile range (IQR) of vapor-phase nicotine concentration at outside entrances of 49 cafés and restaurants in Barcelona, Spain, 2013.

	Nicotine (μg/m³)			
	n	Median (IQR)	Min, max	*P*-value[a]
Total	49	0.41 (0.21, 1.17)	0.08, 2.63	
Roof				0.359
No	33	0.40 (0.17, 1.17)	0.12, 2.35	
Yes	16	0.65 (0.27, 1.15)	0.08, 2.63	
Walls				0.258
No	48	0.40 (0.21, 1.13)	0.08, 2.63	
Yes	1	1.54	–	
Wind direction				0.288
No wind	28	0.43 (0.32, 1.61)	0.13, 2.63	
Lateral	18	0.23 (0.17, 0.77)	0.08, 2.23	
Frontal	2	0.61 (0.52, 0.69)	0.52, 0.69	
Lateral and frontal	1	0.59	–	
Tobacco smell[b]				0.070
No	3	0.16 (0.15, 0.24)	0.15, 0.24	
Yes	45	0.48 (0.22, 1.20)	0.08, 2.63	
No. of smokers				0.104
1–2	21	0.36 (0.18, 0.69)	0.08, 2.35	
3–5	16	0.39 (0.19, 0.57)	0.12, 2.63	
> 5	12	1.15 (0.37, 1.74)	0.15, 1.95	
Minutes someone smoked				0.094
1–10	19	0.32 (0.16, 0.69)	0.08, 1.75	
11–20	19	0.52 (0.24, 1.68)	0.12, 2.35	
21–30	11	0.48 (0.25, 1.20)	0.15, 2.63	

[a] Kruskal-Wallis test.
[b] The sum does not add up to the total due to a missing value.

variables in Table 1 as potential confounders (Table 4). The simplest model with no confounders (model 1) found a direct relationship of increasing nicotine concentration indoors with increasing nicotine concentration at the outside entrance (β=0.4708; p=0.001) which explained 23% of the indoor nicotine concentration (R^2=0.231). Table 4 also shows the saturated model (model 2) adjusted for selected characteristics, in which the association slightly attenuated but remained statistically significant (β=0.4044; p=0.008; R^2=0.372). We did not find any effect-modification in the association between indoor and outdoor nicotine concentrations by the area indoors (p=0.697 for the interaction term in the full model and β=0.4744 in the model for area size ≤ 40 m², p=0.044; and β=0.4618 in the model for area size > 40 m², p=0.006); by the distance to the entrance (p=0.542 for the interaction term and β=0.4662 in the model for distance ≤ 5 m, p=0.007; and β=0.5032 in the model for distance > 5 m; p=0.067); by door status (p=0.735 for the interaction term and β=0.3620 in the model for closed door; p=0.312; and β=0.4953 in the model for open door; p=0.001); or by the number of smokers at the outside entrance (p=0.539 for the interaction term and β=0.4214 in the model for 1–2 smokers, p=0.041; β=0.3140 for 3–5 smokers, p=0.211; and β=0.4291 for > 5 smokers, p=0.232).

Table 2
Median and interquartile range (IQR) of vapor-phase nicotine concentration inside 47 cafés and restaurants in Barcelona, Spain, 2013 according to the door status.

	Closed door				Open door				
	n	Median (IQR)	Min, max	*P*-value[a]	n	Median (IQR)	Min, max	*P*-value[a]	*P*-value[b]
Total	4	0.39 (0.25, 0.53)	0.10, 0.67	–	43	0.81 (0.29, 1.28)	0.08, 3.47	–	0.158
Area indoors				0.655				0.697	
≤ 40 m²	1	0.39	–		21	0.85 (0.29, 1.56)	0.08, 3.47		0.581
> 40 m²	3	0.39 (0.10, 0.67)	0.10, 0.67		22	0.57 (0.36, 1.17)	0.16, 1.79		0.210
Volume indoors				0.121				0.571	
≤ 90 m³	0	–	–		15	0.85 (0.31, 1.60)	0.08, 3.47		–
91–150 m³	2	0.53 (0.39, 0.67)	0.39, 0.67		15	0.48 (0.21, 1.03)	0.10, 1.63		0.881
> 150 m³	2	0.25 (0.10, 0.39)	0.10, 0.39		13	0.64 (0.40, 1.56)	0.16, 1.79		0.089
Distance to the entrance				0.180				0.633	
≤ 5 m	3	0.39 (0.39, 0.67)	0.39, 0.67		27	0.94 (0.25, 1.60)	0.08, 3.47		0.388
> 5 m	1	0.10	–		16	0.49 (0.33, 1.22)	0.21, 1.79		0.102
No. of smokers at the entrance				0.259				0.054	
1–2	2	0.39 (0.39, 0.39)	0.39, 0.39		19	0.81 (0.21, 1.56)	0.08, 1.79		0.549
3–5	1	0.10	–		13	0.48 (0.31, 0.65)	0.21, 1.03		0.107
> 5	1	0.67	–		11	1.28 (0.94, 1.87)	0.10, 3.47		0.311
Minutes someone smoked at the entrance				0.259				0.118	
1–10	2	0.39 (0.39, 0.39)	0.39, 0.39		17	0.42 (0.21, 0.97)	0.08, 1.79		0.894
11–20	1	0.10	–		18	0.95 (0.48, 1.63)	0.21, 3.47		0.100
21–30	1	0.67	–		8	0.72 (0.21, 1.13)	0.10, 2.99		1.000

[a] Kruskal-Wallis test for comparison of median nicotine values across all stratifications, separately for closed and open door.
[b] Kruskal-Wallis test for comparison of median nicotine values when the door is closed *vs* open in each stratum.

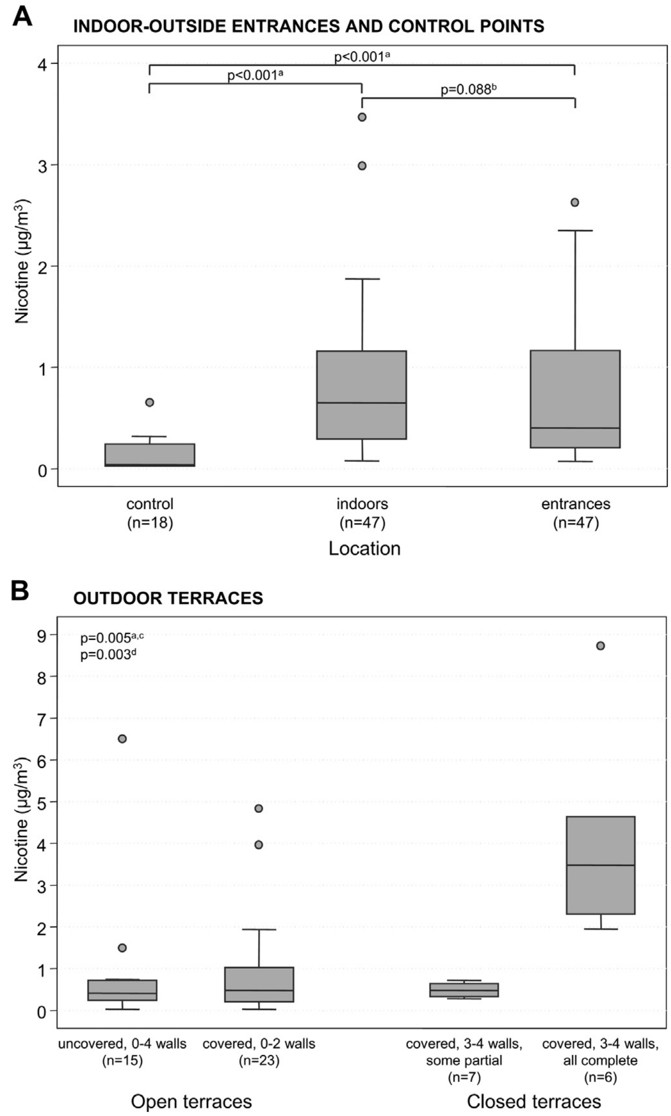

Fig. 1. Vapor-phase nicotine concentration (μg/m^3) indoors and at outside entrances (A) and on outdoor terraces (B) in a sample of cafés and restaurants in Barcelona, Spain, 2013. [a]Mann-Whitney *U* test; [b]Wilcoxon signed ranks test; [c]Kruskal-Wallis test for the comparison between open and closed terraces; [d]*p*-value for trend from an ANOVA with log-transformed nicotine values.

3.2. Measurements on outdoor terraces

On the terraces (n = 51), the overall median nicotine concentration was 0.54 μg/m^3 (IQR: 0.25, 1.14 μg/m^3). Four samples were below the limit of quantification. Significant differences were found in the median nicotine concentrations between open and closed terraces (0.44 *vs.* 0.72 μg/m^3; $p = 0.017$; Table 5, Fig. 1(B)). Among open terraces, those with roofs (n = 11) had higher median nicotine concentrations (0.94 μg/m^3; IQR: 0.25, 1.94 μg/m^3); among closed terraces with a complete roof and ≥ 3 complete walls (both of solid materials and without openings; n = 7), the median nicotine concentration was 2.97 μg/m^3 (IQR: 1.95, 4.64 μg/m^3).

We found significant differences in the median nicotine concentrations based on the number of smokers present during the entire monitoring period (0.27 μg/m^3 when 1–3 smokers were present and 1.24 μg/m^3 when > 6 smokers were present; $p = 0.001$), the minutes someone smoked during the monitoring period (0.24 μg/m^3 for 1–10 min and 1.24 μg/m^3 when > 20 min; $p < 0.001$), and the presence of a tobacco smell (0.19 μg/m^3 when no smell and 0.60 μg/m^3 when smell was perceived; $p < 0.05$). We

Table 4
Multivariate analysis[a] of the relationship between indoor and outdoor nicotine concentrations in cafés and restaurants (Barcelona, Spain, 2013).

	β	95% confidence interval	*P*-value	R^2
Model 1				0.231
Constant	−0.1709	−0.4852, 0.1432	0.279	
Outdoor nicotine concentration	0.4708	0.2131, 0.7286	0.001	
Model 2				0.372
Constant	−1.1100	−2.5636, 0.3434	0.130	
Outdoor nicotine concentration	0.4044	0.1132, 0.6956	0.008	
Area indoors (> 40 m *vs* ≤ 40 m)	0.2756	−0.3730, 0.9244	0.394	
Distance to the entrance (> 5 m *vs* ≤ 5)	−0.1337	−0.7466, 0.4791	0.661	
Door status (open *vs* closed)	0.6591	−0.2464, 1.5646	0.149	
No. of smokers at the entrance				
3–5 *vs* 1–2	−0.2235	−0.8522, 0.4051	0.475	
> 5 *vs* 1–2	0.4515	−0.2376, 1.1407	0.192	
Roof (yes *vs* no)	−0.3319	−0.9258, 0.2620	0.265	
Wind direction				
Lateral *vs* no wind	0.1953	−0.3785, 0.7691	0.494	
Frontal *vs* no wind	0.6047	−0.6738, 1.8833	0.344	
Lateral and frontal *vs* no wind	0.9950	−0.7990, 2.7890	0.268	

[a] Estimates from multiple linear regressions (log transformed nicotine concentrations).

also found differences in nicotine concentrations based on the distance to the door, but there were no significant differences in nicotine concentrations based on the outdoor terrace area or seasonality (Table 5).

We further characterized nicotine concentrations on terraces by assessing the bivariate and multivariate association with all the variables previously considered in Table 5. The model that best fitted the nicotine concentration ($R^2 = 0.396$) included the outdoor terrace area, the season, the type of enclosure, and the number of smokers (Table 6). Nicotine concentration increased in closed terraces (β = 1.0859; $p = 0.010$) and with increasing number of smokers (β = 0.4544; $p = 0.280$ for 4–6 smokers and β = 1.5583; $p = 0.001$ for > 6 smokers on the terrace).

4. Discussion

The assessment of exposure to second-hand smoke via simultaneous measurement of vapor-phase nicotine indoors and at the entrances of cafés and restaurants indicates that tobacco smoke drifts from the outside entrances to the indoor areas. Notably, no differences were observed across the studied variables when the door was open or closed. A possible explanation is that an open door has the potential for higher drift of tobacco smoke but it may also favor more ventilation. We did not record, and as such were not able to control for, the number of people entering or exiting through the door, which may influence the ventilation due to the air currents generated by the transit. However, our data show that the nicotine concentration indoors is significantly related to the nicotine concentration at the outside entrance, independent of other indoor or outdoor variables except the number of smokers at the entrance. Our results confirm previous studies monitoring vapor-phase nicotine (López et al., 2012), particulate polycyclic aromatic hydrocarbons (Zhang et al., 2009), or particulate matter in different settings (Brennan et al., 2010; Edwards and Wilson, 2011; Kaufman et al., 2011; St Helen et al., 2011; Stafford et al., 2010; Sureda et al., 2012; van der Deen et al., 2014).

Table 5
Median and interquartile range (IQR) of vapor-phase nicotine concentration on 51 outdoor terraces of cafés and restaurants in Barcelona, Spain, 2013.

	Nicotine (μg/m^3)			
	n	Median (IQR)	Min, max	*P*-value[a]
Total	51	0.54 (0.25, 1.14)	< 0.06, 8.73	
Outdoor terrace area				0.151
≤ 15 m^2	21	0.50 (0.25, 1.49)	< 0.06, 3.99	
16–30 m^2	12	0.44 (0.16, 0.63)	< 0.06, 0.92	
> 30 m^2	18	0.74 (0.33, 2.29)	< 0.06, 8.73	
Distance to the door				0.010
≤ 3.5 m	20	0.31 (0.21, 0.60)	< 0.06, 1.94	
3.6–5 m	15	0.92 (0.62, 3.97)	0.26, 8.73	
> 5 m	16	0.51 (0.26, 0.97)	< 0.06, 6.50	
Season				0.977
Mild season	31	0.54 (0.27, 1.14)	< 0.06, 8.73	
Hot season	20	0.54 (0.24, 1.18)	< 0.06, 6.50	
Level of enclosure[b]				0.005
Uncovered, 0–4 walls	15	0.41 (0.23, 0.72)	< 0.06, 6.50	0.003[c]
Covered, 0–2 walls	23	0.48 (0.19, 1.02)	< 0.06, 4.83	
Covered, 3–4 walls (some incomplete)	7	0.48 (0.33, 0.65)	0.27, 0.72	
Covered, 3–4 complete walls	6	3.48 (2.29, 4.64)	1.95, 8.73	
Type of enclosure (*law 42/2010*)[d]				0.017
Open	38	0.44 (0.23, 0.92)	< 0.06, 6.50	
Closed	13	0.72 (0.48, 2.97)	0.27, 8.73	
Tobacco smell				0.029
No	3	0.19 (< 0.06, 0.24)	< 0.06, 0.24	
Yes	48	0.60 (0.28, 1.24)	< 0.06, 8.73	
No. of smokers				0.001
1–3	21	0.27 (0.19, 0.50)	< 0.06, 1.95	
4–6	16	0.51 (0.36, 1.61)	< 0.06, 4.64	
> 6	14	1.24 (0.72, 3.97)	0.23, 8.73	
Minutes someone smoked				< 0.001
1–10	7	0.24 (< 0.06, 0.26)	< 0.06, 1.02	
11–20	20	0.36 (0.21, 0.52)	< 0.06, 0.72	
> 20	24	1.24 (0.74, 3.47)	0.23, 8.73	

[a] Kruskal-Wallis test.
[b] According to the presence of any terrace cover (any form of small or large weather protection system) and walls.
[c] *P*-value for trend from an ANOVA with log-transformed nicotine values.
[d] The Spanish law 42/2010 considers *open terraces* as those uncovered, or with a cover and no more than 2 walls or fences; and *closed terraces* as those covered terraces with more than 2 walls or fences.

Table 6
Multivariate analysis[a] of the nicotine concentration on outside terraces of cafés and restaurants in Barcelona, Spain, 2013.

	Bivariate models		Full model	
	β	95% confidence interval	β	95% confidence interval
Outdoor terrace area				
16–30 m^2 *vs* ≤ 15 m^2	−0.5932	−1.5591, 0.3726	−0.5506	−1.4003, 0.2990
> 30 m^2 *vs* ≤ 15 m^2	0.3773	−0.4800, 1.2347	−0.1366	−0.9237, 0.6503
Season (hot *vs* mild)	−0.1562	−0.9420, 0.6295	−0.1228	−0.8580, 0.6124
Type of enclosure (closed *vs* open)	1.0772	0.2515, 1.9029	1.0859	0.2766, 1.8951
No. of smokers at the terrace				
4–6 *vs* 1–3	0.6873	−0.1015, 1.4823	0.4544	−0.3836, 1.2926
> 6 *vs* 1–3	1.6632	0.8366, 2.4897	1.5583	0.6801, 2.4365

[a] Estimates from multiple linear regressions (log transformed nicotine concentrations).

Particulate matter has been the most commonly used airborne marker to monitor second-hand smoke in open and semi-open settings (Sureda et al., 2013). Nevertheless, this marker should be used with caution, as it may have other potential sources besides tobacco smoke. In fact, the correlation between particulate matter and nicotine in outdoor settings is far from satisfactory (Fu et al., 2013; Sureda et al., 2012). Therefore, nicotine, a sensitive and specific marker of tobacco smoke, should be used alongside particulate matter in outdoor settings.

Other variables, such as proximity to the smoking source, outdoor enclosures, and/or wind, have been linked to outdoor second-hand smoke exposure (Licht et al., 2013; Sureda et al., 2013). Some evidence of drift has been found, particularly where free communication exists between indoor and outdoor areas (Edwards and Wilson, 2011; Mulcahy et al., 2005). We observed that drift seemed to occur even in venues where the door was mainly closed. Yet, the presence of an additional set of interior doors does not aid in avoiding this drift (Kaufman et al., 2011), indicating that a closed door does not protect non-smokers who are indoors from tobacco smoke at the entrances, probably because employees and patrons entering and leaving let polluted air drift from outdoors to indoor areas. This exchange of air could also explain why we did not find differences between cold and mild seasons as other studies have (Arku et al., 2015). In Barcelona, temperatures are usually not extreme, and the continuous transit of people through the doors may favor air exchange.

One study assessing tobacco smoke exposure in hospitality venues in eight European countries (López et al., 2012) found non-significant differences between the median nicotine concentrations in indoor and outdoor areas of restaurants where indoor smoking was banned (0.79 μg/m^3 and 0.66 μg/m^3, respectively). These values are slightly higher than those observed in our study and could be attributed to differences in the structure of the outdoor areas, smoking prevalence, legislation on smoking, or differing enforcement of smoke-free laws in the countries studied at the time the study was conducted (2009–2011; López el al, 2012). Nevertheless, our results are not negligible because the maximum observed nicotine values were within 1–10 μg/m^3. Taking nicotine as a specific marker of second-hand smoke, this nicotine concentration range has been linked to morbidity and mortality and found to be carcinogenic in humans. Furthermore, acute and chronic respiratory health effects have been demonstrated in children in homes with occasional smoking (0.1–1 μg/m^3) (WHO, 2000).

When considering outdoor terraces only, we found that the nicotine concentration differs according to the type of enclosure, presence of a tobacco smell, the number of smokers, and the number of minutes someone smoked. Similar results were obtained by Klepeis et al. after studying airborne particle concentrations in 10 public outdoor locations (Klepeis et al., 2007). Cameron et al. (2010) also assessed second-hand smoke exposure outdoors using the $PM_{2.5}$ concentration and found that the presence of overhead covers and roofs alone provided the most robust findings, regardless of the presence and height of walls; and the number of cigarettes in close vicinity (within 1 m) significantly predicted exposure levels, with an increase of the average $PM_{2.5}$ concentration by 34% over the entire time spent at the venue with every additional lit cigarette; in contrast, being situated underneath an overhead cover increased the average $PM_{2.5}$ concentration by 51% over the entire measurement period and by 71% during the time the cigarettes in close vicinity were smoked (Cameron et al., 2010). Other studies using both $PM_{2.5}$ and vapor-phase nicotine concentration also observed an increase in the exposure to tobacco smoke when any kind of overhead cover existed (López et al., 2012; Sureda et al., 2015).

Observational variables, such as tobacco smell, number of smokers, and number of minutes someone smoked, are difficult to assess when the terrace area is large and the observation point is far from the smoke source. In this investigation, having the best observation point was not always possible because it had to be chosen from the available free tables. To overcome this limitation, it may be more appropriate to use two simultaneous observers at different points on the terrace, as both physical and behavioral factors (proximity to smokers) may condition outdoor exposure (Apelberg et al., 2013). However, this limitation would bias our results to the null hypothesis (no differences). Despite these difficulties, we were able to find differences in nicotine concentrations according to some variables. Unfortunately, we did not control for other potentially relevant variables, such as wind speed and direction (Klepeis et al., 2007). We also acknowledge the potential variability in the collection of these observational data. Although all five researchers involved in the fieldwork were trained together, 70% of the indoor measurements were done by the same researcher (MF), and the two researchers collecting data on the terraces noted the same observational variables, which were compared afterwards; the averaged measures were used in case of any difference. Moreover, we used wide ranges of areas and volumes in the stratification, hence reducing the scope for misclassification.

Notably, smoking was observed on terraces where it was expected to be banned according to current Spanish legislation. No-smoking signage was absent on all kinds of terraces, and on most of them ashtrays were available, which sends the message of smoking permissiveness. Closed terraces had the highest nicotine concentration, showing that the smoking ban on outdoor terraces is not enforced and that its compliance should be guaranteed. That was also observed at the beginning of 2015 in an observational study by an association of consumers about the compliance of the law in these and other venues of 12 cities in Spain; the study showed that smoking was allowed in 87% (106 out of 121) of the closed terraces visited, and 98% (119 out of 121) did not have the compulsory no-smoking signage (OCU, 2015).

The operational definition of the level of enclosure may be difficult. Even when a city ordinance in Barcelona regulates different aspects related to terraces, such as the distance to the buildings or some urban elements, there is great variability in the structural conditions, making it difficult to describe and classify them in an operational way. There are diverse definitions in the literature that consider variables such as coverage or number of walls. In addition to the definition included in Spanish law 42/2010, we used four categories to define different levels of enclosure, taking into account the presence of any kind of coverage and the number of walls, and whether they were complete or incomplete. Further investigation should test these or other definitions to allow for comparisons across different studies.

Air monitoring is complex. Air pollution is regularly unevenly dispersed and may vary from season to season; thus, monitoring results represent the specific point and time where and when the measurement was made (WHO, 1999). Moreover, there is a true variability that occurs in relationship to exposure when people are relatively near multiple point sources. Therefore, the main limitation of our results would be that they cannot be generalized without considering this premise. Although we cannot predict the absolute concentration when studying similar exposures to tobacco smoke in other cities, we may generalize about the relative concentrations of nicotine near the entrances, and that they are correlated with indoor concentrations where smoking is not allowed. Moreover, although the concentration in terraces may vary in different contexts, its determinants should be not very different. Also, though we defined the observation point at the outside entrance and on the outdoor terrace, we did not register the precise distance between the sampler cassette and the smoke sources, which were variable in many cases. On the other hand, the use of vapor-phase nicotine to investigate tobacco smoke exposure is a strength of our investigation, because it is tobacco-specific and very sensitive at low concentrations. Most previous studies on exposure to second-hand smoke in outdoor settings have used particulate matter, which is not tobacco-specific and have a worse performance when is measured outdoors than in indoor settings (Fu et al., 2013; Sureda et al., 2012). We used a sample of venues from all districts of Barcelona and made the measurements under real conditions. This design is complex from the point of view of the fieldwork implementation, but it favors the observation of the natural behavior of smokers and reflects the real potential exposure of patrons and workers.

5. Conclusion

Our results indicate that passive exposure to tobacco smoke occurs in indoor areas of hospitality venues in association with smoking at the outside entrances to these venues. Exposure may also occur on outdoor terraces when smokers are present and the terrace is closed to some extent. Smoking in outdoor areas adjacent to smoke-free areas may expose non-smoking patrons and workers to tobacco smoke. Thus, the regulation of smoking in the area near the entrances, as already enacted in some jurisdictions (Azagba, 2015; Lee et al., 2013), is necessary. These regulations are supported by good acceptance by the population (Kennedy et al., 2012; Sureda et al., 2015; Thomson et al., 2009). Thus, the question of whether smoke-free regulations should be extended to outside entrances and outdoor terraces would have an affirmative answer. The appropriate smoke-free area around the entrance is still unclear, though a distance of 6–9 m has been proposed (Hwang and Lee, 2014; Kaufman et al., 2011; Repace, 2005). Informing and making the population aware (workers and patrons) of the potential for tobacco exposure outdoors is advisable. Enforcing smoking regulations on enclosed terraces is of particular importance, and a good start is the use of non-smoking signage in addition to compliance monitoring.

Contributors

MF, XS, NSE and EF conceived the study. MF, NSE, EF, NQ, and JMMS conducted the field work. GN and FC designed and supervised the analytical procedures. MF prepared the database and analyzed the data, with the advice of JMMS and EF. MF drafted the manuscript. All authors contributed substantially to the interpretation of the data and manuscript review, and approved its final version. EF is the guarantor.

Conflict of interest

The funding sources have not any involvement in the study design; in the collection, analysis, or interpretation of data; in the writing of this work; or in the decision to submit the manuscript for publication. The authors declare no conflict of interest.

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