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ORIGINAL ARTICLE

Outdoor ultrafine particle concentrations in front of fast food restaurants

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Ultrafine particles (UFPs) have been associated with negative effects on human health. Emissions from motor vehicles are the principal source of UFPs in urban air. A study in Vancouver suggested that UFP concentrations were related to density of fast food restaurants near the monitoring sites. A previous monitoring campaign could not separate the contribution of restaurants from road traffic. The main goal of this study has been the quantification of fast food restaurants' contribution to outdoor UFP concentrations. A portable particle number counter (DiscMini) has been used to carry out mobile monitoring in a largely pedestrianized area in the city center of Utrecht. A fixed route passing 17 fast food restaurants was followed on 8 days. UFP concentrations in front of the restaurants were 1.61 times higher than in a nearby square without any local sources used as control area and 1.22 times higher compared with all measurements conducted in between the restaurants. Adjustment for other sources such as passing mopeds, smokers or candles did not explain the increase. In conclusion, fast food restaurants result in significant increases in outdoor UFP concentrations in front of the restaurant.

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INTRODUCTION

Ultrafine particles (UFPs) defined as particles <100 nm have been shown to be harmful for human health.[1,2] Because of their small size, UFPs can penetrate deep into the lungs and may enter the blood vessels. Sources of UFPs in outdoor air include combustion processes in especially motorized traffic, industry and residential heating and secondary formation from gaseous precursors.[1–4] A variety of sources of UFPs in indoor air has been identified, including cooking, smoking and electric appliances. Some studies have suggested that high UFP concentrations occur inside restaurants, especially barbecue restaurants[5] and fast food restaurants[6]. Cooking styles influence the concentration of particles emitted in the air, for example, frying (particularly deep frying) produces high particle number emissions. Although studies have reported high UFP or fine particles inside of bars, cafes and restaurants,[5–9] there is limited evidence of the effect that ventilation of indoor air from hospitality venues has on outdoor air quality. A land use regression model from Vancouver, Canada reported that the density of fast food restaurants in 100- or 200-m buffers was one of the predictors of spatial variation of UFPs.[10] A targeted added monitoring campaign in Vancouver could not disentangle the impact of restaurants from high road traffic intensity.[10] Because of the smoking ban in restaurants in many countries, including the Netherlands, smokers nowadays often smoke in front of the restaurants and bars, further complicating monitoring campaigns to assess impacts of (fast food) restaurants on outdoor air quality.

The main objective of this study was to determine the influence of fast food restaurants on outdoor UFP concentrations near the restaurants. The study was performed in a low traffic area in the city center of Utrecht, the Netherlands to limit the effect of other UFP sources. We evaluated the impact of outdoor smoking and other sources on the relationship between proximity to restaurants and outdoor UFP concentration.

METHODS

Study Design

We designed a route in a largely pedestrianized area in the city center of Utrecht (328,577 inhabitants in 2014) (Figure 1) to measure if restaurants increase UFP concentrations. The route is largely free of motorized traffic. Most of the route consists of narrow streets. We selected 17 restaurants distributed over the route. We used mobile monitoring while walking using the DiSCmini in a specially designed backpack to measure 1-s particle number concentrations. The technician stopped for 1–5 min in front of each restaurant and manually recorded the time she was in front of each restaurant. We further recorded the presence of other sources, including smokers, outdoor candle burning and passing motor vehicles, mopeds and (diesel powered) street washing machines with a 1-min resolution. UFP concentrations measured in front of the restaurants were compared with concentrations in between the restaurants. Because of the high density of restaurants along the route, this comparison may underestimate the impact of restaurants as the concentrations not immediately in front of the restaurants may also be affected by restaurant emissions. We therefore also included a “blank area” in the route, which was a small square without any traffic, restaurants and bars (Figure 1). Measurements were taken for 1–3 min in the blank area every monitoring session.

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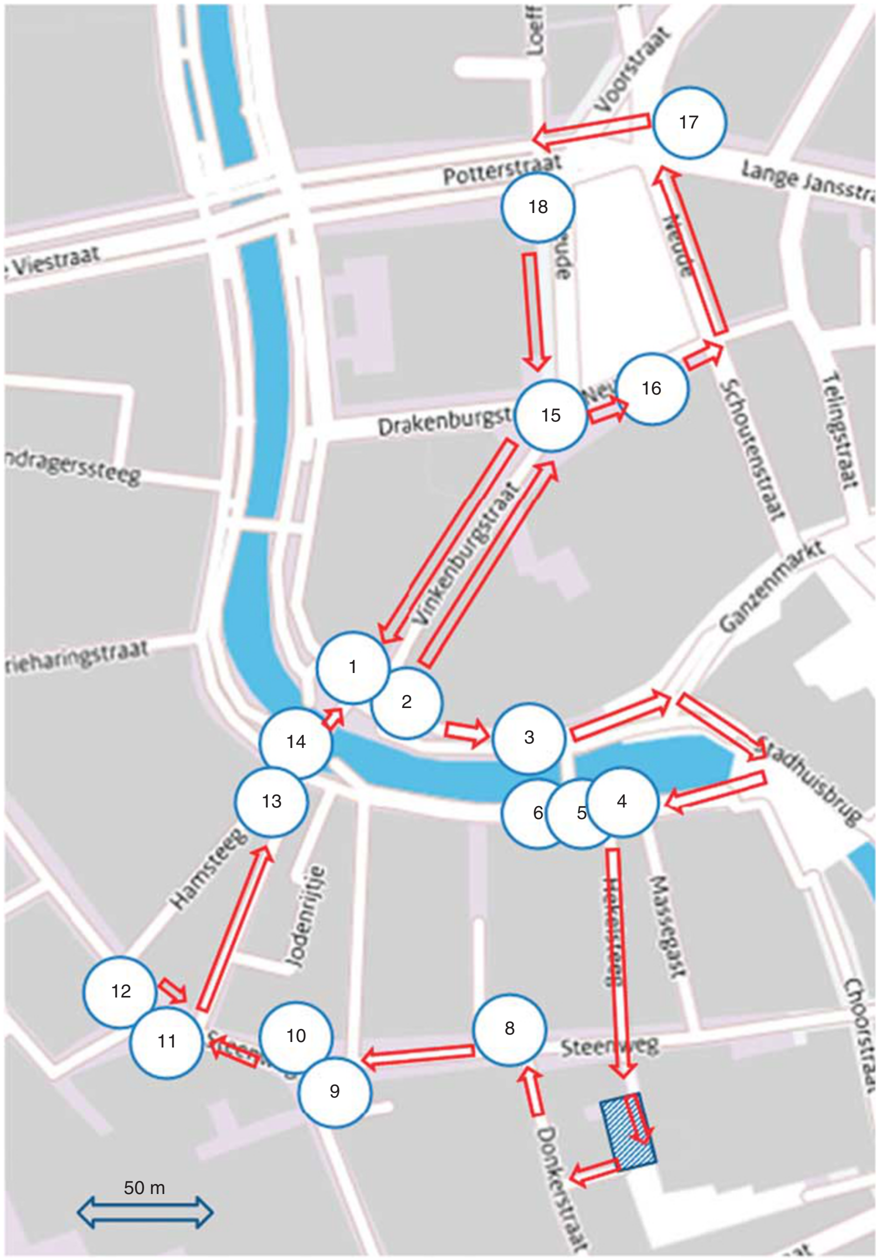

Figure 1. Study area, route and location of restaurants.

Monitoring Method

The DiSCmini (Matter-aerosol, Switzerland) was used to measure particle number concentrations.[11] The DiSCmini is a diffusion size classifier based on electrical charging of aerosols.[11] The instrument measures particles between 10 and 300 nm with a sampling interval of 1 s. The instruments thus does not specifically measure UFPs, but previous studies have documented that particle number concentrations are dominated by UFPs.[1–4] The instrument was calibrated by the manufacturer prior to use. During the experiment, zero checks were performed twice during each monitoring session using a HEPA filter.

Monitoring Route

Eight monitoring sessions were performed, four during midday (between 1130 and 1430 hours) and four during the evening (between 1900 and 2100 hours). Times were selected to avoid the traffic rush hour and to cover the period with high activity of the restaurants. All measurements were performed between 29 October and 13 November 2013. During each sampling session, we also measured the concentration of UFPs in the blank area. We always followed the same route, walking at a moderately slow speed, stopping in front of each restaurant for 1–5 min. Each sampling session lasted about 60 min during lunch time and 35 min in the evening. Restaurants were located in mainly small streets, a square and along the main canal. The restaurants used a variety of cooking methods, with 10 of the 17 restaurants deep-frying food and the remainder using hot cooking plates or hot air ovens. Measurements were made in public streets, not on the premises of the restaurants.

Data Analysis

We processed the DiSCmini data with a *Java tool*, to obtain particle number counts according to the manufacturer's specifications. We compared concentrations of UFPs in front of each restaurant with concentrations measured in between the restaurants and in the blank area.

We used linear regression to investigate the association between UFP concentration and being in front of the restaurants. We further adjusted this association for other sources by including presence of smokers,

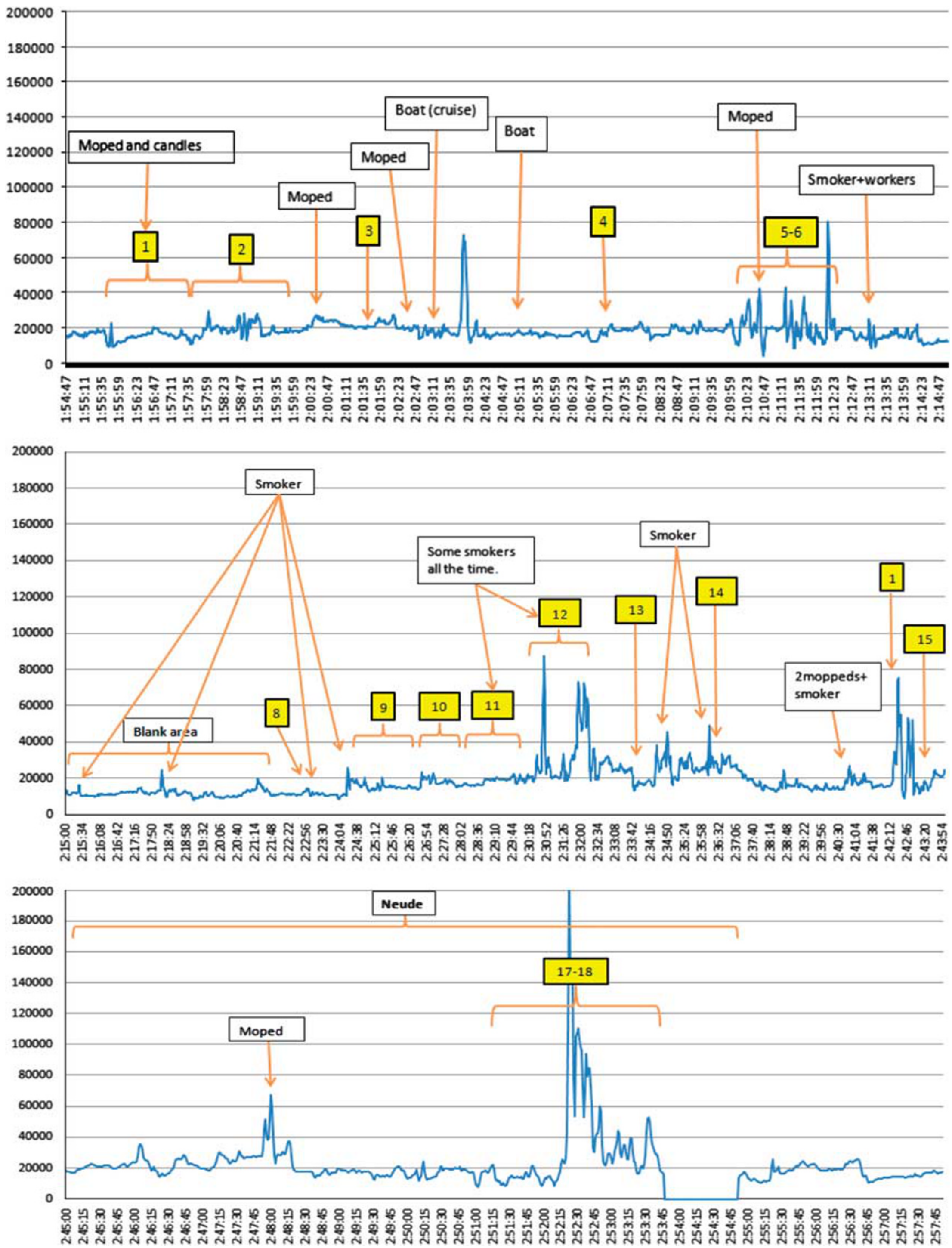

Figure 2. Concentration pattern of UFP (particles/cm^3) on midday 7 November. Label: numbers refer to restaurants.

washing street machines, burning candles, mopeds and vehicles by multiple linear regression. We used the natural logarithm of the UFP concentration as the dependent variable because log-transformation improved normality of the distribution.

RESULTS

Figure 2 shows the concentration of UFP for the monitoring session of midday 7 November as an example. It illustrates the presence of peaks of the UFP concentration in front of the restaurants. We further note the decrease of the concentrations in the blank area. Some high peaks were caused by other sources, such as mopeds, smokers or street washing machines. On average, concentrations of UFPs in the four evening monitoring sessions were higher than the concentration of UFPs during the midday sessions (20,815 particles/cm^3 *versus* 15,550 particles/cm^3).

Overall, we obtained 22,754 valid 1-s observations (6.3 h). A total of 48.7% of these valid UFP measurements were made

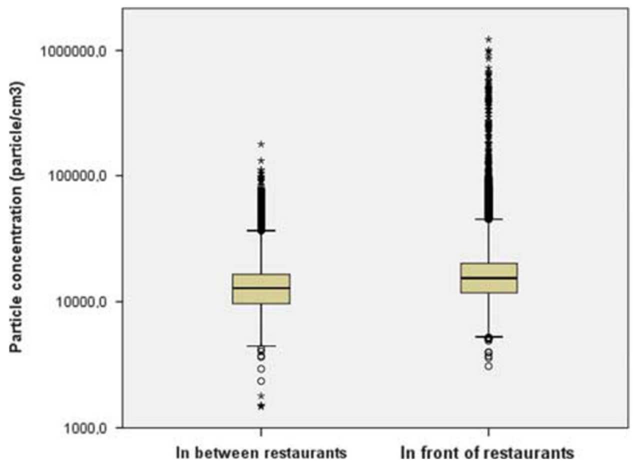

Figure 3. Distribution of particle number concentration (particles/cm^3) in front of the restaurants *versus* in between the restaurants.

Table 1. Ratio UFP concentration in front of the restaurants compared with in between the restaurants, without (model 1) and with (model 2) correction for other sources.

Model	*Frequency*[a] *(%)*	*Ratio*[b]	*95% Confidence interval*	
1				
Restaurant	48.7	1.26	1.24	1.27
2				
Restaurant	48.7	1.22	1.20	1.24
Moped	4.8	1.05	1.02	1.08
Smokers	16.9	0.97	0.95	0.99
Vehicles	2.7	0.99	0.95	1.03
Washing vehicle	1.1	1.35	1.26	1.44
Candles	3.2	1.88	1.81	1.95

[a]Frequency of the presence of source (percentage of valid UFP observations). [b]Comparing UFP concentrations when source is present *versus* absent. Model 2 is a multiple linear regression model, including restaurant proximity and the listed sources. Data affected by other sources were not removed.

in front of a restaurant, 37.5% in between the restaurants and 13.7% in the blank area. Figure 3 illustrates that the average concentration of UFPs in front of the restaurants is slightly higher compared with in between the restaurants. More peaks were measured in front of the restaurants. Figure 3 illustrates the skewed distribution, motivating the logarithmic transformation for the regression analysis.

On average, the concentration of UFP in front of the restaurants was 1.26 times higher than the concentration in between the restaurants (Table 1). Adjusted for other sources, the ratio was slightly reduced to 1.22. All other recorded sources were statistically significant except motor vehicles, likely related to the very low frequency of passing motor vehicles. The largest relative contributions were found for the street washing machines and candles. Presence of smokers was associated with 3% lower outdoor concentrations.

Because the observations in between the restaurants may still be affected by restaurant emissions, we also compared UFP measurements in front of the restaurants with the measurements in the blank area (Table 2). Restaurant UFP concentrations were

Table 2. Ratio UFP concentrations in front of the restaurants and in between the restaurants compared with the blank area, without (model 1) and with (model 2) correction for other sources.

Model	*Ratio*[a]	*95% Confidence interval*	
1			
Restaurant[b]	1.65	1.61	1.68
In between the restaurant[b]	1.44	1.42	1.47
2			
Restaurant[b]	1.61	1.58	1.64
In between the restaurant[b]	1.45	1.43	1.48
Moped	1.04	1.01	1.07
Smokers	0.94	0.92	0.95
Vehicles	1.01	0.97	1.05
Washing vehicle	1.26	1.18	1.34
Candles	1.86	1.80	1.93

[a]Comparing UFP when source is present *versus* absent. [b]Comparing in front of the restaurants and away walking in between the restaurants with those in the blank area. Blank area is an a enclosed square without restaurants and traffic.

1.65 times higher than in the blank area (1.61 after adjustment for other sources). A ratio of 1.14 was found comparing restaurant *versus* walking UFP concentrations. The concentrations measured while walking the route in between the restaurants was 45% higher than in the blank area.

Large differences in UFP concentrations were observed between the 17 restaurants (Table 3, Figure 4). The increase of UFP concentrations in front of mobile stands was slightly but statistically significantly higher than in front of non-mobile restaurants (ratio of 1.29 *versus* 1.25). The geometric mean particle concentration was 16,719 in front of the six mobile stands *versus* 16,265 particles/cm^3 in front of the remaining restaurants (3% higher). In front of the 10 restaurants that deep fried food, on average 10% higher UFP concentrations were measured compared with the 7 restaurants that did not. The location of the restaurant (in a narrow street *versus* a square with more dispersion) did not clearly affect the UFP concentration. Restaurant 16, which is in a line of restaurants/bars situated in a square, has the highest concentration of UFP, likely because of the presence of multiple restaurants, the presence of larger numbers of smokers and burning candles at the outdoor terraces. The concentration of UFP in the area around restaurant 16 was usually higher during the evening, when more candles are burning, than during midday.

Table 3 further illustrates that the calculated UFP contribution by restaurants is larger when a comparison is made with the blank area than with the observations just before and after the restaurant monitoring. Except for restaurant 8, all average concentrations in front of restaurants exceeded the blank area concentration. Restaurant 8 is located closest to the blank area and is more a cafe, with relatively little preparation of fried food which produce high concentrations of UFPs. The average concentration measured in front of the restaurants was higher than the average of the measurements before arriving at the restaurant for 14 of the 17 restaurants. For 12 of the 17 restaurants, the average exceeded the measurements after the restaurant was monitored. In these comparisons, only the observations until the next restaurant were included for comparison.

Table 3. Average of the concentration of UFP (particles/cm^3) measured in front of each restaurant and difference with UFP in the blank area and the average measured directly before and after that.

Restaurants	*Type of cooking*	*Average*	*Difference blank area*	*Difference Before*	*Difference After*
1	Deep fry	15,703	4330	−7129	−3565
2	Deep fry/hot plate/oven	17,520	6147	754	2505
3	Hot plate	17,370	5997	2265	4542
4	Hot plate/hot air oven	13,825	2452	805	328
5 (MS)	Deep fry	26,904	15,531	11,842	11,842
6 (MS)	Deep fry	19,362	7989	3062	3342
Blank area		11,373	—	−1239	−1231
8	Hot air oven	11,071	−302	1108	−2044
9	Deep fry/grill	14,434	3060	254	−2237
10 (MS)	Hot air oven	15,130	3756	2251	−2313
11	Hot air oven	27,301	15,928	11,676	11,051
12	Deep fry	14,386	3013	2573	−4411
13	Deep fry	18,944	7571	−215	6
14 (MS)	Deep fry	18,612	7239	−1862	2088
15 (MS)	Hot plate	17,339	5966	1697	2598
16	Deep fry/hot plate/grill/hot air oven	30,477	19,104	13,996	13,246
17	Hot air oven	21,796	10,423	5315	4565
18 (MS)	Deep fry	18,441	7067	3298	3553

Abbreviation: MS, mobile stand.

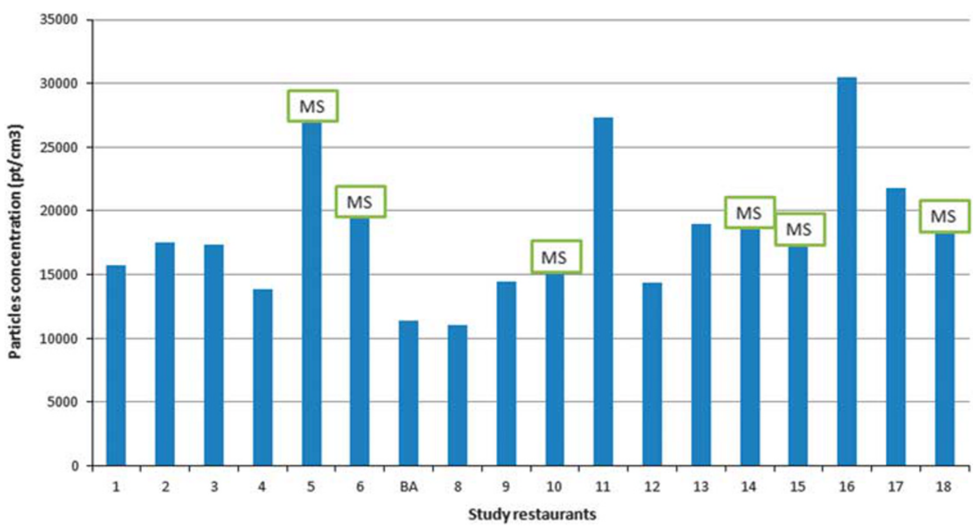

Figure 4. Average of UFP concentration (particles/cm^3) for each restaurant. BA, blank area; MS, mobile stand.

DISCUSSION

A mobile monitoring campaign showed that outdoor concentrations of UFPs were higher in front of fast food restaurants. The increased concentrations were not explained by other sources, such as motorized traffic and outdoor smokers.

Restaurants

Directly in front of the restaurants, outdoor UFP concentrations were 1.22 times higher than measurements made on a route in between the restaurants and 1.61 times higher than in a nearby blank area. Our study supports the observation in a modeling study in Vancouver, which showed that fast food density in a 200-m buffer was a significant predictor of outdoor UFP concentrations.[10] The comparison with the blank area likely overestimates the contribution of restaurants, as other sources may have contributed to the higher background along the monitoring route, including smokers, candle burning, emissions from the few recreational boats in the canal and road traffic (mopeds). The comparison with measurements along the monitoring route likely underestimates the contribution of restaurants, as the impact of restaurant emission may extend beyond the immediate vicinity of the restaurant. We did not attempt to assess the extent of the impact because of the high density of restaurants in the area and because we did not have information available about wind direction. For the observations directly in front of the restaurants, lack of wind data is probably not a main concern because of the typically narrow streets along the monitoring route. A strength of the study is the low traffic intensity along the monitoring route, largely avoiding the main source of primary UFPs in urban areas.[1–4] In the Vancouver study, the authors note that an additional monitoring campaign could not disentangle the impact of fast food restaurants from motorized traffic.[10] A further strength is that we recorded the presence of other sources (smoking, candle burning, passing vehicles) and adjusted the associations between being in front of

a restaurant and UFPs for these sources. Adjustment for these sources made little difference to the estimated effect of restaurants in our study. Smoking in front of the fast food restaurants in our sample was in fact not frequent, as most people do not spend a long time in these restaurants. Outdoor smoking was more common for bars and regular restaurants.

The increase in outdoor UFP concentrations is consistent with previous studies documenting high particle concentrations inside hospitality venues.[8,9] A UFP personal monitoring study showed an average UFP concentration of 94,500 particles/cm^3 inside restaurants compared with an outdoor background of 7900 particles/cm^3.[9] The increases of about 7000 particles/cm^3 in outdoor air we observed in our study (compared with the blank area) thus seem plausible. The measurements were made in public streets and not on the premises of the restaurants. The measurements thus represent exposures that may be relevant for pedestrians/cyclists in the area. As people only spend a short time in front of the restaurants, the direct public health relevance of the increase in pollution is likely limited for pedestrians in the area. The importance of the observation is the documentation that fast food restaurants represent an additional source of UFPs, which may contribute to overall UFP exposures across the city.[10] Possibly the observation of the large difference of the background UFP concentration along the route with a nearby square without local sources is more important in terms of exposure, because the duration of exposure related to shopping is longer.

A large variability of UFP concentrations between restaurants was found. We did not collect systematic information about the restaurants to explain these differences, but differences in cooking styles, volume of cooking, location and design of the ventilation system and distance to the restaurant likely have played a role. We found significantly higher impacts of mobile stands compared with regular restaurants, possibly related to the way food is prepared (frying) and the height and type of ventilation system. Mobile stands typically have their chimney in the back of the caravan. We did not collect systematic information about ventilation systems.

The 1.22 times higher UFP concentration in front of the restaurants is smaller but still substantial when compared with the impact of motorized road traffic on UFP concentrations measured in previous studies. Because we specifically selected a largely motor vehicle-free study area, we do not compare with motor vehicle impacts within our study. Recent studies in the Netherlands found ratios of between 1.3 and 2.7 comparing UFP concentrations at the facade of homes in major roads to urban background.[12–14] A review of studies worldwide showed even larger contrasts for roadside measurements, which were made closer to the roads than the Dutch studies.[3,4]

We performed our study in the fall only. UFP concentrations related to emission of combustion sources typically show highest concentrations in the winter and lowest in the summer season because of poorer dispersion conditions.[1] The measured impact of restaurants may therefore not represent the annual average impact.

Candles, Smoking and Mopeds

UFP concentrations were also significantly related to passing mopeds, candle burning outdoors and municipal street-cleaning vehicles. The ratios in Table 1 translate into concentration increases of 2841 particles/cm^3 in front of the restaurants, 597 particles/cm^3 per passing moped per minute, -371 particles/cm^3 in front of smokers, -91 particles/cm^3 per passing motor vehicle per minute, 4505 particles/cm^3 for washing vehicles and 11,389 particles/cm^3 for candle burning. The significant impact of passing mopeds agrees with a previous Dutch study among cyclists.[15] In our study, the magnitude of the impact of passing mopeds (and of the few cars) may have been underestimated as we recorded the presence of other sources on a 1-min basis and peaks related to passing vehicles may last only for about 10 s.[15] Candles have been shown to affect indoor UFP concentrations in homes and restaurants,[8,16] but to our knowledge no data exist on the effect of candles on outdoor air quality. In a German study, candle burning and cooking were the dominant sources for increased residential indoor UFP concentrations.[16] Street-cleaning vehicles are diesel powered and are less regulated than diesel cars.

We did not find that outdoor smoking increased UFP concentrations. We even found a small negative association, which was reduced to non-significant when the observations while stopping in front of the restaurants were removed. A recent review documented significant increases of outdoor PM2.5 concentrations related to outdoor smoking at hospitality venues and entrances of buildings.[17] In the review, no data on effects of smoking on UFP concentrations were presented. The lack of effect of smoking in our study could be due to the location of our measurements in the street in front of the restaurants as opposed to on the premises of the restaurant in most reviewed studies. Significant decreases in concentrations of PM2.5 within meters from smokers have been reported.[17] An experimental study with a simulated smoking source showed that PM2.5 increased to 73, 11, 4 and 3 μg/m^3 at distances of 1, 3, 6 and 9 m from the source.[18] Further reasons for the lack of an observed effect could include the recording of smoking on a 1-min basis. Smoking has been related to increased UFP in indoor settings.[8,19,20] An experimental study showed that mainstream tobacco smoke contains a sizable fraction of UFPs (count median diameter 0.1 μm) in addition to fine particles.[21]

CONCLUSION

A mobile monitoring campaign showed that outdoor concentrations of UFPs were 1.22 times higher in front of fast food restaurants. The increased concentrations were not explained by other sources, such as motorized traffic and outdoor smokers. The increase in concentration was smaller than previously reported for major roads but still substantial. The public health importance is probably limited for passersby because of the short exposure time. The measurements document that fast food restaurant emissions may contribute to overall UFP concentration variability in urban areas, supporting a study in Vancouver that included fast food density as a predictor in a land use regression model of UFPs. Future studies should collect more information on the source to explain the large variability of UFP concentrations across restaurants.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

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