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Smoking increases air pollution levels in city streets: Observational and fine particulate data

Vimal Patel, George Thomson*, Nick Wilson

Department of Public Health, School of Medicine and Health Sciences, Te Tari Hauora Tumatanui, University of Otago Wellington, PO Box 7343, Wellington South, New Zealand

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ABSTRACT

Introduction: To address the paucity of research around smokefree streets, we: (i) refined existing data collection methods; (ii) expanded on the meagre previous research in this area; and (iii) compared results by differing size of urban centre.

Methods: We refined established methods; a solo observer simultaneously observed smoking and measured fine particulate levels ($PM_{2.5}$) on a route of shopping streets in central Lower Hutt City, New Zealand.

Results: Over 33.6 h of measurement, mean fine particulate levels were 1.7 times higher when smoking was observed than when it was not (7.9 vs 4.8 μg/m^3; $p=0.0001$).

Conclusions: Smoking appeared to be a substantive contributor to fine particulate air pollution in city streets, when compared to levels adjacent to road traffic.

1. Introduction

Smokefree city streets are a frontier domain for denormalising smoking and reducing nuisance and health concerns for non-smokers (American Nonsmokers' Rights Foundation, 2011; Ueda, 2011). These policies are also attracting attention from urban authorities who may be interested in 'healthy' city branding, and reducing litter and fire costs (Schneider et al., 2011). In particular, tobacco smoke pollution (TSP) has been found to contribute to outdoor air pollution as measured by fine particulate ($PM_{2.5}$) levels from work in Canada (Kennedy et al., 2007); the USA (Klepeis et al., 2007); Australia (in Perth (Stafford et al., 2010) and in Melbourne (Cameron et al., 2010)) and New Zealand (Wilson et al., 2011). Further work in Canada found that smoking within nine metres of building entrances significantly contributes to raised $PM_{2.5}$ levels (Kaufman et al., 2011). Previous work in New Zealand observed smoking and measured air quality in central city streets in Wellington, the capital (Parry et al., 2011). But in that study, simultaneous observation of smoking behaviour and measurement of air quality was for a relatively limited period (3.4 h).

To supplement the very limited work on observing smoking and corresponding fine particulate levels on shopping streets (Parry et al., 2011), we aimed to: (i) refine existing methods to simultaneously observe smoking and air quality measurements with a single observer; (ii) conduct these observations and measurements for a much longer period than in the central Wellington study; and (iii) compare our results (from streets in a small urban centre) with previous data from central Wellington (Parry et al., 2011).

The context for the new study was the Lower Hutt City shopping area (Lower Hutt city is adjacent to Wellington). The shopping area comprises two main streets and an adjacent shopping mall (Queensgate)—see http://goo.gl/maps/lXyj. The buildings do not exceed six stories, and rarely exceed two stories. The street footpaths (sidewalks) are generally 3–4 m wide. Compared to Wellington City, Lower Hutt has a lower population (102,700 vs 197,000 people). The Lower Hutt shopping area has lower: foot traffic levels; daytime population; and proportion of businesses with outdoor eating areas.

2. Methods

A trial protocol was developed and tested to ensure our methods were feasible. Using the final protocol, smoking by people outdoors on the street was observed and fine particulate ($PM_{2.5}$) levels were measured while:

(a) Walking along a standard route of shopping streets in central Lower Hutt City of 2.4 km length ($n=35$ occasions), averaging 56 min per sampling period, at 2-hour intervals (starting from

* Corresponding author. Tel.: +64 4 385 5541x6054; fax: +64 4 389 5319.
E-mail addresses: vimal.patel@otago.ac.nz (V. Patel), george.thomson@otago.ac.nz (G. Thomson), nick.wilson@otago.ac.nz (N. Wilson).

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8.30 am to 6.30 pm) on Tuesdays, Fridays and Saturdays between 9 April and 14 May 2011 (route map: http://goo.gl/maps/lXyj).

For each sampling period, a single observer (VP) walked one length of the route on one side of the street, then upon reaching the end of the route, switched to the opposite side of the street and walked the return length. The observer walked in the direction of road traffic flow (of the nearest lane) and counted only people who were seen to be smoking who passed by. The observation area included up to the middle of the road, so that each sampling period would cover the total road and pavement area. Data were only collected on people who were smoking outside (i.e., not within buildings or vehicles) and at these times:

(b) At purposeful settings along this route ($n=5$ occasions, averaging 12 min per sampling period);

(c) Adjacent to rush-hour traffic along this route ($n=1$ occasion for 30 min (route map: http://goo.gl/maps/S4iF)); on Saturday, 7 May 2011.

2.1. Observation

Active smoking was defined as someone holding a lit cigarette/cigar/pipe in their hand/mouth. Wind speed measurements were taken at predetermined locations on the route using a hand-held monitor when walking along the Lower Hutt route or adjacent to rush-hour traffic.

When smoker(s) were observed, data were recorded in real-time on the number of smokers observed and the approximate proximity of smokers (from the observer to the nearest metre). Each smoker observed was counted separately in establishing totals (although it is possible that some may have been re-encountered during the walking).

2.2. Fine particulate measurement

Established methods (Parry et al., 2011) were used to measure fine particulate levels ($PM_{2.5}$; i.e., particles ≤ 2.5 mm in diameter) related to TSP using a portable real-time airborne particle monitor (the TSI SidePak AM510 Personal Aerosol Monitor; TSI Inc., St Paul, MN). The device was carried hidden in the observer's bag to continuously record mean $PM_{2.5}$ levels over 30 s intervals.

To provide background fine particulate levels, data collected at purposeful settings included periods of time away from smokers (lasting ~3–5 min before and after seeing smokers). While adjacent to rush-hour traffic, fine particulate levels were measured and traffic levels counted (using a mechanical counter) from both sides of the road for equal periods of time.

2.3. Data recording

A refinement to previous methods was that all data were entered using a predefined shorthand into a word processing program (Notes; Apple Inc., Cupertino, CA), which automatically assigns timestamp data to entries. This program was loaded on a personal digital assistant (PDA; Apple iPod touch; Apple Inc., Cupertino, CA). To ensure the automatically assigned timestamp, data between the PDA and air monitor were comparable, the clocks of both devices were routinely checked prior to data collection.

Data were retrieved from the PDA and air monitor using the softwares Mail (Apple Inc., Cupertino, CA) and TrakPro (TSI Inc., St Paul, MN) respectively and transferred into a Microsoft Excel database. An array formula was used to automatically align the data collected from the PDA and air monitor based on their respective timestamps. The aligned data were then manually checked to ensure the alignment process was correct. Data were analysed using Excel, OpenEpi (Emory University) and Stata (StataCorp., College Station, TX).

Ethical approval was granted via the University of Otago ethics approval process.

3. Results

The revised methods used were feasible and are likely to produce more robust results than previous methods. In particular, it was possible for a single observer to collect data on observed smoking and measure fine particulate levels. A total of 284 smokers were observed in 32.7 h of walking along the route of shopping streets in central Lower Hutt, which is equivalent to 1.5 observed smokers every ten minutes (see Table 1).

Table 1
Observed smoking and fine particulate levels ($PM_{2.5}$) for various settings on Lower Hutt City streets.

Setting	Mean $PM_{2.5}$ (μg/m^3) when active smokers observed	Mean $PM_{2.5}$ (μg/m^3) when no active smokers observed	Mean $PM_{2.5}$ (μg/m^3) overall	Min. $PM_{2.5}$ (μg/m^3)	Max. $PM_{2.5}$ (μg/m^3)	Sampling Time (min)	Smokers (n)	Smokers per 10 min (n)
Walk-through street circuit	7.9	4.8	5.0	1.0	64.0	1960	284	1.5
Purposeful—stationary 1	76.5	4.3	8.2	3.0	128.0	18.5	1	–
Purposeful—stationary 2	4.6	5.8	5.5	3.0	10.0	10	2	–
Purposeful—stationary 3	8.6	2.1	5.4	1.0	23.0	7	1	–
Purposeful—stationary 4	126.0	8.2	16.0	4.0	153.0	15	1	–
Purposeful—following 1	7.8	4.6	5.7	4.0	9.0	7.5	1	–
Traffic measurement	–	–	4.8	3.0	17.0	32	–	–

Explanation of settings:
Walk-through: While walking along a standard route of shopping streets in central Lower Hutt.
Stationary 1: 1 m from smokers under high shop overhang at bus stop (partially enclosed).
Stationary 2: 2 m, then 8 m upstream from smokers outside bar (not enclosed).
Stationary 3: 1 m, 2 m, 4 m, 6 m and 8 m from smokers (0.7 kmph downstream wind)—corner High Street & Margaret Street (not enclosed).
Stationary 4: Inside bus stop enclosure, after a smoker had left—Bunny Street.
Following 1: ~2 m behind smoker (not enclosed)
Traffic measurement:both sides of Queens Drive from 5:15–5:45pm (240 vehicles counted).
Mean wind speeds:
Walk through: 3.3 km/h (n=252 measurements; range=0.3–13.6 kmph).
Traffic measurement: 2.1 km/h ($n=1$ measurement).

3.1. Particulate levels

The measurement of fine particulate levels had high face validity, with elevated $PM_{2.5}$ levels when people were observed smoking. While walking along the route of shopping streets in central Lower Hutt, mean $PM_{2.5}$ levels were 1.7 times higher in the collective 2.2 h when smoking was observed than when it was not (7.9 vs 4.8 μg/m^3, Kruskal–Wallis [KW] test for two groups, $p=0.0001$, see Table 1). The mean distance of observed smokers (from the observer) was 2.6 m. The mean wind speed measured on the route of shopping streets was 3.3 kmph ($n=252$ measurements; range=0.3–13.6 kmph).

For purposeful sampling alone (excluding rush-hour traffic measurements), mean $PM_{2.5}$ levels were 4.5 times higher when smoking was observed than when it was not (25.1 vs 5.6 μg/m^3, KW test, $p=0.055$). While standing next to one smoker at a bus stop (which only had a high shop overhang), mean $PM_{2.5}$ levels were 76.5 μg/m^3 with a peak level of 128.0 μg/m^3 (see Table 1).

For *all* sampling (i.e., all walkthrough sampling and purposeful sampling except that adjacent to rush-hour traffic), mean $PM_{2.5}$ levels were almost two times higher when smoking was observed than when it was not (9.3 vs 4.8 μg/m^3, KW test, $p=0.0001$). Similarly, for purposeful sampling adjacent to rush-hour traffic in Lower Hutt (also 9.3 vs 4.8 μg/m^3, KW test, $p=0.0001$) A dose–response pattern between proximity to people smoking and $PM_{2.5}$ levels was also apparent. Mean $PM_{2.5}$ levels when smokers were approximately 1, 2 and 3 or more metres from the observer were 10.5, 8.3 and 7.3 μg/m^3 respectively (KW test, $p=0.1293$). Mean $PM_{2.5}$ levels for multiple smokers were significantly higher than those for only one smoker (9.6 vs 9.2 μg/m^3, KW test, $p=0.0204$) (see Table 2 and Fig. 1).

4. Discussion

Our results confirm that fine particulate levels significantly increase when smoking is observed on shopping streets, over a much larger time period than for previous work in central Wellington City streets, and when passing only 25% of the smokers per hour found in that previous work.

4.1. Observed smoking and fine particulate levels

Fine particulate levels when smokers were observed were lower in Lower Hutt than previous research in central Wellington (for all observations, purposeful and when walking: 9.3 vs 14.2 μg/m^3; and only when walking: 7.9 vs 9.3 μg/m^3) (Parry et al., 2011). This is probably because smoking was observed more frequently in central Wellington compared to Lower Hutt (7 vs 1.5 smokers every 10 min). Alternately, pavements in central Wellington may be more sheltered by tall buildings, and more 'enclosed' compared to Lower Hutt (e.g., due to lower overhanging roofs and/or higher pedestrian foot traffic levels, which would effectively reduce the 'open space' for cigarette smoke dispersal). Nevertheless, wind speeds are generally higher in central Wellington than Lower Hutt (means of measurements from official meteorological stations during the observation dates; 18.1 vs 8.3 kmph respectively) (Personal email from Ross Marsden, New Zealand MetService, 8 September 2011).

The background $PM_{2.5}$ level when smokers were *not* observed was similar to being adjacent to rush-hour traffic in Lower Hutt and in central Wellington, (Parry et al., 2011) (4.8 μg/m^3 and 5.0 μg/m^3 respectively). However, it is higher than mean levels measured in other outdoor recreational settings in the Wellington

Table 2
Pooled fine particulate levels ($PM_{2.5}$) in relation to observed smoking on Lower Hutt City streets.

	Sampling duration (h)	Mean $PM_{2.5}$ (μg/m^3)	Standard deviation $PM_{2.5}$ (μg/m^3)	Min. $PM_{2.5}$ (μg/m^3)	Max. $PM_{2.5}$ (μg/m^3)
Overall	33.6	5.1	4.6	1	153
Smokers observed	2.2	9.3	13.8	1	153
No smokers observed	31.5	4.8	2.9	1	64
Smokers at 1 m	0.4	10.5	17.8	1	128
Smokers at 2 m	0.9	8.3	4.8	2	27
Smokers at ≥ 3 m	0.8	7.3	4.8	1	29
Only one smoker	1.8	9.2	15.0	1	153
Multiple smokers	0.4	9.6	6.3	1	31

Notes: Pooled data from all sampling methods, except traffic measurements in Lower Hutt.

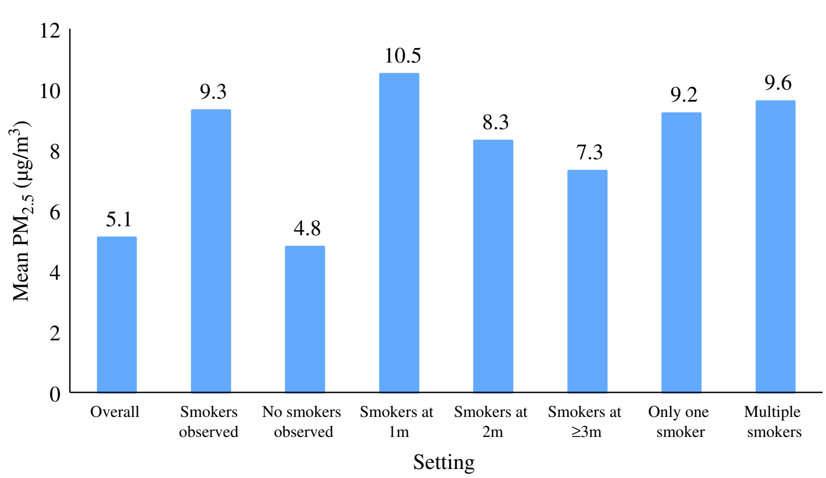

Fig. 1

area, (Wilson et al., 2011) (2 μg/m^3) or in central Wellington during periods with 'quiet' traffic, (Parry et al., 2011) (2.9 μg/m^3). This would suggest that the proportionate effect of smoking on producing fine particulate levels on shopping streets *without* traffic pollution would be even greater than indicated by our study.

Our other findings of very high peak $PM_{2.5}$ levels and dose–response patterns for particulates for both the number and proximity of smokers are consistent with previous research in central Wellington (Parry et al., 2011) and we have replicated them in the setting of a smaller and less densely populated central city area. These results have implications for protecting public health and urban policy planning, given that pedestrians are largely confined to street pavements.

4.2. Quality of the methods

Our refinements to an established protocol, (Parry et al., 2011) were to: (i) record observational data into a PDA; (ii) align observational and fine particulate data automatically; and (iii) simultaneously observe smoking and measure TSP levels for *all* observations of smoking in city streets with a single observer. These refinements which aimed to maximise data quality are likely to produce more robust results than previous methods.

To represent smoking throughout the course of a week, data were systematically collected on a standardised route on Tuesdays, Fridays and Saturdays. The density of pedestrians was such that identifying active smokers was not problematic. The amount of data collected on observed smoking in the streets and corresponding fine particulate levels is ten times greater than the largest previous study, (Parry et al., 2011) (33.6 vs 3.4 h), allowing for much greater statistical precision. Nevertheless, we did not control for all environmental factors that could affect TSP levels (see (section 4.3)).

However, data were collected in just one city at specific times over 5 weeks during one season of the year (autumn). Thus our results may not be fully representative of smoking in Lower Hutt City streets throughout the year (and will not necessarily be readily generalisable to other New Zealand cities). We also did not measure the *prevalence* of smoking in the street (with all observed people as the denominator), as this is problematic when the moving observer method is used and the observation area is constantly changing.

4.3. Further research

This type of study repeated over time in other outdoor settings (e.g., parks, playgrounds, bus stops) locally, nationally and internationally can provide objective comparisons of the extent of smoking, compliance with smokefree laws and TSP levels. Possible refinements include collecting smoking prevalence data and other variables of potential relevance (e.g., pedestrian foot and adjacent road traffic levels, the extent of physical enclosure, the density of venues producing fine particulates from cooking (take-aways and restaurants) (Wilson et al., 2011), and continuous and real-time wind speed/direction). Such additional data may help explain differences in TSP on shopping streets between small and large cities, albeit potentially requiring additional observers and study resources.

Health sector promotion of intervention and systematic evaluation studies would allow the effects of policy changes to be examined as the number and implementation levels of smoke-free outdoor area policies increase over time.

4.4. Policy implications

Urban policy could protect pedestrians from smoking, especially those confined to pavements, and those around outdoor seating (e.g., for cafés). Such smokefree policies for streets could also help limit the drift of TSP indoors (Wilson et al., 2011). There are some precedents for smokefree street policies (Broder, 2006; San Diego Union-Tribune, 2007; Meagher, 2011; Ueda et al., 2011;Wang, 2008; Ogilvie, 2010; The Tribune, 2010) which could help further denormalise smoking, and reduce litter and environmental damage (Thomson et al., 2008; Slaughter et al., 2011).

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References

American Nonsmokers' Rights Foundation, 2011. Smokefree Lists, Maps, and Data: Outdoor Area Lists. American Nonsmokers' Rights Foundation 〈http://www.no-smoke.org/goingsmokefree.php?id=519〉 (last accessed 4 September 2011).

Broder, J., 2006. Smoking Ban Takes Effect, Indoors and Out. New York Times, New York.

Cameron, M., Brennan, E., Durkin, S., Borland, R., Travers, M.J., Hyland, A., Spittal, M.J., Wakefield, M.A., 2010. Secondhand smoke exposure (PM2.5) in outdoor dining areas and its correlates. Tobacco Control 19, 19–23.

Kaufman, P., Zhang, B., Bondy, S.J., Klepeis, N., Ferrence, R., 2011. Not just 'a few wisps': real-time measurement of tobacco smoke at entrances to office buildings. Tobacco Control 20, 212–218.

Kennedy, R., Elton-Marshall, T., Sendzik, T., 2007. Tobacco smoke pollution in outdoor hospitality environments–a study of $PM_{2.5}$ levels in restaurants and bars. Proceedings of the 13th Annual Society for Nicotine and Tobacco Research Conference, Austin, Texas.

Klepeis, N.E., Ott, W.R., Switzer, P., 2007. Real-time measurement of outdoor tobacco smoke particles. Journal of the Air & Waste Management Association 57, 522–534.

Meagher, C., Carp Expands Smoking Ban. Santa Barbara Independent. 26 January 2011.

Ogilvie, F., 2010. Council calls for smoking ban in Tasmanian CBDs. ABC Radio-Sydney, NSW 〈http://www.abc.net.au/worldtoday/content/2010/s3092833.htm〉 (last accessed 20 September 2011).

Parry, R., Prior, B., Sykes, A.J., Tay, J.L., Walsh, B., Wright, N., Pearce, K., Richmond, G., Robertson, A., Roselan, J., Shum, P.Y., Taylor, G., Thachanamurthy, P., Zheng, T.T., Wilson, N., Thomson, G., 2011. Smokefree streets: a pilot study of methods to inform policy. Nicotine & tobacco research 13, 389–394.

Schneider, J.E., Peterson, N.A., Kiss, N., Ebeid, O., Doyle, A.S., 2011. Tobacco litter costs and public policy: a framework and methodology for considering the use of fees to offset abatement costs. Tobacco Control 20 (Suppl 1), i36–i41.

San Diego Union-Tribune, 2007. El Cajon bans smoking in most public places. San Diego Union-Tribune, San Diego.

Slaughter, E., Gersberg, R., Watanabe, K., et al., 2011. Toxicity of cigarette butts, and their chemical components, to marine and freshwater fish. Tobacco Control 20 (Suppl 1), i25–i29.

Stafford, J., Daube, M., Franklin, P., 2010. Second hand smoke in alfresco areas. Health promotion journal of Australia 21, 99–105.

The Tribune, Smoking ban approved in SLO. The Tribune. San Luis Obispo. 2010.

Thomson, G., Wilson, N., Edwards, R., Woodward, A., 2008. Should smoking in outside public spaces be banned? Yes. British Medical Journal 337, a2806.

Ueda, H., Armada, F., Kashiwabara, M., Yoshimi, I., 2011. Street smoking bans in Japan: a hope for smoke-free cities? Health Policy 102, 49–55.

Wang, A., Berkeley approves smoking ban. ABC 7 KGO-TV. Berkeley, CA, 25 March 2008. 〈http://abclocal.go.com/kgo/story?section=news/local&id=6042407〉 (last accessed 20 September 2011).

Wilson, N., Edwards, R., Parry, R., 2011. A persisting secondhand smoke hazard in urban public places: results from fine particulate (PM2.5) air sampling. The New Zealand Medical Journal 124 (1330), 34–47.