Variability of Exposure to Fine Particulates While Cycling

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1 Introduction

The connection between exposure to airborne particulate matter (PM) and adverse health consequences is a topic of hot debate (Kappos et al., 2004). Of particular focus recently have been the finer fractions, particularly those with an aerodynamic diameter of less the 2.5 microns ($PM_{2.5}$), because of their deeper penetration into the gas exchange region of the lung. While current regulatory standards for $PM_{2.5}$ (shown together with standards for PM_{10} in Table 1) reflect a maximum concentration not to be exceeded over one day and one year, recent epidemiological evidence suggests peak exposures of one hour or less may be more relevant from a health perspective (Michaels, and Kleinman, 2000). The implications are that it has become increasingly important to know with greater precision the microenvironments in which higher levels of particulate concentrations occur and how long individuals spend in these microenvironments (and therefore potentially at risk of higher exposure) as they go about their daily business.

Table 1: Current Regulatory Standards for Fine Particulate Matter

Pollutant	Averaging period	Maximum concentration (µg/m^3)			EPHC goal for maximum allowable exceedences within 10 years
		Australia	U.S.	Europe	
PM_{10}	1 day	50	150	50	5 days a year
	1-year			40	
$PM_{2.5}$	1 day	*25*	65	25	Not fixed as yet
	1-year	*8*	15	-----	

Source: Environmental Protection and Heritage Council (EPHC) http://www.ephc.gov.au

Over the last year, we have developed and tested an approach for assessing the risk of exposure to $PM_{2.5}$ at fine levels of spatial and temporal disaggregation while traveling by various modes of transport (Greaves, 2006). The approach combines the capabilities of new personal Global Positioning System (GPS) devices and portable particle monitors to shed new light on the inherent variability in pollution levels in different travel microenvironments and more importantly identify the location and magnitude of 'hotspots' of $PM_{2.5}$. The focus of the current paper is cyclist exposure to $PM_{2.5}$, something which has become highly topical given the strong recent push for this mode on health grounds, primarily in response to the growing obesity epidemic (Pucher and Djikstra, 2003). Specifically, we report on the results of a monitoring campaign conducted during May and June of 2005. The aim was to study exposure while cycling in a range of microenvironments typically experienced by cyclists, including main arterials, back streets, off-road bike-paths, and parks.

2 Experimental Set-up

The experimental set-up used to collect and record $PM_{2.5}$ at high levels of spatial and temporal resolution comprises the Neve personal GPS data logger and the AM510 SidePak™ personal aerosol monitor, manufactured by TSI Inc (Figure 1). The Neve device has been the culmination of 18 months of collaboration between our group and an Australian manufacturer. In addition to possessing all the known advantages of GPS (accurate capture of location, time, velocity, and heading information, easily viewable within a Geographic Information System (GIS) etc), the shape, size and light weight of the device (103 grams) make it easy to attach to the bicycle using an off-the-shelf mobile phone carrying case as shown in Figure 1. The AM510 SidePak™ personal aerosol monitor provides estimates of second-by-second concentrations of $PM_{2.5}$ using nephelometric (light-scattering) techniques. As shown in Figure 1, it was attached to the cyclist in much the same way as a mobile phone or beeper with the sampling tube being clipped to the strap on the helmet as near as possible to the breathing zone of the cyclist. As detailed in Greaves (2006), there are certain caveats with this measurement method of which the user needs to be aware, particularly in how it relates to gravimetric (weight-based) methods. However, for the purposes of the current study, which requires identification of pollution variability and hotspots at fine scales of temporal resolution, the technique is intrinsically appealing.

Figure 1: The Personal GPS Device and Portable Aerosol Monitor

3 Results

Data were collected during May and June 2005, which mark the transition from autumn to winter in Sydney. Days are typified at this time of year by mild daytime temperatures (average 18^0C) and cold nights (average 10^0C) interspersed with the occasional days of heavy rain. Ambient pollution levels are generally well below mandated air quality standards at this time of year although there is quite marked variability across the metropolitan area. In total, 63 trips were made, totalling around 32 hours of cycling, which covered a range of routes, different times-of-day and weather conditions. Note, the number of evening runs were restricted (on safety grounds) due to the drawing in of the evenings associated with winter.

3.1 Summary Results

Table 1 presents results summarised by time-period. The highest average levels were recorded during the morning peak period (7:30–9:00 a.m.), which is in line with results from previous studies (Greaves, 2006; Alm et al., 1998). Levels are also higher in the evening peak (5:00–7:00pm) than off-peak times with the lowest values being recorded on weekends. This should, however, be tempered somewhat by the fact that much of the weekend trips were on bike-paths and less-trafficked roads, as this is more typical of the type of cycling done at these times.

Table 2: Summary Results by Time-Period

Time-Period	$PM_{2.5}$ (µg/m^3)		
	Mean	SD	Max Value
7.30-9am	26.4	34.8	2659.0
9am-5pm	12.8	28.2	3089.0
5-7pm	19.9	41.7	2630.0
7-12pm	15.7	17.0	192.0
Week-ends (all times)	11.3	20.6	1628.0
All data points	*16.5*	*31.0*	*3,089.0*

Table 3 provides a similar summary by roadway type. The roadway type categories are those provided with the GIS network we had available for this study, which are derived from Austroads classifications. As expected, the highest levels are on highways, with the lowest levels off-road and in parks, although there is little differentiation among the remaining road types. This suggests that (perhaps not too surprisingly) a simple roadway type (selected in this case based on what information we had conveniently available in the GIS) needs to be supplemented by additional network and traffic descriptors (e.g., densities, mix) to gain a better insight of causes of variability.

Table 3: Summary Results by Roadway Type

Roadway Type (Austroads)	$PM_{2.5}$ (µg/m^3)		
	Mean	SD	Max Value
300 = 'Highways'	23.1	38.7	2630.0
302 = 'Main roads'	13.8	11.5	494.0
303 = 'Local connector roads'	14.9	43.9	3089.0
304 = 'Local neighbourhood roads'	11.2	16.4	714.0
400 = 'Pathways & pedestrian roads'*	14.8	14.3	190.0
All On-road	*17.2*	*31.9*	*3089.0*
Off-road & Parks	6.9	9.2	165.0

*These are next to major roads.

We also investigated how $PM_{2.5}$ levels varied by time-of-day on particular facility types. Figure 2 presents this information for highways in the form of a box-plot, which is a useful way of gaining a sense of the variability as well as the average (or median in this case) value. While the impact of the peaks is as expected, particularly the morning peak, it is also interesting to note that off-peak levels are in actuality very low. The suggestion is that for cyclists time-of-day may be more crucial in route choice decisions than the route itself per se. We acknowledge this may be specific to the routes selected here, but nevertheless it remains an interesting issue for further investigation.

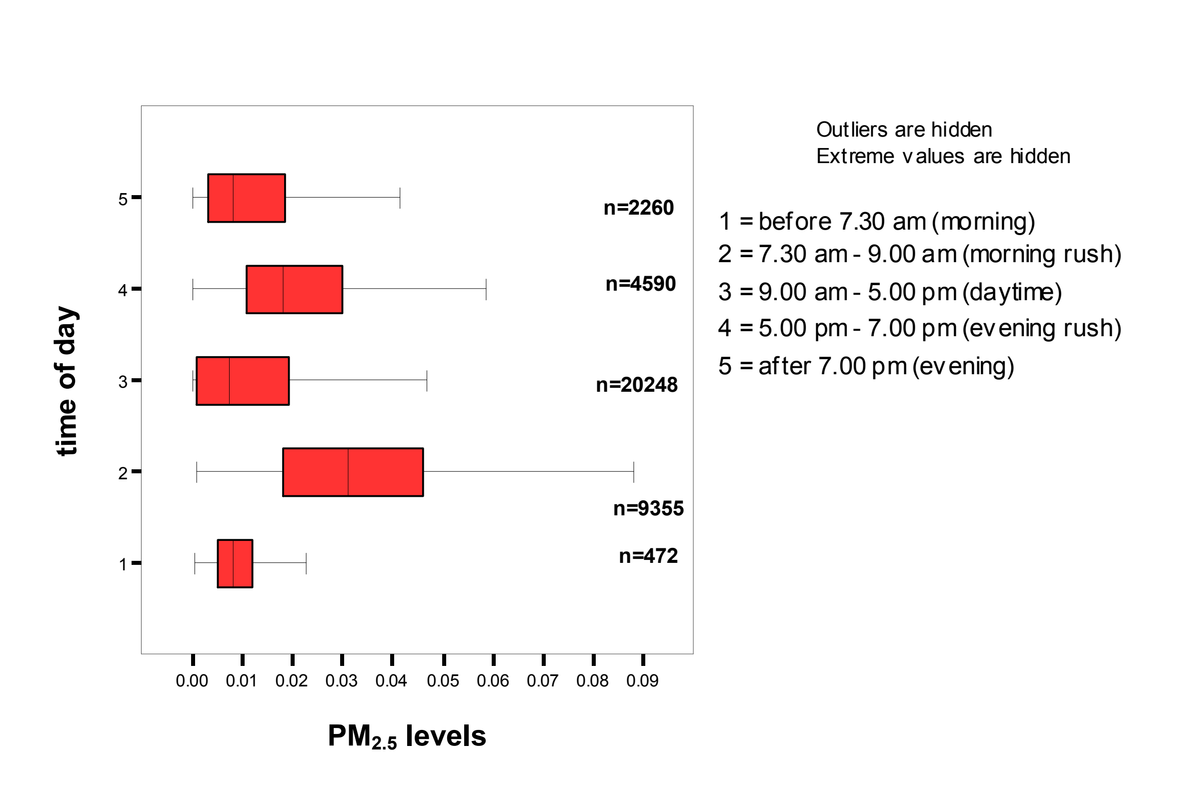

Figure 2: Time-of-Day Breakdown for Highways (Roadway Type 300)

3.2 Micro-level Insights

As we have shown previously (Greaves, 2006), the use of average summaries give an overall impression, but do not tell the full story of what is going on within trips. Of particular concern is the identification of 'hotspots', that is instances of (often substantially) elevated levels of $PM_{2.5}$. We observed many occurrences of hotspots, which were attributed to specific network situations and particular vehicles, most notably buses and trucks.

3.2.1 Intersections

A situation, which frequently produced hotspots, was at intersections both on the approach and exits. Figure 3 shows examples of three large intersections where the cyclist was frequently exposed to high concentrations of $PM_{2.5}$.The reasons were attributed to being caught behind idling vehicles and then accelerating vehicles once the lights went green. There was also the phenomenon of emissions from crossing traffic while waiting for signals to turn green, particularly at pedestrian crossings, which are commonly used by cyclists to traverse the busier and more dangerous roads in Sydney.

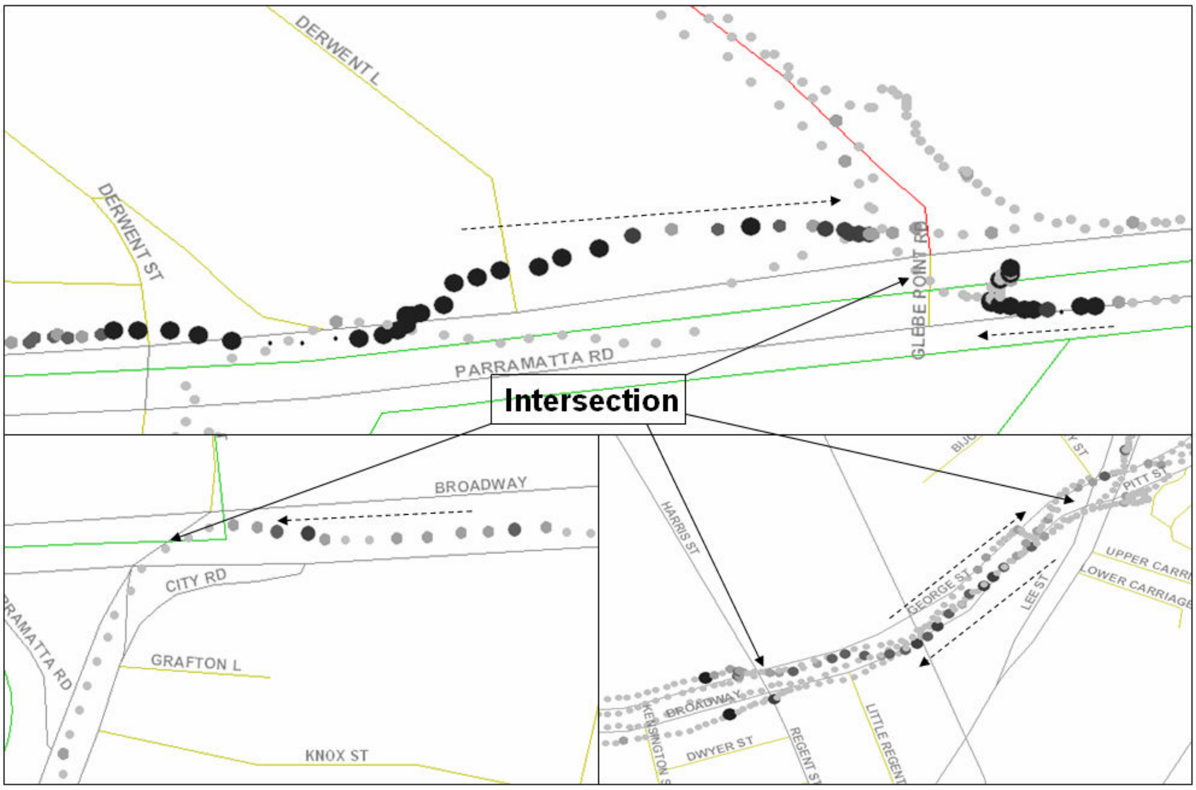

Figure 3: Hotspots at Intersection Approaches

3.2.2 Street Environment Influences

Another seemingly causal factor for hotspots of $PM_{2.5}$ was the street environment. Figure 4 takes one short morning trip to demonstrate, using GIS plots matched to time-series data, two such situations where this consistently occurred, namely travelling uphill in medium/heavy traffic and when the road narrowed. The reason for the elevated levels when travelling uphill (as opposed to downhill) can be attributed to both the fact that vehicles have greater emissions when going uphill and the cyclist is travelling at lower speeds, leaving them exposed for a longer period. This, combined with deeper and more frequent breathing associated with exertion, explains why cyclists often report feeling particularly bad when travelling uphill in medium/heavy traffic. In terms of the narrowing of roads, the issue here is when buildings are located closer to the road this provides a ‘canyon’ effect, which traps the particles.

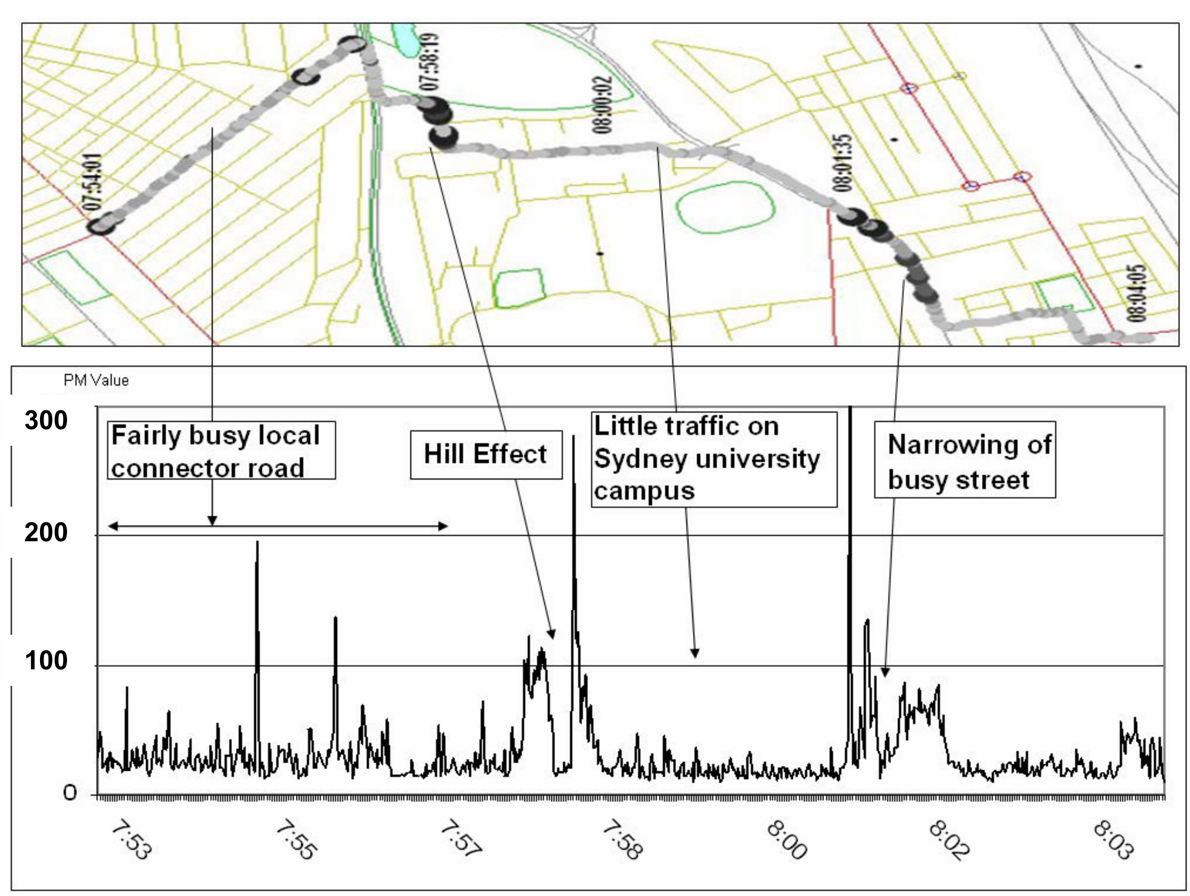

Figure 4: GIS Plot and Time-series for standard morning trip

3.2.3 Parks and Off-road Facilities

It came as no surprise that the plots comparing parks and off-road facilities corroborated what the statistics told us, namely that $PM_{2.5}$ levels were substantially lower. Figure 5 shows levels recorded in Centennial Park on a Sunday, when there is both a high level of cyclist and (incidentally) vehicular activity. The levels are notably lower than on city roads

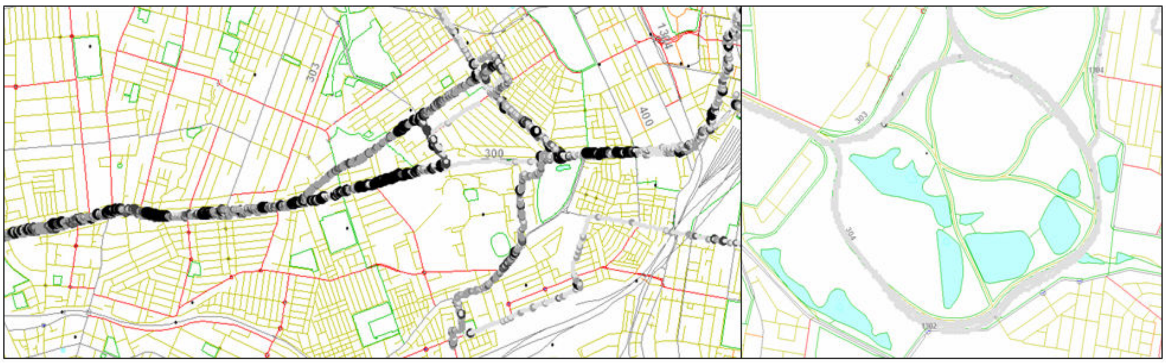

Figure 5: City roads (left) compared to Centennial Park (right)

3.2.4 Impacts of Route Choice

Cyclists generally prefer the most direct routes between origin-destination pairs. Highways and main roads are often easy to follow, while designated cycling routes can be hard to follow, time consuming and confusing. Figure 6 displays two trips with a common origin-destination made one directly following the other. Trip 1 follows a designated cycling route set out by the local council, while Trip 2 runs primarily along a heavily trafficked, three lane arterial, Parramatta Road. The average $PM_{2.5}$ level was 15 μg/m^3 for Trip 1 and 28 μg/m^3 for Trip 2 with Trip 2 also witnessing several hotspots.

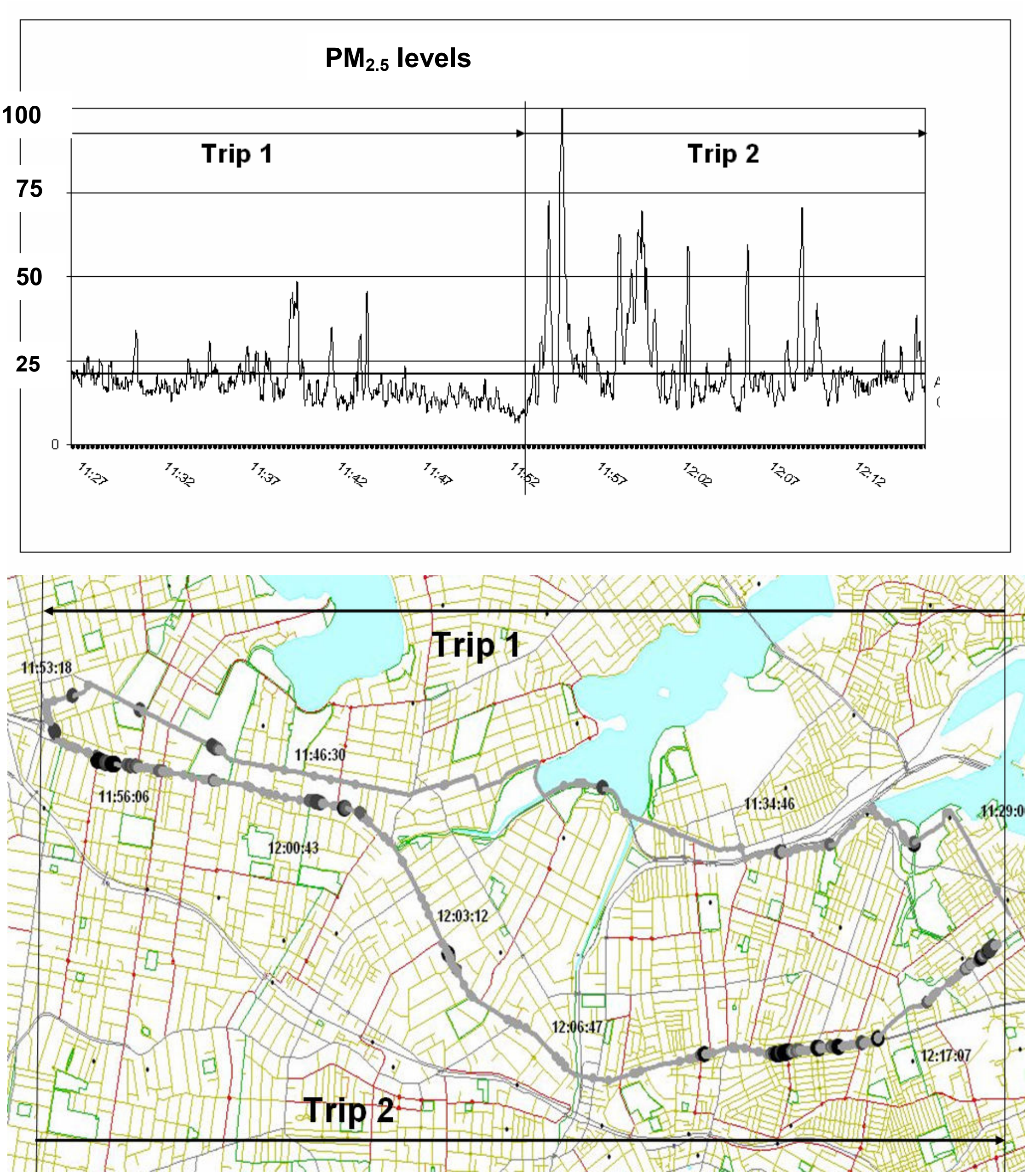

Figure 6: Time-series and GIS plot for comparison of trips on different routes.

4 Conclusions

Despite the largely exploratory nature of this study, there are a number of important insights and messages for cyclists to take away using this approach. First, it must be stated that when taken over a trip, the levels are generally quite low, in the main being below the value of 25 μg/m^3 (which it must be emphasised is a daily standard anyway) suggested in Table 1. While this may lead to the conclusion there is little to worry about, this hides the fact that there are situations where $PM_{2.5}$ levels are higher on average, primarily on busy roads during the morning peak. In addition, several hotspot situations were observed, particularly behind specific vehicles, at busy intersections, going uphill in medium/heavy traffic, and on busy roads where the terrain forces cyclists to be in close proximity to cars. The magnitude of these hotspots is anywhere from two to ten times the recommended standard but are only typically experienced for a few seconds at a time.

The question of whether this is anything for cyclists to be concerned about is one that needs to be answered with the help of medical experts. Clearly, indicating the levels of (in this case) fine particles is only one part of the puzzle. We also need to know how much of this is being breathed in and how this affects different people. The former issue is a function of ventilation rates and intensity, both of which are elevated when cycling, while many questions still remain on the latter issue. Whatever the exact cause-effect, it is clear cyclists can take measures to reduce their potential risk of exposure to fine particles by following some fairly common-sense options. First, is to think carefully about road position and try to avoid directly breathing in vehicular exhaust, although admittedly sometimes this is simply not possible on narrow roads. Second, is to select routes that avoid heavily-trafficked roads, something which is being made increasingly easy by the delineation of designated cycling routes by local councils and road authorities across Australia. Third, is to cycle during times when there is lower traffic intensity, if there is some flexibility in departure time choice. A final point to make is that while there are more drastic options for directly reducing the inhalation of particles such as dust-masks, these are designed to keep out coarse particles, not the fine particles, which are the subject of concern here.

5 References

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