Traffic pollution while commuting – Does commute mode matter?

C. E. Peyroux[1], L. S. Bussen[1], S. B. Costello[1], K. N. Dirks[2]

[1]*Department of Civil and Environmental Engineering, Faculty of Engineering, University of Auckland, Private Bag 92019, Auckland, New Zealand*
[2]*School of Population Health, Faculty of Medical and Health Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand*

Correspondence: Kim Dirks, k.dirks@auckland.ac.nz

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Abstract

The transport microenvironment contributes significantly to the total daily air pollution of people living in urban environments. This study uses carbon monoxide as a traffic pollution indicator to compare the exposures associated with seven common transport modes (walking, running, cycling, bus, train, car and motorised scooter) traversing a popular commuting route in Auckland, New Zealand during the morning rush hour for one period of observation in summer and one in winter. The results suggests that air pollution exposures for motorised scooters are the highest of all modes. However, the overall air pollution dose associated with the commute is low because of the short commute time. The active mode commuters experienced the highest doses (the three highest of the seven modes in both summer and winter). Strategies to ensure additional separation of the active mode commuters from the main line of traffic are needed to help reduce the air pollution doses associated with active modes and increase their modal share in a transport system that in currently highly car-dominated.

1. Introduction

Air pollution from road traffic consists of many different chemical constituents, including carbon monoxide (CO), which is a major pollutant originating from petrol-driven engines. With the introduction of improved vehicle emissions technology, such as catalytic converters, the levels of CO emissions from cars have decreased over the last decade or so in many cities worldwide, including in Auckland (Auckland Council, 2013). Despite the increased interest in other vehicle-generated pollutants such particulate matter, a major constituent of emissions from diesel vehicles, CO remains in use as a tracer in many traffic-related air pollution studies; it is the only of the major vehicle emission constituents for which a low-cost instrument is available that is able to record high-time-resolution time series data and is sufficiently portable that is able to be carried by individuals whether running, cycling or travelling by motorised transport. The New Zealand Standard for CO is 8 ppm for an 8-hour moving average (Ministry for the Environment, 2014).

Studies involving portable air quality monitoring equipment have revealed that, despite the relatively short amount of time spent commuting compared to other daily activities, it contributes significantly to the total daily dose (the product of the concentration times the time of exposure) of those living in urban areas. For example, Lim et al. (2015) found that it accounted for 17% of the average daily dose of CO for a subset of Aucklanders sampled, while Dons et al. (2012) suggest 21% for black carbon. Irrespective of the air pollution constituent, the level of exposure tends to be high during periods of peak traffic (Duci et al., 2003), especially during the early morning when vertical mixing tends to be suppressed due to a lack of convection in the atmosphere and pollutants often accumulate within a relatively thin layer immediately above the ground surface.

Commuting occurs via many different modes, including active modes, such as walking, running and cycling, and by the use of public transport, including bus and train travel. In Auckland, the modal share is highly car dominated with 91% of the total kilometres travelled involving a journey that includes the use of a car and 1% allocated to travel by bicycle (Statistics New Zealand, 2015). The main obstacles to cycling identified in an Auckland survey of attitudes to cycling are 'safety concerns' and 'inadequate infrastructure' (Wang *et al*., 2012). This is being addressed to some extent by the rapid expansion of Auckland's cycling infrastructure as part of the transport component of Auckland's Unitary Plan (Auckland Council, 2014).

The choice of mode a person makes determines the specific route taken; in the case of public transport, the route is fixed but when travelling by private motorised vehicle or active modes, choices are made based on a number of factors including travel distance and expected travel time in light of congestion. For active modes, especially, the topography will also be a significant consideration due to the level of physical exertion required.

Many studies comparing air pollution exposure for different modes require the commuters to travel the same route irrespective of mode (e.g. Duci et al., 2003, Int Panis et al., 2010, Dirks et al., 2012). This allows for easier comparison of exposures between modes as the commuters all experience the same urban topography (street canyons along the route, for example) and infrastructure (density of traffic lights, for example) throughout their commute. However, in reality, people make route choices based on their mode, so allowing commuters to choose their route may be more realistic in terms of the exposures and the dose they would receive given their mode choice. The route chosen will impact on the air pollution dose experienced by the commuter due to the variation in the air pollution levels, the travel time and the breathing rate required to meet the level of exertion needed for a given mode along a given route (Dirks et al., 2012).

Commuter air pollution exposure studies investigating different modes and focusing specifically on carbon monoxide have been conducted both worldwide (Flachsbart et al, 1987, Duci et al, 2003, Saksena et al, 2008), as well as in New Zealand, specifically, in Christchurch (Liu, 2009) and in Auckland (Dirks et al., 2012 and Grange et al., 2014). In comparison with all other modes of commuting, research has shown that motorcyclists tend to exhibit the highest levels of personal exposure to traffic pollution (Vellopoulou and Ashmore, 1998, Saksena et al. 2008, De Bruin et al. 2004). This may be explained by the motorcyclist's tendency to travel close to the exhaust of other vehicles in the main flow of traffic. Also, depending on the nature of the helmet used, there is the potential for a lack of physical barrier between the source (including the motorcyclist's own vehicle) and the motorcyclist's respiratory system. In a similar manner, the exposure levels experienced by car commuters may be influenced by the low (often the lower edge of the windshield) intake point of the ventilation system (Chan et al., 1999) and located close to the exhaust of the vehicle in front, suggesting that the proximity to the pollution source is a significant influencing factor of a commuter's personal exposure.

Studies have also found that exposures for modes removed to some extent from the traffic pollution sources, such as for cyclists and pedestrians, tend to be less than for those travelling in motorised vehicles (Boogaard, et al., 2009, Rank et al., 2001). These findings were confirmed by Grange et al. (2014) where pollution concentrations experienced by car commuters and cyclists on a fixed route in Auckland were compared. The authors found that, even for cyclists traveling without the benefit of a cycle lane, the small additional separation from the centre of the road because of travel on the edge of the road was sufficient to lead to a significant reduction in pollution concentrations experienced compared to car commuters.

Public transport modes are similarly affected as the vehicles sometimes use dedicated busways (Dirks et al., 2012) or tend to favour travel near the curbside lanes rather than the middle lanes of the road in order to facilitate stopping at bus stops, albeit at the risk of experiencing spikes in pollution due to self-polluting as commuters board and exit the bus (Lim et al, 2015). Train commuters have been found to experience significantly lower levels of air pollution than travel by other modes (Chertok, et al., 2004, Namdeo et al., 2014), though travel by train (and bus) tends to involve some pedestrian time, or other mode, at either or both ends of the journey.

While the studies described above suggest that exposures can vary between modes, they are limited by the number of modes investigated simultaneously, with few (and none in New Zealand) considering five or more modes simultaneously. Two of the most relevant studies include Saksena et al. (2008) who investigated four modes simultaneously, and measured CO and PM_{10} for Vietnam but for an environment very different to that explored here. Chertok et al. (2004) investigated five modes but used passive samplers, thus providing long-term averages of exposure over many commutes but lacking in detail in terms of temporal variability. This study was carried out in Sydney.

In addition to the exposure (the average concentration experience while commuting), some studies have also considered the commute duration as an influential factor in assessing the impact of the air pollution on the commuter (Saksena et al., 2008, Dirks et al., 2010); the more time spent in the road corridor microenvironment, the higher the air pollution dose for the commuter. In addition to travel time, it is also important to consider the level of physical activity required by the commuter as this has an impact on the amount of polluted air inhaled over the period of the commute. The minute ventilation (the product of the breathing rate and the volume of air per breath) has been used for this purpose in many air pollution studies (Int Panis et al, 2010, Zurrbier et al., 2009). For non-active modes, an adult commuter's minute ventilation has been shown to range from 9.5-15.1 L min^{-1}(Int Panis, et al., 2010), with 12 L min^{-1} commonly assumed (Zuurbier et al., 2009). For active mode commuters, the minute ventilation varies considerably between commuters depending on their level of physical exertion (Int Panis et al., 2010, Zuurbier et al., 2009). However, the literature suggests that the minute ventilation for an active mode commuter of two to five times that of non-active commuter is a reasonable approximation (Zuurbier et al., 2009 and Int Panis et al, 2010). To date, only a few studies consider the minute ventilation, the commute time as well as the concentration experienced during commuting in comparing transport modes in relation to air pollution dose (Int Panis et al., 2010, Dirks et al., 2012 and de Hartog et al., 2010).

The purpose of this paper is to assess and compare the doses of CO experienced by commuters on a popular commuting route in Auckland when travelling by various modes, namely by car, scooter (small motorcycle), bus, train, cycling, walking and running, taking into account both the travel time and the estimated minute ventilation associated with each mode. This study builds on that of Int Panis et al. (2010) and Dirks et al. (2012) by investigating further common modes of transport, in this case, seven modes simultaneously, and comparing doses between seasons (winter and summer), using portable CO air pollution technology that is able to measure exposures at high time resolution.

2. Methods

2.1. Location

This study was conducted in Auckland, New Zealand's largest city with a population of over 1.4 million (New Zealand Census, 2013). Auckland is located on a narrow isthmus, thus experiencing frequent sea breezes. The climate is subtropical with warm humid summers and damp mild winters.

2.2. Trials

For each of the two field trials, there were seven commuters, each travelling via a different mode. The private motorised commuters travelled via scooter and car, the public transport commuters by bus and train while the active mode commuters cycled, ran and walked. Each commuter was free to choose the specific route from the specified start to the specified end point that most suited their mode, within the constraint of public transport routes for those travelling by public transport and with a view to arriving at work in a relatively short amount of time. The commute chosen for this study was a common commuting corridor with heavy traffic flows and which presents a commuter with a variety of reasonable options for all of the modes investigated. For the particular commute, there was no dedicated cycleway; cyclists travelled along the edge of the road and pedestrians travelled along the footpath immediately adjacent to the road. Commuting began at 8:00am for each of the trials and ended when the commuter reached the specified destination.

The two trials took place on 7 March 2013 (summer) and 11 July 2013 (winter). The commute was from the suburb of Greenlane to Newmarket, as shown in Figure 1. The bus, scooter, bicycle, runner and walker all followed the same direct route along a busy arterial road while the car driver chose a slightly longer route to avoid congestion. Both the bus and train commuter had short walks at the beginning and end of their journeys. The train commuter was restricted to the train line and with a train stop located in close proximity to the starting point of the commute. The car commuters set their ventilation mode to 'new air' and kept their windows closed throughout the period of the commute. On the days of the trials, there was no precipitation and the winds were light (less than 2 m/s).

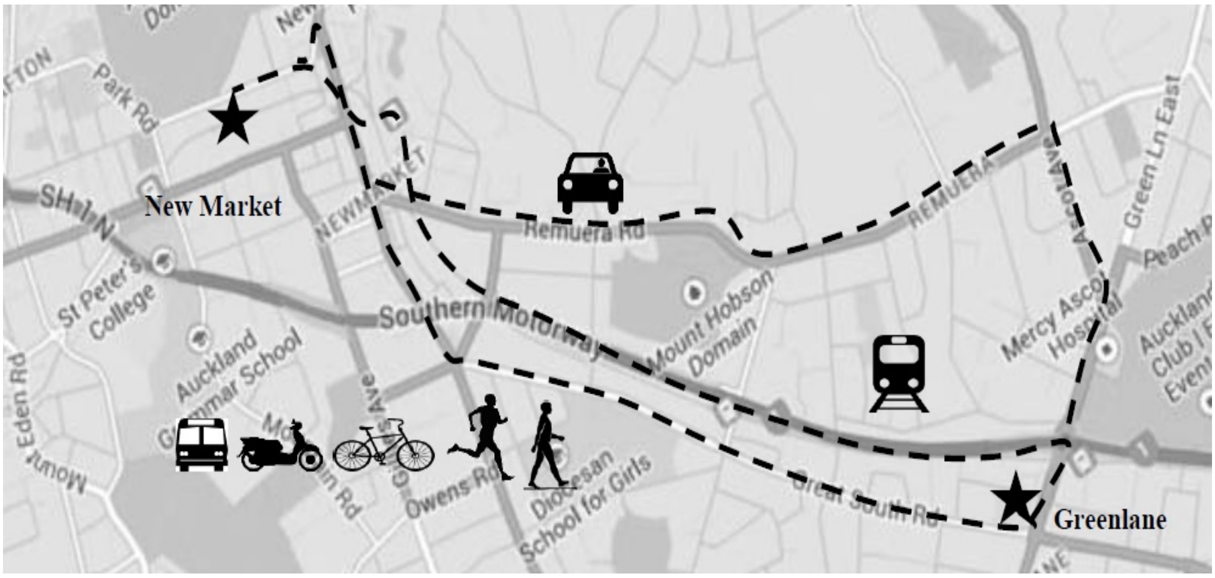

Figure 1 : Routes chosen for the various modes. The stars represent the starting (Greenlane) and end (Newmarket) points of the commute

2.2 Instrumentation

Each commuter was equipped with a Langan T15v portable CO monitor (Langan Products Inc.) and a GPS device to track their location in time and space while commuting. For this study, the Langan and GPS devices were set to log every 20 seconds. A 'bump' test (a test of consistency between monitors in response to an exposure spanning a range of concentrations) was performed on the Langan monitors immediately prior and following each of the trials. While no lab-based calibration was performed immediately prior to deployment, the bump test gave assurance that the monitors were highly consistent in their response. The monitors were placed is a carry pouch that was either worn around the commuter's waist or placed on the passenger seat in the case of the car commuter.

2.3 Inhalation Rates and Physical Activity Factors

Estimates of commuter dose of carbon monoxide were made by measuring the CO levels based on personal exposure and recording the commute time while assuming minute ventilations according to those suggested in the literature. For the non-active commuters, a minute ventilation of 12 L min^{-1} was assumed. For the active mode participants, 36 L min^{-1}, 48 L min^{-1} and 60 L min^{-1} were assumed for walkers, cyclists and runners, respectively, corresponding to 'exercise factors' of 3, 4 and 5, respectively. The dose (in PPM min) was then assumed to be a product of the average CO concentration, the commute time and the 'exercise factors'.

3. Results

3.1 Basic Results

Table 1 presents the descriptive statistics of the measured concentrations of CO and travel times for each of the modes for each of the two trials (summer and winter) while Figure 2 shows the average CO for each of the modes for each of the seasons. Figures 3 and 4 show time series of concentrations for the seven modes, separately for the active modes and the motorised modes for both the summer and winter trials, respectively. Figure 5 shows the mean dose of air

	Car	Scooter	Train	Bus	Bicycle	Run	Walk
Trial 1 - Summer							
Time (minutes)	20	10	31	27	13	18	35
Mean (ppm)	**0.91**	**1.87**	**0.46**	**1.12**	**0.73**	**0.50**	**0.86**
Median (ppm)	0.86	1.68	0.39	1.30	0.59	0.39	0.71
Minimum (ppm)	0.57	0.37	0.13	0.48	0.04	0.00	0.00
Maximum (ppm)	1.25	6.18	1.52	2.54	2.54	2.77	3.48
N	121	61	187	163	79	109	211
Ratio relative to car	**1.00**	**2.1**	**0.51**	**1.23**	**0.80**	**0.55**	**0.95**
Trial 2 - Winter							
Time (minutes)	12	12	34	31	12	16	42
Mean (ppm)	**1.40**	**2.01**	**0.62**	**1.03**	**1.22**	**0.65**	**1.00**
Median (ppm)	1.51	1.56	0.60	0.87	0.94	0.59	0.82
Minimum (ppm)	0.00	0.53	0.20	0.31	0.37	0.00	0.25
Maximum (ppm)	3.11	7.42	2.31	2.60	7.42	2.43	7.31
N	73	73	205	187	85	97	253
Ratio relative to car	**1.00**	**1.44**	**0.44**	**0.74**	**0.87**	**0.46**	**0.71**

Table 1: Descriptive statistics of the CO concentrations observed and the travel times for the two trials (summer and winter) and the various modes based on a 20 s averaging time. The 'Ratio relative to car' is the ratio of the mean for the mode of commuting relative to that of car travel for the given season.

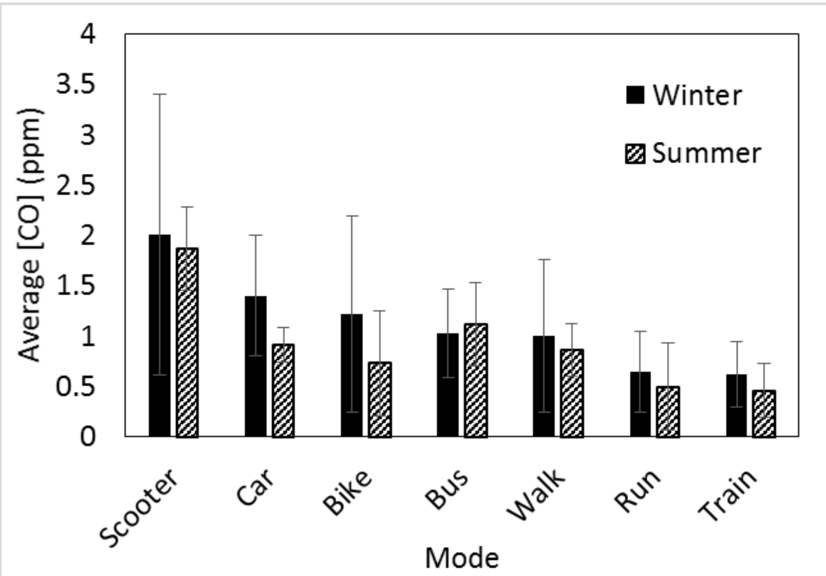

Figure 2: Average concentration for each of the modes of commuting and the two seasons (error bars are standard deviations).

pollution experienced by each of the commuters for both winter and summer, taking into account the exposure, the travel time as well as the minute ventilation assumed for each mode.

The levels of CO recorded for all of the commutes for both the summer and the winter trial are considerably below New Zealand's Standard for CO of 8 ppm for an 8-hour average. However, the traces do generally show significant minute-by-minute variability suggesting that the road (or other close source) is having a significant impact on the levels experienced.

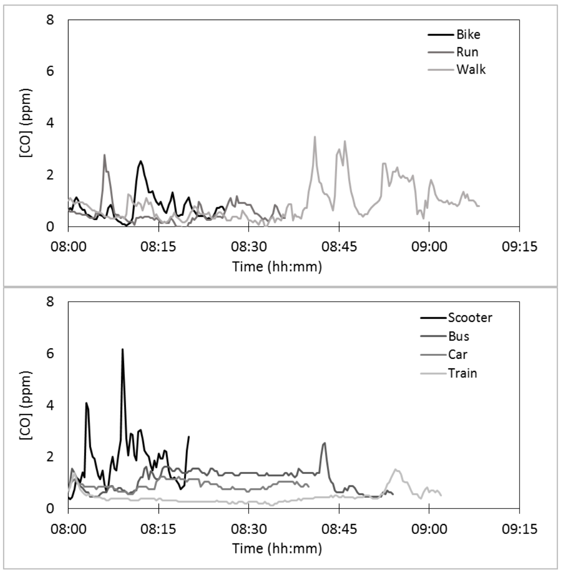

Figure 3 : Time series of carbon monoxide concentrations for commuters travelling by active modes (top), and motorised modes (bottom) for the summer season

The average travel time across all modes was 20 minutes and varied considerably between modes (ranging from 10 to 42 minutes). The scooter was the fastest mode (10 and 12 minutes) while walking and commuting by train were the slowest (35 and 42 minutes for walking and 31 and 34 minutes for the train)

The average concentrations experienced during the commutes were significantly higher during the winter than in summer based on a paired t-test for the different modes between summer and winter ($t = 2.67$, $df = 6$, $p = 0.037$), reflecting the higher ambient levels that tend to be experienced at that time of the year (see Figure 2).

The time series (Figures 3 and 4) show the high temporal variability in the concentrations experienced by each of the modes but that of the scooter in particular. The two highest peaks in the summer trial were experienced by the scooter rider while the three winter peaks (all around 8 ppm) were experienced by the scooter rider, the cyclist and the walker, all modes not protected by a physical barrier. The bus and train commuters in particular showed little temporal variability in concentration throughout the commute, other than when they were walking at the beginning and end of their commute.

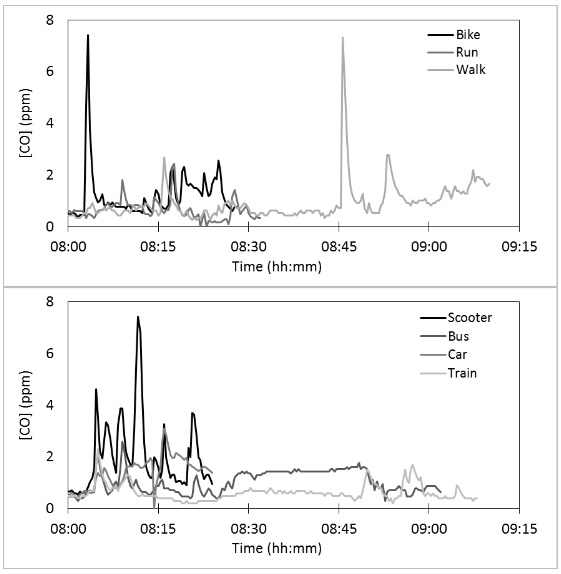

Figure 4: Time series of carbon monoxide concentrations for commuters travelling by active modes (top) motorised modes (bottom) for the winter season.

The mean concentrations experienced by the commuters also varied between travel modes. The scooter experienced the highest amongst all modes for both the summer and the winter trials (1.87 ppm and 2.01 ppm, respectively) while the runner experience the second lowest for both summer and winter (0.50 ppm and 0.65 ppm) and the train the lowest for both summer and winter (0.46 ppm and 0.62 ppm).

When travel time and minute ventilation are taken into account, and compared in terms of the air pollution dose, the active modes fare the worst; all three active modes place in as the three worst for both the summer and winter trials (see Figure 5). The train, car and scooter commuters experience the lowest three doses for both the summer and winter trials.

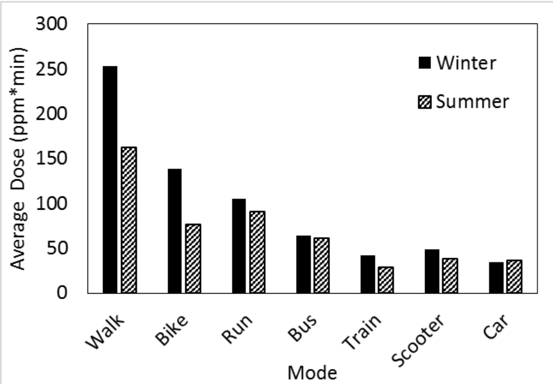

Figure 5: Mean dose of carbon monoxide (product of the concentration, the travel time in minutes and the exercise factor) for each of the modes of commuting and the two seasons.

4. Discussion and Conclusions

The results of this study highlight the importance of taking into account both the travel time and the minute ventilation when comparing modes of commuting for air pollution effects. While the active modes of running and walking benefit from travel along the side of the road (rather than down the middle), they require a significant level of physical exertion and travel speed (for walking at least and also running, depending on the route) is slow, leading to high doses. In contrast, while scooter riders and car commuters experience high concentrations, given the sedentary nature of the mode and the often relatively quick travel speed, they experience the lowest doses.

Relative to scooter drivers, car commuters are protected by a physical barrier, helping to avoid the peaks in concentration experienced by the scooter drivers. The concentrations experienced by the bus commuters were remarkably steady across both the summer and winter trials consistent with the air ventilation system having been set to ‘recirculate’. In the present study, the short-term spikes in concentrations observed in one study as air is exchanged while commuters embark and disembark (Lim et al, 2015) were not seen here. Train commuters experienced the lowest exposures and commute times were very slow, even for a route suited to train travel. This is because of the time required to walk to the destination from the train station as well as the waiting time, an inevitability for all those who use public transport. The doses of air pollution associated with train travel (as well as bus commuters) will therefore be heavily influenced by the walking (or other) component of the commute, segments that contribute to much of the variability.

The active modes benefit from the separation from the main line of traffic, yielding relatively low mean concentrations. However, they can be slow in comparison with other modes for this type of commute journey. This is particularly the case for walking – the added travel time, in addition to the increased ventilation, results in a high dose compared to other modes. Of course, in states of heavy congestion and especially with the provision of a separate cycleway, cycling may result in a lower commute time compared to travel by car.

A significant limitation of this study is that only two trials were conducted: one during the summer and one during the winter. This meant it was not possible to assess any statistical significance between the means recorded for the different modes. None-the-less, the order of modes from highest to lowest in terms of both average concentrations and dose were relatively consistent between the two days of observation.

There are many known health benefits associated with physical activity, and commuting by cycling, walking or running is one effective way of facilitating the achievement of the recommended minimum levels of physical activity for healthy living. In fact, the significant benefits of active modes, including increased physical activity, have been found to outweigh the negative impacts of increased air pollution exposure (de Hartog et al., 2010). None the less, it is important to continue to seek ways to ensure the negative impacts such as air pollution exposure, are minimised through appropriate transport infrastructure development to ensure active mode commuting is as safe as possible. This may include an increased availability of cycleways and footpaths, an increased separation of such footpaths and walkways from the road, options to travel through parks, as well as pedestrian-friendly traffic light phasing designed to minimise pedestrian wait times at intersections.

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