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HotM2 article

Potential pollution exposure reductions from small-distance bicycle lane separations

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ABSTRACT

Many studies have compared the exposure of cyclists to those taking other modes of transport and compared exposure differences between backstreet routes and main roads. In this study, we employ the use of three bicycles travelling in unison to sample concentrations of ultrafine particles (UFPs), carbon monoxide (CO) and fine particulate matter ($PM_{1.0}$) at three different distances from the traffic flow, in a central city park area of Christchurch, New Zealand. Similar research has been done using stationary equipment, but this may not accurately represent exposure differences while moving with a stream of vehicles. Three cyclists were equipped with a set of identical instruments and rode continuously along a road, the road's sidewalk (7 m away) and an off-road path (19 m away), for a total of 6 h and 45 min, over 5 afternoon sampling runs during fall. Data were analysed in the form of linear mixed-effects models, with cyclist position (distance from edge of nearest traffic lane), wind speed, and temperature, having statistically significant effects on mean exposures ($p < 0.05$). Mean exposure to UFPs and CO were approximately 20–30% ($p < 0.01$) lower at the sidewalk and 40–50% lower at the path, than at the road ($p < 0.01$). These results highlight the potential exposure benefits of segregating cycleways, which helps inform city planning. Separating cycle lanes on key routes could help reduce cyclists' cumulative intake of pollutants, especially on heavily-trafficked roads.

1. Introduction

Active-mode transport, i.e. walking and cycling, is increasingly promoted as a healthier and environmentally cleaner alternative to passive forms of travel, particularly private vehicles. In Germany, Denmark and the Netherlands, continued investment in cycling infrastructure has improved safety and efficiency to such an extent that bicycle trips now account for at least 33% of all journeys for mid-sized cities like Utrecht and Copenhagen (Gössling, 2013). At a nationwide level, the population of the Netherlands makes around 30% of all trips by bicycle. For USA, Australia and New Zealand, this figure is 30 times lower, at only 1% (Pucher and Buehler, 2008). A lack of safe infrastructure, injury statistics and subsequent perceived and real risk of injury, severely inhibits the growth of cycling uptake in these countries (Macmillan et al., 2014; Piatkowski et al., 2014). High incomes and high rates of car ownership also mean that there is less societal will to demand an increase in government active-mode and public transport spending. This highlights a need for strong scientific studies that

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demonstrate quantifiable benefits in expanding active-mode infrastructure, thereby improving city liveability while decreasing traffic congestion and associated emissions.

In addition to enhancing the built environment in terms of sustainability and aesthetic value, numerous cost-benefit analyses show that there are considerable health and social equity gains to be made by improving city cycling infrastructure (Fraser and Lock, 2011; Gotschi, 2011; Macmillan et al., 2014; Saelensminde, 2004). In New Zealand, a recent study projected a 40-year cost-benefit ratio of between 1:10 and 1:25 following implementation of segregated cycleways and bicycle-friendly speed reduction on key urban streets (Macmillan et al., 2014). The bulk of this benefit is made up of a significant reduction in all-cause mortality as a result of an overall increase in physical activity across city-wide populations. International studies have also shown that risk of injury is around 10 times lower while using segregated cycleways, compared to being on roadways without cycle infrastructure (Harris et al., 2013; Teschke et al., 2014, 2012). Additional positives include a reduction in vehicle emissions, which leads to diminished health impacts from Traffic-Related Air Pollutants, commonly abbreviated as TRAP. Innumerable health studies have reported an association between exposure to traffic pollutants and a range of health ailments such as respiratory problems and various cancers (Clark et al., 2010; Evans et al., 2014; Heck et al., 2013; Raaschou-Nielsen et al., 2011; Riley et al., 2012). Any effective strategies which aid in reducing and/or mitigating the long-term intake of these air toxics can only be beneficial to population health.

Considering people spend up to 90% of their time indoors (McCreddin et al., 2013), the daily commute has been shown to represent a disproportionately high contribution to overall daily exposure. For UFPs (ultrafine particles <100 nm), a study by Fruin et al. (2008) in Los Angeles found that 36% was attributable to commuting by car. A similar study in Jakarta, Indonesia put the same value for UFPs at 25%, but for CO, the commute was responsible for 60% of total daily exposure (Both et al., 2013). For cyclists, recent work by Ragettli et al. (2013) in Basel, Switzerland, calculated that the commute contributed 21% of daily UFP exposure during winter but only 5% during summer. The commute contribution was halved if the cyclist took backstreets, and similar reductions (35–40%) have been noted by others (Zuurbier et al., 2010). The reduced exposure benefits of cyclists taking backstreets and off-road paths have also been investigated in Australia and New Zealand. Cole-Hunter et al. (2012) explored differences between three high and low-proximity (to traffic) bicycle commute routes into the centre of Brisbane, Australia. They determined cyclist heart-rate-ventilation associations to estimate inhaled UFP counts, finding that taking the low exposure routes resulted in inhaled counts 48% lower than the high exposure routes. Another in Christchurch, New Zealand closely matched the results from Basel and Brisbane, with a 52% reduction for UFP exposure along an off-road, low-exposure route compared to using the main roads (Kingham et al., 2013; Pattinson, 2009).

At a finer spatial scale, other cycling and pedestrian-based exposure studies have observed considerable reductions when moving from one side of the road to the other and from the kerbside to building-side of the pavement (Berghmans et al., 2009; Hertel et al., 2008; Kaur et al., 2005). Subsequently, it is of significant interest to better quantify what these potential micro-spatial reductions may be, over longer time periods, across multiple days. Where space allows, further separating cycle lanes and pedestrian paths from adjacent traffic sources is an attractive planning option for improving safety and enticing active-mode traffic into an area. The added bonus of reducing exposures to particulates and gases strengthens the argument, yet very few studies assess this in detail.

A segregated cycleway project in Portland, USA, inspired a team of researchers to come up with a novel approach to assess cyclist exposure before and after the project; the cycle lane was shifted from the roadway to along the kerbside, with parking spaces providing a 3.5 m buffer zone (Kendrick et al., 2011). Ultrafine particle counting instruments were placed inside a parked car, with the inlets sampling air from both sides of the vehicle, thus simulating exposure in both the new bicycle lane and next to the traffic flow, in the cycle lane's previous position. They found that exposure in the bicycle lane was up to 38% lower than at the roadside, with the greatest difference occurring within the busiest traffic conditions. In addition, they recorded a further 25% decrease from the cycle lane to the sidewalk. The authors concluded that particle dynamics (condensation and coagulation into larger particles) most likely explain the rapid decay, rather than parked cars acting as a barrier, as the decline in concentrations from cycle lane to sidewalk (no barrier) was also substantial. Another project in Auckland, New Zealand, aimed to quantify variation in exposure and inhaled CO dose, between a roadway, cycle lane and pedestrian path, using the respective modes of transport - driving, cycling and walking (Grange et al., 2014). Mean CO concentrations were 38% lower for the cyclist, compared to the driver (1 m separation) and levels recorded by the pedestrian were 80% lower than the cyclist (4.5 m separation). However, once respiration rates were accounted for, it was established that the active-mode travellers would require a separation distance of 6–14 m before inhaled dose was equivalent to that of the car driver. A major limitation of this study is that each mode travelled apart, at diverging speeds ranging from 8–36 km h^{-1}, meaning measured differences could be influenced by highly localised variation (meteorology, traffic speed and composition), rather than being a direct result of horizontal separation away from the roadway centreline. The presence of extreme spikes in concentrations when encountering vehicles is well-documented in the literature (Kaur et al., 2007; Kingham et al., 2013; Pattinson et al., 2014).

While the results of both studies are encouraging, it is unclear whether similar reductions would be achieved if repeated measurements were made simultaneously, using the same mode of transport i.e., multiple non-stationary, concurrent measurements. To the authors' knowledge, no previous study has assessed this for more than two positions relative to the roadway. In this paper, we present results from work done as an extension to a larger, inter-modal comparison (Kingham et al., 2013). Three identical sampling bicycles were deployed along the same route, riding in unison at low speed, in order to characterise exposure differences. Like the Portland example, the goal was to quantify prospective exposure benefits gained from shifting cycle lanes from the roadway edge to the pavement-side zone, with parked cars providing physical separation.