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Review article

Comparison of air pollution exposures in active vs. passive travel modes in European cities: A quantitative review

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ABSTRACT

Background: Transport microenvironments tend to have higher air pollutant concentrations than other settings most people encounter in their daily lives. The choice of travel modes may affect significantly individuals' exposures; however such considerations are typically not accounted for in exposure assessment used in environmental health studies. In particular, with increasing interest in the promotion of active travel, health impact studies that attempt to estimate potential adverse consequences of potential increased pollutant inhalation during walking or cycling have emerged. Such studies require a quantification of relative exposures in travel modes.
Methods: The literature on air pollution exposures in travel microenvironments in Europe was reviewed. Studies which measured various travel modes including at least walking or cycling in a simultaneous or quasi-simultaneous design were selected. Data from these studies were harmonized to allow for a quantitative synthesis of the estimates. Ranges of ratios and 95% confidence interval (CI) of air pollution exposure between modes and between background and transportation modes were estimated.
Results: Ten studies measuring fine particulate matter ($PM_{2.5}$), black carbon (BC), ultrafine particles (UFP), and/or carbon monoxide (CO) in the walk, bicycle, car and/or bus modes were included in the analysis. Only three reported on CO and BC and results should be interpreted with caution. Pedestrians were shown to be the most consistently least exposed of all across studies, with the bus, bicycle and car modes on average 1.3 to 1.5 times higher for $PM_{2.5}$; 1.1 to 1.7 times higher for UFP; and 1.3 to 2.9 times higher for CO; however the 95% CI included 1 for the UFP walk to bus ratio. Only for BC were pedestrians more exposed than bus users on average (bus to walk ratio 0.8), but remained less exposed than those on bicycles or in cars. Car users tended to be the most exposed (from 2.9 times higher than pedestrians for BC down to similar exposures to cyclists for UFP on average). Bus exposures tended to be similar to that of cyclists (95% CI including 1 for $PM_{2.5}$, CO and BC), except for UFP where they were lower (ratio 0.7).
Conclusion: A quantitative method that synthesizes the literature on air pollution exposure in travel microenvironments for use in health impact assessments or potentially for epidemiology was conducted. Results relevant for the European context are presented, showing generally greatest exposures in car riders and lowest exposure in pedestrians.

Contents

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1. Introduction

Travel microenvironments may represent settings of greatest exposures to air pollutants throughout daily activities for many people. While a small portion of time may be spent commuting, this activity may lead to a substantial contribution to total daily exposures and inhalations of air pollutants. A study conducted in Barcelona for example found that respondents only spent 6% of their time traveling, but the activity contributed to 11% of their exposure to nitrogen dioxide (NO_2) and 24% of their inhalation of NO_2 (de Nazelle et al., 2013). These comparatively high peaks of exposure may have associated adverse health effects. For example, time spent in transportation modes (car, public transportation or bicycle) was shown to be associated with the onset of myocardial infarctions in a relatively large case-crossover study (1459 cases) (Peters et al., 2013). Experimental studies have shown sub-clinical effects of exposures while cycling, walking, or taking the bus in urban environments (Adar et al., 2007; McCreanor et al., 2007; Strak et al., 2009; Weichenthal et al., 2011).

Promoting walking and cycling for travel is seen as a promising solution to the physical inactivity pandemic, while also providing multiple co-benefits such as reductions in air pollution, noise, or traffic injuries (de Nazelle et al., 2011). Thus, health impact studies now attempt to estimate both positive and negative effects from being physically active while exposed to increased pollutant inhalation during walking or cycling (Mueller et al., 2015). Such studies require a quantification of relative exposures to pollutants in different travel modes. Data available locally or informal summaries of existing literature have typically been used (de Hartog et al., 2010; Rojas-Rueda et al., 2011).

Additionally, concerns are arising regarding air pollution epidemiologic research and the use of exposure assessments in which activity patterns are not fully accounted for, leading to bias in exposure-response estimates (Ragettli et al., 2015; Setton et al., 2011). While personal monitoring of air pollution exposure is currently too expensive to be used on the wide scale of entire cohorts in epidemiologic studies, future studies may be able to integrate information from daily activity patterns into their exposure assessments (de Nazelle et al., 2009; Dons et al., 2014). In particular, the development of smart phone and sensor technologies that allow seamless tracking of individuals renders such approaches much more feasible by potentially reducing costs and participant burden (de Nazelle et al., 2013; Nieuwenhuijsen et al., 2014). However, even when such detailed data of people's whereabouts and level of activity are possible, knowledge on the pollutant concentration and relative exposures in different travel modes are needed. This is particularly true when the combined effects of air pollution and physical activity are to be investigated (Andersen et al., 2015).

With the increasing numbers of studies on exposures in different travel modes, a few reviews have been published (Bigazzi and Figliozzi, 2014; Karanasiou et al., 2014), but none yet have attempted to provide a quantitative synthesis of findings from measurement studies. This paper summarizes the state of knowledge and provides quantitative estimates of relative exposures for different transportation modes in Europe.

2. Methods

A literature review on air pollution exposure for various modes of transport across Europe was completed. In this context, exposure refers to the concentration levels to which one is exposed to in a given environment, as opposed to time-weighted concentrations. Data from selected studies were harmonized to allow for a quantitative comparison. Ratios and 95% confidence interval (CI) of air pollution exposure between transportation modes and with respect to backgrounds concentrations were computed.

2.1. Literature review

Articles published between the 1st January 2000 and 28th of June 2016 in peer-review journals were searched in PubMed, ISI web of knowledge, Google Scholar, and ScienceDirect, for a combination of search terms on travel modes and air pollutants (see Appendix A). Additionally, articles appearing in the "related citations" and "cited by" were checked. Articles were then selected according to the following criteria:

i) Monitoring studies of air pollution concentrations in transportation microenvironments in Europe;
ii) At least one active travel mode (walking or cycling) compared to one or more other modes or compared to background concentrations;
iii) An experimental design which includes a comparison between modes on the same or close to the same routes, with concomitant or near-concomitant sampling for selected modes;
iv) After inspection of most commonly measured pollutants, only articles reporting particulate matter of size less than 2.5 μm ($PM_{2.5}$), black carbon (BC), ultrafine particles of size less than 0.1 μm (UFP), or carbon monoxide (CO) were selected;
v) Articles with insufficient information to compute the parameter estimates (i.e. mean, standard deviation and sample size) for the lognormal distributions (geometric means and geometric standard deviations) were excluded.

2.2. Data harmonization and derivation of ratios

Monitoring studies of exposure concentrations are very diverse in study design and means of reporting the data. Many studies report and compute exposure to pollutants concentration assuming it follows a normal distribution, although it has been demonstrated to follow a

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