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Exposure to noise and air pollution by mode of transportation during rush hours in Montreal

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ABSTRACT

According to the World Health Organization, air pollution and road traffic noise are two important environmental nuisances that could be harmful to the health and well-being of urban populations. Earlier studies suggest that motorists are more exposed to air pollutants than are active transportation users. However, because of their level of physical activity, cyclists also inhale more air pollutants. The main objective of this paper is to measure individuals' levels of exposure to air pollution (nitrogen dioxide – NO_2) and road traffic noise according to their use of different modes of transportation.

Three teams of three people each were formed: one person would travel by bicycle, one by public transit, and the third by car. Nearly one hundred trips were made, from various outlying Montreal neighbourhoods to the downtown area at 8 am, and in the opposite direction at 5 pm.

The use of mixed models demonstrated that public transit commuters' and cyclists' levels of exposure to noise are significantly greater than motorists' exposure. Again, using mixed models, we found that although the levels of exposure to the NO_2 pollutant do not significantly differ among the three modes, the inhaled doses of NO_2 pollutant are more than three times higher for cyclists than for motorists due to their stronger ventilation rate. It is hardly surprising that the benefits of physical activity are of course greater for cyclists: they burn 3.63 times more calories than motorists. This ratio is also higher for public transport users (1.73) who combine several modes (walking, bus and/or subway and walking).

1. Introduction

The concentrations of air pollutants and level of traffic noise generated by road transportation represent a major public health issue (Kim et al., 2012; Zuurbier et al., 2010). Aware of the problems caused by road traffic in terms of the quality of life and health of individuals living in urban environments, authorities in many cities around the world have focused on developing networks of bicycle paths to reduce the dependence on cars. In this regard, according to a 2013 survey conducted by the City of Montreal, there was a nearly 60% increase in the number of bicycle trips since 2008 (Ville de Montréal, 2017). Many factors have contributed to this increase in the modal share of cycling, especially in central neighbourhoods on the Island of Montreal. For example, over the past twenty-five years (1991–2016), the Island of Montreal cycling network was expanded from 270 km to 732 km (Houde et al., 2018), and in 2009 a bike sharing system was set up in Montreal, and the number of stations as well as the number of bicycles have continually grown up to the present time. Despite these efforts made to encourage the practice of bicycling in the City of Montreal, cycling still has a relatively low mode share for commuting, compared with the car and public transit (3.9%, compared with 50.1% and 36.5%, according to Statistics Canada data for 2016).

The period of the rush-hour commute constitutes a micro-environment that is very interesting to study regarding exposure to air pollutants and road traffic noise, given the high levels and pollution peaks, measured at these times of the day (Laumbach et al., 2015). In addition this is a time of day many people are travelling and it has been shown to have the potential to disproportionately contribute to an individuals' daily exposure (Hill and Gooch, 2007). Comparisons of the levels of exposure to pollutants with various modes of transportation—mainly by car, public transit, and cycling—have been made in a number of cities, particularly: Sydney for nitrogen dioxide (NO_2) (Chertok et al., 2004), Barcelona for carbon monoxide (CO) and $PM_{2.5}$ particles (De Nazelle et al., 2012), New Delhi for $PM_{2.5}$ (Goel et al., 2015), Athens for CO (Duci et al., 2003), Stockholm for NO_2 (Lewne et al., 2006), Shanghai for $PM_{2.5}$ (Liu et al., 2015), London for $PM_{2.5}$ (Kaur et al.,

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2005), Beijing for CO and $PM_{2.5}$ (Huang et al., 2012; Yan et al., 2015), Forshan (China) for $PM_{2.5}$ (Wu et al., 2013), Dublin for $PM_{2.5}$ and PM_{10} (Nyhan et al., 2014), Arnhem (the Netherlands) (Zuurbier et al., 2010), and Santiago (Chile) for $PM_{2.5}$ (Suárez et al., 2014). In a recent systematic review of 39 studies comparing exposure to and inhalation of air pollutants with different modes of transportation, Cepeda et al. (2017) conclude that motorists and public transit commuters have higher levels of exposure than cyclists and pedestrians. However, because of their higher levels of ventilation, cyclists followed by pedestrians may, depending on individual respiration rates, inhale more pollutants. On the other hand, to our knowledge, there have been no studies attempting to compare exposure to noise during rush hours according to the mode of transportation.

The main objective of this study is therefore to measure individuals' levels of exposure to air pollution and road traffic noise during rush hours in Montreal, according to three modes of transportation (car, cycling, and public transit). More specifically, the aim is to meet the following research sub-objectives: 1) compare travel times for rush-hour trips to or from the downtown area using three modes of transportation (car, cycling, public transit); 2) compare the levels of exposure to noise and air pollution; and 3) compare the doses of pollutants inhaled during the trips and the levels of physical activity.

2. Methods

2.1. Study design and routes

Eight urban studies students—four women (aged 21 to 28) and four men (aged 24 to 32)—and a professor in charge of the project (age 43) made the trips in mid-June 2016. Three teams of three people each were formed: one person travelled by bicycle, one by public transit, and the third by car. Each participant kept the same mode of transportation throughout the period. Due to the high summertime temperatures (mean = 28.7 °C; sd = 4.3), the trips by car were made with the windows open (without controlled ventilation settings). The trips were made from various outlying Montreal neighbourhoods to the downtown area at 8 am, and in the opposite direction at 5 pm.

Eighteen round trips of approximately ten kilometres each way had previously been selected using Google Maps. A total of 108 trips were thus made (18 × 2 trips (1 trip each way) × 3 modes of transportation). The destinations selected downtown are either centres of higher education—Concordia University, INRS Urbanisation Culture Société, McGill University, and Université du Québec à Montréal—or important employment centres such as the Stock Exchange Tower and Complexe Guy-Favreau (government services and shopping complex) (Fig. 1). The origins of the trips correspond to the intersection of two residential streets in outlying Montreal boroughs, particularly Ahuntsic–Cartierville, Rosemont–La Petite-Patrie, Montréal-Nord, Verdun, Saint-Laurent, etc. The members—motorists, cyclists and public transit commuters—of each of the three teams started their trips at exactly the same time. Also, the participants had a Google Maps route sent to them on their portable phones so that they would make the fastest possible trip with their mode of transport.

After cleaning up the data (elimination of trips not made or trips uncompleted due to rain), 99 trips were retained, representing nearly 65 h and more than 1000 km collected on the Island of Montreal (Table 1). It should be noted that some trips were also excluded due to improper use of a device by one of the participants or because of a defective device. In concrete terms, for a given team, if one of the participants (the cyclist, for example) did not have a value for a particular device (e.g. the noise dosimeter), the trips of the other two members of the team (the motorist and the public transit commuter) were also eliminated. In short, 99 valid trips were made, 93 were retained in order to measure noise, 60 to measure exposure to air pollution, and 54 to measure the participants' heart rate (Fig. 2).

2.2. Measurements of individual exposure

Data collection was based on the use of three types of devices: 1) nine Aeroqual Series 500 Portable Air Quality Sensors, 2) nine Brüel & Kjaer Personal Noise Dose Meters (Type 4448), and 3) nine Garmin GPS watches (910 XT). All the participants retained the same devices throughout the collection period. We used these devices to measure the individuals' exposure to air pollution (NO_2) and noise (dB(A)) as well as their heart rates, and to obtain a GPS trace of the trip. The Aeroqual devices have two sensors—nitrogen dioxide (NO_2) and temperature and humidity sensors—that record the average NO_2 value (μg/m^3), the temperature in degrees Celsius, and the percentage of humidity every minute. According to the Aeroqual supplier's product information, the NO_2 sensor has the following characteristics: range (0–1 ppm), minimum detection (0.005 ppm), accuracy of factory calibration (< ± 0.02 ppm 0–0.2 ppm; < ± 10% 0.2–1 ppm), and resolution (0.001 ppm). The Brüel & Kjaer devices record the average decibel levels (dB(A)) every minute (Laeq 1 min.). As recommended by the manufacturer, all Personal Noise Dose Meters (Type 4448) were calibrated once a day using the Sound Calibrator Type 4231.

In order to estimate the inhalation or uptake pollutant dose, we first need to obtain a measure of ventilation (breathing parameter). We then simply multiply the measure of exposure to the pollutant by the minute ventilation value (VE). To do this, two methodological approaches are generally employed.

The first consists in setting the ventilation values for each mode for all the trips (Dirks et al., 2012; Dons et al., 2012; Huang et al., 2012). The United States Environmental Protection Agency provides a whole series of values for inhalation rates by age group, sex, and level of activity (U.S. EPA, 2011), which can then be used (Huang et al., 2012). Similarly, based on the Allan and Richardson (1998) and Panis et al. (2010), Dons et al. (2012) set ventilation values per minute in considering the type of activity (home-based activities, sleep, work, etc.), the mode of transportation (car driver, car passenger, by bike, on foot, by bus, etc.), and the sex.

The second approach involves varying the inhalation rates throughout the trip by equipping the participants with devices to measure, in real time, either their heart rate (Nyhan et al., 2014) or their energy expenditure using an accelerometer (De Nazelle et al., 2012), based on which one can estimate ventilation, or, instead, to directly measure ventilation with a portable cardiopulmonary indirect breath-by-breath calorimetry system (Panis et al., 2010). For example, Nyhan et al. (2014) use heart rate monitors (Actiheart ®) to obtain heart rate values that vary throughout the trip. Then, to obtain a measure of ventilation, they use the regression equations obtained by Zuurbier et al. (2009) between ventilation (dependent variable) and heart rate (independent variable) for 34 individuals who had performed a submaximal test on a bicycle ergometer (during the physical test, the minute ventilation, breathing frequency and tidal volume were measured using a pneumotachometer, and the heart rates were recorded with Polar RS400 heart rate monitors). Finally, it is worth noting that Dons et al. (2017) have recently proposed an interesting comparison of several methods of estimating the inhaled dose of pollutant using wearable sensors.

The approach used here to precisely estimate ventilation and the inhaled dose of NO_2 throughout the trips is very similar to that employed by Zuurbier et al. (2009). Each participant performed a progressive, continuous and maximal effort test at the *Physical Activity and Health Laboratory* using the Garmin Forerunner 920XT heart rate monitor watch. The raw heart rate data obtained with the Garmin watch were averaged over 15 s using the MATLAB spline interpolation technique (MathWorks, 2018) in order to fill in the missing data. The metabolic parameters [ventilation rate, minute ventilation, oxygen consumption, and metabolic equivalents (METs)] were measured by indirect calorimetry (MOXUS, Model S-3A, AEI Technologies, PA, USA). The protocol included measures at rest (5 min per position—lying,