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Commuting behaviors and exposure to air pollution in Montreal, Canada

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HIGHLIGHTS

- Urban air pollution level was measured by a sensitive PAH metabolite biomarker.
- All types of commuting during rush hours increase exposure to urban air pollution.
- No significant difference in urinary 1-OHP variation was found by mode of commuting.

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ABSTRACT

Background: Vehicular traffic is a major source of outdoor air pollution in urban areas, and studies have shown that air pollution is worse during hours of commuting to and from work and school. However, it is unclear to what extent different commuting behaviors are a source of air pollution compared to non-commuters, and if air pollution exposure actually differs by the mode of commuting. This study aimed to examine the relationships between commuting behaviors and air pollution exposure levels measured by urinary 1-OHP (1-hydroxypyrene), a biomarker of exposure to polycyclic aromatic hydrocarbons (PAHs).
Methods: A cross-sectional study of 174 volunteers living in Montreal, 92 females and 82 males, aged 20 to 53 years was conducted in 2011. Each participant completed a questionnaire regarding demographic factors, commuting behaviors, home and workplace addresses, and potential sources of PAH exposure, and provided a complete first morning void urine sample for 1-OHP analysis. Multivariable general linear regression models were used to examine the relationships between different types of commuting and urinary 1-OHP levels.
Results: Compared to non-commuters, commuters traveling by foot or bicycle and by car or truck had a significantly higher urinary 1-OHP concentration in urine ($p = 0.01$ for foot or bicycle vs. non-commuters; $p = 0.02$ for car or truck vs. non-commuters); those traveling with public transportation and combinations of two or more types of modes tended to have an increased 1-OHP level in urine ($p = 0.06$ for public transportation vs. non-commuters; $p = 0.05$ for commuters with combinations of two or more types of modes vs. non-commuters). No significant difference in urinary 1-OHP variation was found by mode of commuting.
Conclusion: This preliminary study suggests that despite the mode of commuting, all types of commuting during rush hours increase exposure to air pollution as measured by a sensitive PAH metabolite biomarker, and mode of commuting did not explain exposure variation.

1. Introduction

In urban areas, vehicular traffic is a major source of air pollution. The International Agency for Research on Cancer has classified exhaust from diesel engines as carcinogenic to humans, and emissions from gasoline engines as possible carcinogens (IARC, 1983–1996, 2012). In addition, a recent study reported that traffic-related fine particulate air pollution ($PM_{2.5}$) contributed to 8% of deaths from cardiopulmonary disease, 12.8% of deaths from lung cancers, and 9.4% of deaths from ischemic heart disease, globally (Evans et al., 2013).

Several studies have reported traffic-related air pollutant levels, such as different sizes of particulate matter (PM), to be up to four times higher during rush hours than at other times of the day (Knibbs et al., 2011; Yu et al., 2012). Since most commuters travel from home to their workplace or school during peak traffic volume hours, air pollution exposure levels among commuters is of potential concern (Akland et al., 1985; Knibbs et al., 2011; Zuurbier et al., 2010). Some researchers

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suggest that all commuters in urban areas are exposed to increased levels of air pollution during rush hours compared to levels at other times of the day, regardless of their type of commuting behavior (Briggs et al., 2008; Knibbs and de Dear, 2010; Knibbs et al., 2011). For example, a study conducted in Belgium reported that up to 30% of exposure to black carbon (a traffic-related air pollutant) is attributable to commuting everyday among commuters (Dons et al., 2012). However, to our knowledge, there is no published study comparing air pollution exposure levels between commuters and non-commuters using a biomarker which has been demonstrated as a good air pollution exposure measurement (Castano-Vinyals et al., 2004). Although a few studies have monitored air pollution levels according to different types of commuting, findings are inconsistent (de Nazelle et al., 2011; Knibbs and de Dear, 2010; Namdeo et al., 2014; Ragettli et al., 2014).

Polycyclic aromatic hydrocarbons (PAHs) are major sources of traffic-related air pollutants in urban areas (Hansen et al., 2008; Pachón et al., 2013). A major urinary metabolite of pyrene, 1-hydroxypyrene (1-OHP), has been widely used for traffic and PAH exposure measurement (Strickland and Kang, 1999). Montreal is the second most populous city in Canada, and has been identified as an urban area with traffic pollution concerns (Crouse et al., 2010, 2012; Labreche et al., 2010), and this motivated us to examine associations between commuting behaviors and exposure to air pollution using urinary 1-OHP as an air pollution biomarker in Montreal, Canada.

2. Methods

2.1. Study design and study population

A cross-sectional study was conducted between June and July of 2011 in Montreal Quebec. The inclusion criteria were: male or female 20–50 years; without cancer, liver or kidney disease; residing at their current address for at least three months; employed or attending school.

Based on a widely accepted assumption that "96% of the vehicles' pollutants disperse at 152.4 m (500 ft) on a windless day" (Gunier et al., 2006; Miao et al., 2014a; Pearson et al., 2000), the DMTI CanMap® Route Logistics file and postal code boundary file from 2011 were used to obtain postal codes within three 'buffer' zones in Montreal: individuals living within 500 ft (152.4 m) of major roads/highways (high traffic impact zone); those living within 500–750 ft (152.4–228.6 m) of major roads/highways (medium traffic impact zone); and those living with a 750–1000 ft (228.6–304.8 m) buffer from major roads/highways (low traffic impact zone) (DMTI Spatial Inc. CanMap® RouteLogistics, 2011a; DMTI Spatial Inc. Platinum Postal CodeOM Suite, 2011b; Miao et al., 2014a). Random sampling was conducted within each traffic impact zone using the household telephone numbers associated with postal codes, to make sure the sample had variability in exposure levels. After telephone screening, 624 persons were willing to participate. Ultimately, 177 participants (92 females and 82 males; aged 20 to 53) met the study criteria and were included in this study. To minimize spatial correlation bias, volunteers who lived in different houses/buildings were chosen to participate. This study was approved by the Queen's University Health Sciences Research Ethics Board and the Ethics Committee of Research on Health Sciences at the Université de Montréal.

2.2. Data collection

Study staff phoned potential participants' homes and a password-protected database was created to record telephone screening results. Once participants had agreed to participate, research staff visited their homes to deliver a consent form and guide, instructions for data collection, the questionnaire, and a bottle for urine collection with added Thymol, an antibacterial agent. Participants completed a self-administered questionnaire including: age, sex, ethnicity, alcohol consumption, household income, commuting behaviors, home and workplace addresses, whether their residence was located within 100 m of a highway, and potential sources of PAH exposure other than traffic, such as smoking and the consumption of barbecue, fried or smoked meat. Participants provided a complete 'first-morning-void' urine sample using a 1 L Wide Mouth Nalgene bottle. The samples were kept refrigerated, and within 24 h staff retrieved them from participants' homes and delivered them to Dr. Bouchard's laboratory at the Université de Montréal. Urinary volume was measured prior to freezing at −20 °C.

2.2.1. 1-OHP analysis

Determination of total 1-OHP consisted of an enzyme hydrolysis (1 h after buffering with sodium acetate), solid-phase extraction using Sep-pak C18 cartridges of urine samples (10 ml each) followed by ultra-high-performance liquid chromatography analysis (Agilent 1290 series UHPLC) coupled to fluorescence detection (Bouchard and Claude, 1999). Urinary 1-OHP levels were corrected for creatinine concentrations (Miao et al., 2014a). For each batch of urine analysis, quality control samples of pools of urine were conducted (Miao et al., 2014a). Among 177 urine samples, two samples were under the detection limit for 1-OHP analysis; and three samples had interference peaks and removed from the analysis.

2.2.2. Distance between home and workplace/school

Each participant's home and workplace/school in Montreal were geocoded based on their postal code and/or street addresses using ArcMap 10.1 (ESRI, 2011). Projected coordinates (X, Y) to UTM Zone 18 in meter from longitude and latitude of each location were exported from ArcMap and imported to SAS software system to calculate the distance between home and workplace/school using the formula below.

$$\text{Distance between home and workplace/school} = \sqrt{(x_2-x_1)^2+(y_2-y_1)^2}$$

where x_1, y_1 and x_2, y_2 are coordinates in meter projected from longitude and latitude of home and workplace/school, respectively.

2.2.3. Exposure and outcome variables

Commuting behavior was captured by asking about routine transportation by bus, metro/train, bicycle, foot, motorcycle, truck, car, or combinations of at least two of the transport modes. Non-commuters ($n = 12$) are defined as persons who work at home, run a home business, or students who study at home and use on-line and distance learning. The outcome is the biomarker 1-OHP in urine.

2.2.4. Potential confounders

Age and body mass index (BMI) may influence the kinetics of pyrene elimination, and thus influence the level of urinary 1-OHP (Hansen et al., 2008). Similarly, age and BMI may influence lifestyle preferences and behaviors that could affect exposure to PAHs. In addition, traffic exposure is related to the commuting distance (between residence and workplace/school). Therefore, we included these three confounders in all models. In addition, smoking, living close to a highway, consumption of barbequed meat, household income, ethnicity, sex, and alcohol consumption were assessed as potential confounders based on previous studies (Crouse et al., 2009; Hansen et al., 2008; Miao et al., 2014a).

2.3. Statistical analysis

After log transformation of urinary 1-OHP levels, residuals generated from the multivariate general linear regression models showed near normal distribution and variance of residuals was constant. Multivariable generalized linear models (GLM) were used to examine the relationship between levels of 1-OHP in urine and commuting behaviors. For confounder assessment, a backward change-in-estimate selection procedure was conducted, where variables that changed the main

exposure effect by greater than 10% were retained in a final model (Rothman et al., 2008). All statistical analyses were performed using SAS (version 9.2, SAS Institute, Cary, North Carolina).

3. Results

Table 1 describes the characteristics of the study population. Mean age (±SD) of participants was 36 ± 8.3 years. The median of 1-OHP was 84.30 nmol/mol creatinine, with a range of 0.50–735.30 nmol/mol creatinine. The distribution of log 1-OHP showed a near normal distribution with a geometric mean (GM) of 79.31 nmol/mol creatinine and a geometric standard deviation (GSD) of 2.62.

Fig. 1 presents a box plot of 1-OHP levels according to commuting behaviors, illustrating that the levels among commuters were higher than those of non-commuters. Tables 2 and 3 show the results of the relationships between commuting behaviors and log transformed urinary 1-OHP levels from GLM models, while adjusting for age, BMI, sex, household income, smoking status in the 48 h prior to urine collection, living within 100 m of a highway, and the distance between home and workplace/school. Compared to non-commuters, commuters had higher urinary 1-OHP concentrations in urine (β: 0.74, p = 0.02, 95% CI: 0.14–1.33 for log transformed 1-OHP in urine). This higher level of biomarker was seen in each type of commuting, by public transportation (bus, metro or train) (β: 0.75, p = 0.06, 95% CI: −0.05–1.54), by car or truck (β: 0.78, p = 0.02, 95% CI: 0.12–1.43), by foot or bicycle (β: 0.97, p =

Table 1
Characteristics of study population.

Variables	Total (N = 174)		1-OHP in urine (nmol/mol creatinine)				
	N	%	Arith. mean	Arith. SD	Median	Geometric mean	Geometric SD
Age (mean: 36, SD: 8:27)							
20–30	51	29	120.69	4.41	87.20	82.51	2.44
31–40	60	34	124.95	4.37	82.60	78.76	3.32
41–53	63	36	101.94	4.35	83.10	77.33	2.13
Sex							
Male	82	47	100.65	4.27	82.90	71.38	2.60
Female	92	53	128.49	4.47	86.10	87.12	2.63
BMI (mean: 24.5, SD: 4.65)							
<25	104	60	132.79	4.51	91.65	91.18	2.58
25–29.9	44	25	83.02	4.11	68.35	61.18	2.75
30+	20	11	104.88	4.38	87.10	80.00	2.18
Missing	6	3	85.57	3.83	34.65	46.17	2.97
Ethnicity							
European	118	68	118.42	4.39	82.35	80.62	2.73
Others	55	32	107.46	4.32	85.50	75.38	2.40
Missing	1	1	–	–	–	–	–
Household income							
<$30,000	27	16	109.16	4.36	91.40	78.61	2.24
$30,000–$49,999	57	33	122.60	4.34	97.00	76.92	3.45
$50,000–$79,999	40	23	106.70	4.41	86.30	82.26	2.14
≥$80,000	48	28	118.70	4.38	73.45	79.91	2.37
Missing	2	1	–	–	–	–	–
Alcohol consumption							
≤5 drinks/week	126	72	114.49	4.40	88.25	81.32	2.50
>5 drinks/week	47	27	119.24	4.32	76.60	75.10	3.00
Missing	1	1	–	–	–	–	–
Smoking within 48 h of urine collection							
No	119	68	88.32	4.15	63.70	63.64	2.38
Yes	47	27	172.87	4.83	131.50	125.51	2.77
Missing	8	5	179.93	4.95	194.55	141.47	2.38
Barbecue/fried/smoked meat within 48 h of urine collection							
No	112	64	113.91	4.32	83.55	75.15	2.87
Yes	62	36	118.01	4.47	85.15	87.43	2.16
Living within 100 m of highway							
No	117	67	103.94	4.26	68.90	70.70	2.77
Yes	55	32	140.94	4.62	103.40	101.53	2.24
Missing	2	1	–	–	–	–	–
Distance between home and workplace/school[a] (m) (mean: 6867, median: 5660; 1st tertile: ≤4411; 4411 < 2nd tertile ≤ 7967; 3rd tertile: >7967)							
1st tertile (lowest; mean: 2081, median: 1968)	46	28	135.28	4.57	100.20	96.54	2.37
2nd tertile (mean: 5838, median: 5724)	45	28	111.26	4.32	77.70	74.90	2.86
3rd tertile (highest; mean: 12,788, median: 11,666)	45	28	102.98	4.27	68.60	71.81	2.71
Missing	26	16	133.50	4.57	106.25	96.08	2.44
Commuting behavior							
Non-commuter	12	7	61.61	3.79	38.35	44.35	2.27
Bus	4	2	123.35	4.52	135.85	92.16	2.84
Metro/train	13	7	115.23	4.49	73.70	89.14	2.10
Bicycle	6	3	200.28	4.91	140.10	136.10	2.59
Foot	7	4	149.10	4.82	97.00	124.47	1.91
Car	59	34	114.43	4.45	95.70	85.97	2.47
Truck	2	1	–	–	–	–	–
Combined	59	34	111.01	4.24	61.30	69.26	2.93
Missing	12	7	126.79	4.43	101.65	84.34	2.85

[a] Non-commuters were excluded, which included 7 people ran home business; 2 people stated home addresses were the same with their workplaces. Due to confidentiality issue, we were not able to provide distance for the remaining 3 people.

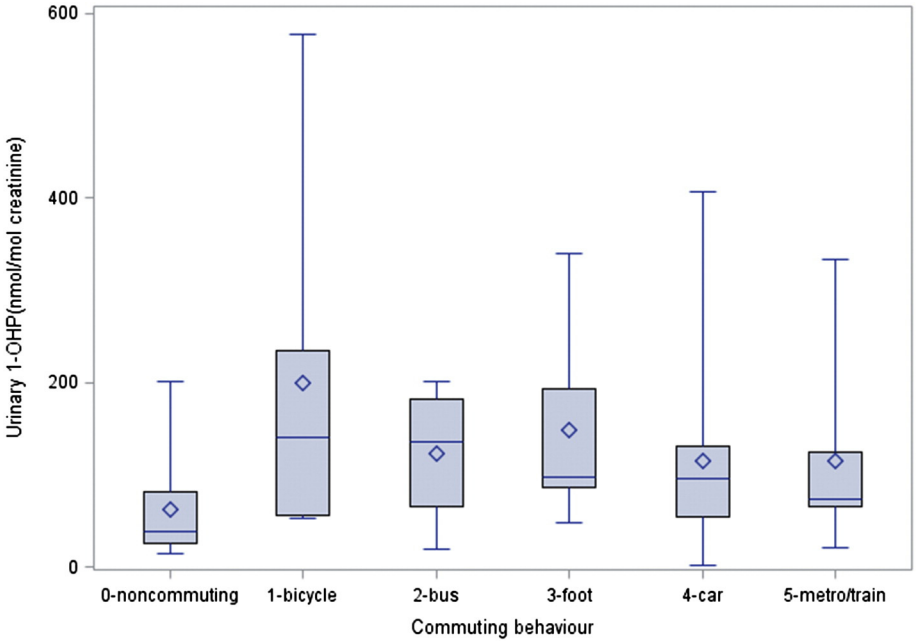

Fig. 1. Distribution of urinary 1-OHP concentrations by commuting behaviors. 1) The distribution of 1-OHP for participants commuting by truck (7-truck) was not shown since only 2 commuters used this form of transportation for their travels; 2) The above Box-and-whisker plots show 25th to 75th quartiles (box), median (the line in the box), mean (the symbol of diamond in the box), and minimum and maximum values (lowest and highest lines) (see Table 1 for numbers per group).

0.01, 95% CI: 0.20–1.74), and in combinations of two or more types of commuting modes (β: 0.62, p = 0.05, 95% CI: 0.00–1.25). Compared to commuting by public transportation, no difference of urinary 1-OHP variability was found among modes of commuting by private vehicles (car or truck) (β: 0.24, p = 0.54, 95% CI: −0.54–1.02), on foot/by bicycle (β: 0.05, p = 0.86, 95% CI: −0.54–0.65), and combinations of two or more modes (β: −0.09, p = 0.77, 95% CI: −0.68–0.50) (Table 3).

4. Discussion

In 2013, it was estimated that 3.3 million commuters make 8 million trips daily in Montreal, and this will increase to 10.2 million trips by 2016 (Quebec, 2013). Montreal has a number of serious transportation issues including heavy traffic, noise, safety concerns, and air pollution, which peak during rush hours (Quebec, 2013). Our findings support this concern with objective PAH biomarker measurements: commuters have greater exposure to air pollution than non-commuters. However, mode of commuting, by public transportation, car/truck, bicycle, or walking did not lead to differences in urinary 1-OHP levels.

To our knowledge, this is the first published report using a biomarker to compare air pollution exposure levels between commuters and non-commuters. There have been reports of other biomarkers among subjects before and after exposure to rush hour traffic (de Nazelle et al., 2011; Li, 2012; Yu et al., 2012; Zuurbier et al., 2011b), such as

Table 2
Relationship between log transformed 1-OHP levels in urine and commuting behaviors among workers or students (N = 135), using a multivariate GLM model.

Variables	Adjusted[a] estimate (β)	p-Value		95% CI	p-Trend
Age	−0.003	0.74	−0.02	0.02	
BMI	0.01	0.65	−0.03	0.04	
Sex					
Female	0.30	0.07	−0.02	0.62	
Male	–	–	–	–	
Household income					
<$30,000	–	–	–	–	
$30,000–$49,999	0.24	0.37	−0.28	0.75	
$50,000–$79,999	−0.20	0.45	−0.72	0.32	
≥$80,000	0.04	0.88	−0.49	0.57	0.41
Smoking in 48 h					
No	−0.77	<.0001	−1.13	−0.40	
Yes	–	–	–	–	
Living within 100 m of highway					
No	−0.22	0.23	−0.58	0.14	
Yes	–	–	–	–	
Distance between home and workplace/school (km)	−0.03	0.11	−0. 06	0. 006	
Commuting behavior					
Commuters [b]	0.74	0.02	0.14	1.33	
Bus, metro or train	0.75	0.06	−0.05	1.54	
Bicycling or foot	0.97	0.01	0.20	1.74	
Car, truck	0.78	0.02	0.12	1.43	
Combination of two or more	0.62	0.05	0.00	1.25	
Non-commuters	–	–	–	–	

[a] All variables except commuters were from one GLM model.
[b] Commuting behavior was categorized as commuters and non-commuters, and adjusted for age, BMI, sex, household income, smoking within 48 h of urine collection, living within 100 m of a highway, and the distance between home and workplace.

Table 3
Relationship between log transformed 1-OHP levels in urine and commuting modes among commuters (with public transportation as a comparison) (N = 123), using a multivariate GLM model.

Variables	Adjusted estimate[a] (β)	p-Value	95% CI		p-Trend
Age	−0.01	0.53	−0.03	0.01	
BMI	0.01	0.54	−0.03	0.05	
Sex					
Female	0.28	0.11	−0.06	0.62	
Male	–	–	–	–	
Household income					
<$30,000	–	–	–	–	
$30,000–$49,999	0.32	0.26	−0.24	0.88	
$50,000–$79,999	−0.23	0.42	−0.78	0.32	
≥$80,000	0.08	0.78	−0.48	0.63	0.34
Smoking in 48 h					
No	−0.80	<.0001	−1.18	−0.42	
Yes	0.00	.	.	.	
Living within 100 m of highway					
No	−0.29	0.13	−0.66	0.08	
Yes	–	–	–	–	
Distance between home and workplace/school (km)	−0.03	0.10	−0.06	0.01	
Commuting behavior					
Bus, metro or train	–	–	–	–	
Bicycling and foot	0.24	0.54	−0.54	1.02	
Car, truck	0.05	0.86	−0.54	0.65	
Combination of two or more	−0.09	0.77	−0.68	0.50	

[a] All variables were from one GLM model.

malondialdehyde (MDA) in exhaled breath condensate, which showed an increase after subjects were exposed to 2 h of heavy traffic. On the other hand, in the Netherlands blood cell counts and blood coagulation markers did not differ with exposure to air pollution (Zuurbier et al., 2010, 2011a). A study in China using personal monitors to measure $PM_{2.5}$ and CO found that cyclists had the highest traffic exposure levels compared to traveling by bus and taxi ($p < 0.05$) (Huang et al., 2012). This is in contrast with other studies that reported participants who walked or biked experienced lower exposures to PM and other air pollutants than those using other commuting modes (de Nazelle et al., 2011; Kaur et al., 2007). In addition, two studies indicated that individuals traveling by car were exposed to heavier traffic-related air pollution (Chertok et al., 2004; Kingham et al., 2013). The geographic locations in which these types of studies take place, as well as choices made by walkers/cyclists to use low or high traffic routes explain at least some of these disparate results.

There is a lack of consensus on the ideal biomarker to use when assessing the impact of air pollution on commuters, and not all biomarkers are sufficiently sensitive for use in such studies. Air pollution represents a mixture of pollutants, whereas biomarker levels in tissue, blood and urine may reflect either the uptake of only specific pollutants (such as PAH), or biological changes secondary to exposure in very specific time windows (Hansen et al., 2008). While it is not possible to find an ideal biomarker to reflect the complex mixture of air pollution exposure, our results suggest that urinary 1-OHP is a sensitive biomarker for traffic variation measurements. Measurements of 1-OHP are more specific to air pollution components and their biological intake than other biomarkers or personal monitors, in that 1-OHP levels in urine not only represent uptake of PAH and but also recent air pollution variation (Hansen et al., 2008). Therefore, compared to previous studies, the main strength of this study is lack of exposure misclassification since we use an accurate biomarker. Another study's strength is that we considered variables together in multivariable regression analyses and we controlled for confounders.

Non-commuters were identified as participants who did not routinely travel from home to workplace/school during peak traffic hours; thus, we assumed that non-commuters had lower traffic exposures than commuters. Recognizing that non-commuters can be exposed to traffic related air pollution, we included another potential exposure contributor, that is, residential traffic exposure defined as living within 100 m of highways in the multivariate models. Due to lack of data, we were unable to take into account the height of the residence, which may have led to misclassification of residential traffic exposure.

Unlike some other studies showing that commuters are exposed to varying levels of air pollution exposure depending on their choice of travel, this study did not find a difference between commuting modes. This could be due to our small sample size, and therefore our study results should be considered preliminary.

Although we were not able to record time spent on commuting from home to work/school, we developed a proxy of 'time spent on roads' by applying GIS methodology to calculate the distance between homes to work/school, and controlling for this in multivariable models. This calculated distance was a proxy measurement.

Commuters who travel by personal vehicles may be in closer proximity to vehicular engine exhaust than commuters using public transit, and thus may be exposed to higher levels of PAH and other pollutants. Compromised personal car air ventilation systems might not disperse these pollutants effectively (Knibbs et al., 2011). Commuting by public transportation, however, has its own pollution exposure issues. A study reported in 2005 found that when windows of school buses were open, higher exposures were observed due to the emissions of nearby vehicles or the buses own diesel engine (Sabin et al., 2005). For pedestrians and cyclists, exercise may increase breathing rates, which may increase inhalation of air pollutants (Dirks et al., 2009; Yu et al., 2012). Individual level exposure to traffic-related air pollution is influenced by the time/day on specific roads, the types of vehicles and engines, and weather conditions when traveling on the road (Zuurbier et al., 2010). Future research should take all of these factors into account, and the use of mobile monitors and GIS may lead to more accurate measurements (Miao et al., 2014b).

From a public health perspective, many people living in urban settings where pollution levels are high routinely commute by bicycle or on foot as an effort to increase physical activity and decrease cost (Rabl and de Nazelle, 2012). It is unfortunate that this effort is compromised by increased exposure to air pollution that is documented as harming health. To reduce air pollution exposure while commuting, municipalities could consider designating specific thoroughfares for use by pedestrians and non-motorized vehicles only (Hatzopoulou et al., 2013). Future collaborations between government, science and industry to create more 'green' travel options may mitigate this risk to commuters.

5. Conclusion

This preliminary study suggests that despite the mode of commuting, all types of commuting during rush hours increase exposure to air pollution as measured by a sensitive PAH metabolite biomarker, and mode of commuting did not explain exposure variation.

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