Personal Exposure Levels to O₃, NO_x, PM₁₀ and the Association to Ambient Levels in two Swedish Cities

Susanna Haga (✉ susanna@lohman-haga.com)

Goteborgs universitet Sahlgrenska Akademin <https://orcid.org/0000-0002-4977-2322>

Annika Hagenbjörk

Umeå Universitet Medicinska fakulteten: Umea Universitet Medicinska fakulteten

Anna-Carin Olin

Goteborgs universitet Sahlgrenska Akademin

Bertil Forsberg

Umeå Universitet Medicinska fakulteten: Umea Universitet Medicinska fakulteten

Ingrid Liljelind

Umeå Universitet Medicinska fakulteten: Umea Universitet Medicinska fakulteten

Hanne Krage Carlsen

Goteborgs universitet Sahlgrenska Akademin

Lars Modig

Umeå Universitet Medicinska fakulteten: Umea Universitet Medicinska fakulteten

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Abstract

Background

Exposure to air pollution is of great concern for public health although studies on the associations between exposure estimates and personal exposure are limited and somewhat inconsistent. We aimed to quantify the associations between personal NO_x, ozone and PM₁₀ exposure levels to ambient levels, and the impact of climate and time spent outdoors in two cities in Sweden.

Methods

Subjects (n=65) from two Swedish cities participated in the study. The study protocol included personal exposure measurements at three occasions, or waves. Personal exposure measurements of NO_x, ozone, and PM₁₀, were performed for 10 days and 24 hours respectively, and the participants kept a diary on activities. Stationary monitoring stations provided hourly data of NO_x, ozone, and PM, as well as data on air temperature and relative humidity. Data were analysed using mixed linear models with the subject-id as a random effect and stationary exposure and covariates as fixed effects.

Results

Personal exposure levels of NO_x, ozone, and PM₁₀ were significantly associated with levels measured at air-pollution monitoring stations. The associations persisted after adjusting for temperature, relative humidity, city, and wave, but the modelled estimates were slightly attenuated from 2.4% (95% CI 1.8-2.9) to 2.0% (0.97-2.94%) for NO_x, from 3.7% (95% CI 3.1-4.4) to 2.1% (95% CI 1.1-2.9%) for O₃ and from 2.6% (95% 0.9-4.2%) to 1.3% (95% CI -1.5-4.0) for PM₁₀. After adding covariates, the degree of explanation offered by the model (coefficient of determination, or R²) did not change for NO_x (0.64 to 0.63), but increased from 0.46 to 0.63 for O₃, and from 0.38 to 0.43 for PM₁₀.

Conclusions

Personal exposure to NO_x, ozone and PM have moderate to good association with levels measured at urban background sites. The results indicate that stationary measurements are valid as measure of exposure in environmental health risk assessments, especially if they can be refined using activity diaries and meteorological data. Approximately 50-70% of the variation of the personal exposure was explained by the stationary measurement, implying occurrence of misclassification in studies using more crude exposure metrics, potentially leading to underestimates of the effects of exposure to ambient air pollution

Background

Ambient air pollution is the largest environmental public health risk and is estimated to be responsible for approximately one in every ninth premature deaths annually worldwide ((WHO 2016). In average, 2.9 years of life-expectancy are lost globally due to exposure to air-pollutants (Lelieveld et al. 2020).

As air pollution is a complex mixture of different compounds, having both natural and anthropogenic origin, the ambient concentrations may vary depending of sources and local meteorological factors such as temperature, relative humidity, wind speed and direction (Grundström et al. 2015). In densely populated urban areas, traffic-related air pollutants at street level such as particulate matter (PM), nitrogen oxides (NO_x) and ozone (O₃) are of greatest concern as they are associated with severe both acute- and long-term health effects, particularly respiratory disease (WHO 2016). Particulate matter (PM), complex mixtures of solid and liquid particles suspended in the air, can be of both anthropogenic and natural origin and are characterized by their size. Particles with an aerodynamic diameter smaller than 10 µm, PM₁₀, mainly deposit in central airways but a small fraction will also reach the small airways (inner diameter < 2 mm), whereas fine particles smaller than 2,5 µm (PM_{2,5}) reach further into the very peripheral airways and to a larger extent deposit in the transition zone, between conducting and acinar airways (Pinkerton KE 2000). The most prominent sources of PM₁₀ are local emission related to traffic (Segersson et al. 2017), but PM₁₀ levels are also influenced by long-range transport, which may account for up to 70% of the background levels in urban areas (Petit et al. 2019; Carlsen et al. 2020).

NO_x which is the common term for the nitrogen oxides NO and NO₂ and the primary source of NO_x in urban areas originates from fossil fuel combustion in vehicles. In the presence of sunlight, NO_x reacts with volatile organic compounds whereby ground-level ozone (O₃), a powerful oxidant and airway irritant, is formed. In urban areas, high levels of ozone occur due to influx of long-range transport and locally emitted precursor gases, mainly NO_x (Hagenbjörk et al. 2017). Ozone tends to peak in spring at high latitudes due to meteorological variation (Boleti et al. 2020).

Although air pollution concentration measured at stationary monitoring stations are not very representative of exposure (Johannesson et al. 2007), using exposure models such as dispersion models validated against stationary measurements, are standard exposure assessment methods in studies of health risks in humans (Dias and Tchepel 2018). Misclassification of exposure leads to reduced accuracy (Berkson error), or underestimates of health risk in epidemiological studies (Sheppard et al. 2012), which has been observed for a number of respiratory health outcomes (Hart et al. 2015; Van Roosbroeck et al. 2008; Weichenthal et al. 2015).

The current work is part of a larger study designed to investigate the effects of air pollution and birch pollen exposure in individuals with birch allergy and asthma and healthy controls at different seasons of the year.

The aim of the present study was to quantify the agreement between urban background and personal exposure of NO_x, ozone and PM₁₀ in order to increase our knowledge of monitored concentrations at urban background stations as substitutes for personal exposure in population studies. Another aim was to estimate to what extent factors such as geographic location, meteorology, and self-reported exposure (i.e. time spent outdoor in traffic) affect the associations.

Methods

Study protocol

Two Swedish cities were included in the study, Gothenburg in the south (57° N) and Umeå in the north (63° N), and adult individuals were invited to participate in the study. In Umeå, participants were recruited from the clinical part of the GA₂LEN (Global Allergy and Asthma European Network) study (Jarvis et al. 2012) and in Gothenburg by advertisement at the University of Gothenburg and in a local newspaper. A total of 65 individuals aged 27–76 years and mean age 48.7 years, were included in the study (table 1).

The study protocol included a 10-day personal exposure measuring period at three separate occasions for each subject; the first occasion, wave 1, took place during April/May 2015. The second wave (wave 2) in November 2015 and the third wave (wave 3) in April/May 2016. The participants filled out an activity diary throughout the sampling period in which time spent in different environments such as 1) indoors, 2) outdoors in dense traffic and 3) outdoors (not in traffic) was documented. Following each sampling period, the participants underwent a thorough clinical examination. After the first measuring period (wave 1) a few participants dropped out of the study due to withdrawal, medical issues or moving. A total of 50 participants completed all three measuring periods, waves 1, 2 and 3, Fig. 1.

Out of the initial 65 participants, personal measurements of all three pollutants (NO_x, ozone and PM₁₀) were obtained from 61 subject in wave 1, from 54 subjects in wave 2 and from 44 subjects in wave 3. Also, there were 48 subject who had three repeated (e.g. measured in all three waves) measurements of ozone, 47 subjects who had three repeated NO_x measurements and 45 subjects with three completed measurements of PM₁₀ in all three waves. The reasons for non-complete data at wave 1 are lost samplers, and a few participants deciding to withdraw from certain measurements. From wave 1 to wave 2 and 3, a few participants dropped out due to moving, medical issues unrelated to the study, and finding the protocol and the measurement equipment unhandy. 64 participants filled out the activity diary for wave 1, but only 52 had valid replies. For wave 2 and 3, we received 47 and 44 valid replies, respectively.

Personal exposure measurements, samplers, and chemical analysis

NO_x and ozone

Passive samplers for NO_x and ozone were attached to a fabric cord resembling a necklace and placed as close to the breathing zone as possible. Participants were instructed to wear the samplers all day and place them by the bed when sleeping. In case of precipitation they were told to shield the samplers from getting wet.

NO_x and ozone were measured with the Ogawa diffusive sampler (Ogawa & Company, Pompano Beach, FL, USA) as 10-day averages of each compound. The Ogawa sampler is cylindrical and has a two-ended

design with a diffusion barrier, and a coated filter between two stainless screens on each side. NO_x was collected on one Ogawa badge provided with a filter coated with triethanolamine (TEA) and an oxidizing substance, 2-phenyl-4,4,5,5-tetramethylimidazoline-1-oxyl-3-oxide (PTIO) added to oxidize NO to NO₂. The nitrite content of the collection filter was determined by ion chromatography as described previously (Hagenbjörk-Gustafsson, 2010). The detection limit was 0.12 µg/m³ for a 10-day sampling period of NO_x.

For ozone measurements another Ogawa badge was used holding collection filters coated with a nitrite-based solution. Ozone oxidizes nitrite to nitrate on the filter and the nitrate content of the filter was after extraction determined by ion chromatography according to a modified method of the standard operation procedure, published by Ogawa (www.ogawausa.com). The nitrate concentration was used to calculate the amount of ozone on each filter. The detection limit was 0.86 µg/m³ for a 10-day sampling period of ozone. In cases where ozone was measured below this level (n = 3), it was substituted with the detection limit (0.86 µg) divided by two (Schisterman et al. 2006).

The coated filters for NO_x and ozone were supplied by the manufacturer (Ogawa, USA). All samplers were prepared and analyzed at the division of Occupational and Environmental Medicine, Umeå University, Umeå.

PM₁₀

Active sampling of PM₁₀ was performed for 24 hours prior to the clinical visit. Each participant was handed out a backpack equipped with an AirChek® XR5000 personal air sampling pump (SKC Inc., Eighty Four, PA, USA), mounted with a single-stage Personal Modular Impactor (PMI) sampler for PM₁₀ collection (SKC Inc., Eighty Four, PA, USA) and an airflow of 3.0 L/min. The airflow was calibrated prior to and at the end of the 24-hour sampling period. The PMI sampler was mounted with a 25-mm pre-oiled impaction disc on top of the filter cassette with a 2 µm pre-weighted Millipore PTFE collection filter for gravimetric analysis at Occupational and Environmental Medicine, School of Public Health and Community Medicine at University of Gothenburg, Gothenburg, Sweden.

Stationary measurements

NO_x, ozone and PM

In Gothenburg, the local environment department provided hourly data on NO_x, PM₁₀, and ozone concentrations. The measurements were performed at the main measurement station in Gothenburg, "Femman" situated at a roof top (height 27 m) in central Gothenburg (57° 42.52 'N, 11° 58.23 'E). NO_x was measured with a chemiluminescence detector (Model T200 NO/NO₂/NO_x Analyzer, Teledyne API, San Diego, USA).

PM₁₀ was measured by using Tapered Element Oscillating Microbalance technique (Thermo Scientific™1405 TEOM™ Continuous Ambient Particulate Monitor, Thermo Fischer Scientific, Waltham,

USA). Ozone measurements were carried out by using UV photometry (Monitor Labs, 03 ML 9811, Monitor Labs, Karlsruhe, Germany).

In Umeå, NO_x and ozone were measured at the former municipality background station at a roof top (height 20 m) located in the city centre of Umeå (63° 79.47 'N, 20° 29.18 'E). NO_x was measured using a chemiluminescence analyser (Monitor Labs model 9841, Monitor Europe, Cheltenham, U.K). Hourly data of ozone was provided by a UV photometer (Monitor Labs model 9810, Monitor Europe, Cheltenham, U.K). Measurements of PM₁₀ was only provided at a street station in central Umeå and therefore not included in the study, however PM_{2.5} was measured at an urban background station (preschool Uven, 63° 82.09 N, 20° 28.96 E) about one kilometre from the city centre. 24-hourly data of PM_{2.5} was provided from IVL, Swedish Environmental Research Institute, and was measured by a standard gravimetric measurement method (Leckel SEQ47/50, Leckel Ingenieurbüro GMBH, Berlin, Germany).

An annual mean background exposure level of PM_{2.5} was modelled in the Swedish Clean Air and Climate project with dispersion modelling (Segersson et al. 2017) and matched with the participants' residential address coordinates.

Meteorological data

The Swedish Meteorological and Hydrological Institute provides hourly data on air temperature, relative humidity and wind speed and direction measured centrally in Gothenburg (57° 71.56 N, 11° 99.24 E) and at Umeå airport (63° 79.47 N, 20° 29.18 E), approximately 4 km from the city centre.

Statistical methods

For each participant, we matched the time window of personal exposure to each pollutant (of 24 hours or 10 days) with data from the stationary monitoring station for the corresponding time. For personal and stationary measurements, we calculated mean and standard deviation. For self-reported time spent in- and outdoors (self-reported exposure) we calculated median and interquartile range (IQR) as these variables were strongly skewed. Individuals who had personal and stationary measurements from at least one study wave were included in the study.

The data were analysed using mixed linear models, a standard method in the field (Delfino et al. 2006)

$$\log(Y) = \beta_1 \text{Stat_exp} + \beta_2 \text{Time} + \beta_3 \text{Temp} + \beta_4 \text{RH} + \beta_5 \text{City} + \beta_6 \text{Wave} + (1 \mid \text{ID})$$

where Y, the dependent variable is personal-measured exposure, Stat_exp is stationary monitor-measured exposure, Time is time spent outside in dense traffic, Temp is temperature at the same interval as the main exposure, RH is relative humidity at the same interval as the main exposure, City denotes the study location and Wave is the study season. ID is the personal identification number of every individual inserted as a random effect. To test for further random effects, study wave and city were also tested as random effects in the models, but the model fits were not improved, and those variables were entered as covariates.

The dependent variables for each model were transformed with natural logarithms to approach normality.

First, the personal exposure was modelled as a function of the levels measured at the monitoring site of the corresponding pollutant, then the covariates weather and temperature were added, then city and study wave. Study wave was treated first as a three-level variable for the three waves, then as a two-level variable to indicate spring season (waves 1 and 3) or fall season (wave 2). In a separate analysis, covariates “time spent in traffic”, “time outdoors not in traffic”, “total time outdoors” and “time indoors” were added to models to estimate their individual effects. As a sensitivity analysis, we analysed individuals with birch allergy and asthma separately to determine if any eventual exposure avoidance (less self-reported time spent in traffic) influences the association between personal and stationary levels.

To quantify the variance explained by the models the conditional coefficient of determination (R^2) was determined for the models (Nakagawa and Schielzeth 2013). The analysis was performed with R studio, and the “lme4” package (Bates et al. 2014). The level of significance was set to $p < 0.05$.

Results

Personal and stationary levels of NO_x and ozone and PM₁₀

NO_x levels were higher in wave 2, i.e. the fall season, for both personal and stationary measurements at both locations. For ozone, a strong seasonal variation was seen in Umeå with highest levels in spring seasons (wave 1 and 3). This seasonal variation was not as clearly seen in Gothenburg, even though the levels were highest in the first wave (spring) compared to waves 2 and 3. PM₁₀ levels had only minor seasonal variation.

Comparing stationary and personal measurements of air-pollution levels, in general the personal measurements indicated lower exposure than the stationary measurements. The differences were most pronounced for ozone, with stationary levels of 53.7 ± 10.6 and 56.9 ± 19.4 $\mu\text{g}/\text{m}^3$, compared to personal levels of 7.2 ± 5.2 and 5.9 ± 4.5 $\mu\text{g}/\text{m}^3$ in Gothenburg and Umeå, respectively. The personal NO_x exposure levels in Umeå as well as the personal PM₁₀ exposure levels in Gothenburg was however an exception, as the levels were similar or higher than levels registered at the stationary monitoring stations (Table 2 and Fig. 2).

Modelled data of PM_{2.5} at residential address

The modelled background exposure to PM_{2.5} at the residential address was lower in Umeå than in Gothenburg (mean 6.6 $\mu\text{g}/\text{m}^3$ and 0.66 $\mu\text{g}/\text{m}^3$, $p < 0.001$). Using modelled background data to adjust for location did not improve the model fits or change the association between personal and stationary monitor measured PM (data not shown).

Activity diary

Participants in Gothenburg reported spending significantly more time in dense traffic than those in Umeå at all study waves (median 94, 64, and 86 minutes in Gothenburg vs 52, 46, and 51 minutes in Umeå), whereas there were only small non-systematic differences in the reported time spent outdoors outside dense traffic, and indoors, between the two study locations. During spring season (wave 1 and 3), the study participants reported spending more time outdoors than in fall season (wave 2) (Table 3).

Regression analysis

A likelihood ratio test revealed that a two-level variable of “study wave” (non-pollen season versus pollen season) was the best fit for NO_x and ozone ($p < 0.05$). However, for PM, three levels (one for each study wave) produced a better model fit ($p < 0.05$), and better Akaike’s information criteria (AIC), but worse Bayes information criteria (BIC)(Table S2), so the three-level variable was selected for the remaining analysis of PM.

In mixed models, the levels of the pollutant measured at the urban background stations were significantly associated with the log-transformed personal exposure levels of the same pollutant. After adjusting for temperature, relative humidity, city, and spring seasons (waves 1 and 3) vs fall (wave 2) the regression slopes were less steep but remained statistically significant for NO_x and O_3 . The degree of explanation (R^2) of the unadjusted models were moderate at 0.38 for PM_{10} , marginally higher for O_3 at 0.46 and 0.63 for NO_x . However, the degree of explanation increased after introducing covariates for O_3 and PM_{10} but nearly unchanged for NO_x (Table 4). Relative humidity was statistically significantly associated with NO_x and O_3 before adjusting for city and wave. City was statistically significantly associated with O_3 . For O_3 and PM_{10} exposure, there was a negative association with spring season. The proportion of variation explained by the models (R^2) was highest for the NO_x model at 0.64 for the fully adjusted model. For O_3 , the fully had adjusted model R^2 was 0.63, and for PM_{10} it was 0.43 (Table 4) indicating a modest degree of explanation.

Comparing the influence of different metrics of self-reported exposure (Time spent outdoors or in traffic) on the associations between personal and stationary exposure levels (Table 5), we found that for NO_x , time in traffic and total time outdoors were positively associated with the personal exposure, and the estimate of the stationary measurement station was slightly lower than the main analysis (Table 4). For O_3 , time outdoors not in traffic and total time outdoors were positively associated personal exposure, and time spent indoors was negatively associated with personal exposure. Again, the estimated association with the stationary measurements were lower than in the main analysis. For PM_{10} , no self-reported exposure was associated with personal exposure (Table 4). However, for PM_{10} , the coefficient of association was increased in models adjusted for time spent outdoors or in traffic, but only reached statistical significance in the model adjusted for time spent in traffic (Table 5).

Discussion

In this panel study 65 participating individuals from two Swedish cities with substantially different background pollution levels and meteorology, reported their daily activities, and personal exposure was simultaneously monitored for up to three measurement periods. We found that stationary measures of exposure to NO_x , O_3 and PM_{10} were statistically significantly associated with personal exposure in unadjusted, mixed models with individual as random effects (Table 4). After adding covariates, such as meteorological variables, city and wave, stationary PM was no longer statistically significantly associated with personal PM, but for all three outcomes the model fits were improved after adding covariates as indicated by increases in R^2 . The fully adjusted models of NO_x and O_3 explained more than 50% of the variation in the personal exposure, although the number of observations decreased due to dropout and non-participation, especially for the self-reported exposure in the activity diary. In comparison, the crude correlation between stationary and personal monitoring tended to be weak, with r values ranging between 0.12 and 0.46 (Table S1), with personal measured being lower (Table 2) indicating that using the mixed-model design to account for personal behaviour and characteristics has advantages over correlation methods.

Participants in Gothenburg generally reported spending more time outdoors in dense traffic which is logical as Gothenburg is a larger city with substantially more dense traffic and volume compared to Umeå (Carlsen et al. 2017) (Table 3). In general, people spend most of their time indoors. In the current study, the participants reported spending an average of around 21 hours indoors in both spring (wave 1 and 3) and winter (wave 2).

The time outdoors in dense traffic was significantly associated with personal NO_x exposure and as expected, contributed significantly to the individuals' exposure (table 5). For ozone, total time spent outdoors, time spent outdoors not in traffic, and time inside were significantly associated with personal exposure to ozone (time spent indoors was negatively correlated), whereas the association with time spent in dense traffic was also positive, it did not reach statistical significance, possibly because of the complex chemical reactivity pattern of ozone in dense traffic.

Time spent indoors was negatively correlated with all personal exposures, although it only reached statistical significance for O_3 . Also, for PM_{10} , the association between personal exposure and stationary measurements were stronger after adjusting for time spent in dense traffic, although the association for time spent in traffic did not reach statistical significance, perhaps because time spend in dense traffic strongly influence the personal exposure measurements (Table 5).

To improve the adjustment for location, we adjusted for modelled annual background levels of $\text{PM}_{2.5}$ instead of city. However, this variable did not improve the model fit and did not modify the effect of the stationary PM_{10} exposure (Table S3) in the short term. As Gothenburg is in the southern part of Sweden, a larger proportion of air pollutants is due to long range transport from more southern parts of Europe compared to Umeå in the northern part of Sweden. However, air pollutants are generated both locally and

transported some distances with the wind but have little within-city gradient and are thus not likely to influence the results of this study. Furthermore, because of its reactivity, NO_x decays in the atmosphere within days before it can be subjected to long-range transport away from the source. The size of the proportion of PM contributed from long-range transport is a matter of debate and wide ranges have been reported. Johannesson et al. 2007 observed associations between 24-hours of urban background and personal levels of $\text{PM}_{2.5}$ particles with a correlation coefficient of 0.61 (Spearman) but spending time outdoors was only a predictor for the Fe-trace element. In a multi-centre study in heterogeneous environments the authors compared land use regression (LUR)-based exposure with personal exposure and found that LUR predicted personal exposure to soot and NO_2 , in some sites with R^2 from 0.35–0.44 (Montagne et al. 2013) For $\text{PM}_{2.5}$ and NO_x , there were no significant correlations. Measuring in elderly subjects during spring, summer and winter, found that LUR model-predicted ozone and $\text{PM}_{2.5}$ showed moderately associations with personal exposure levels, whereas model-predicted NO_2 was not associated with personal NO_2 (Sahsuvaroglu et al. 2009). Thus, there are no consensus regarding personal exposure to air pollutants based on stationary measurements and therefore until now, it has also been difficult to sort out if certain exposures are more harmful, which to some extent can be explained by rough exposure assessments that will blur the effects of specific exposures. In studies that aimed to quantify the effect of measurement error, it was found that risk estimates increased after adjustment for measurement error (Hart et al. 2015). This important point will be addressed in future analysis of the collected data as no health risks were addressed in the current study

Strengths and limitations

The study design with thorough sampling and repeated measures on the same individual during three monitoring waves as well as parallel self-reported activity ensures that our data has high internal validity. The study was performed using an identical study protocol and identical equipment for measurements of personal exposure, in two distinct geographical locations with different meteorology and background exposure, which ensured that the data had good variability.

Due to various reasons, among them a comprehensive study protocol and a few lost samplers, not all subjects were included in all measurements in all study waves, however, a comparison of the demographic characteristics and exposure of the individuals who did not complete all exposure measurements ($n = 18$) versus those who did ($n = 47$) found no statistically significant differences.

Conclusion

In this study, there were moderate to good associations between personal and stationary measurements of NO_x , ozone, and PM, which were strengthened by data on meteorology and covariates. The absolute levels of ozone showed substantially lower personal exposure levels compared to stationary levels. The addition of self-reported time spent in traffic improved the model in the case of NO_x and ozone, whereas

for PM₁₀, self-reported time spent in traffic or outdoors was not significant, perhaps reflecting the importance of exposure other than traffic, e.g. occupational exposure.

The observed results support that stationary measurements are valid as measure of exposure in environmental health risk assessments, especially if they can be refined using activity diaries and measures of meteorology. Nevertheless, only 50-70% of the variation in the personal exposure was explained by the stationary measurement, implying occurrence of misclassification in studies using more crude exposure metrics, potentially leading to underestimates of the effects of exposure to ambient air pollution

Abbreviations

PM : Particulate matter

PM_{2.5} : Particulate matter $\leq$ 2.5 micrometers in diameter

PM₁₀ : Particulate matter $\leq$ 10 micrometers in diameter

O₃ : Ozone

NO_x : Nitrogen oxides

NO₂ : Nitrogen dioxide

SD : Standard deviation

IQR : Interquartile range

RH : Relative humidity

R² : Coefficient of determination

LUR: Land use regression

AIC : Akaike's information criteria

BIC : Bayes information criteria

Declarations

Ethics approval and consent to participate:

The protocol was approved by the Regional Ethical Review Board at the University of Gothenburg (Dnr: 681-14). All participants included in the present study gave their written consent.

Consent for publication:

Not applicable

Availability of data and materials:

The datasets used and/or analysed during the current study are available from the corresponding author on request.

Competing interests:

The authors declare that they have no conflict of interest in relation to the current manuscript.

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Authors' contributions:

SLH contributed to the design of the study, collection and interpretation of data and writing of the manuscript; AH is responsible for the chemical analysis and participated in the data collection and drafting of the manuscript; A-CO Initiated the study, supervised the methodology, were responsible for the resources and reviewed drafts of the manuscript; BF participated in the design of the study and the responsibility for resources and reviewed drafts of the manuscript; IL Participated in the design, data collection, supervision and draft of the manuscript; HKC participated in the validation, formal statistical analysis and draft of the manuscript; LM participated in the data collection, interpretation of the data, and drafting of the manuscript. The authors read and approved the manuscript before submission.

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Tables

Due to technical limitations, all tables are only available as a download in the Supplemental Files section.

Figures

Figure 1

A total of 65 participants were recruited to participate in the study. A few participants dropped out of the study due to withdrawal, medical issues or moving. A total of 50 participants completed all three measuring periods (waves 1, 2 and 3).

Figure 2

Personal and stationary exposure. One PM outlier is omitted, Stationary PM is Umeå is PM2.5.

Supplementary Files

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