**Abstract**

**Background:** Personal exposure to pollutants is influenced by various outdoor and indoor sources. The aim of this study was to evaluate the exposure of Athens citizens to toluene and xylene, excluding exposure from active smoking.

**Methods:** Passive air samplers were used to monitor volunteers, their homes and various urban sites for one year, resulting in 2400 measurements of toluene and xylene levels. Since both indoor and outdoor pollution contribute significantly to human exposure, volunteers were chosen from occupational groups who spend a lot of time in the streets (traffic policemen, bus drivers and postmen), and from groups who spend more time indoors (teachers and students). Data on individual and house characteristics were obtained using a questionnaire completed at the beginning of the study; a time-location-activity diary was also completed daily by the volunteers in each of the six monitoring campaigns.

**Results:** Average personal toluene exposure varied over the six monitoring campaigns from 53 to 80 µg/m³. Urban and indoor concentrations ranged from 47 – 84 µg/m³ and 30 – 51 µg/m³, respectively. Average personal xylene exposure varied between 56 and 85 µg/m³ while urban and indoor concentrations ranged from 53 – 88 µg/m³ and 27 – 48 µg/m³, respectively. Urban pollution, indoor residential concentrations and personal exposures exhibited the same pattern of variation during the measurement periods. This variation among monitoring campaigns might largely be explained by differences in climate parameters, namely wind speed, humidity and amount of sunlight.

**Conclusion:** In Athens, Greece, the time spent outdoors in the city center during work or leisure makes a major contribution to exposure to toluene and xylene among non-smoking citizens. Indoor pollution and means of transportation contribute significantly to individual exposure levels. Other indoor residential characteristics such as recent painting and mode of heating used might also contribute significantly to individual levels. Groups who may be subject to higher exposures (e.g. those who spent more time outdoors because of occupational activities) need to be surveyed and protected against possible adverse health effects.
Background

Toluene and xylene (o-, m- and p-isomers) are widespread in the environment because they have been used in many commercial products. Vehicle exhaust is considered to be the main source but non-professional use of paints, glues, adhesives, varnishes, lacquers, shoe polishes and cigarette smoke contribute significantly, especially to levels in the internal environment and to personal exposure [1-3].

At high concentrations, toluene and xylene have serious adverse effects on human health. Toluene vapor is heavier than air and may travel along the ground, but harmful air contamination levels can be reached rather quickly by evaporation of toluene at 20°C. Toluene has a lower clearance rate in winter than in summer. The acute and chronic effects of toluene, and to a lesser degree of xylene, on the central nervous system are of most concern. In addition, there is concern about potential effects on reproduction and hormone balance in women, and hormone imbalances in exposed males have also been reported [4-6].

In occupational settings, official agencies (OSHA, ACGIH, HSE, DFG) have established an 8-hour time-weighted average permissible exposure limit (TWA PEL) of 100 ppm (375 mg/m³ and 435 mg/m³ for toluene and xylene isomers, respectively). Levels only slightly above the 8-hour TWA may cause lack of coordination and amnesia. Even levels lower than 50 ppm cause drowsiness, moderate fatigue and headaches [7]. The World Health Organization has recently recommended a guideline for ambient toluene exposure to protect against developmental neurotoxicity: 260 µg/m³ (68 ppb) as a weekly average concentration.

Athens, like most large cities all over the world, has air pollution problems. These were made worse by poor town layout, location (surrounded by mountains), intense sunlight and low wind speed. Emission of toluene has been calculated as 20 million tons per year, one of the largest among European towns [8]. In Athens, fixed point monitoring stations have very recently started to measure hydrocarbon concentrations, but very little comparative research has been conducted to give consistent estimates of exposures of individuals in the general population or of indoor pollution [9-13]. The main goal of the present study was to estimate personal exposures to toluene and xylene by monitoring fifty volunteers, their homes and various urban sites over one year. Another goal was to examine the relationship between toluene and xylene pollution in indoor, urban and personal air. Benzene measurements included in the study have already been published elsewhere [14].

Methods

Sampling

A radial symmetry sampler, Radiello® Model 3310 Passive Sampling System, was used. This sampler works by spontaneous transfer of gas molecules through a diffusive barrier. It comprises a cylindrical microporous diffusive body and an absorbing cartridge, also cylindrical, placed coaxially inside the diffusive body. When the assembled apparatus is exposed, it is necessary only to note the days and times when exposure begins and ends [15]. Subjects and their homes were also equipped with radial path diffusive samplers (Radiello) to measure the time-weighted average (TWA) concentrations of toluene and xylene in the breathing zone over a 108-hour period. At night, personal samplers were set on the volunteers’ bedside tables. The samplers were desorbed with carbon disulfide, shaken for 30 minutes and analyzed by gas chromatography coupled with mass spectrometry. This analytical method has been described in detail elsewhere [15]; its detection limit is 0.2 µg/m³. The overall reliability of the sampling device has been judged as excellent by the European Reference Laboratory for Air Pollution (ERLAP) of the Joint Research Centre of Ispra and the sampler has been widely used [16,17]. Measurements with these samplers performed contemporaneously with ours gave comparable results [9,13].

The whole sampling campaign was repeated every two months over one year (September 1997 to September 1998). Each monitoring campaign lasted from Monday morning to Friday evening and used Radiello samplers in 100 sites around Athens. Fifty volunteers and their homes were monitored over the same period. The campaign included 2400 measurements and losses did not exceed 7% in any sampling period. The experimental database comprised 1140 environmental data and 556 and 564 personal and home pollution data, respectively.

The 100 sampling sites chosen for urban monitoring were distributed on the intersections of a multi-scale grid drawn over the town map. The mesh size was approximately 400 m. Eighty percent of the sites lay in the city center and its periphery (i.e. almost 13 squares kilometers). The other 20% lay in two background zones (northeast and southeast) with sparse traffic and parks. Each sampling site was uninterruptedly monitored from Monday morning (6 to 8 am) to Friday afternoon (6 to 8 pm) on six occasions through the year. On site, each sampler was placed inside a shelter hung on a lamppost about 3 m high. Personnel employed to place the samplers at the beginning of the campaign and collect them at the end were trained and supervised by members of the research project (CC & ECA). The volunteers were selected on the basis of expected exposure level. People who for occupational reasons spend a lot of time in the street, such as bus...
drivers, policemen and postmen, composed the first
group. The lower expected exposure group comprised
teachers and students. Volunteers were selected on the
basis of two criteria: non-smoking and job located in the
city centre. Ten persons were selected in each of the fol-
lowing categories: teachers, students, bus-drivers, post-
men and policemen. All volunteers gave their written
informed consent. After the 50 volunteers were selected,
personal exposure was determined directly over the series
of six 108-hour (4.5 day) sampling periods. The personal
sampler used was attached to the volunteer’s lapel and
during the night was set on the bedside table. At the end
of each day in each sampling period, volunteers were
instructed to complete a diary stating their activities dur-
ing the sampling period.

The home microenvironments monitored were located in
the greater Athens basin. Although all volunteers worked
in the city centre, about two thirds of their houses were
located outside the city centre in less urban regions, and a
few houses were located in the Athens suburbs. These
areas had lower population and traffic densities and there-
fore were typically less congested, and ambient air con-
centrations were expected to be lower.

**Statistical analysis**

Univariate analyses were performed to examine the cov-
ariates age, sex, room-mates’ smoking habits, job title,
time spent outdoors, transportation mode and house
characteristics (floor, location, recent painting, heating
mode, proximity to gasoline station and proximity to
busy road). We applied linear mixed-effects regression
models to estimate the significant prognostic factors for
toluene and xylene exposure levels using maximum likeli-
hood and restricted/residual maximum likelihood meth-
ods [18]. Mixed effects models had the advantage of
adjusting for invariant factors by fixed-effects models and
accounting for individual differences by random- effects
models [19]. In our mixed-effects models, we treated sub-
jects’ personal and home characteristics as fixed effects
and each subject as a random effect. The measurement
period was used to identify repeated observations. Type III
sums of squares were used to calculate the effects in the
models. The multivariate linear mixed model included all
the variables that contributed significantly to the final
model (Wald statistics, criterion p < 0.05). For each factor,
the regression coefficient and 95% confidence interval
(95% CI) were calculated. All statistical analyses were per-
formed with SPSS 11.0 software.

**Results**

The study population had an average age of 36.3 years and
consisted predominantly of men (66%). Each sampling
campaign lasted 108 hours. In each measurement period,
subjects spent an average of 26.3 hours outdoors (sd
13.8). Time spent outdoors differed markedly between
occupational groups. Teachers and students spent, as an
annual average, less than 15 hours per sampling period
outdoors, 50% during their free time, while bus drivers
and traffic policemen exceeded 40 hours outdoors, almost

| Table 1: Job and house characteristics of volunteers (n = 50) and corresponding annual (median) toluene and xylene measurements (µg/m³) |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Transportation means                                          | n | %   | Personal | House | Personal | House |
| By foot                                                       | 7 | 14  | 46.0     | 52.4  | 56.0     | 55.9  |
| By foot and vehicle                                           | 35| 70  | 56.0     | 55.9  | 55.9     | 55.9  |
| By vehicle                                                   | 8 | 16  | 71.6b    | 74.9b | 71.6b    | 74.9b |
| Use of vehicle in work                                       |   |     |          |       |          |       |
| Yes                                                          | 28| 56  | 72.5b    | 75.9b | 72.5b    | 75.9b |
| No                                                           | 22| 44  | 52.0     | 55.4  | 52.0     | 55.4  |
| Smoker room-mate                                             |   |     |          |       |          |       |
| Yes                                                          | 15| 30  | 64.0     | 65.9  | 64.0     | 65.9  |
| No                                                           | 35| 70  | 63.0     | 67.7  | 63.0     | 67.7  |
| City area                                                    |   |     |          |       |          |       |
| Center                                                       | 42| 84  | 64.0     | 67.7  | 64.0     | 67.7  |
| Suburbs                                                      | 8 | 16  | 55.2     | 65.3  | 55.2     | 65.3  |
| Proximity to gasoline station                                 |   |     |          |       |          |       |
| Yes (< 50 m)                                                  | 3 | 6   | 91.9a    | 52.0a | 91.9a    | 52.0a |
| No                                                           | 47| 94  | 61.7     | 65.9  | 61.7     | 65.9  |
| Proximity to busy road                                       |   |     |          |       |          |       |
| Yes (< 50 m)                                                  | 16| 32  | 65.5     | 67.2  | 65.5     | 67.2  |
| No                                                           | 34| 68  | 63.0     | 67.4  | 63.0     | 67.4  |

Significant differences, *P < 0.05, **P < 0.01
80% during work activities. In Table 1, the job and house characteristics of volunteers are presented along with the corresponding measurements of toluene and xylene (see also additional file 1, Table 1, for further residential characteristics). An arterial road with traffic density of more than 5000 vehicles per day which judged independently by two professional drivers as busy road.

Urban levels, indoor residential concentrations and personal exposures to toluene and xylene during the six sampling periods are presented in Tables 2 and 3. Table 4 shows average wind speed, humidity, amount of sunlight and temperature for all six measurements. As shown in these tables, personal exposures varied between 53 – 80 and 56 – 85 µg/m³ for toluene and xylene, respectively. The higher values were observed mainly during the first two periods i.e. Autumn and Winter, when the wind speed did not exceed 0.5 m/s. Indoor residential concentrations varied between 30 and 51 µg/m³ and 27 and 48 µg/m³ for toluene and xylene, respectively. Urban levels ranged from 47 to 84 and 53 to 88 µg/m³ for toluene and xylene, respectively. Personal exposures followed similar trends to urban and indoor pollution throughout the study period (Figures 1 and 2).

Correlations between personal exposures and indoor concentrations were weaker for xylene than for toluene, and, as expected, for other seasons than for winter. The correlation coefficient (r) between personal exposure and residential level varied between 0.33 and 0.82 (all campaigns 0.57) for toluene and between 0.20 and 0.65 (all campaigns 0.39) for xylene (see additional file 1, Table 2).

Personal exposures to and indoor concentrations of toluene and xylene are presented in Figures 3 and 4 according to occupational group. Teachers and students differed significantly from other groups in respect of personal exposure to both toluene and xylene (p < 0.01).

**Indoor pollution**

For xylene, indoor pollution was influenced by location (centre or suburb), proximity to busy road and proximity to gasoline station (Table 1). Heating mode, recent painting, and type/floor of house also affected indoor concentrations, but owing to small numbers did not reach a conventional level of significance (Figure 5; see also additional file 1: Table 1). The use of oil and natural gas ovens during the 2nd and 4th sampling periods (the colder ones) raised indoor concentrations (mainly for xylene, p = 0.065) and personal exposures, but there is a high likelihood of effects related to other sources of exposure since few homes had such types of heating. The five houses with fireplaces exhibited low indoor concentrations because they were all located in the less polluted suburbs. Finally,

### Table 2: Personal, indoor and outdoor concentrations of toluene (µg/m³) in the six periods

| Period | Personal Mean | Median | 10th–90th percentiles | Indoor Mean | 10th–90th percentiles | Urban Mean | Median | min–max |
|--------|---------------|--------|------------------------|-------------|------------------------|------------|--------|---------|
| 1st–SEP| 90.7          | 79.6   | 53.0–130.8             | 50.6        | 23.1–81.6              | 99.8       | 84.1   | 37.3–256.8 |
| 2nd–DEC| 72.0          | 69.6   | 46.1–120.7             | 41.0        | 21.5–131.3             | 76.7       | 68.2   | 22.7–225.6 |
| 3rd–FEB| 74.9          | 63.0   | 35.2–123.1             | 39.6        | 13.8–68.4              | 74.8       | 65.5   | 34.2–143.8 |
| 4th–APR| 80.1          | 58.9   | 34.7–147.8             | 37.0        | 15.9–79.9              | 59.6       | 53.9   | 19.5–125.4 |
| 5th–JUN| 58.2          | 53.3   | 26.2–97.8              | 30.4        | 16.2–97.0              | 53.3       | 46.9   | 18.2–113.1 |
| 6th–SEP| 69.4          | 59.0   | 30.7–109.1             | 33.1        | 17.5–67.6              | 77.7       | 66.3   | 29.0–241.1 |
| Annual | 74.3          | 63.0   | 34.1–115.5             | 38.9        | 19.4–82.5              | 73.6       | 63.3   | 18.2–256.8 |

### Table 3: Personal, indoor and outdoor concentrations of xylene (µg/m³) in the six periods

| Period | Personal Mean | Median | 10th–90th percentiles | Indoor Mean | 10th–90th percentiles | Urban Mean | Median | min–max |
|--------|---------------|--------|------------------------|-------------|------------------------|------------|--------|---------|
| 1st–SEP| 89.4          | 84.6   | 53.5–141.9             | 48.4        | 20.3–79.6              | 101.5      | 88.3   | 41.4–263.0 |
| 2nd–DEC| 75.9          | 71.6   | 49.1–113.8             | 39.7        | 22.1–117.0             | 85.6       | 74.6   | 28.0–180.5 |
| 3rd–FEB| 74.5          | 63.8   | 39.7–141.3             | 39.2        | 16.9–67.9              | 85.6       | 75.8   | 41.2–197.9 |
| 4th–APR| 83.1          | 63.2   | 30.7–147.7             | 37.1        | 18.7–92.9              | 71.5       | 63.0   | 23.2–167.4 |
| 5th–JUN| 60.7          | 56.0   | 26.6–97.5              | 27.4        | 16.2–49.4              | 64.0       | 53.3   | 21.1–160.9 |
| 6th–SEP| 75.5          | 63.9   | 38.2–122.8             | 31.9        | 20.9–51.5              | 88.8       | 76.4   | 35.4–229.2 |
| Annual | 76.6          | 67.4   | 37.8–123.3             | 36.2        | 19.5–72.9              | 82.8       | 72.3   | 21.1–263.0 |
multivariate analysis of indoor residential concentrations showed that only seasonal or climate variation, mainly wind speed, remained an important factor for both toluene and xylene; indoor concentrations decreased by 40–50 µg/m³ per 1 m/s increase in wind speed.

**Personal exposure**

Occupational group, transportation mode and the use of vehicle during work had significant impacts on personal exposure to toluene and xylene (Table 1, Figures 3 and 4). Heating mode and recent painting had effects of borderline significance (0.05 < p < 0.10) on personal exposure to toluene and xylene (Figure 6).

Table 5 shows the important prognostic factors in the multivariate analysis of personal exposure to toluene and xylene. Adjusted for seasonal/climate variation, personal exposure was determined by indoor residential concentration and time spent outdoors in the city center; and, for toluene, the means of transportation also contributed.

**Discussion**

In this study, non-smoking citizens of Athens were selected among people who, owing to occupational duties, spent a lot of time in the streets, and people who spent more time indoors in schools or offices. Those who spent more working or leisure time in the heavily polluted city center were expected to be highly exposed, given the pattern of pollution of Athens (i.e. pollution comes from outdoors). Although inferences about a population are problematic when volunteers are used because of the potential for selective participation, the use of volunteers is suitable for investigating the relationships among predictors of personal exposure [20].

Urban levels of toluene and xylene were generally high. The average annual indoor residential concentrations were found to be 39 µg/m³ and 36 µg/m³ for toluene and xylene, respectively. These levels are in the same order as those found in other studies in Athens and cities with similar characteristics, and lower than some other Mediterranean cities [9-13,21-28]. The average annual personal exposures were found to be 63 µg/m³ and 67 µg/m³ for toluene and xylene, respectively. Urban toluene pollution very rarely (<2% of all measurements) exceeded the limit of 260 µg/m³ proposed by WHO as a weekly average. In this particular setting, the toluene and xylene measurements probably represented the expected levels of exposure of the vast majority of non-smoking citizens of Athens who were not occupationally exposed.

Urban and indoor air pollution and personal exposure exhibited the same pattern of variation among the measurement periods. This variation among monitoring cam-

### Table 4: Climate parameters (means) during the six monitoring campaigns

| PERIOD | Temperature (°C) | Wind speed (m/s) | Humidity (%) | Sunlight (hours) |
|--------|-----------------|-----------------|-------------|-----------------|
| 1st - SEP | 23.2 | 0.5 | 57 | 9.9 |
| 2nd - DEC | 13.0 | 0 | 70 | 4.2 |
| 3rd - FEB | 12.5 | 2.4 | 81 | 2.7 |
| 4th - APR | 10.4 | 2.2 | 62 | 7.6 |
| 5th - JUN | 23.6 | 4.0 | 54 | 10.2 |
| 6th - SEP | 21.8 | 3.7 | 69 | 7.2 |

### Table 5: Multivariate associations between personal exposure to toluene and xylene (µg/m³) and characteristics of study population

| | TOLUENE beta (95% CI) | P | XYLENE beta (95% CI) | P |
|-----------------|------------------------|---|-----------------------|---|
| Transportation means | | | | |
| Foot | 19.13 (4.6, 33.6) | 0.012 | NS | |
| Vehicle | 5.44 (-12.6, 23.5) | 0.541 | | |
| Both | 0.582 (0.22, 0.94) | 0.003 | 1.184 (0.78, 1.59) | <10⁻³ |
| Time spent outdoors (hours) | | | | |
| Home levels (µg/m³) | 0.554 (0.45, 0.65) | <10⁻³ | 0.561 (0.38, 0.74) | <10⁻³ |
| Wind speed (m/s) | -54.15 (-89.9, -18.4) | 0.004 | -41.03 (-68.1, -13.9) | 0.004 |
| Humidity (%) | 2.96 (1.3, 4.7) | <10⁻² | 2.53 (0.9, 4.2) | 0.003 |
| Sunshine (hours) | 10.46 (4.4, 16.5) | 0.001 | 9.23 (3.5, 14.9) | 0.002 |

Beta: regression coefficient; CI: confidence interval; RC: reference category; NS: not significant
Paigns might be explained by differences in climate parameters, namely wind speed, humidity and amount of sunlight. It was also anticipated that changes in transport and modernization of the bus fleet during the study period would to some extent have influenced atmospheric pollution levels, especially in the city centre. The most important change was a project for replacing the old buses entirely with new ones equipped with anti-pollution devices. More than 100 buses were replaced during the study period; in addition, increased numbers of dedicated bus lanes improved running conditions.

Figure 1
Toluene levels (median values) during monitoring periods.
Indoor concentrations of toluene and xylene are often significantly higher than external air levels [29,30]. Lebret found an internal/external ratio of 8 in Holland, while Gilli found a ratio of 3 in Torino, Italy [31,32]. In contrast, our results showed an indoor/outdoor toluene air pollution ratio of 0.64 for houses within the environmental sampling areas, although the samples were not obtained directly outside the homes. The ratio for xylene concentrations was 0.54. Probably poor emission materials and characteristics related to the Athens climate, such as frequent ventilation and use of non-absorbent materials for wall and floor coverings, account for this result. The frequent ventilation of houses in Athens lowered indoor pollution because such ventilation usually takes place when

Figure 2
Xylene levels (median values) during monitoring periods.
urban pollution is lower (not rush hour) and there are putative indoor emission sources, so the infiltration of outdoor air is beneficial. This argument is supported by the finding that differences between outdoor and indoor levels were lower during the spring and summer periods (continuous infiltration of outdoor air). Compared to others studies, we found weak but not significant effects on indoor air pollution from environmental smoke, heating mode, type and floor of house, and recent painting [2,3,29-34].

Indoor air contributes significantly to human exposure. In poorly-ventilated buildings, indoor emission sources have a more significant influence on hydrocarbon con-
centrations than infiltration of outdoor air [[26,35] and [1]]. In our study, correlations between personal exposure and indoor concentrations were higher for toluene than for xylene and lower in summer than other seasons, probably because factors outside houses have a predominant effect on the personal exposure pattern. Adjusted for climate variation, significant factors influencing personal exposure were indoor pollution, total time spent in the polluted city center, and means of transportation used.

In contrast to other studies, we found no differences among urban BTX ratios during the measurement periods, but there were differences in personal exposure and especially in indoor concentrations (see additional file 1,

**Figure 4**
Average annual xylene levels among occupational groups.
Table 3) [14,18,24]. This finding might be explained by the putative effects of indoor sources. The correlation between toluene and xylene was quite good (coefficient 0.59–0.86), similar to those reported in other studies [23,29]. Comparing the factors that influence exposure to benzene, toluene and xylene, it was found that proximity to a gasoline station or a busy road, and a smoker roommate, had a much greater impact on both personal exposure and indoor residential levels of benzene (though volunteers were instructed to avoid exposure to environmental smoke and gasoline refueling). On the other hand, the factors that had some degree of influence on toluene and/or xylene concentrations, such as heating...

Figure 5
Heating mode and indoor residential xylene concentrations during monitoring periods.
mode and recent painting, had no impact on benzene levels [14,18].

**Conclusion**

In Athens, Greece, the time spent outdoors during work or leisure is a major contributor to hydrocarbon exposure among non-smoking citizens. Indoor pollution and means of transportation contribute significantly to individual levels. Other factors such recent painting, smoking room-mate and mode of heating might contribute significantly to individual levels of toluene and xylene exposure. Identification of specific groups of people who may be subject to higher exposure is an important step towards

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**Figure 6**

Recent painting in participants’ houses and personal exposure to toluene.
preventing possible adverse health effects and a prerequisite for evidence-based intervention.

Competing interests
The author(s) declare that they have no competing interests.

Authors' contributions
ECA participated in data collection, carried out the statistical analysis and drafted the manuscript. CC participated in the design, coordination of the study, data collection and helped in the revision. AL participated in the design and coordination of the study and helped in the revision. All authors read and approved the final manuscript.

Additional material

Additional File 1
Sample contains Tables 1, 2and 3 Table 1 shows house characteristics in relation to annual (median) toluene and xylene measurements (µg/m³) Table 2 shows correlation coefficients between personal exposure and indoor residential concentration during the six monitoring campaigns Table 3 shows Benzene:Toluene:Xylene (BTX) ratios during the measurement periods
Click here for file [http://www.biomedcentral.com/content/supplementary/1471-2458-6-50-S1.doc]

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