Original Contribution

Living near Main Streets and Respiratory Symptoms in Adults

The Swiss Cohort Study on Air Pollution and Lung Diseases in Adults

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The Swiss Cohort Study on Air Pollution and Lung Diseases in Adults (SAPALDIA), conducted in 1991 (SAPALDIA 1) in eight areas among 9,651 randomly selected adults aged 18–60 years, reported associations among the prevalence of respiratory symptoms, nitrogen dioxide, and particles with an aerodynamic diameter of less than 10 μ g/m³. Later, 8,047 subjects reenrolled in 2002 (SAPALDIA 2). The effects of individually assigned traffic exposures on reported respiratory symptoms were estimated, while controlling for socioeconomic and exposure- and health-related factors. The risk of attacks of breathlessness increased for all subjects by 13% (95% confidence interval: 3, 24) per 500-m increment in the length of main street segments within 200 m of the home and decreased in never smokers by 12% (95% confidence interval: 0, 22) per 100-m increment in distance from home to a main street. Living within 20 m of a main street increased the risks of regular phlegm by 15% (95% confidence interval: 0, 31) and wheezing with breathing problems by 34% (95% confidence interval: 0, 79) in never smokers. In 2002, the effects related to road distance were different from those in 1991, which could be due to changes in the traffic pollution mixture. These findings among a general population provide strong confirmation that living near busy streets leads to adverse respiratory health effects.

cohort studies; environmental exposure; geographic information systems; motor vehicles; prevalence; respiratory tract diseases; Switzerland

Abbreviations: OR, odds ratio; PM_{10} , particles with an aerodynamic diameter of less than 10 $\mu g/m^3$ ($PM_{2.5}$ defined analogously); SAPALDIA, Swiss Cohort Study on Air Pollution and Lung Diseases in Adults.

Ambient air pollution is recognized to have adverse effects on respiratory health (1–3). In the first cross-sectional survey of the Swiss Cohort Study on Air Pollution and Lung Diseases in Adults (SAPALDIA), fixed-site annual means of particles with an aerodynamic diameter of less than $10 \ \mu g/m^3$ (PM₁₀) and nitrogen dioxide were found to

be associated with respiratory symptoms (4) and lung function (5) in 1991. Moreover, differences in nitrogen dioxide exposure levels within study areas were found to be associated with differences in lung capacity (6). These results have contributed to the implementation of World Health Organization air quality standards in the 1990s (7). Subsequent

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debate about cost-effective measures to reduce the adverse health effects of outdoor air pollution has triggered research efforts to identify and quantify sources of particles and the respective health effects (2, 8–12).

Evidence is growing that particles from mobile sources are associated with daily mortality or the risk of cardiopulmonary mortality (9, 13-15). Several studies have reported adverse respiratory effects from traffic exposures among children (16-20) and occupationally traffic-exposed policemen (21) and street cleaners (22). In a US veterans study, an increased risk of persistent wheeze was associated with living within 50 m of a major roadway (23), while an increased risk of chronic bronchitis was found for those living at busy roads in a random sample of women in Germany (24).

No studies thus far have examined traffic effects in a general adult population. We used data from SAPALDIA conducted in 1991 (SAPALDIA 1) and 2002 (SAPALDIA 2) to investigate associations between traffic exposures and the 12-month period prevalence of respiratory symptoms in a random adult population sample. We tested the hypotheses that a greater distance of the home address to the closest main street is associated with a reduced risk of respiratory symptoms and that a denser street network around the home, as well as living very close to a main street, increases such risks. In addition, we evaluated whether the effect estimates in 1991 differed from those in 2002 because of the changes in automobile emissions and, thus, ambient concentrations of traffic-related pollutants (25–27).

MATERIALS AND METHODS

Study population and design

SAPALDIA, commenced in 1991, aims at investigating the long-term health effects of air pollution in a general adult population. Eight study areas were chosen to represent various conditions of geography, climate, degree of urbanization, and air pollution in Switzerland. In four urban (Aarau, Basel, Geneva, Lugano), two rural (Payerne and Wald), and two alpine (Montana and Davos) areas, random population samples of persons aged 18-60 years, who had been residents in the respective area for at least 3 years, were drawn from the local registries of inhabitants in 1991 (28). Of 9,651 participants examined in 1991, 8,047 subjects reenrolled in the study in 2002 and provided basic information on health status (29). In the current analysis, information from 3,500 subjects of SAPALDIA 2 had to be excluded because of missing reported symptoms (n = 999) and other insufficient information (n = 2,501) (Web table 1). (This information is described in a supplementary table posted on the Journal's website (http://aje.oxfordjournals.org/).) Ethical approval for the study was given by the central ethics committee of the Swiss Academy of Medical Sciences and the cantonal ethics committees for each of the eight examination areas. Participants were required to give written consent before any part of the health examination was conducted. Detailed descriptions of the 1991 and 2002 examinations can be found elsewhere (28, 29).

Detailed characteristics of the cohort are given in Web table 1. From 1991 to 2002, the proportion of current smokers had dropped, environmental tobacco smoke exposures had clearly decreased, and the proportion of Swiss nationals had increased. Exclusion criteria for the current analyses were low quality of geocoding, missing covariates, no available symptom data, living less than 1 year at the SAPALDIA 2 address, or living outside the SAPALDIA study areas. For SAPALDIA 1 subjects, those excluded did not differ from those included in the analysis for most covariates, with the exception of a significantly smaller proportion of those excluded reporting current occupational exposures and never smoking. Among SAPALDIA 2 subjects, those excluded differed from those included in the analyses: They were more likely to be male, current smokers, and younger, and they reported less environmental tobacco smoke and occupational exposures.

Questionnaire-based assessment of respiratory symptoms

Health examinations conducted at the eight local centers in 1991 and 2002 included, among others, a standardized, computer-assisted interview based on the European Community Respiratory Health Survey questionnaire (30) and measurements for atopy (total immunoglobulin E and allergen-specific immunoglobulin E against a mix of common inhalant allergens (Phadiatop and Pharmacia CAP System; Pharmacia Diagnostics AB, Uppsala, Sweden)). A skin prick test for eight inhalant allergens was conducted in 1991. The questionnaire in both surveys consisted of identical questions on the history of respiratory symptoms, allergic diseases, general health, living and working environment, smoking habits, and exposure to environmental tobacco smoke. The following respiratory symptoms, reported for the 12 months preceding the interview, were used as health outcomes in this analysis: "attacks of breathlessness," "wheezing with breathing problems," and "wheezing without colds" (symptoms typically associated with asthma) and "regular cough" and "regular phlegm" (typically associated with bronchitis); definitions are given in the Appendix.

Assignment of individual exposure estimates

To take into account the previously documented spatial variability of traffic-related pollution within an area (12, 31– 38), we used geographic information system data to assign individual traffic exposure estimates at each subject's residence, where people spend the majority of their time (39). Findings that indoor levels of traffic-related compounds are highly correlated with outdoor levels (40–42) and that frontdoor levels of black smoke are significant predictors of personal black smoke exposures (43) justify using traffic estimates at the home address to approximate individual traffic exposure. Subjects' 1991 and 2002 addresses were geocoded by matching the addresses to the building registry of the Swiss Federal Statistical Office (44). Only high-quality matches, defined as matching at the house number level or to the nearest neighbor's house number, were used for this analysis to reduce exposure misclassification. The distance from the 1991 and 2002 home coordinates to the closest main street (major road) or highway (refer to Appendix

| | | SAPALDIA 1 | (1991) | | SAPALDIA 2 (2002) | | | | |
|---|------------------------------|------------|-----------|----------|-----------------------------|------------|-----------|----------|--|
| Respiratory symptoms (last 12 months) | Subjects in | Subjects 6 | excluded† | | Subjects in | Subjects e | excluded§ | | |
| (last 12 monato) | GEE* model $(n = 8,452)$ (%) | No. | % | p value‡ | GEE model $(n = 4,547)$ (%) | No. | % | p value‡ | |
| Attacks of breathlessness, day or night | 8.7 | 1,194 | 10.4 | 0.061 | 7.7 | 2,498 | 8.7 | 0.147 | |
| Wheezing with breathing problems | 6.1 | 1,196 | 8.6 | 0.001 | 6.3 | 2,501 | 7.2 | 0.142 | |
| Wheezing without colds | 7.3 | 1,196 | 10.6 | < 0.001 | 7.9 | 2,501 | 8.7 | 0.266 | |
| Regular cough | 16.4 | 1,194 | 18.3 | 0.090 | 16.3 | 2,495 | 16.9 | 0.564 | |
| Regular phlegm | 13.0 | 1,194 | 15.8 | 0.007 | 15.1 | 2,494 | 13.8 | 0.148 | |

TABLE 1. Prevalences of reported respiratory symptoms in the SAPALDIA* cohort population, Switzerland, 1991 and 2002

- * SAPALDIA, Swiss Study on Air Pollution and Lung Diseases in Adults; GEE, generalized estimating equation.
- † Subjects with geocoding on street or community level (n = 417) or with one or more missing covariates (n = 782).
- ‡ Comparison of subjects in GEE model and of excluded subjects using chi-square tests.

table 1 for definitions), as well as the length of main street segments within a 200-m perimeter around the home coordinates, was computed on the basis of VECTOR25 (Swiss Federal Office of Topography, Wabern, Switzerland; http:// www.swisstopo.ch) (45). In addition, a binary variable was created to indicate whether or not there was a main street within 20 m of the home.

In addition, regional background concentrations of PM₁₀ in 1990 and 2000 were estimated by a dispersion model at a 200- \times 200-m resolution (46, 47) and assigned to each participant's geocoded addresses in 1991 and 2002, respectively. The background concentration accounts for imported primary and secondary particles, as well as domestic biogenic particles, and depends on altitude as a result of inversions. The modeled PM₁₀ concentrations (mean: $22.6 \,\mu\text{g/m}^3$) were validated against PM₁₀ measurements (mean: 21.4 μg/m³) at 44 fixed monitoring sites in Switzerland in 2000, resulting in a Pearson's correlation coefficient of 0.74 (46).

Statistical analysis

Generalized estimating equation models were used to assess associations between the odds of symptom reports and the proxy variables for traffic exposure. With from one to two observations per subject, the correlation of outcomes within a subject could be described by a compound symmetry model (xtgee function in STATA statistical software (48)). Robust standard errors were estimated with the Huber/ White/sandwich estimator of variance (48). The effects of traffic exposures on reported respiratory symptoms were estimated with variables combining exposures at both time points (common slope). To obtain separate effect estimates for 1991 and 2002, we used the same model with two survey-specific exposure variables (separate slopes).

The generalized estimating equation regression models controlled for a standard set of socioeconomic factors (sex, age, low education, and nationality), exposure-related factors (active and passive smoking, current and past occupational exposures, and regional background PM₁₀), and health-related factors (atopy, early respiratory infections, family history of asthma and atopy, maternal smoking, and body mass index) as previously used in SAPALDIA 1 (4). In preliminary analyses, we tested quadratic terms for age and body mass index but could not find evidence for nonlinear associations with these two covariates. Dummy variables for the month of interview and the study area were also included. In the SAPALDIA 2 data set, records from subjects living outside a SAPALDIA study area were excluded. Separate analyses were conducted for never smokers, urban and rural/alpine regions, and men and women, respectively.

For sensitivity analyses, we repeated the models, excluding subjects with inconsistent information on smoking status. Furthermore, we evaluated the impact of exposure misclassification on the effect estimates by first restricting analyses to subjects with geocoding of addresses at the house number level and then including additional subjects with low-quality geocoding of addresses. We also ran models with side street variables for the proxy variables for traffic exposure.

All statistical analyses were conducted with STATA, version 8.0 SE, statistical software (48).

RESULTS

Table 1 presents the crude prevalence of reported respiratory symptoms for the 12 months preceding each interview. In both SAPALDIA 1 and SAPALDIA 2, the prevalence ranged between 6 percent (wheezing with breathing problems) and 16 percent (regular cough). Subjects excluded from the SAPALDIA 1 analysis generally had a higher prevalence of reported symptoms than did those included. Never smokers consistently reported less symptoms in 1991 (4) and 2002 (data not shown).

In 1991, participants lived at an average distance of 84 m to a main street, with an average of 660 m of main street segments within 200 m of their homes (table 2). Twenty percent of the participants lived within 20 m of a main street. In 2002, the corresponding averages changed to 95 m and 600 m, respectively, and only 17 percent of the participants lived within 20 m of a main street. Generally, urban

[§] Subjects with geocoding on street or community level (n = 619), living less than 1 year at the SAPALDIA 2 address (n = 438), living outside the study region (n = 549), or with one or more missing covariates (n = 895). For 999 subjects, no data on symptoms were available.

Distribution of the traffic exposure proxies in the SAPALDIA* cohort population, Switzerland, 1991 and 2002 TABLE 2.

| SAPALDIA I (1991) Mean SD* Minimum 25th 50th 75th 60th 75th 60th 75th Maximum No. % All subjects† 8.452 8.4 9.3 1 2.684‡ 660 4.11 0 387 638 9.30 2.666 1,722 2.0 All subjects† 8.452 6.4 1.0 2.684‡ 660 4.11 0 387 638 2.666 1,041 2.2 6.6 1,041 2.6 1.0 1.2 2.666 1,041 2.6 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 1.0 2.6 1.0 2.6 1.0 2.6 1.0 2.6 1.0 </th <th></th> <th>No.</th> <th></th> <th>_</th> <th>Distance to the</th> <th></th> <th>next main street (m)</th> <th>(m)</th> <th></th> <th></th> <th>Length</th> <th>Length of main street segments within 200 m (m)</th> <th>et segme</th> <th>nts withir</th> <th>1 200 m (n</th> <th>(-</th> <th>Living within 20 m of main street</th> <th>nin 20 m street</th> | | No. | | _ | Distance to the | | next main street (m) | (m) | | | Length | Length of main street segments within 200 m (m) | et segme | nts withir | 1 200 m (n | (- | Living within 20 m of main street | nin 20 m street |
|--|--------------------------|-------|------|-----|-----------------|------|----------------------|------|---------|------|--------|---|----------|------------|------------|---------|--------------------------------------|--------------------|
| 8,452 84 93 1 23 54 110 2,684‡ 660 411 0 387 638 930 2,666 1,722 33 4,547 67 16 18 487 803 416 0 516 780 1,064 2,666 1,071 5 3,905 104 115 1 26 68 141 0 516 780 1,064 5666 1,041 681 4,130 89 96 1 24 55 110 2,684 661 409 0 386 640 930 2,666 1,041 681 4,322 85 97 1 24 55 110 2,684 661 409 0 390 637 932 2,384 728 2,793 77 79 1 2 4 10 0 386 678 679 932 2,384 728 < | | | Mean | SD* | Minimum | 25th | 50th | 75th | Maximum | Mean | SD | Minimum | 25th | 50th | 75th | Maximum | No. | % |
| 8,452 84 93 1 23 54 110 2,684‡ 660 411 0 387 638 930 2,666 1,722 4,547 67 65 1 4 8 487 803 416 0 516 780 1,064 2,666 1,041 3,905 104 115 2 68 141 2,684‡ 660 414 0 586 419 731 1,810 681 4,322 85 97 1 2 68 141 616 930 637 932 2,666 883 3,761 89 96 5 24 57 116 932 642 413 0 374 616 909 2,384 833 2,793 77 79 11 2,684 647 410 0 374 616 909 2,384 728 134 144 10 389 67 | SAPALDIA 1 (1991) | | | | | | | | | | | | | | | | | |
| 4,547 67 65 1 21 46 88 487 803 416 0 516 780 1,064 2,666 1,041 681 3,905 104 115 1 26 68 141 2,684‡ 493 336 0 286 419 731 1,810 681 4,130 84 10 2,684‡ 661 409 0 286 419 731 1,810 681 4,130 86 96 5 24 57 116 932 642 413 0 396 678 999 2,384 839 2,793 77 79 1 2 48 109 602 694 410 0 379 678 968 2,666 839 2,793 77 19 602 694 410 0 379 679 2,666 630 2,846 678 968 2,666 <t< td=""><td>All subjects†</td><td>8,452</td><td>84</td><td>93</td><td>-</td><td>23</td><td>5</td><td>110</td><td>2,684‡</td><td>099</td><td>411</td><td>0</td><td>387</td><td>638</td><td>930</td><td>2,666</td><td>1,722</td><td>20</td></t<> | All subjects† | 8,452 | 84 | 93 | - | 23 | 5 | 110 | 2,684‡ | 099 | 411 | 0 | 387 | 638 | 930 | 2,666 | 1,722 | 20 |
| 3,905 104 115 1 26 68 141 2,684‡ 493 336 0 286 419 731 1,810 681 4,130 84 90 1 23 53 109 932 659 414 0 383 640 930 2,666 883 84 433 640 930 6,686 883 84 443 0 390 637 966 883 839 84 86 839 86 839 86 878 966 893 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 839 728 848 728 848 728 848 728 848 728 744 748 < | Urban | 4,547 | 29 | 92 | - | 21 | 46 | 88 | 487 | 803 | 416 | 0 | 516 | 780 | 1,064 | 2,666 | 1,041 | 23 |
| 4,130 84 90 1 23 53 109 932 659 414 0 383 640 930 2,666 883 2 4,322 85 97 1 24 55 110 2,684‡ 661 409 0 390 637 932 2,844 839 3,761 89 96 5 24 57 116 932 642 413 0 396 678 968 2,666 630 1,898 86 106 11 2,684‡ 662 694 410 0 398 678 678 680 5,666 630 56 630 56 56 630 56 630 56 630 56 66 630 56 66 630 56 66 630 56 56 630 56 56 630 56 630 56 630 56 56 630 <t< td=""><td>Rural and alpine</td><td>3,905</td><td>104</td><td>115</td><td>-</td><td>56</td><td>89</td><td>141</td><td>2,684‡</td><td>493</td><td>336</td><td>0</td><td>286</td><td>419</td><td>731</td><td>1,810</td><td>681</td><td>17</td></t<> | Rural and alpine | 3,905 | 104 | 115 | - | 56 | 89 | 141 | 2,684‡ | 493 | 336 | 0 | 286 | 419 | 731 | 1,810 | 681 | 17 |
| 4,322 85 97 1 24 55 110 2,684‡ 661 409 0 390 637 932 2,384 839 3,761 89 96 5 24 57 116 932 642 413 0 374 616 909 2,384 728 2,733 77 79 1 22 48 109 602 694 410 0 379 678 968 2,384 728 739 678 678 968 630 2,384 728 739 678 678 968 630 2,384 728 738 678 678 678 678 678 678 678 678 679 | Men | 4,130 | 84 | 06 | - | 23 | 23 | 109 | 932 | 629 | 414 | 0 | 383 | 640 | 930 | 2,666 | 883 | 21 |
| 3,761 89 96 5 24 57 116 932 642 413 0 374 616 909 2,384 728 2,733 77 79 1 22 48 109 602 694 410 0 398 678 968 2,666 630 53 1,898 86 106 11 24 57 111 2,684 60 398 678 670 364 571 1,044 2,174 763 364 78 364 763 364 < | Women | 4,322 | 82 | 26 | - | 24 | 22 | 110 | 2,684‡ | 661 | 409 | 0 | 330 | 637 | 932 | 2,384 | 839 | 19 |
| 2,793 77 79 1 22 48 109 602 694 410 0 398 678 968 2,666 630 2 1,898 86 106 1 24 57 111 2,684‡ 647 406 0 379 620 902 2,133 364 4,547 95 16 1 24 54 102 880 726 414 0 346 567 857 2,174 763 2,374 79 13 907 586 329 0 244 406 884 1,896 315 2,424 94 95 1 26 62 127 907 612 407 0 348 577 874 318 315 2,424 94 95 1 26 62 127 907 612 407 0 348 577 874 138 <td< td=""><td>Never smokers</td><td>3,761</td><td>88</td><td>96</td><td>2</td><td>24</td><td>22</td><td>116</td><td>932</td><td>642</td><td>413</td><td>0</td><td>374</td><td>919</td><td>606</td><td>2,384</td><td>728</td><td>19</td></td<> | Never smokers | 3,761 | 88 | 96 | 2 | 24 | 22 | 116 | 932 | 642 | 413 | 0 | 374 | 919 | 606 | 2,384 | 728 | 19 |
| 4,547 95 96 10 37 620 902 2,133 364 4,547 95 96 1 26 64 127 907 600 398 0 346 567 857 2,174 763 2,374 79 1 24 54 102 880 726 414 0 415 711 1,014 2,174 448 2,374 79 1 24 54 102 880 726 414 0 415 711 1,014 2,174 448 2,374 79 1 24 54 162 329 0 244 406 684 1,896 315 315 2,424 94 95 1 26 62 127 907 612 407 0 348 577 874 419 2,161 99 102 2 26 63 120 880 | Current smokers | 2,793 | 1 | 26 | - | 22 | 48 | 109 | 602 | 694 | 410 | 0 | 398 | 829 | 896 | 2,666 | 630 | 23 |
| 4,547 95 96 1 26 64 127 907 600 398 0 346 567 857 2,174 763 2,374 79 1 24 54 102 880 726 414 0 415 711 1,014 2,174 748 2,173 112 109 1 24 54 42 329 0 244 406 684 1,896 315 2,123 96 98 1 26 62 127 907 612 407 0 348 577 874 1,98 419 2,161 99 102 3 28 67 131 907 586 402 0 328 546 846 2,138 169 1,058 91 93 5 26 63 120 880 616 365 600 874 1,988 169 1,328 | Former smokers | 1,898 | 98 | 106 | - | 54 | 22 | Ξ | 2,684‡ | 647 | 406 | 0 | 379 | 620 | 905 | 2,133 | 364 | 19 |
| ects† 4,547 95 96 1 26 64 127 907 600 398 0 346 567 857 2,174 763 763 77 2,374 79 79 1 24 54 102 880 726 414 0 415 711 1,014 2,174 448 70 410 2,374 79 79 1 24 54 102 880 726 414 0 415 711 1,014 2,174 448 70 2,173 112 109 1 27 66 126 907 586 387 0 244 406 684 1,896 315 71 2,424 99 102 3 28 67 131 907 586 402 0 328 546 846 2,138 749 3,000 89 102 3 28 67 131 907 586 616 385 60 874 1,988 169 3,000 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 3,000 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 3,000 89 1,000 89 1,000 89 1,000 80 3,000 80 1, | SAPALDIA 2 (2002) | | | | | | | | | | | | | | | | | |
| 2,374 79 79 1 24 54 102 880 726 414 0 415 711 1,014 2,174 448 nd alpine 2,173 112 109 1 30 79 153 907 462 329 0 244 406 684 1,896 315 2,123 96 98 1 27 66 126 907 586 387 0 345 550 838 2,174 344 2,142 99 102 3 28 67 131 907 586 402 0 328 546 846 2,138 352 smokers 1,058 91 93 5 26 63 120 880 616 385 0 361 571 869 2,174 2,49 1,988 smokers 1,328 90 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 1,98 | All subjects† | 4,547 | 92 | 96 | - | 56 | 64 | 127 | 206 | 009 | 398 | 0 | 346 | 267 | 857 | 2,174 | 292 | 17 |
| nd alpine 2,173 112 109 1 30 79 153 907 462 329 0 244 406 684 1,896 315 315 112 123 96 98 1 27 66 126 907 586 387 0 345 550 838 2,174 344 344 344 344 344 344 344 344 344 3 | Urban | 2,374 | 79 | 79 | - | 54 | 24 | 102 | 880 | 726 | 414 | 0 | 415 | 711 | 1,014 | 2,174 | 448 | 19 |
| 2,123 96 98 1 27 66 126 907 586 387 0 345 550 838 2,174 344 34 smokers 2,124 94 95 1 26 62 127 907 612 407 0 348 577 874 2,138 419 1 smokers 2,161 99 102 3 28 67 131 907 586 402 0 328 546 846 2,138 352 1 smokers 1,058 91 93 5 26 63 120 880 616 385 0 365 600 874 1,988 169 1 sr smokers 1,328 90 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 1 | Rural and alpine | 2,173 | 112 | 109 | - | 30 | 26 | 153 | 206 | 462 | 329 | 0 | 244 | 406 | 684 | 1,896 | 315 | 15 |
| 2,424 94 95 1 26 62 127 907 612 407 0 348 577 874 2,138 419 19 2,161 99 102 3 28 67 131 907 586 402 0 328 546 846 2,138 352 1 1,058 91 93 5 26 63 120 880 616 385 0 365 600 874 1,988 169 1 1,328 90 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 1 | Men | 2,123 | 96 | 86 | - | 27 | 99 | 126 | 206 | 286 | 387 | 0 | 345 | 220 | 838 | 2,174 | 344 | 16 |
| 2,161 99 102 3 28 67 131 907 586 402 0 328 546 846 2,138 352 352 1,058 91 93 5 26 63 120 880 616 385 0 365 600 874 1,988 169 169 1,328 90 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 7 | Women | 2,424 | 98 | 92 | - | 56 | 62 | 127 | 206 | 612 | 407 | 0 | 348 | 222 | 874 | 2,138 | 419 | 17 |
| ; 1,058 91 93 5 26 63 120 880 616 385 0 365 600 874 1,988 169 ·· 1,328 90 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 ·· | Never smokers | 2,161 | 66 | 102 | က | 58 | 29 | 131 | 206 | 286 | 402 | 0 | 328 | 546 | 846 | 2,138 | 352 | 16 |
| 1,328 90 89 1 25 60 122 540 609 401 0 361 571 869 2,174 242 · | Current smokers | 1,058 | 91 | 93 | 2 | 56 | 63 | 120 | 880 | 919 | 382 | 0 | 365 | 009 | 874 | 1,988 | 169 | 16 |
| | Former smokers | 1,328 | 06 | 88 | - | 22 | 09 | 122 | 540 | 609 | 401 | 0 | 361 | 571 | 869 | 2,174 | 242 | 18 |

Subjects included in the generalized estimating equation models (with high-quality geocoding and a complete set of covariates). Excluding one subject with a distance of 2,684 m to the closest main street results in a maximum distance of 932 m. SAPALDIA, Swiss Study on Air Pollution and Lung Diseases in Adults; SD, standard deviation.

participants lived closer to main streets within a denser street network than did their rural counterparts. Never smokers lived farther away from main streets within a lighter street network than did current smokers. In the rural but not the urban areas, lower social status was associated with living close to a main street.

Table 3 shows the influence of distance on respiratory symptoms estimated by the generalized estimating equation regression model with and without adjustment for covariates. For each 100-m increment in distance to the closest main street, the adjusted risk of reporting regular phlegm was reduced by 7 percent. For the other symptoms, a tendency for reduced risks was observed (odds ratio (OR) < 1). In never smokers, each 100-m increment in distance to the closest main street was associated with a 12 percent reduced risk for attacks of breathlessness.

The length of main street segments within 200 m around the home was positively associated with a 13 percent (per 500 m) increased risk of attacks of breathlessness in all subjects (and 20 percent increased risk in never smokers who also had a higher risk of wheezing without cold (18 percent)). For other symptoms, a tendency for increased risks was observed (OR > 1).

Living within 20 m of a main street was associated with a 15 percent increased risk of regular phlegm in all subjects and a 34 percent increased risk of wheezing with breathing problems in never smokers. Larger effect estimates were obtained without adjustment for potential confounders in all subjects but not in never smokers. Removing regional background PM₁₀ from the model changed the effect estimates only very slightly (data not shown).

Figure 1 shows the adjusted odds ratios for attacks of breathlessness for the second, third, and fourth quartiles of distance to the closest main street and length of main street segments, relative to the first quartile. It suggests consistent exposure-response associations for both traffic proxies, particularly among never smokers.

Separate analyses for the four urban and four rural/alpine areas resulted in rather unstable estimates, and there was no systematic pattern distinguishing associations in urban and rural areas (data not shown). Evidence for adverse effects on respiratory health from living close to side streets was not found (data not shown). Excluding subjects with inconsistent information on smoking status (n = 275) had little impact on the effect estimates. Generally, restricting the analysis to subjects with geocoding matched on house numbers (i.e., excluding those with nearest neighbor matches) resulted in stronger effect estimates, while inclusion of subjects with low quality of geocoding (on street or community level) resulted in slightly weaker effect estimates, as would be expected for reduced and increased exposure misclassification. Comparisons of the effect estimates between SAPALDIA 1 and SAPALDIA 2 suggest that traffic effects on the reported respiratory symptoms became weaker from 1991 to 2002. Effect estimates for distance to main street changed relatively little, while effects for length of main street segments within 200 m disappeared. In contrast, the estimated effects on wheezing from living within 20 m of a main street became stronger in 2002, particularly in men where the difference for wheezing without a cold (from

TABLE 3. Unadjusted and adjusted odds ratios and 95% confidence intervals of reported respiratory symptoms associated with traffic exposure proxies for the SAPALDIA* cohort population, Switzerland, 1991 and 2002

| | | Entire sample | (n = 12,9) | 999)† | | Never smoker | rs (n = 5,9 | 922)‡ |
|--|---------------|-------------------------------|---------------|-------------------------------|---------------|-------------------------------|---------------|-------------------------------|
| Respiratory symptom | Ur | nadjusted | Α | djusted§ | Ur | nadjusted | Α | djusted§ |
| during last 12 months | Odds ratio | 95% confidence interval | Odds ratio | 95% confidence interval | Odds ratio | 95% confidence interval | Odds ratio | 95% confidence interval |
| Distance to closest main street (per 100 m) | | | | | | | | |
| Attacks of breathlessness | 0.86 | 0.79, 0.94 | 0.93 | 0.85, 1.01 | 0.84 | 0.75, 0.94 | 0.88 | 0.78, 1.00 |
| Wheezing with breathing problems | 0.93 | 0.85, 1.02 | 0.95 | 0.87, 1.04 | 0.90 | 0.79, 1.04 | 0.91 | 0.79, 1.05 |
| Wheezing without cold | 0.91 | 0.84, 0.99 | 0.97 | 0.89, 1.06 | 0.89 | 0.78, 1.03 | 0.91 | 0.78, 1.06 |
| Regular cough | 0.91 | 0.87, 0.97 | 0.96 | 0.90, 1.01 | 0.98 | 0.90, 1.08 | 1.00 | 0.91, 1.10 |
| Regular phlegm | 0.88 | 0.82, 0.94 | 0.93 | 0.87, 0.99 | 0.97 | 0.88, 1.07 | 1.01 | 0.91, 1.12 |
| Length of main street segments within 200 m (per 500 m) | | | | | | | | |
| Attacks of breathlessness | 1.23 | 1.14, 1.33 | 1.13 | 1.03, 1.24 | 1.26 | 1.12, 1.41 | 1.20 | 1.05, 1.38 |
| Wheezing with breathing problems | 1.10 | 1.00, 1.21 | 1.09 | 0.98, 1.21 | 1.13 | 0.97, 1.31 | 1.15 | 0.97, 1.35 |
| Wheezing without cold | 1.15 | 1.06, 1.24 | 1.06 | 0.97, 1.16 | 1.17 | 1.01, 1.34 | 1.18 | 1.01, 1.39 |
| Regular cough | 1.06 | 1.00, 1.12 | 1.00 | 0.94, 1.07 | 1.10 | 0.99, 1.22 | 1.08 | 0.96, 1.21 |
| Regular phlegm | 1.13 | 1.07, 1.20 | 1.06 | 0.98, 1.13 | 1.11 | 1.00, 1.23 | 1.06 | 0.94, 1.20 |
| Living within 20 m of a main street | | | | | | | | |
| Attacks of breathlessness | 1.21 | 1.03, 1.41 | 1.16 | 0.99, 1.35 | 1.09 | 0.85, 1.40 | 1.06 | 0.82, 1.37 |
| Wheezing with breathing problems | 1.24 | 1.04, 1.48 | 1.19 | 0.99, 1.43 | 1.34 | 1.00, 1.78 | 1.34 | 1.00, 1.79 |
| Wheezing without cold | 0.99 | 0.83, 1.17 | 0.94 | 0.78, 1.12 | 1.03 | 0.75, 1.41 | 1.05 | 0.76, 1.45 |
| Regular cough | 1.03 | 0.91, 1.16 | 0.96 | 0.85, 1.09 | 0.94 | 0.75, 1.18 | 0.93 | 0.75, 1.17 |
| Regular phlegm | 1.18 | 1.03, 1.34 | 1.15 | 1.00, 1.31 | 1.06 | 0.84, 1.33 | 1.06 | 0.84, 1.34 |

^{*} SAPALDIA, Swiss Study on Air Pollution and Lung Diseases in Adults.

OR = 0.95 in 1991 to OR = 1.46 in 2002) reached statistical significance (p = 0.04).

DISCUSSION

We found evidence that residential exposure to traffic is associated with asthmatic and bronchitic symptoms, in particular with attacks of breathlessness, wheezing with breathing problems, wheezing without a cold, and regular phlegm. Our findings are consistent with those of previous epidemiologic studies on traffic exposures that reported associations with persistent wheeze (23), bronchitic symptoms (21–23), and chronic bronchitis (24) in adults and with wheeze (17–19) and cough (18) in children. The strengths of our study

 $[\]dagger n = 12,994-12,999$ observations from 8,553-8,555 subjects.

 $[\]ddagger n = 5,921-5,922$ observations from 3,819-3,820 subjects.

 $[\]S$ Estimated odds ratios for the SAPALDIA cohort adjusted for sex, age, education, nationality, active and passive smoking, current and past occupational exposures, atopy, early respiratory infections, family history of asthma and atopy, maternal smoking, body mass index, regional background particles with an aerodynamic diameter of less than 10 μ m/m³, month of interview, and area.

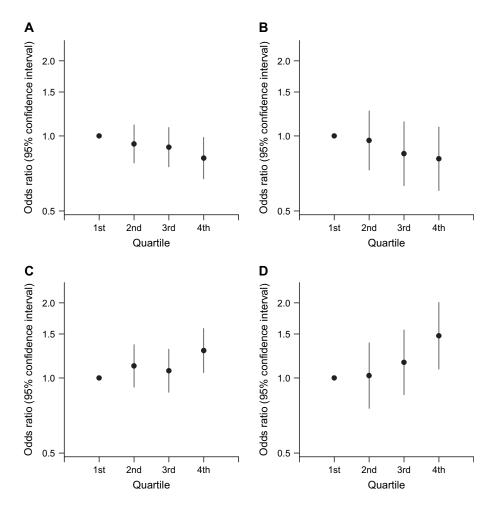


FIGURE 1. Adjusted odds ratios (and 95% confidence intervals) for reported attacks of breathlessness by quartiles of "distance to the closest main street" (first: 0-23 m; second: 24-58 m; third: 59-117 m; fourth: 118-2,684 m, top) and by quartiles of "length of main street segments around the home address" (first: 0-366 m; second: 367-596 m; third: 597-892 m; fourth: 893-2,666 m, bottom) for the entire sample and for never smokers (the lowest quartile category serving as the reference group) in the SAPALDIA cohort population, Switzerland, 1991 and 2002. A, distance (all subjects); B, distance (never smokers); C, length (all subjects); D, length (never smokers). For information on the adjustment variables, refer to the "Statistical analysis" section of the text. SAPALDIA, Swiss Cohort Study on Air Pollution and Lung Diseases in Adults.

include its population-based design and the individually assigned traffic exposures using objective data. We demonstrated consistent results using three different proxies of traffic exposure. An exposure-response association was clearly shown for attacks of breathlessness. We found a tendency for stronger respiratory effects in never smokers and in men. In sensitivity analyses, the effect estimates proved to be stable. The effect estimates in 2002 were weaker than those in 1991, especially in men. That the observed associations were not confounded by regional background PM₁₀ further supports the hypothesis that living close to main streets leads to health effects that cannot be attributed to background air pollution.

Period prevalence of respiratory symptoms

As the reported symptoms reflect the period prevalence during the 12 months preceding the surveys, they may capture primarily the response to exposure during the respective 12-month periods. The assigned traffic exposures also relate to the individual residences during the respective time periods. The underlying hypothesis that traffic exposures during these 12 months are the most relevant exposure terms is supported by findings of a prospective study in children, where respiratory symptoms fluctuated concurrently with annual pollutant means (49).

Changes over follow-up

One weakness of using proxies for traffic exposure is that the actual scaling or exposure levels of traffic exhaust at the two time points are likely not comparable. Emission factors of vehicles have generally decreased over the 11-year follow-up period, although not to the same extent for all components and vehicle categories (25). Between 1990 and 2000, the vehicle road performance (vehicle km/year) has increased by about 16 percent in Switzerland (25). The composition of the Swiss car fleet has also changed, with a substantial increase of cleaner Euro1 and Euro2 cars and diesel cars meeting European antipollution rules (from 6 to about 10 percent) (25). These changes have led to an overall 36 percent decrease of traffic-related nitrogen oxide emissions (25), resulting in a similar decrease of nitrogen oxide concentrations at urban monitoring sites close to traffic, while levels of primary pollutant decreased only slightly at rural and background sites (50). This implies that the underlying quantitative exposure of the three traffic proxies has changed since 1991, which may result in a change of the proxy gradient and lead to weaker or stronger relative risks per exposure unit. Our data show, indeed, a trend to weaker or even vanishing associations in 2002 for most of the symptoms with all three exposure proxies. The fact that there are exceptions suggests that these changes did not affect exposure proxies and symptoms uniformly. The general increase in road performance in Switzerland has led to more traffic congestion. Together with the increased share of diesel cars, these secular trends may have resulted in higher proportions of diesel particles and of other primary pollutants emitted by stop-and-go traffic compared with moving traffic. This might explain the enhanced associations of wheezing symptoms with "living within 20 m of a main street," in line with a recent study demonstrating that children living close (<100 m) to stop-and-go traffic had an increased risk for wheezing without a cold (51). Our finding is also consistent with increased resuspended particulate matter from traffic ingestion, although the specific toxicologic relevance of exhaust versus resuspended particles is not yet clear.

On average, the SAPALDIA study population experienced a reduction of exposure to main streets between the two surveys. The SAPALDIA 2 subjects lived at a greater distance to the closest main street and were surrounded by less main street segments, and a lower proportion of them was living very close to a main street. This reflects the tendency of subjects to move to agglomerations and rural areas. However, such shifts on the proxy exposure scales would not affect risk estimates if traffic characteristics had not changed.

Limitations

Although the exposure proxies are indirect measures of traffic-related exposure, there is evidence that the levels of traffic-related components of air pollution are associated with the distance from a main street (31, 32) and with the street density around a location (52). In Switzerland, the proportion of traffic-related compounds was higher at curbside sites than at background and rural sites (53). In a Dutch study, the distance to the nearest major road explained 28 percent of the variation of PM_{2.5} filter absorbance, while the distance to the closest road explained only 3 percent (52). In the SAPALDIA cohort, no health effects were observed for the side street variables. Second, the surrogates of traffic exposure are proxies for the exposure level at home outdoors. Studies reporting indoor levels of traffic-related compounds to be highly correlated with outdoor levels (40–42) suggest that outdoor levels are also relevant for total personal ex-

posures to traffic (39). Another limitation of the surrogates is that they do not take into account individual differences in the time spent at home and in other environments, such as workplaces or in traffic while commuting (39). Yet, personal carbon monoxide measurements showed that the time spent in traffic increases short-term peak exposures but not 48-hour average exposures (54). Average daily carbon monoxide exposures were found to be dominated by the home location (54) and by indoor levels at home (55), where most of the time is spent (39). These findings suggest that longterm exposures to traffic-related pollutants may be sufficiently captured by estimates for the home outdoors. By including fixed-area effects in the models, we estimated average effects within but not across study areas, thereby diminishing comparability problems. Another limitation of the study is that the health outcomes are self-reported symptoms. Even if awareness of symptoms varied more strongly with traffic exposure than symptom prevalence, our findings would indicate that traffic exposure influences the quality of life. Further, a number of subjects had to be excluded from analysis because of missing data or low quality of geocoding. This might raise concern about potential selection bias. However, we examined whether baseline associations between respiratory symptoms and traffic exposure proxies differed between subjects having been included in our SAPALDIA 2 analysis and subjects who were not. Differences could be seen for attacks of breathlessness, where associations appeared to be weaker among subjects not included in the follow-up analysis but, for all the other symptoms with statistically significant adjusted odds ratios in table 3, the differences were small.

Conclusions

Our results provide evidence for the adverse effects of traffic exposures on respiratory health, consistent with previous studies associating traffic exposures with respiratory symptoms (17-19, 21-23), increased mortality (9-11, 13-15), and childhood asthma (16, 20). We conclude that living close to main streets or in a dense street network increases the risks for certain respiratory symptoms in adults, particularly for asthma-related symptoms such as attacks of breathlessness and wheezing and for bronchitic symptoms such as regular cough and phlegm. These effects appear to be independent of modeled regional background PM₁₀. Our findings in a random sample of the adult population of Switzerland provide further support to the hypothesis that traffic exhausts are relevant to respiratory health.

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REFERENCES

1. Bascom R, Bromberg PA, Costa DA, et al. Health effects of outdoor air pollution. State of the art part I and part II.

- Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. Am J Respir Crit Care Med 1996;153:3-50, 477-98.
- 2. Brunekreef B, Holgate ST. Air pollution and health. Lancet 2002;360:1233-42.
- 3. D'Amato G, Holgate ST, eds. The impact of air pollution on respiratory health. In: European respiratory monograph. Vol 7. Monogr 21. Cambridge, MA: Maney Publishing North America, 2002:1-282.
- 4. Zemp E, Elsasser S, Schindler C, et al. Long-term ambient air pollution and respiratory symptoms in adults (SAPALDIA study). Am J Respir Crit Care Med 1999;159:1257-66.
- 5. Ackermann-Liebrich U, Leuenberger P, Schwartz J, et al. Lung function and long term exposure to air pollutants in Switzerland. Study on Air Pollution and Lung Diseases in Adults (SAPALDIA) Team. Am J Respir Crit Care Med 1997;155: 122 - 9
- 6. Schindler C. Ackermann-Liebrich U. Leuenberger P. et al. Associations between lung function and estimated average exposure to NO₂ in eight areas of Switzerland. The SAPALDIA Team. Swiss Study of Air Pollution and Lung Diseases in Adults. Epidemiology 1998;9:405–11.
- 7. World Health Organization. Air quality guidelines for Europe. 2nd ed. Copenhagen, Denmark: World Health Organization,
- 8. Brunekreef B, Sunyer J. Asthma, rhinitis and air pollution: is traffic to blame? Eur Respir J 2003;21:913-15.
- 9. Laden F, Neas LM, Dockery DW, et al. Association of fine particulate matter from different sources with daily mortality in six U.S. cities. Environ Health Perspect 2000;108:941-7.
- 10. Tsai FC, Apte MG, Daisey JM. An exploratory analysis of the relationship between mortality and the chemical composition of airborne particulate matter. Inhal Toxicol 2000;12(suppl 2): 121 - 35.
- 11. Schwartz J, Laden F, Zanobetti A. The concentration-response relation between PM(2.5) and daily deaths. Environ Health Perspect 2002;110:1025-9.
- 12. Krzyzanowski M, Kuna-Dibbert B, Schneider J. Health effects of transport-related air pollution. Copenhagen, Denmark: World Health Organization, 2005.
- 13. Finkelstein MM, Jerrett M, Sears MR. Traffic air pollution and mortality rate advancement periods. Am J Epidemiol 2004; 160:173-7.
- 14. Hoek G, Brunekreef B, Goldbohm S, et al. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet 2002;360:1203-9.
- 15. Nafstad P, Haheim LL, Wisloff T, et al. Urban air pollution and mortality in a cohort of Norwegian men. Environ Health Perspect 2004;112:610-15.
- 16. Gauderman WJ, Avol E, Lurmann F, et al. Childhood asthma and exposure to traffic and nitrogen dioxide. Epidemiology 2005;16:737-43.
- 17. Brauer M, Hoek G, Van Vliet P, et al. Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children. Am J Respir Crit Care Med 2002;166:1092-8.
- 18. Nicolai T, Carr D, Weiland SK, et al. Urban traffic and pollutant exposure related to respiratory outcomes and atopy in a large sample of children. Eur Respir J 2003;21:956-63.
- 19. Venn AJ, Lewis SA, Cooper M, et al. Living near a main road and the risk of wheezing illness in children. Am J Respir Crit Care Med 2001;164:2177-80.
- 20. Zmirou D, Gauvin S, Pin I, et al. Traffic related air pollution and incidence of childhood asthma: results of the Vesta casecontrol study. J Epidemiol Community Health 2004;58:18-23.

- 21. Wongsurakiat P, Maranetra KN, Nana A, et al. Respiratory symptoms and pulmonary function of traffic policemen in Thonburi. J Med Assoc Thai 1999;82:435-43.
- 22. Raaschou-Nielsen O, Nielsen ML, Gehl J. Traffic-related air pollution: exposure and health effects in Copenhagen street cleaners and cemetery workers. Arch Environ Health 1995; 50:207-13.
- 23. Garshick E, Laden F, Hart JE, et al. Residence near a major road and respiratory symptoms in U.S. veterans. Epidemiology 2003:14:728-36.
- 24. Heinrich J, Topp R, Gehring U, et al. Traffic at residential address, respiratory health, and atopy in adults: the National German Health Survey 1998. Environ Res 2005;98:240–9.
- 25. BUWAL. Die Luftschadstoffemissionen des Strassenverkehrs 1980–2030. (The air pollutant emissions of the traffic 1980– 2030). (In German). Bern, Switzerland: Bundesamtes für Umwelt, Wald, und Landschaft, BUWAL, 2004.
- 26. Stemmler K, Bugmann S, Buchmann B, et al. Large decrease of VOC emissions of Switzerland's car fleet during the past decade: results from a highway tunnel study. Atmos Environ 2004;39:1009-18.
- 27. Infras. Handbook emission factors for road transport (HBEFA). Bern, Switzerland: Federal Office of the Environment,
- 28. Martin BW, Ackermann-Liebrich U, Leuenberger P, et al. SAPALDIA: methods and participation in the cross-sectional part of the Swiss Study on Air Pollution and Lung Diseases in Adults. Soz Präventivmed 1997;42:67-84.
- 29. Ackermann-Liebrich U, Kuna-Dibbert B, Probst-Hensch NM, et al. Follow-up of the Swiss Cohort Study on Air Pollution and Lung Diseases in Adults (SAPALDIA 2) 1991-2003: methods and characterization of participants. Soz Präventivmed 2005;50:245-63.
- 30. Burney PG, Luczynska C, Chinn S, et al. The European Community Respiratory Health Survey. Eur Respir J 1994;7: 954-60.
- 31. Zhu Y, Hinds WC, Kim S, et al. Concentration and size distribution of ultrafine particles near a major highway. J Air Waste Manag Assoc 2002;52:1032-42.
- 32. Roorda-Knape MC, Janssen NA, de Hartog J, et al. Traffic related air pollution in city districts near motorways. Sci Total Environ 1999;235:339-41.
- 33. Roemer WH, van Wijnen JH. Differences among black smoke, PM(10), and PM(1.0) levels at urban measurement sites. Environ Health Perspect 2001;109:151-4.
- 34. Kim S, Shen S, Sioutas C. Size distribution and diurnal and seasonal trends of ultrafine particles in source and receptor sites of the Los Angeles basin. J Air Waste Manag Assoc 2002;52:297-307.
- 35. Röösli M, Theis G, Künzli N, et al. Temporal and spatial variation of the chemical composition of PM10 at urban and rural sites in the Basel area, Switzerland. Atmos Environ 2001; 35:3701-13.
- 36. Oglesby L, Künzli N, Röösli M, et al. Validity of ambient levels of fine particles as surrogate for personal exposure to outdoor air pollution—results of the European EXPOLIS-EAS Study (Swiss Center Basel). J Air Waste Manag Assoc 2000; 50:1251-61.
- 37. Smargiassi A, Baldwin M, Pilger C, et al. Small-scale spatial variability of particle concentrations and traffic levels in Montreal: a pilot study. Sci Total Environ 2005;338: 243-51.
- 38. Hoek G, Meliefste K, Cyrys J, et al. Spatial variability of fine particle concentrations in three European areas. Atmos Environ 2002;36:4077-88.

- 39. Schweizer C, Edwards RD, Bayer-Oglesby L, et al. Indoor time-microenvironment-activity patterns in seven regions of Europe. J Expo Sci Environ Epidemiol 2006. Advance Access publication. (DOI: 10.1038/sj.jes.7500490).
- 40. Götschi T, Oglesby L, Mathys P, et al. Comparison of black smoke and PM2.5 levels in indoor and outdoor environments of four European cities. Environ Sci Technol 2002;36:
- 41. Mathys P. Elemental analysis of airborne fine particulate matter. Basel, Switzerland: University of Basel, 2002.
- 42. Cyrys J, Pitz M, Bischof W, et al. Relationship between indoor and outdoor levels of fine particle mass, particle number concentrations and black smoke under different ventilation conditions. J Expo Anal Environ Epidemiol 2004;14: 275-83.
- 43. Sorensen M, Loft S, Andersen HV, et al. Personal exposure to PM(2.5), black smoke and NO(2) in Copenhagen: relationship to bedroom and outdoor concentrations covering seasonal variation. J Expo Anal Environ Epidemiol 2005;15:1–10.
- 44. Swiss Federal Statistical Office. Swiss census 2000. Bern, Switzerland: Bundesamt für Statistik (BFS), 2003.
- 45. ArcGIS, version 9.0. Redlands, CA: ESRI (Environmental Systems Research Institute), 2004.
- 46. BUWAL. Modelling of PM10 and PM2.5 ambient concentrations in Switzerland 2000 and 2010. Bern, Switzerland: Bundesamtes für Umwelt, Wald, und Landschaft, BUWAL,
- 47. BUWAL. Modellierung der PM10-Belastung in der Schweiz. (In German). Bern, Switzerland: Bundesamtes für Umwelt, Wald, und Landschaft, BUWAL, 1999. (No. 310).
- 48. StataCorp LP. Stata statistical software. College Station, TX: StataCorp LP, 2003.
- 49. McConnell R, Berhane K, Gilliland F, et al. Prospective study of air pollution and bronchitic symptoms in children with asthma. Am J Respir Crit Care Med 2003;168:790-7.
- 50. Kuebler J, van den Bergh H, Russell AG. Long-term trends of primary and secondary pollutant concentrations in Switzerland and their response to emission controls and economic changes. Atmos Environ 2001;35:1351-63.
- 51. Ryan PH, LeMasters G, Biagini J, et al. Is it traffic type, volume, or distance? Wheezing in infants living near truck and bus traffic. J Allergy Clin Immunol 2005;116:279–84.
- 52. Brauer M, Hoek G, van Vliet P, et al. Estimating long-term average particulate air pollution concentrations: application of traffic indicators and geographic information systems. Epidemiology 2003;14:228-39.
- 53. Hueglin C, Gehrig R, Baltensperger U, et al. Chemical characterisation of PM2.5, PM10 and coarse particles at urban, near-city and rural sites in Switzerland. Atmos Environ 2005; 39:637-51.
- 54. Scotto di Marco G, Kephalopoulos S, Ruuskanen J, et al. Personal carbon monoxide exposure in Helsinki, Finland. Atmos Environ 2005;39:2697–707.

55. De Bruin YB, Carrer P, Jantunen M, et al. Personal carbon monoxide exposure levels: contribution of local sources to exposures and microenvironment concentrations in Milan. J Expo Anal Environ Epidemiol 2004;14:312–22.

APPENDIX

Definition of reported respiratory symptoms

Respiratory symptoms are defined as a positive answer to the following question(s): attacks of breathlessness: "Have you had an attack of shortness of breath that came on during the day when you were at rest at any time in the last 12 months?" or "Have you been awakened by an attack of shortness of breath at any time in the last 12 months?"; wheezing: "Have you had wheezing or whistling in your chest at any time in the last 12 months?"; wheezing with breathing problems: wheezing and "Have you had breathing problems when you had this wheezing or whistling?"; wheezing without colds: wheezing and "Have you had this wheezing or whistling when you did not have a cold?"; regular cough: "Do you usually cough in the morning after getting up?" or "Do you usually cough during the day, or at night?"; and regular phlegm: "Do you usually bring up any phlegm from your chest in the morning after getting up?" or "Do you usually bring up any phlegm from your chest during the day or at night?".

APPENDIX TABLE 1. Classification and definition of street categories based on VECTOR25*

| Street class | Definition | Street category according to VECTOR25 |
|--------------|---------------------|---------------------------------------|
| Side street | At least 2.8 m wide | Third-class street |
| | At least 4 m wide | Neighborhood street |
| Main street | At least 4 m wide | Second-class street |
| | At least 6 m wide | First-class street |
| | No separated lines | Major road |
| | Separated lines | Highway |

* VECTOR25 is a digital landscape model of Switzerland and consists of nine thematic layers: road network, railway network, other traffic, hydrographic network, primary surfaces, buildings, hedges and trees, functional surfaces, and single objects. Refer to the Swiss Federal Office of Topography (http://www.swisstopo.ch) for more information.