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Respiratory Symptoms and Annoyance in the Vicinity of Coal-Fired Plants

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This study constitutes one part of a program for assessing the impact of coal-fired power plants on the surrounding communities. A questionnaire was mailed to a total of 12,000 subjects living in six areas with coal-fired plants and in matched reference areas. The participation rate was 77.3%. In one coal-fired plant/reference area pair, a more detailed medical examination was carried out among subjects who reported symptoms of the respiratory tract. The match between coal-fired plant and reference areas was successful primarily in three pairs. Neither respiratory symptoms nor disease rates were increased among adults or children near any of these plants, but one plant seemed to give rise to annoyance. For the remaining coal-fired plants, consistently higher prevalences of respiratory tract symptoms and annoyance were observed in the surrounding population. The effects cannot, however, conclusively be related to the coal-fired plants. It should be pointed out that the air pollution levels were relatively low, also in the vicinity of most of the plants in this study.

Introduction

Emissions from fossil-fueled power plants contain substances which have been associated with various health effects. Sulfur dioxide, nitrogen oxides, and particulates are some of the main constituents of the emissions from coal-fired plants. Exposure to these and other agents in urban and industrial areas has been linked to both acute and chronic effects in the respiratory system as well as to annoyance reactions (*1–7*). However, causal interpretations of associations between specific compounds and effects have to be made with caution. The agents that have been measured should be regarded as index substances. Results of different studies may thus not be comparable because of differences in exposure to substances not monitored.

Very few epidemiological studies have specifically investigated the health implications of emissions from coal-fired power plants. A correlation between attack rates and air pollution levels was shown in a group of asthmatics living near a U.S. coal-fired plant (*8*). The plant had no abatement devices which resulted in very high concentrations of air pollutants in the vicinity. Annoyance resulting from air pollution and noise were reported in a survey conducted near three U.S. coal-fired plants (*9*). No data on air pollution levels were given, which makes it difficult to evaluate the findings.

The primary aim of the present work was to investigate target areas near coal-fired plants of modern design and to determine whether health effects could be observed among neighboring residents. Comparisons were also made with areas near plants of older design as well as with residential areas without power plants. In addition, an intensified study was made in one of the areas of subjects believed to be sensitive to air pollution. This study has been reported elsewhere (*10*).

Materials and Methods

Study Subjects

The study is based on information obtained from questionnaires mailed to about 12,000 individuals from 12 "target populations" representing six locations near coal-fired plants in Finland as well as six matched reference areas. The area "pairs" are designated by the letters A–F.

The target population for the survey were men and women, aged 15 to 64, who had lived at least three years in a target area. A random sample of about 900–1100 subjects per target area was drawn from the national population register and mailed a questionnaire in 1981. The number of participants and the final response rates by area are presented in Table 1. Altogether, 5354 men and 5956 women participated in the survey. The final response rate among men was 74.1% and among women 80.5%, giving a total of 77.3%. There were no important differences in response rate between the various coal-fired plant areas and corresponding reference areas.

The questionnaire, which is presented in full else-

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Table 1. Sample sizes and response rates in areas with coal-fired plants and matched reference areas.

		Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
Sample size	Exp[a]	976	977	1058	967	880	980
	Ref[b]	971	970	1083	980	886	986
Participants	Exp	704	719	842	764	675	754
	Ref	739	717	904	761	726	767
Response rate, %	Exp	72.1	73.6	79.6	79.0	81.9	77.9
	Ref	76.1	73.9	83.5	77.7	81.9	77.8

[a] Area with coal-fired plant.
[b] Reference area.

where (*11*), was divided into several sections and began with general questions about marital status, education, occupation, size and type of residence, and satisfaction with the residential area. A following section dealt with the respondent's state of health. It explored symptoms usually associated with chronic bronchitis, asthma, and allergic reactions. There were also questions about annoyance caused by noise and air pollution, smoking habits as well as opinions and attitudes relating to environment and health. The final part of the questionnaire inquired about symptoms and diseases of the respiratory tract among children under the age of 15 in the respondent's family.

Medical examinations were performed on a subsample from the study group, i.e., individuals who on their questionnaire indicated respiratory impairment or irritative symptoms possibly related to environmental exposures. This subsample consisted of 171 subjects from the coal-fired plant area D and its reference area. Apart from an extensive medical interview these individuals were subjected to laboratory evaluations including pulmonary function tests.

The Power Plants and Study Areas

Table 2 gives some technical data on the power plants in the study areas. Three plants producing only electric power were included in the study, i.e., Plants C, E, and F. Plants A and Plant B as well as Plant D are electric power and district heating plants. Plant E is the largest power plant unit in Finland (1000 MW).

In 1981, the year of the study, Plant A had the largest dust emissions of all the plants, i.e., more than 1500 tons. None of the other plants had emissions exceeding 500 tons. In 1980 Plants A and Plant E emitted more than 2000 tons of dust. The comparatively low emission from Plant E in 1981 is due to the fact that the plant was in use only sporadically.

The capacity of the coal piles differs considerably, from 0.1 megaton in Plant B to 1.8 megatons in Plant E. In all plants the coal is spread over the pile and compressed by bulldozers. This may cause a dust load in adjacent areas. In Plant A the loading of fly ash on trucks takes place in an open shed whereas in the other plants loading is done in an enclosed space.

When studying potential health effects and annoyance caused by the coal-fired plants, it is important also to take into consideration emissions in the area from other industrial activities and from motor traffic. Figure 1 shows the SO_2 emission sources in the Helsinki region together with the locations of the plant and reference areas A, B, and D. Besides the coal-fired plants under study and a couple of oil-fired plants, there is only one major SO_2 source located in the area.

Estimates of SO_2 concentrations in ambient air have been made for the Helsinki region from model calculations based on SO_2 emission data and data on meteorology (*12*). Figure 1 shows the estimated yearly mean SO_2 concentrations for 1977. The levels roughly correlate with concentrations obtained from measurements. According to the estimates, the annual mean SO_2 levels in central Helsinki have dropped about 30% from 1970 to 1980 due to increased district heating, resulting in reduced emissions from low local sources. A more detailed description of all power plant sites with respect to air pollution measurements and disturbing sources

Table 2. Technical data for the coal-fired plants.

	Output, MW			SO_2 emission (t/year)[a]		Dust emission (t/year)[b]	
Plant	Electricity	Heating	Stack height, m	1980	1981	1980	1981
Plant A	180	140	87	4180	4760	1 426	1018
	230	370	150	8445	13000	696	650
Plant B	24	116	100	1700	1500	170	150
Plant C	80	—	85	3700	1600	1100	420
Plant D	80	165	150	2100	1700	130	110
Plant E	1000	—	150	37000	2700	2400	130
Plant F	220	—	150	6300	1900	439	118

[a] Data for plants A, D, and E are based on calculation from sulfur content in the coal and assuming that 5% of the sulfur is bound to the ash. Data for the other plants are based on measurements.
[b] Data for plants A and E are based on calculations from the ash content (15%) in the coal and from dust collector efficiency. Data for the other plants are based on measurements.

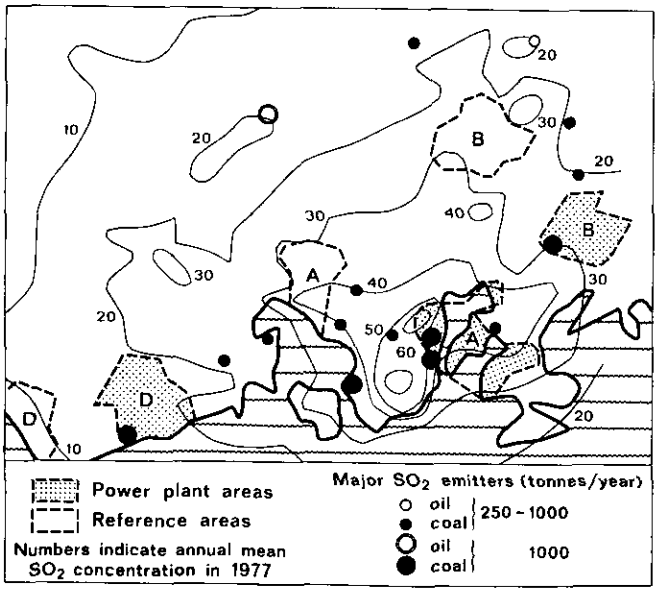

FIGURE 1. Location of power plant areas and reference areas in the Helsinki region as well as major SO_2 emitters. Isopletes indicate the estimated annual mean SO_2 concentration in 1977.

of air pollution, e.g., motor traffic, etc., is given elsewhere (*11*).

Statistical Methods

Prevalences of symptoms and diseases are sex-specific and age-standardized, using all the subjects studied as standard population. Chi-square tests without Yate's correction were used in the statistical analyses, and two-sided p-values are given. Smoking, education and occupation were controlled in other analyses (*11*), but the results were essentially the same as those reported below.

Results

Some socioeconomic background information and data on smoking habits for the study subjects in the different areas are given in Table 3. In three coal-fired plant areas, i.e., A, C, and F, the percentage of respondents with less than 9 years of education and/or industrial work is higher than in the reference areas. For smoking habits the only noteworthy difference within individual pairs is for Plant A and its reference area, which have 39% and 31% current smokers, respectively. From the socioeconomic data and information on other sources of air pollution in the areas (*11*), it could be concluded that the match between exposed and reference areas was successful primarily for the Plants B, D and E.

Table 4 shows the prevalence rates of respiratory tract symptoms by areas. For "hawking" there are increased rates in five coal plant areas, reaching statistical significance in two areas. The rate ratios, computed by dividing the rate in the exposed area with the rate in the reference area, range up to 1.3. The symptom "cough without phlegm" also had significantly increased rate ratios in two areas, while no pronounced differences between exposed and reference areas could be seen for "cough with phlegm" or "cough with phlegm > 3 months." For "acute dyspnea" only one coal plant area showed a significantly elevated rate ratio.

All the respiratory tract symptoms studied were highly associated with smoking. Figure 2 shows the prevalence rates among smokers and nonsmokers for these symptoms in the pooled exposed and reference areas, respectively. Among smokers 47% reported hawking, compared to only 26% of the nonsmokers. In the pooled groups, the rate ratio for smoking amounted to 1.8 and was similar in both the pooled coal plant and reference areas. The more specific symptoms of chronic bronchitis were more strongly associated with smoking. The rate ratio for "cough with phlegm" and for its more pronounced manifestation "cough with phlegm more than 3 months in a year" was about 3.3. The symptom "acute dyspnea" also had an increased rate ratio (1.7) in smokers. The rate ratios for respiratory tract symptoms among smokers living near the coal power plants and in the reference areas were similar.

The prevalence of physician-verified diagnoses of chronic bronchitis or emphysema in the questionnaire was 3.8% in the pooled reference area, and there were no pronounced differences within or between area pairs. Among these respondents respiratory symptoms were as prevalent in the pooled coal plant areas as in the pooled reference areas. The prevalence rates ranged from about 75% (hawking) to about 50% (cough with phlegm > 3 months). About 3% reported bronchial asthma verified by a physician. Prevalences were similar in the different areas. In the pooled material, acute dypsnea attacks in these subjects were equally prevalent in the coal plant and reference areas.

The prevalence rates for irritation in the throat, nose, and eyes in the pooled reference group were 35.0%, 28.6%, and 24.6%, respectively. These symptoms were reported as occurring "often" by 6.3%, 8.2%, and 5.6%, respectively. In the pooled material, the rate ratio for irritation in the throat by those living in coal plant areas was 1.2 ($p < 0.01$). There were no consistent differences between area pairs for irritation of the nose or eyes. Furthermore, the rate ratios were not elevated in coal plant areas for respiratory symptoms in children of the survey participants.

Diagnoses based on the clinical and laboratory examination carried out in plant area D and its reference area, are shown in Table 5. Of the 171 subjects examined, 7% had no respiratory or eye symptoms at the time of examination and were therefore regarded as healthy. A further 24% had such mild and/or unspecific symptoms that no diagnosis could be set. For 23% of the cases the diagnosis was allergic rhinitis or conjunctivitis. Half of these subjects had a known allergen which had been clinically verified. The other half had typical allergic symptoms and/or an elevated IgE level in serum.

Chronic bronchitis was diagnosed in 22% of the sub-

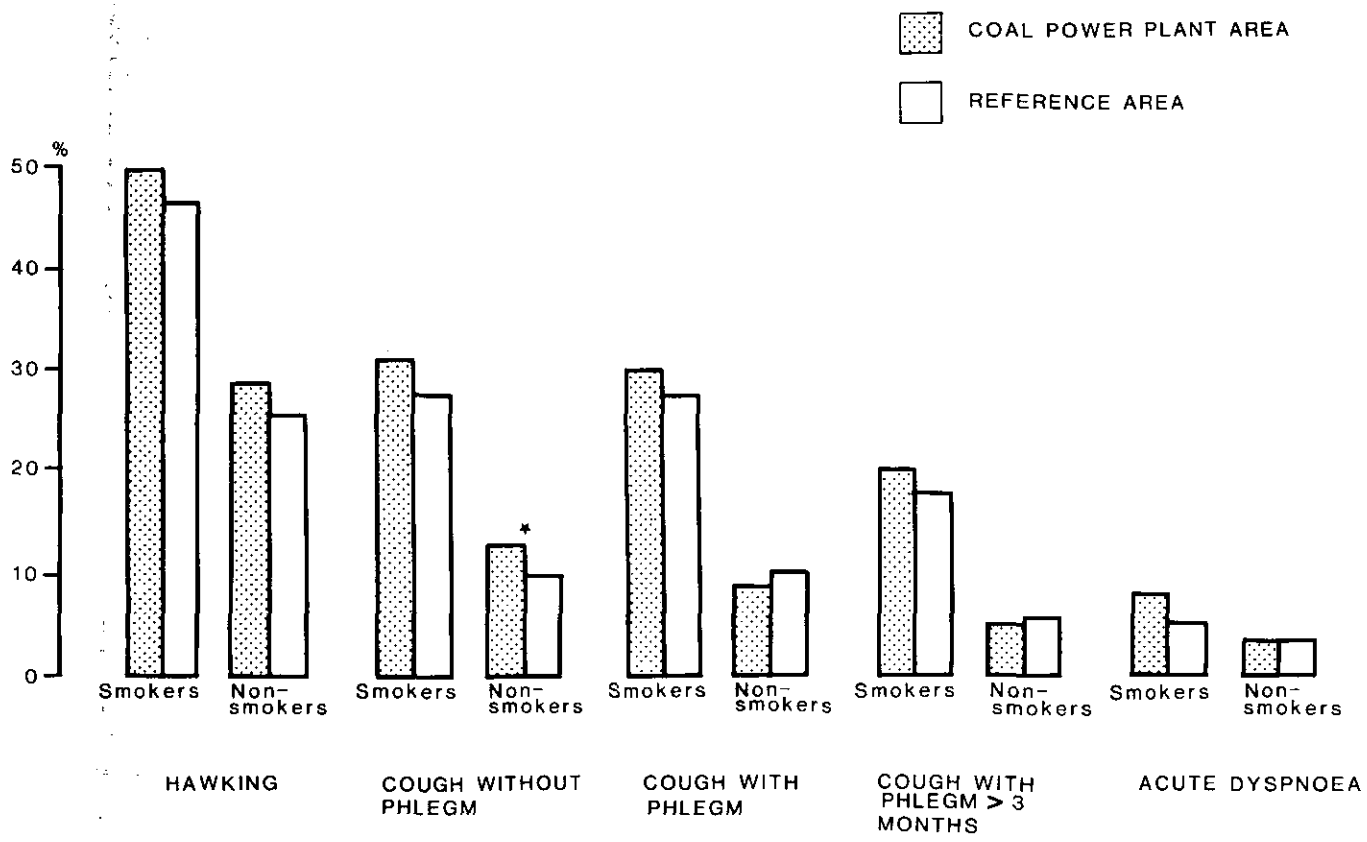

FIGURE 2. Prevalence of respiratory tract symptoms among smokers and nonsmokers in areas with coal-fired power plants and in reference areas. Asterisks (*) denote $p < 0.01$.

Table 3. Education, occupation and % smokers of populations in areas with coal-fired plants and reference areas.

		Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
Education							
< 9 years	Exp[a]	35.3	36.2	40.4	19.3	42.1	46.6
	Ref[b]	18.4	32.4	33.6	22.0	52.2	40.8
Occupation							
Agriculture	Exp	—	—	0.4	0.1	15.6	4.0
Industrial	Exp	17.3	22.0	27.7	11.7	20.1	34.2
White collar	Exp	36.5	30.5	17.9	46.6	14.3	17.2
Service	Exp	20.4	21.9	20.6	16.4	18.6	14.2
Other	Exp	25.8	25.6	33.5	25.3	31.4	30.4
Agriculture	Ref	0.1	0.6	0.3	0.3	5.4	6.7
Industrial	Ref	10.2	22.1	26.1	18.3	37.4	22.9
White collar	Ref	39.7	32.5	17.7	39.5	12.3	17.4
Service	Ref	21.1	22.2	21.7	16.7	14.9	25.1
Other	Ref	28.9	22.7	34.1	25.2	30.0	28.0
Smoking							
Current	Exp	38.9	35.5	33.4	33.8	29.3	30.8
Former	Exp	18.9	17.1	15.0	19.8	17.7	17.8
Current	Ref	31.3	32.1	32.3	35.1	28.7	29.5
Former	Ref	17.4	19.3	15.3	22.7	14.0	16.3

[a] Area with coal-fired plant.
[b] Reference area.

jects. The predictability for this disease in subjects reporting cough (without phlegm) and cough with phlegm > 3 months was 32 and 58%, respectively. Smoking was the suspected etiology of chronic bronchitis in 55 of 64 cases. Only a few subjects had bronchial asthma or other diseases. In all, smoking and allergy was the probable cause in 35 and 26%, respectively, of the cases with respiratory tract symptoms.

Table 4. Prevalence (%) of respiratory tract symptoms in areas with coal-fired plants as well as in reference areas.

		Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
Hawking	Exp†	40.0†	41.1	40.0	32.3	21.7*	36.5†
	Ref[b]	30.6	37.3	36.1	31.4	29.5	27.5
Cough without phlegm	Exp	21.1	20.3	24.7†	15.4	10.7	20.3†
	Ref	16.0	21.8	17.4	15.7	13.4	11.8
Cough with phlegm	Exp	18.4	18.9	17.7	13.9	13.5	15.7
	Ref	16.9	18.3	14.2	14.1	13.2	12.5
Cough with phlegm, > 3 months	Exp	12.2	11.7	11.7	8.0	7.9	11.6
	Ref	12.1	11.4	9.3	10.0	8.1	7.7
Acute dyspnea	Exp	6.8	3.7	4.7	2.9	3.8	4.8
	Ref	3.6	4.3	3.2	3.8	4.7	4.2

[a] Area with coal-fired plant.
[b] Reference area.
*$p < 0.01$.
†$p < 0.001$.

Table 5. Main clinical diagnosis according to symptoms reported in a questionnaire among subjects living near a coal-fired plant or in a reference area.

	Diagnosis								
Symptom	Healthy	For observation	Chronic bronchitis	Vasomotoric rhinitis	Allergic rhinitis or conjunctivitis	Bronchial asthma	Cough	Other disease	Total
Cough without phlegm	1	15	23	1	11	2	17	3	73
Cough with phlegm	–	7	27	–	7	2	13	2	58
Cough with phlegm, > 3 months	–	5	23	–	4	1	5	2	40
Wheezing attacks	–	1	6	–	4	3	3	–	17
Nasal irritation	1	23	15	3	36	4	17	3	102
Eye irritations	6	17	16	1	26	1	13	2	83
Total number of subjects[a]	12	41	37	3	39	5	27	7	171

[a]The same subject may have several symptoms.

The proportion of respondents reporting annoyance due to soot, dust, or fly ash was greater in coal-fired plant areas than in reference areas in all comparisons but one (Table 6). The rate ratios of exposed versus reference areas ranged between 1.0 and 4.6. The highest proportions were found near plants A and C. These plants were both located in urban and/or industrialized areas. Only near plant E, which was located in a rural area, did those residents identifying the power plant as the most important source of soot, dust or fly ash constitute a majority (57%) among those reporting annoyance (not shown in table).

Annoyance due to odors was reported more frequently in coal-fired plant areas than in reference areas in four out of six comparisons, three comparisons being statistically significant ($p < 0.01$). Large proportions

Table 6. Annoyance due to soot, dust, or fly ash and annoyance due to odors in areas with coal-fired plants and matched reference areas.

Cause of annoyance		Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
Soot, dust or fly ash	Exp[a]	31.9†	13.1	41.4†	11.7	15.6†	14.6†
	Ref[b]	13.1	13.6	9.0	8.3	6.1	5.4
Odors	Exp	17.4	5.5	59.4†	6.7*	7.1	19.3†
	Ref	13.3	7.8	15.5	3.1	5.1	60.1

[a]Area with coal-fired plant.
[b]Reference area.
*$p < 0.01$.
†$p < 0.001$.

Table 7. Annoyance due to soot, dust, or fly ash and responses citing power plant as most important source of annoyance near two coal fired plants.

Plant	Distance of *respondents* from plant, km	Number subjects	% annoyed	% citing power plant
Plant A	< 1	148	58.7	24.4
	1–2	114	63.2	10.7
	2–3	55	18.1	3.8
	3–5	352	13.1	2.0
Plant D	< 2	331	12.7	4.2
	2.5	60	13.3	7.0
	3	343	9.4	1.2

were found especially in plant area C and the reference area to plant F, which both had sulfate-cellulose industries.

The occurrence of annoyance due to soot, dust, or fly ash was further investigated in two of the coal-fired plant areas. In area A, the proportion reporting annoyance due to soot, dust, or fly ash was substantially greater in the subareas less than 2 km from the plant than in the subareas further away (Table 7). A distance gradient could also be discerned in the proportion claiming that a power plant was the most important source of the annoying air pollution. Corresponding results were not found in area D, where the proportions reporting annoyance were similar for the different subareas.

Discussion

The match between plant and reference areas was successful primarily for three area pairs, i.e., B, D, and E. As a rule, no consistent differences were seen within these pairs in the prevalence of various respiratory tract symptoms among the respondents or their children. This indicates that the coal-fired plants had no major influence on the occurrence of these health effects in the surrounding population. The mean concentrations of SO_2, NO_2, soot, and suspended particulates in ambient air during 1981–82 in area D and in its reference area were similar and low, i.e., below 30 $\mu g/m^3$ (*10*). In area B and its reference area, yearly SO_2 concentrations in 1977 were estimated to be 25 to 35 $\mu g/m^3$ (*11*). The levels were even lower in area E and could be expected to be low also in its reference area. The exposure levels in these areas are thus appreciably lower than those associated in the literature (*13–15*) with respiratory symptoms or diseases.

On the other hand, three of the comparisons involved coal-fired plant areas that had more industries and road traffic than their corresponding reference areas (areas A, C, and F). Respiratory symptoms and diseases were somewhat more prevalent in these areas than in the reference areas. The prevalence of "hawking," "cough without phlegm" and "irritation in the throat" was elevated in these areas with rate ratios of 1.3 to 1.8. The symptoms "cough with phlegm" and "cough with phlegm > 3 months" show consistently, but not significantly, increased rate ratios in these three coal plant areas. The four respiratory symptoms are not independent, as they are answers to four consecutive items in the questionnaire. According to the validation study performed in area D and its reference area, the two symptoms involving "cough with phlegm" indicate "chronic bronchitis" in almost every second case.

The differences in ambient SO_2 concentrations (and possibly also other air pollutants) are probably greatest between the coal plant and the reference areas in area pairs A, C and F (*11*). Unfortunately, measurements of ambient air concentration are scanty, but it has been estimated that differences in yearly mean SO_2 concentration between area A and its reference area were up to 30 $\mu g/m^3$ during the 1970s. It should be pointed out that the area with the highest SO_2 concentrations was estimated to have yearly SO_2 concentrations (in 1977) of about 65 $\mu g/m^3$ and that health effects have consistently been reported in the literature only above 100 $\mu g/m^3$ (for SO_2 and particulates) (*15*).

Annoyance due to soot, dust or fly ash was also more common in plant areas A, C, and F than in their reference areas. In view of the other important sources of air pollution in the areas, these effects cannot be tied conclusively to emissions from the coal-fired plants. The high proportion reporting "power plant" as the most important source of annoyance in the immediate vicinity of plant A does, however, indicate a substantial impact of the plant in this area. It is also noteworthy that a majority of the subjects reporting annoyance due to soot, dust or fly ash in area D claimed that "power plant" was the most important source. This plant was located in a rural area.

Several studies have emphasized the importance of attitudes to the source of annoyance for reported annoyance (*16,17*). In the present study, attitudes to air pollution were studied by a series of cumulative items (*11*). Attitude scores were only slightly related to reported annoyance and could not explain the differences in annoyance between plant areas and their reference areas.

In summary, consistent increases in the prevalences of respiratory symptoms and annoyance were detected in three urban or industrialized areas with coal-fueled plants. To the extent that measurements or estimates of ambient air exposure levels are available, the concentrations are lower than those hitherto associated with health effects. The specific influence of emissions from the coal power plants on the respiratory symptoms cannot, however, be assessed for these areas. In three rural or suburban areas with coal-fueled plants, no increases were detected in the prevalence of respiratory symptoms or diseases but annoyance seemed to be related to emissions from one of the plants.

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