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Respiratory symptoms and conditions related to occupational exposures in machine shops

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Objectives Since there are few data on the effects of metalworking in populations representing a variety of metal companies or on dose–response relationships concerning metalworking, this study investigated the relationship between occupational exposures in machine shops and the occurrence of upper and lower respiratory symptoms, asthma, and chronic bronchitis.
Methods A cross-sectional study of 726 male machine workers and 84 male office workers from 64 companies was conducted in southern Finland. All of the participants filled out a questionnaire, and aerosol measurements were performed in 57 companies.
Results Exposure to metalworking fluids (MWF) showed a greater risk [odds ratio (OR) ≥2] for upper-airway symptoms, cough, breathlessness, and current asthma than exposures in office work did. Exposure to aerosol levels above the median (≥0.17mg/m^3 in the general workshop air) was related to an increased risk (OR ≥2) of nasal and throat symptoms, cough, wheezing, breathlessness, chronic bronchitis, and current asthma. Machine workers with a job history of ≥15 years experienced increased throat symptoms, cough, and chronic bronchitis.
Conclusions This large study representing machine shops in southern Finland showed that machine workers experience increased nasal and throat symptoms, cough, wheezing, breathlessness, and asthma even in environments with exposure levels below the current occupational exposure limit for oil mists. The study suggests that improving machine shop environments could benefit the health of this workforce. It also suggests that it is time to consider reducing the current Finnish occupational exposure limit for oil mist or introducing the use of other health-relevant indicators of exposure.

Key terms asthma, chronic bronchitis, machinists, metal-working fluid.

Machine workers in manufacturing fabricated metal products are exposed to several agents that could adversely affect respiratory health. The most common exposures are metalworking-fluid emulsions and lubricating oils, but machinists may also inhale aerosols from surrounding processes, such as welding or painting. Metalworking fluids are used for cooling, lubricating, and removing metal chippings from the machining site. They are mixtures of base oil (mineral, vegetable, or synthetic oil) and various additives, including preservatives, biocides, emulsifiers, and corrosion inhibitors.

Case reports have identified occupational asthma in relation to exposure to oil mists (1), metals (including chromium, nickel, and cobalt) (2–3), and ethanolamines (4). Register-based studies have suggested an increased risk of asthma, or more specifically occupational asthma, among machine workers (5–7). A recent Finnish population-based case–control study on new cases of adult asthma showed an increased odds ratio of 4.52 (95% confidence interval 2.35–8.70) for metalworking men when they were compared with administrative personnel and professionals (8). However, this increase has not been reflected in the Finnish Register of Occupational Diseases, in which occupational asthma was reported at a lower rate for machinists than for the total working population (9). As a consequence of these studies, there

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has been concern in Finland and elsewhere that work-related asthma or at least milder forms of respiratory disease are underdiagnosed among machine workers.

Previous studies focusing on specific workplaces, mainly in the automobile industry, have linked exposure to metalworking fluids with respiratory symptoms, lung function changes, and occupational asthma, bronchitis or allergic alveolitis (10–20). Most of these studies were conducted in North America. Our literature search did not identify any previous study that had addressed the respiratory effects of metalworking in a population representing a wide variety of machining work. In addition, there are relatively few data on the exposure–response relationship between machining work and respiratory symptoms and diseases.

The aim of this study was to investigate the relationship between occupational exposures in machine shops in southern Finland and the occurrence of upper and lower respiratory symptoms, chronic bronchitis, and asthma. First, the occurrence of these symptoms or diseases among machine workers was compared with that among office workers. Then, the occurrence of these symptoms or diseases was compared between the machine workers with higher and lower exposure to aerosols and between those with longer and shorter durations of metalworking.

Study population and methods

Study design and population

This study was a cross-sectional study of machine and office workers in metal industries located in and around the cities of Helsinki, Tampere, and Turku in southern Finland. The data collection took place in the winter of 2002–2003. The companies were selected from the membership list of the Mechanical Engineering Employers in Finland to represent machine shops in southern Finland. Companies who had machining as one of their main activities were invited to participate. Our aim was to recruit an approximately similar number of machine workers (N=250–300) from small enterprises (with <15 machine workers), medium-size enterprises (with 15–50 machine workers), and large enterprises (with >50 machine workers) to ensure that small enterprises would not be underrepresented in our sample, as we thought that small enterprises might have worse work conditions and therefore could have more workers with health problems. Altogether 82 companies were contacted and 64 companies participated in the study (78%). The participating companies did different types of machining, including manufacturing bodies and parts of machines, vehicles and weapons, making tools, metal packages, pipes and valves, and manufacturing metal structures for construction. The contact information of all of the machinists or machine maintenance men (hereafter referred to as machine workers when combined) with regular exposure to metal-working fluids was obtained from the personnel manager or the safety officer. A letter containing information on the study was sent to all of the potential participants approximately 1 week before the planned interview, and consent was requested in the beginning of the interview. This study was approved by the ethics committee of the Hospital District of Helsinki and Uusimaa.

Altogether 961 machine workers with regular exposure to metalworking fluids were invited to participate in the study. A total of 757 machine workers (response rate 79%) participated (216 from small companies, 212 from medium-size companies, and 329 from large companies). The machine workers had to have a minimum exposure of 1 hour/week to metalworking fluids to be included. Altogether 86% of them worked with metalworking fluids daily, and all of them had work periods with daily use of such fluids. Only 4% of the machine workers were women (N=31). Women were therefore excluded as this percentage was too low for statistical analyses. The final study population included 692 machinists (95%) and 34 maintenance workers (5%), altogether 726 machine workers.

The control population consisted of male clerks and professional staff, such as technical draftsmen, draftsmen using computer-assisted design techniques, and engineers, working in the offices of the companies. The controls did not work with metalworking fluids more than 1 hour a month and had not worked with such fluids for more than 1 month ever during their lifetime. Of a total of 85 such office workers, 84 (99%) participated. The final study population (exposed + controls) consisted of 810 men.

Questionnaire

A computer-assisted telephone interview (CATI) was carried out by a trained interviewer with plenty of experience with it. CATI is an interactive computer system that aids the interviewer to ask questions over the telephone and enter the answers into a database immediately. The program controls the interview logic, branching to or skipping questions as needed according to the responses of the interviewee, and it validates the logic of the data as they are entered. The exposure part of the questionnaire was designed specifically for this study, while the part on respiratory symptoms and diseases was modified from the questionnaire used in the Finnish Environment and Asthma Study that was originally designed for studying general population samples (8, 21–23). The questionnaire inquired about personal characteristics, occupational history, use of chemicals and other agents, job tasks, preventive measures, smoking, and the occurrence of upper and lower respiratory symptoms, asthma, skin symptoms, and some general symptoms. The questions on atopy were based mainly on the Nordic occupational skin questionnaire (24). According to the requirements set by the ethics committee, the names of the interviewees were removed from the data prior to the analysis. In order to be able to combine the workplace measurements with the corresponding questionnaire data, the identification codes of the machine workers' main machine, as well as the department, were requested.

Air measurements

Worksites were visited in 60 companies to assess work habits, ventilation, and other exposure control systems and to measure aerosol concentrations at the machines (in the breathing zone of the operating machinist) and in the general air of the machining departments. Of the 64 companies, 4 were not visited, 2 of which had only one or two machinists and 2 of which had their machining workshop located far from the study area, although their main building was in the area. Aerosol measurements were conducted in 57 companies using a handheld real-time aerosol photometer, personal DataRAM (MIE Inc, Bedford, MA, USA) (25–26). DataRAM measured the mass concentration of aerosols in the size range 0.1–10 µm by measuring the amount of light scattered by the airborne particles of the materials. The measured aerosol consisted of a mixture of a mist of metalworking fluids and particles from dusts and fumes generated by the processes in the workplace air. Measurements were carried out in the operating area of all the machines that were used during the worksite visit, the aerosol photometer being held in the breathing zone of each observed worker for 1–5 minutes during an active machining period and the average value being recorded. A total of 674 machines were observed, and altogether 380 breathing-zone measurements were conducted. The rest of the machines were not in use at the time of the visit; therefore their aerosols were not measured. In addition, general workair (ie, the air in the passage areas and between the machines but not close to the machine openings) was monitored for 30 minutes to 2 hours in each machine shop, and the average value over the monitoring period was recorded (a total of 57 measurements). The measurements took place at varying times between 0800 and 1600.

Outcome assessment

The respiratory outcomes of interest were upper and lower respiratory symptoms and fever (as a marker for potential humidifier fever or allergic alveolitis) that the participants had experienced repeatedly or for a prolonged period during the past 12 months, at times other than in connection with a cold. Upper-respiratory symptoms included nasal, throat, and eye symptoms and had to occur at least weekly to fulfill our outcome criteria. Lower-respiratory symptoms included cough, phlegm production, wheezing, and breathlessness. Cough and phlegm had to occur at least weekly to fulfill the outcome criteria, while for wheezing and breathlessness at least monthly occurrence was needed. Chronic bronchitis was defined as the occurrence of both chronic cough and phlegm production during the last year. In addition, the occurrence of asthma currently and ever was investigated. Ever asthma was defined on the basis of a report of physician-diagnosed asthma ever during the worker's lifetime. Current asthma was defined on the basis of a report of physician-diagnosed asthma and current use of asthma medication.

Exposure assessment

First, the occupational exposures in the machine shops were assessed on the basis of current job as a machine worker (ie, machinist or machine maintenance worker), and the unexposed control group was formed of clerks or professionals working in the offices. Almost all of the machine workers reported exposure to metalworking fluids (99%) and lubricating oils (96%). As practically all of the workplaces used several types of metalworking fluids, it was not possible to classify the machine workers into different categories of exposure to metalworking fluids.

Second, the machinists were divided into higher and lower exposure groups by the median aerosol concentration (i) in the breathing zone and (ii) in the general air of the workshop. The total number of machinists that could be combined with respect to the breathing-zone measurements by using the machine and department codes recorded in the interview was 290. Another 121 workers could be linked to the department and thereby to the general air measurements, although their main machine was not identified or actively used during the workplace visit. Therefore they could not be linked to the breathing-zone measurements. The total number of machinists in the analysis of the general workair measurements was therefore 411.

Third, the machine workers were divided according to a longer or shorter occupational history in metalworking according to the median duration.

Data analysis

The odds ratio (OR) was used as the measure of effect. The models included the symptom or disease of interest as the outcome (symptom or disease present or symptom or disease absent). In addition, any respiratory symptom present was compared with no symptoms. We also formed two symptom indices, one for upper-respiratory symptoms (no symptoms, nasal, throat or eye symptoms) (scale 0–3) and one for lower-respiratory symptoms (no symptoms, cough, phlegm production, wheezing or breathlessness) (scale 0–4) by giving the value 1 for each symptom present and 0 if not present and summing the values. An ordinal regression was used to assess the relations between these symptom indices and exposures. The ordinal regression model assumes that more symptoms mean a more "severe condition". The model used was the proportional odds model. In the proportional odds model, which is a direct generalization of the binary logistic regression model, the odds ratios between each pair of levels is assumed to be the same regardless of which two adjacent levels are chosen. Thus the odds ratio reported as output from this model for a four-level ordinal regression is actually a weighted average of the three individual odds ratios as we increase from one level to the next. The three individual odds ratios are assumed to be the same by the model and thus the odds ratio in this model is fairly robust.

Four sets of models were analyzed with four exposure variables: (i) exposure based on being currently a machine worker (coded 1) versus being clerk or professional working in an office (the reference category); (ii) exposure represented by a relatively high aerosol level in the breathing zone [≥ median (0.12 mg/m^3) concentration] (coded 1) versus a low aerosol level [<median (0.12 mg/m^3) concentration] (reference category); (iii) exposure represented by a relatively high aerosol level in the workshop general air [≥ median (0.17 mg/m^3) concentration] (coded 1) versus a low aerosol level [<median (0.17 mg/m^3) concentration] (reference category); and (iv) exposure based on a long occupational metalworking history [≥ median (15 years)] versus a shorter history [< median (15 years)] (reference category). We also analyzed the odds ratio of symptoms or conditions according to increasing quartiles of aerosol concentration in the workshop general air to explore potential dose–response relationships. In the multivariate regression analyses, adjustment was made for age (continuous variable), smoking (current, ex, never smoker), and atopy in childhood (atopic skin or respiratory disorders during childhood or school age versus no such atopic diseases) as potential confounders.

Results

Characteristics of the study population

The characteristics of the study population are presented in table 1. These factors were considered potential confounders and were adjusted for in the multivariate analyses.

Worktasks and exposures

The vast majority of the study population consisted of full-time machine workers with a traditional, mixed metalworking exposure. Altogether 99% of the machine workers reported working with metalworking-fluids daily, 86% on a regular basis and the rest during work periods lasting at least 1 week at a time. The most common jobs were CNC (computer numerical control) or NC (numerical control) machinist, turner, and grinder, and the most common processes were turning and milling. Multiple-operation machining centers were commonly used. About 60% of the machine workers reported operating several machines, and 76% did some maintenance work on their own machine. A total of 90% handled freshly machined metal pieces numerous times every day, 78% got splashes of metalworking fluids on their skin daily, and 85% used compressed air in cleaning the fabricated pieces.

Altogether 87% of the metalworking fluids were water-miscible (ie, emulsifiable oils, semisynthetic and synthetic metalworking fluids). According to the safety data sheets, altogether 62 products of metalworking fluids were used, and in most of the workplaces several types of metalworking fluids were used simultaneously. The most common materials included stainless and non-alloyed steels, cast iron, and aluminum. Although variation was observed in the machine enclosures and ventilation, most of the workplaces paid adequate attention to exposure control, and no serious defaults were observed. The median aerosol concentration in the breathing zone of the machinists was 0.12 (range 0.001–3.00) mg/m^3, and the geometric mean was 0.12 (SD 4.07) mg/m^3. The

Table 1. Characteristics of the machine and office workers.

Characteristic	Machine workers (N=726)				Office workers (N=84)			
	N	%	Mean	SD	N	%	Mean	SD
Smoking [a]								
Current	283	39	·	·	21	25	·	·
Ex	169	23	·	·	11	13	·	·
Never	273	38	·	·	51	62	·	·
Childhood or school age atopy	107	15	·	·	17	20	·	·
Age (years)	·	·	40.1	10.9	·	·	41.6	9.6
Duration of employment [b] in the metal industry for metal workers; in office work for the controls	·	·	15.3	10.7	·	·	10.1	9.6

[a] Smoking was missing for 1 metal worker and 1 office worker.
[b] Duration was missing for 2 machine workers.

median concentration in the general air of the machine workshops was 0.17 (range 0.007–0.67) mg/m^3, being 0.15 (range 0.007–0.67) mg/m^3 for the small companies, 0.28 (range 0.03–0.6) mg/m^3 for the medium-size ones, and 0.13 (range 0.05–0.27) mg/m^3 for the large ones. The corresponding geometric means were 0.15 (SD 2.41) mg/m^3, 0.13 (SD 2.84) mg/m^3, 0.19 (SD 2.39) mg/m^3, and 0.14 (SD 1.76) mg/m^3, respectively.

Occurrence of respiratory symptoms and diseases

The occurrence of respiratory symptoms and conditions among the machine and office workers are presented in table 2. In general, all of these symptoms and asthma, apart from wheezing, were more common among the machine workers than among the office workers. The occurrence of many symptoms was over twofold for the machine workers. The occurrence of any respiratory symptom was 31.5% for the small companies, 36.5% for the medium-size ones, and 27.9% for the large ones.

Effects of machining work

Table 2 also shows crude and adjusted odds ratios for the respiratory symptoms, fever, and respiratory diseases in relation to machining work as compared with office work. The risk of upper-airway and eye symptoms was consistently increased among the machine workers, nasal symptoms showing statistical significance (adjusted OR 6.2, 95% confidence interval (95% CI) 1.9–20.0). The odds ratios for cough, breathlessness, and current asthma were ≥2 in relation to machining work. The confidence intervals were generally rather wide because of the small control group (office workers). The odds ratio for the occurrence of any respiratory symptom was significantly increased in relation to machining work (OR 2.5, 95% CI 1.3–4.6), as was also the risk of the upper respiratory symptom index (OR 4.2, 95% CI 1.8–9.9).

Effects related to aerosol level and duration of metalworking

Table 3 shows the adjusted odds ratios for respiratory symptoms or conditions and fever for the machine workers exposed to relatively high, compared with low aerosol concentrations, when the median concentration was used as the cut-off point. The odds ratios for nasal and throat symptoms, cough, wheezing, breathlessness, and asthma were increased in relation to high aerosol levels, especially to the levels in the general air of the workshop. These increased risks were statistically significant, apart from that for asthma, which did not reach statistical significance, probably because of the smaller number of participants with this disease. However, the odds ratio for ever asthma was high (OR 4.1) in relation to a high aerosol concentration in the breathing zone, and the odds ratio for current asthma was high (OR 3.6) in relation to a high average aerosol exposure in the

Table 2. Occurrence of upper- and lower-respiratory symptoms and respiratory conditions among the machine and office workers and the crude and adjusted odds ratios (OR) with their 95% confidence intervals (95% CI) in relation to machining work compared with office work (reference category, OR 1).

Symptom or disease	Machine workers (N=726)		Office workers (N=84)		Crude OR	95% CI	Adjusted OR [a]	95% CI
	N	%	N	%				
Any symptom [b]	223	31.3	13	15.5	2.5	1.4–4.6	2.5	1.3–4.6
Nasal symptoms	137	18.9	3	3.6	6.3	2.0–20.3	6.2	1.9–20.0
Throat symptoms	26	3.6	1	1.2	3.1	0.4–23.0	3.6	0.5–27.3
Eye symptoms	47	6.5	2	2.4	2.8	0.7–11.9	2.8	0.7–11.9
Cough	66	9.1	3	3.6	2.7	0.8–8.8	2.5	0.8–8.1
Phlegm production	90	12.4	7	8.3	1.6	0.7–3.5	1.4	0.6–3.3
Wheezing	39	5.4	5	6.0	0.9	0.3–2.4	0.9	0.3–2.3
Breathlessness	29	4.0	2	2.4	1.7	0.4–7.3	2.0	0.5–8.8
Fever	15	2.1	1	1.2	1.8	0.3–13.4	1.9	0.2–14.7
Chronic bronchitis	31	4.3	3	3.6	1.2	0.4–4.1	1.0	0.3–3.5
Asthma								
Current	12	1.7	1	1.2	1.4	0.2–10.8	2.2	0.3–17.7
Ever	36	5.0	4	4.8	1.0	0.4–3.0	1.3	0.4–4.0
Symptom index								
Upper respiratory (scale 0–3)	–	.	–	.	4.2 [c]	1.8–9.9	4.2 [c]	1.8–9.9
Lower respiratory (scale 0–4)	–	.	–	.	1.7 [c]	0.9–3.4	1.6 [c]	0.8–3.2

[a] Adjusted for age, smoking habits, and atopic disorders during childhood or school age.
[b] Occurrence of any upper (nasal, throat, or eye symptoms) or lower (cough, phlegm, wheezing, or breathlessness) respiratory symptom.
[c] Calculated by ordinal regression; see the Methods section.

workshop. In addition, the risk of chronic bronchitis was increased in relation to high aerosol exposure in the workshop. The risks with respect to the index for upper-respiratory symptoms and that for lower-respiratory symptoms were significantly increased in relation to high aerosol exposure levels.

Table 4 shows the adjusted odds ratios for increasing quartiles of the aerosol concentrations in the general air of the workshops. A dose–response relationship was indicated for nasal and throat symptoms, cough and phlegm production, breathlessness, chronic bronchitis, ever asthma, and the index for lower respiratory symptoms. For most of the outcomes the median concentration seemed to be the level above which the risk increased.

Table 5 presents the crude and adjusted odds ratios of symptoms or conditions in relation to work for ≥15 years versus work for <15 years in the metal industry. The group with a long metalworking history had a significantly increased risk of throat symptoms, cough, and chronic bronchitis.

Discussion

This rather large study of metal industries in southern Finland found that exposure to machining work was related to an increased risk of upper-airway symptoms, cough, breathlessness, and current asthma when

Table 3. Adjusted odds ratios (OR) with their 95% confidence intervals (95% CI) for upper- and lower-respiratory symptoms and respiratory conditions among the machine workers in relation to a high aerosol concentration in the breathing zone or the average air concentration in the workshop when compared with a low aerosol level (reference category, OR 1)

Symptom or disease	High exposure in breathing zone (≥0.12 mg/m³) (N=152)		High exposure average in workshop (≥0.17 mg/m³) (N=212)	
	Adjusted OR [a]	95% CI	Adjusted OR [a]	95% CI
Any symptom [b]	2.0	1.2–3.2	2.4	1.5–3.6
Nasal symptoms	1.8	1.0–3.3	2.2	1.3–3.7
Throat symptoms	1.7	0.6–5.0	3.4	1.2–9.9
Eye symptoms	1.1	0.5–2.5	1.5	0.7–3.2
Cough	2.2	1.0–4.8	3.1	1.5–6.4
Phlegm production	1.6	0.8–3.1	1.9	1.0–3.5
Wheezing	4.8	1.6–14.8	4.0	1.5–10.3
Breathlessness	7.0	1.6–31.9	7.1	2.0–24.9
Fever	1.3	0.2–8.4	1.7	0.3–9.9
Chronic bronchitis	1.6	0.5–4.5	2.8	1.0–7.5
Asthma				
Current	– [c]	..	3.6	0.6–19.9
Ever	4.1	0.8–20.5	1.7	0.6–5.1
Symptom index				
Upper respiratory (0–3)	1.4 [d]	0.9–2.4	2.1 [d]	1.4–3.4
Lower respiratory (0–4)	2.2 [d]	1.3–4.0	2.8 [d]	1.7–4.7

[a] Adjusted for age, smoking habits, and atopic disorders during childhood or school age.
[b] Occurrence of any upper (nasal, throat, or eye symptoms) or lower (cough, phlegm, wheezing, or breathlessness) respiratory symptom.
[c] There were too few observations to calculate the OR.
[d] Calculated by an ordinal regression; see the Methods section.

Table 4. Adjusted odds ratios (OR) with their 95% confidence intervals (95% CI) for upper- and lower-respiratory symptoms and respiratory conditions among the machine workers in relation to increasing aerosol exposure in the general workshop air. The reference category (OR 1) was the lowest quartile of exposure.

Symptom or disease	1st quartile (<0.09 mg/m³)	2nd quartile (0.09–<0.17 mg/m³)		3rd quartile (0.17–<0.28 mg/m³)		4th quartile (0.28–0.67 mg/m³)	
	OR	Adjusted OR [a]	95% CI	Adjusted OR [a]	95% CI	Adjusted OR [a]	95% CI
Any symptom [b]	1	1.1	0.6–2.1	2.6	1.4–4.8	2.4	1.3–4.4
Nasal symptoms	1	1.2	0.5–2.5	2.3	1.1–4.8	2.5	1.2–5.0
Throat symptoms	1	0.6	0.1–3.6	2.1	0.5–9.0	3.2	0.8–12.4
Eyes symptoms	1	0.5	0.2–1.6	1.1	0.4–2.9	1.2	0.5–3.0
Cough	1	12.8	1.6–101.6	22.0	2.8–171.3	18.5	1.6–101.6
Phlegm	1	1.3	0.5–3.4	1.9	0.8–4.8	2.5	1.1–5.7
Wheezing	1	1.0	0.2–5.1	4.0	1.0–15.4	4.0	1.1–14.8
Breathlessness	1	0.5	0.04–5.3	3.5	0.7–18.1	6.7	1.4–31.5
Fever	1	1.1	0.1–18.9	1.0	0.1–15.5	2.7	0.3–27.5
Chronic bronchitis	1	5.1	0.6–45.1	7.9	0.9–67.8	8.6	1.1–69.7
Asthma ever	1	2.1	0.4–12.5	3.2	0.6–17.5	2.1	0.4–12.7
Symptom index							
Upper respiratory (0–3)	1	0.9 [c]	0.4–1.7	1.9 [c]	1.0–3.6	2.0 [c]	1.1–3.8
Lower respiratory (0–4)	1	1.9 [c]	0.8–4.4	3.3 [c]	1.5–7.6	4.5 [c]	2.1–9.7

[a] Adjusted for age, smoking habits, and atopic disorders during childhood or school age.
[b] Occurrence of any upper (nasal, throat, or eye symptoms) or lower (cough, phlegm, wheezing, or breathlessness) respiratory symptom.
[c] Calculated by an ordinal regression; see the Methods section.

Table 5. Crude and adjusted odds ratios (OR) with their 95% confidence intervals (95% CI) for upper- and lower-respiratory symptoms and respiratory conditions among the machine workers in relation to ≥15 years of machining work when compared with <15 years of such work (reference category, OR 1).

Symptom or disease	Crude OR	95% CI	Adjusted OR [a]	95% CI
Any symptom [b]	1.2	0.9–1.7	1.2	0.8–1.9
Nasal symptoms	1.1	0.7–1.5	1.3	0.8–2.0
Throat symptoms	3.0	1.2–7.3	3.3	1.1–9.9
Eye symptoms	1.4	0.8–2.6	1.0	0.5–2.2
Cough	1.5	0.9–2.4	2.1	1.1–4.2
Phlegm production	1.9	1.2–3.0	1.5	0.8–2.7
Wheezing	1.2	0.6–2.3	1.0	0.4–2.4
Breathlessness	1.1	0.5–2.2	0.9	0.3–2.3
Fever	0.8	0.3–2.1	0.8	0.2–2.9
Chronic bronchitis	2.1	1.0–4.5	2.7	1.0–7.3
Asthma				
Current	1.6	0.5–5.1	3.5	0.7–18.0
Ever	1.0	0.5–2.0	1.9	0.7–4.9
Symptom index				
Upper respiratory (0–3)	1.2 [c]	0.8–1.6	1.2 [c]	0.7–1.8
Lower respiratory (0–4)	1.5 [c]	1.0–2.2	1.5 [c]	0.9–2.4

[a] Adjusted for age, smoking habits, and atopic disorders during childhood or school age.
[b] Occurrence of any upper (nasal, throat, or eye symptoms) or lower (cough, phlegm, wheezing, or breathlessness) respiratory symptom.
[c] Calculated by an ordinal regression; see the Methods section.

compared with exposure to office work, although the hygienic conditions were, in general, good in the workshops. The median aerosol concentration in the breathing zone of the machinists was 0.12 mg/m^3, and the median aerosol concentration in the general air of the workshops was 0.17 mg/m^3, the former being measured during machine operation for 1–5 minutes and the latter being measured in the general air of the workshops for 0.5–2 hours. The medium-size workplaces had a slightly higher median air aerosol concentration than the small and large companies, and this slightly higher median was reflected in a slightly higher prevalence of respiratory symptoms, but the differences between them were not statistically significant. An increased risk of upper-airway symptoms and cough suggested the importance of irritant mechanisms, while hypersensitivity-type mechanisms were likely to be important with respect to breathlessness, asthma, and rhinitis-type symptoms. Naturally there is a lot of overlap in the symptoms related to these two mechanisms, and both mechanisms could be of significance in a metalworking environment. Long-term exposure to metalworking seemed to increase the risk of mainly irritant-type symptoms, namely, throat symptoms, cough, and chronic bronchitis.

Among the machine workers, exposure to aerosol levels higher than the median was related to an increased risk of nasal and throat symptoms, cough, wheezing, breathlessness, and asthma, and there was a trend towards an increasing risk with an increasing level of aerosols for many of these symptoms, when analyzed according to the quartiles of exposure. This finding is interesting since the measured aerosol concentrations were generally well below the recommended exposure level (REL) set by the National Institute for Occupational Safety and Health (NIOSH) for total particulates (0.5 mg/m^3) and thoracic particulates (0.4 mg/m^3), quantified with gravimetric methods and applicable for machining operations (27, 28).

In Finland, extractable oil mist has traditionally been measured in machine shops, its occupational exposure limit (OEL) being 5 mg/m^3 (8-hour time-weighted average). Extractable oil mist forms only a minor part of the total aerosols of modern water-miscible metalworking-fluid emulsions, and thus its concentration in the machine shops of our study would be clearly smaller than that of the aerosol. Due to this situation and the fact that even the total aerosol concentrations were low, it is evident that the current Finnish occupational exposure limit for oil mist should be lowered substantially, at least to comply with the current recommendation of the American Conference of Governmental Industrial Hygienists: 0.2 mg/m^3 (29). In addition, other more-relevant indicators of exposure to metalworking fluids, such as total aerosols, should be applied. This suggestion is supported by our detailed exposure assessment study in 10 of the companies included in our current study (30).

Validity issues

The participation rate of this study was good for both the machine workers (79%) and the office workers (99%). The small sample size of the office workers was a limitation of this study. It can be explained by the fact that, as the studied machine workers were men, we limited our control group to male office workers. On the other hand, the relatively large sample of machine workers allowed us to use an internal comparison group of workers exposed to low aerosol levels to explore potential exposure–response relationships by comparing increasing exposure groups to the low exposure group according to the measured aerosol concentrations and by comparing the workers according to their duration of metalworking.

The cross-sectional study design was another limitation. Some influence of a selection phenomenon, called the healthy worker effect, cannot be excluded, namely, if machine workers quit work because of symptoms or diseases prior to our study, our effect estimates would underestimate the true effects. Indeed, the finding that long-term exposure to metalworking increased mainly the risk of irritant-type symptoms, while high current aerosol levels increased also the risk of hypersensitivity-type symptoms, suggests that some selection from the workforce due to hypersensitivity diseases, such as asthma, was likely to have occurred over the long-term. Another possible selection concerned the fact that people with diseases such as respiratory allergies are more likely to enter office work, and this possibility would lead to an underestimation of the true effects of machining work, as the office control group would have been "enriched" with persons with allergies.

The exposure assessment was conducted with the use of three methods (current work tasks and reported exposures, aerosol measurements, and the duration of metalworking), and all of these methods consistently showed significant adverse respiratory effects. This consistency supports the existence of such a relationship between exposures in metal work and adverse respiratory effects. First, the study participants were categorized on the basis of current occupation and questionnaire responses about exposures. Both the machine workers and office workers answered the computer-assisted interview in a similar way. Then, the current exposure levels were assessed on the basis of measurements of aerosol concentrations with an aerosol photometer that has been widely used for exposure measurements in machine shops (15, 25–26). It has the advantage of not only measuring the concentration of metalworking fluids, but also providing a measure of the actual exposure to an aerosol mix of different workplace exposures. DataRAM has been reported to overestimate exposure when compared with gravimetric methods (15, 26). Such findings suggest that the exposure levels measured in our study would have actually been even lower if measured by a gravimetric method. Measurements carried out in the breathing zone of machine workers obviously give a better assessment of a worker's exposure than measurements in the general air of workshops, but, interestingly, in our study, both assessment methods gave very similar results with respect to health effects. It is obvious that the short-term DataRam measurements were rough estimates of the long-term exposure, but it was not possible to conduct longer measurements for reasons of feasibility. In the workplaces with poor ventilation, oil mist could have accumulated during the workday, but such an accumulation was not observed in the short-term measurements or visually during the worksite visits. Some misclassification of exposures is inevitable in this type of a large epidemiologic study, at least with respect to the dose, but, as the exposure assessment components of the study were carried out without knowledge of the symptom or disease status of the workers, any misclassification was likely to be random and thus potentially lead to some underestimation of the true risks.

One drawback of the exposure assessment was that only part of the interviewees could be linked reliably with the workplace aerosol measurements, since (i) the aerosol measurements were conducted in only 57 machine shops, (ii) not all of the machines were actively operated during the worksite visits and, in such situations, aerosols could not be measured, and (iii) the ethics committee required us to delete the names of the interviewees from the data; therefore we had to use machine codes and department codes for linking the questionnaire data to the measurements.

Synthesis with previous knowledge

Using a realtime aerosol photometer (DataRAM), O'Brien et al (26) measured exposure to metalworking fluids in 23 small machine shops in the United States. The time-weighted average for 8-hour exposure ranged from 0.04 to 1.82 mg/m^3. Sprince et al (15) also measured aerosol concentrations using the same type of method in an automobile transmission plant and found the geometric mean of total aerosol to be 0.33 (range 0.04–1.44) mg/m^3. The mean total aerosol mass quantified with gravimetric analysis was generally <0.5 mg/m^3 in the North American studies (17, 31, 32). This comparison with recent literature on exposures suggests that the occupational exposures in the Finnish machine shops were compatible with or lower than those in North America. The effect of the type of metalworking fluid has been evaluated in some studies, but the results have been inconsistent (14, 15, 17, 26).

Some previous studies in automobile industries have investigated respiratory effects in relation to aerosols. The study by Kennedy et al (12) included 89 machine operators and 42 assembly workers and found that exposure to metalworking fluids was significantly related to a ≥5% postshift decrement in the forced expiratory volume in 1 second (FEV_1). Such an FEV_1 response is a predictor of occupational asthma; therefore, these results could be compatible with ours with respect to current asthma. The same group also found an increased risk of cough, phlegm, and wheeze in relation to current exposure to any metalworking fluid among 1042 machinists and 769 assembly workers from three automobile facilities in the United States (14). Two other cross-sectional studies from the United States (15, 17) found increased risks of respiratory symptoms, including throat irritation, cough, phlegm, and chest tightness, among machinists. Thus their results are compatible with those of our study.

Concluding remarks

This large study representing metal workshops in southern Finland showed that, despite rather high hygienic standards in the companies, machine workers had an increased risk of upper-respiratory symptoms, cough, breathlessness, and current asthma when they were compared with office workers. The aerosol concentrations in these workplaces were in general low, but an internal comparison of the machine workers suggested that exposure to aerosol concentrations above the median, especially in the general workshop air (0.17 mg/m^3), was related to both upper and lower respiratory symptoms and asthma. Our results indicate that improving the work environment of machine workers, for example, by fitting machines with enclosures, installing local exhausts, and re-designing processes, could benefit the health of this workforce. Clinicians should be aware of the links between respiratory symptoms and asthma to machining work. This study also suggests that it is time to consider reducing the Finnish occupational exposure limit for oil mist and to use total aerosols or other more health-relevant indicators of exposure in machining environments.

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