ORIGINAL ARTICLE

A cross-sectional study of exposures, lung function and respiratory symptoms among aluminium cast-house workers

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ABSTRACT

Objectives To investigate exposures, respiratory symptoms, lung function and exposure—response relationships among aluminium cast-house workers.

Methods A cross-sectional study was conducted among 182 workers. Exposure data were used to model exposure to irritants. Lung function and questionnaire data on respiratory symptoms were compared to a general population sample and an internal reference group. Blood samples were taken from 156 workers to examine total IgE, eosinophils and sensitisation to common allergens.

Results Average daily mean exposure to inhalable dust, metals, hydrogen fluoride, fluoride salts and sulphur dioxide was relatively low compared to reference values. Airflow patterns in the hall were disturbed regularly and resulted in pot emissions with high concentrations of fluorides. Peak exposures to chlorine gas occurred intermittently due to production process disturbances. Workers reported significantly more respiratory symptoms (continuous trouble with breathing (prevalence ratio (PR) 2.5; 95% CI 1.2 to 5.3), repeated trouble with breathing (PR 1.8; 95% CI 1.1 to 3.0), wheezing (PR 1.4; 95% CI 1.1 to 1.8), asthma attack (ever) (PR 2.8; 95% CI 1.7 to 4.6) and doctor diagnosed asthma (PR 2.6; 95% CI 1.5 to 4.4). Regression analysis showed significantly lower FEV_1 values (-195 ml) and FVC values (-142 ml) compared to a general population sample. Lung function did not differ between groups.

Conclusion This epidemiological study suggests cast-house workers in the aluminium industry are exposed to respiratory hazards. Exposure—response relationships could not be demonstrated but this study supports preventive measures in the work environment with a focus on (peak) exposures to irritants.

What this paper adds

- ► Respiratory diseases and adverse respiratory health effects are common among workers in the aluminium industry.
- ► Working as an aluminium cast-house worker has not previously been associated with adverse respiratory health effects.
- ► This study provides important new data about peak exposures to irritants including fluorines and chlorine.
- ► This epidemiological study examines the respiratory hazards experienced by aluminium cast-house workers.
- ► This study supports preventive measures in the work environment with a focus on (peak) exposures to irritants.

Respiratory symptoms among aluminium smelter workers are reported by potroom workers as well as ingot mill and anode workers.[13] However, until now, working as an aluminium cast-house worker has not been associated with adverse respiratory health effects.[14–16]

Field found that the prevalence of asthma-like symptoms in potroom workers in the aluminium industry ranged from 20% to 57% and that there was a similar range in aluminium casting workers.[14] In a study of 30 workers from an aluminium casting plant, Godderis et al found among no significant difference in any of the respiratory questionnaire categories or in the results of spirometry tests between cast-house personnel and referents.[15]

Despite modernisation of an aluminium production factory in Bosnia and Herzegovina aimed at reducing the amount of harmful substances at work, high concentrations of chlorine in the cast-house remained the biggest problem.[16]

We carried out a study among aluminium cast-house workers with long-standing respiratory symptoms because the hygienic measures taken so far did not lead to a decrease respiratory complaints.

The aim of our study was to assess (peak) exposures, the prevalence of respiratory symptoms and lung function among aluminium cast-house workers in an aluminium producing plant in the Netherlands.

INTRODUCTION

Respiratory health effects and diseases are well known in the aluminium industry[1–5] and exposure to irritants in the aluminium industry is associated with respiratory symptoms and asthma.[6–10] Associations between respiratory symptoms and particulate and gaseous fluorides have been reported in potroom workers[11] and between respiratory symptoms and total fluorides and inhalable dusts in aluminium smelters.[12] Bronchial responsiveness in aluminium potroom workers reporting work-related asthmatic symptoms was reported to be related to fluoride plasma levels, but the mechanism has still to be clarified.[2]

METHODS

Study design, participants and setting

We identified 182 eligible aluminium cast-house workers who were potentially exposed to airway irritants in an aluminium producing plant in the Netherlands. We obtained written, informed consent from 157 (86%) workers; only a few of the remaining 25 (14%) workers gave their reasons for not participating (eg, having a chronic illness or leaving the plant for another job). In the summer of 2008 we conducted a cross-sectional study among the 157 consenting workers: 151 (96%) completed the questionnaire, 155 (99%) underwent spirometric lung function tests and 156 (99%) gave blood samples.

We used data from the Dutch contribution to the European Community Respiratory Health Survey (ECRHS),[17] a general population sample, to compare symptom prevalence between the two groups. We used data from males aged between 30 and 65 (n=144 aluminium cast-house workers and n=1000 subjects from the ECRHS population). For analysis of lung function data, we only used data from Caucasian males aged 30—65 (n=138 aluminium cast-house workers and n=972 subjects from the ECRHS population) as there were too few female or non-Caucasian workers in the population of aluminium cast-house workers.

Production process

Aluminium production consists of at least two operations. The first is electrolytic production of aluminium with prebaked anodes using the Hall-Héroult process. Alumina (aluminium oxide) arrives at the plant and is fed into furnaces filled with liquid electrolyte (containing cryolite). The alumina is dissolved at 960°C and an electric charge of 140 000 A is passed through the solution. The alumina splits off and the aluminium sinks to the bottom of the furnace, is removed and is transported to the foundry/cast house in transport ladles. The second operation is aluminium casting. Aluminium is degassed with chlorine before casting and is mixed with other materials to obtain the correct quality and properties to meet customers' requirements. The aluminium is then cast in the form of rolling ingots or extrusion billets in vertical casting machines. The plant produces 160 000 tonnes of aluminium annually (110 000 tons of new aluminium and another 50 000 tonnes through remelting and recycling).

Exposure assessment

Personal full-shift inhalable dust samples were collected in the workers' breathing zones using PAS-6 sampling heads and mixed cellulose ester filters at a flow rate of 2 l/min. One personal sample and two area sedimentation samples were analysed for several metals using inductively coupled plasma analysis.

Workers' exposure to fluorides was assessed by short-term (18—55 min) and full-shift (6—8 h) personal and area sampling of gaseous and particulate fluorides, using MDHS 35/2.[18] Particulate and gaseous fluorides were captured and analysed separately using disposable three-piece plastic filter cassettes. In addition, over two working days, all eligible cast-house workers and 13 controls were asked to provide a urine sample before and after each shift in a collection cup pre-treated with 0.2 g EDTA. A total of 55 samples were collected and analysed according to NIOSH Method 8308 with results expressed as milligrams fluoride per gram of creatinine.[19] To explore exposure emissions within the cast-house area, real-time hydrogen fluoride (HF) concentrations were measured with tunable diode laser (TDL) technology, using a commercially available TDL-based instrument (GasFinder; Boreal Laser, Spruce Grove, Alberta, Canada). Sulphur dioxide and chlorine were measured during walk-through sessions on several days using a commercially available real-time instrument with substance-specific toxic sensors (QRAE$^+$; RAE Systems BeNeLux BV, Capelle a/d IJssel, The Netherlands).

Based on current job title, relative distance to emission sources of respiratory irritants and expected duration of the presence of each job title in the cast-house area during the day, all workers were divided into three exposure groups with increasing (expected) exposure to respiratory irritants. The exposure groups were defined based on a semi-quantitative exposure assessment. When creating the groups, we used the specified task description of all jobs in the cast-house area in combination with the available exposure measurements. Unfortunately, we were not able to define the groups based on exposure measurements only as personal exposure levels could not be exactly quantified for several agents. Instead, we had to use surrogates of exposure, for example the distance between the activity and known sources of HF emissions, and if taking samples (with short-term chlorine exposure) was part of the regular activity.

Questionnaire

Participants completed a self-administered standardised questionnaire supplemented with questions about respiratory, mucous membrane[20] and atopic symptoms, smoking habits and work history. Some of the questionnaire items were taken from the ECRHS.

Spirometry

Spirometry was carried out by experienced technicians according to European Respiratory Society standards using a pneumotachograph with specific software (Pneumotachograph and 4.66 software; Jaeger, Würzburg, Germany).[21] Age- and height-adjusted spirometric reference values of the European Community for Steel and Coal were used.[21] Non-specific bronchial hyper-responsiveness was assessed by methacholine bromide challenge. Methacholine bromide was administered during a controlled inspiratory capacity breathing Dosimeter technique using the Aerosol Provocation System with a Medic-Aid nebuliser (Jaeger), starting with diluent and followed by doubling of doses of methacholine bromide from 0.12 mg to a maximum dose of 1.87 mg (7.8 µmol), the cut-off point for a normal response.[21] The test was stopped when a fall of 20% in FEV$_1$ (forced expiratory volume in 1 s) was observed (PD20) or the maximum cumulative dose was reached. If necessary, bronchoconstriction was treated with inhalation of salbutamol.[22]

We defined airway obstruction as a FEV$_1$ <80% of predicted and a FEV$_1$ to FVC (forced vital capacity) ratio of ≤70%.

Serology and eosinophil count

Blood samples were cooled and transported to a nearby hospital laboratory for analyses. The concentration of eosinophils was measured with a Cell-Dyn Sapphire analyser (Abbott Laboratories, Abbott Park, Illinois, USA). An increased concentration of eosinophils was defined as ≥0.4×10^9/l. We used enzyme immunoassays to assess total serum IgE and specific IgE reactions to a panel of common environmental allergens (house dust mites, cat, dog, and grass and birch pollen). Total and specific IgE to common aeroallergens were analysed in our laboratory based on adjusted previously published methods.[23] A total IgE of >100 kU/l and/or at least one positive reaction to common allergens was defined as atopy.

Epidemiological and statistical analysis

All statistical analyses were performed using SAS v 9.1. Data for 144 male workers aged between 30 and 65 years were used to

compare the prevalence of respiratory symptoms among workers with the prevalence in the general population sample. Data for 138 Caucasian male workers aged between 30 and 65 years were used to compare spirometric test results among workers with those of the general population sample. Multiple linear regression analysis was used to compare personal characteristics and the spirometric test results of workers with those of the general population sample, adjusting for age and height. Spirometric test results were also investigated by multiple linear regression analysis (PROC REG), adjusting for age, height and smoking habits (categorical variable: never, former or current smoker). The accuracy of regression models was examined by using Cook's D influence statistic, residual plots and partial regression residual plots and when indicated, sensitivity analyses were performed with log-transformed lung function variables.

Workers were assigned to different exposure groups based on their current job in their self-reported work history. Data for 140 Caucasian male workers (all ages) were used to compare respiratory symptoms between different exposure groups within the study population using minimally irritant exposed workers as an internal reference group. Data for 139 Caucasian male workers (all ages) were used to compare spirometric test results between different exposure groups within the study population using minimally irritant exposed workers as an internal reference group. Spirometric test results in different exposure groups were also investigated by multiple linear regression analysis (PROC REG), adjusting for age, height and smoking habits. For all questionnaire items, we calculated prevalence ratios (PR) and 95% CIs by log binomial regression analysis.[24] A starting value of −4 for the intercept was used to prevent convergence problems.[25] PRs were adjusted for age and smoking habits. Two-sided p values of 0.05 or less were considered to represent associations unlikely to be due to chance.

RESULTS
Participants
The personal characteristics of the aluminium cast-house workers are given In table 1 and include the numbers of workers in the exposure groups, the median years of employment, spirometry and blood test results.

Exposure assessment
A total of 88 personal inhalable dust samples were available (GM 0.76 mg/m^3; GSD 2.35 mg/m^3; range 0.05−5.79 mg/m^3). All samples were below the occupational exposure limit (OEL) for inhalable dust (10 mg/m^3), with an overall probability of exceedance of the OEL of 0.1%.

Metal analyses in personal and sedimentation dust revealed that the main metals in the dust were aluminium (47−90%), iron (15−18%), magnesium (2−14%) and sodium (1−15%). In addition, small amounts (0.1−3%) of other metals were found (borium, chromium, copper, manganese, selenium and titanium). No detectable levels of beryllium were found.

Measurement of the full-shift personal fluoride exposure of workers (N=6) showed detectable but relatively low fluoride exposure levels (range of total fluoride exposure 0.021− 0.261 mg/m^3), with HF accounting for 53−63% of the total fluoride exposure (gaseous and particulate). The full-shift fluoride area samples (N=6) were well below the Dutch 8 h OELs (1.5 mg/m^3 for HF and 2.5 mg/m^3 for inorganic fluorides), except for one sample taken high (approx 8 m above ground

Table 1 Characteristics of aluminium cast-house workers (n=151)

Sex	
Male (%)	150 (99.3)
Caucasian (%)	141 (93.4)
Age, years	
Median	45
IQR	13
Smoking status (%)	
Current smoker	76 (50.3)
Former smoker	42 (27.8)
Never smoked	33 (21.9)
Exposure to irritants (%)	
High	45 (29.8)
Moderate	51 (33.8)
Low	55 (36.4)
Duration of employment (n=148)	
Median years of employment	19
IQR	16
Spirometry (n=155)	
FEV$_1$ % pred (SD)	103.1 (14.4)
FVC % pred (SD)	108.7 (13.8)
PEF % pred (SD)	115.2 (20.3)
FEV$_1$/FVC % (SD)	77.2 (6.9)
Methacholine bromide challenge (n=149)	
BHR (%)	17 (11.4)
Serology (n=156)	
Atopy (%)	50 (32.1)
Total IgE >100 kU/l	18 (11.5)
Sensitised to ≥1 common allergen	15 (9.6)
Total IgE >100 kU/l and ≥1 common allergen	17 (10.9)
Blood test (n=150)	
Eosinophils ≥0.4×10^9/l (%)	18 (12.0)

BHR, non-specific bronchial hyper-responsiveness; FEV$_1$, forced expiratory volume in 1 s; FEV$_1$/FVC, forced expiration ratio; FVC, forced vital capacity; PEF, peak expiratory flow; % pred, percentage of the predicted value.

level) in the cast-house area directly above one of the melting/mixing furnaces. All short-term fluoride area samples (N=17) were below the detection limit. The low average fluoride concentrations were confirmed by the urine samples (N=55), with urine concentrations up to 1.81 mg fluoride/g creatinine. Post-shift fluoride urine values were slightly elevated for most workers compared with the pre-shift values, but all values were well below the American Conference of Governmental Industrial Hygienists-Biological Exposure Indices or German Biologische Arbeitsplatztoleranzwerte values for urinary fluorides.

HF emissions, measured with the real-time TDL-based instrument, are shown in figure 1. Each time a transport ladle was emptied into a melting/mixing furnaces, high levels of HF could be measured in the smoke plume above the furnaces, which were much higher than the short-term exposure limit for HF of 1.5 ppm, and were occasionally as high as 60 ppm. Similar peak emissions occurred every few minutes within the cast-house area. The amount of smoke generated during this activity varied greatly, but the height of the HF peak did not vary much and seemed to be independent of (visible) smoke generation.

Real-time walk-through monitoring sessions showed no detectable levels of sulphur dioxide within the cast-house area. Chlorine concentrations were low during most walk-through monitoring sessions, but could rise to 8.8−11.8 mg/m^3 (3−4 ppm) on several occasions when workers were taking test samples out of the induction oven (a daily activity taking only a few minutes). On one occasion a chlorine peak of 88.5 mg/m^3 (30 ppm) was measured which appeared to be due

September 30th 2008 holding furnace 13 and 14

October 17th 2008 holding furnace 15 and 18

October 13th 2008 holding furnace 15-19
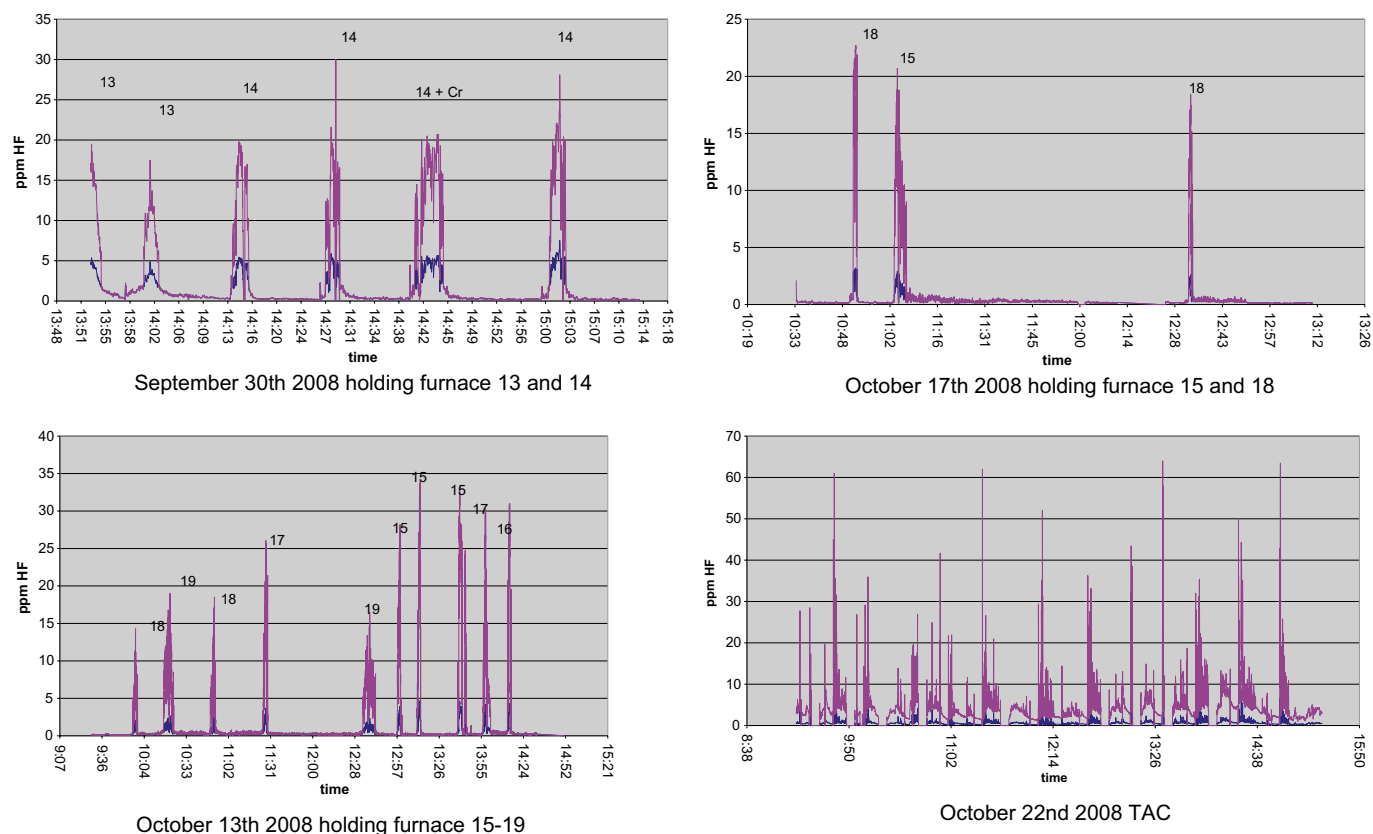

October 22nd 2008 TAC

Figure 1 Hydrogen fluoride measurements over time with peak exposures during furnace filling and sodium cleaner with AlF$_3$ (TAC) (averaging time of the sampler 2 s). HF, hydrogen fluoride.

to a leakage in one of the chlorine ducts; during the same sampling session workers said that similar leakages occurred on a regular base.

Questionnaire and spirometry
Compared with the Dutch ECRHS population, cast-house workers reported significantly more continuous and repeated trouble with breathing, exercise induced shortness of breath, wheezing, self-reported asthma attacks and physician diagnosed asthma attacks (table 2).

The spirometric test results of 138 Caucasian male aluminium cast-house workers showed significant differences in FEV$_1$ and FEV$_1$/FVC values (percentage of the predicted value) compared to a general Dutch population sample after adjusting for smoking habits (table 3).

Regression analysis showed that aluminium cast-house workers had significantly lower FEV$_1$ values (−195 ml) and FVC values (−142 ml) compared to a general Dutch population sample after adjusting for age, height and smoking habits (table 4). Regression coefficients for age and height were comparable to those from reference regression equations from the European Respiratory Society. Current and former smokers generally had lower lung function compared with non-smokers. Cook's D influence statistic and residual plots indicated that FER assumptions underlying ordinary least squares regression were not completely met. Logarithmic transformation of the FER resulted in a somewhat better fit, but did not change associations, indicating the robustness of the model.

Exposure−response relationship
Workers in the high exposure group reported significantly more eye symptoms during their work (PR 5.5, 95% CI 1.2 to 24.9) and workers in the moderate exposure group reported significantly more chest tightness symptoms when waking up (PR 3.0, 95% CI 1.1 to 8.2) compared to an internal reference group. Furthermore, there were no significant differences in self-reported respiratory symptoms among exposure groups. There were also no significant differences among exposure groups in bronchial hyper-responsiveness, atopy and eosinophils ≥0.4×10^9/l. An unadjusted logistic regression analysis was used to explore associations between total years of employment at the plant and atopy (OR=1.0, 95% CI 1.0 to 1.0) and eosinophil levels ≥0.4 (OR=1.0, 95% CI 1.0 to 1.1). No significant associations were observed.

The spirometric test results of 139 Caucasian male aluminium cast-house workers showed no significant differences (percentage of the predicted value) compared to a minimally exposed internal reference group after adjusting for smoking habits (data not shown). Regression analysis also showed no significant differences compared to a minimally exposed internal reference group after adjusting for age, height and smoking habits.

Work-related airway symptoms
Of 151 cast-house workers, 21 (13.9%) reported an asthma attack (ever). Of these 21 workers, 10 (47.6%) reported having had an asthma attack (ever) before they had started working at the plant, 8/21 (38.1%) after they had started working at the plant and in 3/21 (14.3%) it was not clear whether they had asthma attacks before or after they had started working at the plant.

Of 151 workers, 75 (49.7%) reported having work-related upper and/or lower airway symptoms, 16 (21.3%) of whom reported an asthma attack (ever) and 14 (18.7%) of whom

Table 2 Adjusted prevalence ratios with 95% CI of respiratory symptoms in cast-house workers and a general Dutch population sample of the European Community Respiratory Health Survey

	Comparison with external reference population†		
	Aluminium cast-house workers n=144	General population n=1000	
	n (%)	%	PR (95% CI)
Trouble with breathing			
Ever	53 (36.8)	18.9	1.9 (1.5 to 2.5)*
Continuously	9 (6.3)	2.7	2.5 (1.2 to 5.3)*
Repeatedly	18 (12.5)	6.9	1.8 (1.1 to 3.0)*
Cough symptoms			
Daily cough	22/55 (40)	14.7	
Daily cough with phlegm	18/51 (35.3)	11.2	
Shortness of breath (SOB) and wheezing			
Exercise induced SOB	46 (31.9)	19.4	1.7 (1.3 to 2.3)*
Awakened due to SOB	11 (7.6)	6.1	1.4 (0.7 to 2.6)
Wheezing	47 (32.6)	24.1	1.4 (1.1 to 1.8)*
Wheezing with SOB	37 (25.7)	14.6	1.8 (1.3 to 2.5)*
Awakened due to chest tightness	20 (13.9)	12.4	1.2 (0.8 to 1.8)
Asthma			
Asthma attack (ever)	20 (13.9)	5.2	2.8 (1.7 to 4.6)*
Asthma attack, doctor diagnosed	17 (11.8)	4.8	2.6 (1.5 to 4.4)*

*p<0.05; adjusted for age and smoking habits (categorical variable: never, former or current smoker).
†Males only, aged between 30 and 65.
PR, prevalence ratio.

Table 3 Personal characteristics and spirometric test results of aluminium cast-house workers versus a general Dutch population sample of the European Community Respiratory Health Survey

	Cast-house workers† n=138	General population† n=972
Age (years), mean (SD)	47 (8.1)	48 (10.2)
Smoking status (%)		
Current smoker	48	42
Former smoker	30	38
Never smoked	22	20
FEV_1 % pred (SD)	102.8 (14.2)*	106.0 (17.2)
FVC % pred (SD)	108.6 (13.5)	109.2 (14.4)
PEF % pred (SD)	115.9 (20.8)	115.6 (21.9)
FEV_1/FVC % (SD)	76.8 (7.0)*	78.5 (8.3)
‡Airway obstruction	6 (4.3)	51 (5.2)

*p<0.05; adjusted for smoking habits.
†Caucasian males only, aged between 30 and 65.
‡Airway obstruction (FEV_1/FVC <70% and FEV_1 <80% pred).
FEV_1, forced expiratory volume in 1 s; FEV_1/FVC, forced expiration ratio; FVC, forced vital capacity; PEF, peak expiratory flow; % pred, percentage of the predicted value.

reported they had changed job because of their symptoms. Of these 14 cast-house workers who had changed job, 10 (71.4%) reported an asthma attack (ever), 4 (40%) of them after they had started working at the plant. In the group with work-related upper and/or lower airway symptoms, 64/69 workers (92.8%) reported that their symptoms improved on non-working days.

An additional analysis of Caucasian males (n=140) showed that cast-house workers who reported work-related upper and/or lower airway symptoms, reported significantly more asthma attacks (ever) (PR 3.7, 95% CI 1.3 to 10.6) after adjusting for age and smoking habits compared to those who did not report upper and/or lower work-related airway symptoms.

In an additional interview with the 14 cast-house workers who changed jobs, 13 (92.9%) confirmed that they changed job as a result of their work-related upper and/or lower airway symptoms. One worker reported to have had work-related upper and/or lower airway symptoms and an asthma attack (ever) changed his job as a result of Ménière's syndrome. Five (38.5%)

of these 13 workers reported an exposure incident, three of which were chlorine gas incidents. Nine (69.2%) of the 13 workers had asthma and used asthma medications; eight of the nine were treated by a pulmonologist and one by a general physician. Seven of the nine stated that they had no asthma symptoms when they started working at the plant. Of the other four workers in the group of 13, one had chronic obstructive pulmonary disease and three had no clear diagnosis.

DISCUSSION
Aluminium cast-house workers reported significantly more respiratory symptoms and showed significantly lower spirometric values compared to a sample of the Dutch ECRHS population.

The average daily mean exposure to inhalable dust, metals, HF, fluoride salts and sulphur dioxide was relatively low compared to reference values. However, high emission of fluoride occurred above the furnaces. The ventilation in the cast-house consisted of a natural ventilation system with ventilation grids automatically opening and closing in a controlled manner. When the ventilation grids were open, the outside wind influenced the airflow patterns within the cast house, disturbing the upward airflow patterns above the ovens. This resulted in pot emissions with high concentrations of fluorides spreading into the workplace. Measurements showed that peak exposures to chlorine gas occurred as a result of production process disturbances.

Table 4 Multiple linear regression analysis of pulmonary function variables on age, height and smoking habit in a population of cast-house workers‡

	FEV_1 (ml)		FVC (ml)		PEF (ml/s)		FEV_1/FVC %	
Determinant	β Coefficient	95% CI	β Coefficient	95% CI	β Coefficient	95% CI	β Coefficient	95% CI
Intercept	−3329	−4306 to −2352	−6223	−7272 to −5174	−2849	−5946 to 248	111	98 to 124
Age	−38*	−41 to −34	−33*	−37 to −27	−64*	−76 to −52	−0.26*	−0.31 to −0.21
Height	5204*	4690 to 5717	7290*	6739 to 7842	9263*	7635 to 10 891	−11*	−18 to −4
Smoking status (%)§								
Current smoker	−236*	−329 to −143	−124*	−224 to −24	−424*	−720 to −129	−2.66*	−3.87 to −1.44
Former smoker	−31	−129 to 67	−42	−147 to 62	209	−100 to 518	0.12	−1.15 to 1.39
Cast house¶ workers	−195*	−306 to −85	−142*	−260 to −24	−155	−505 to 194	−1.26†	−2.70 to 0.18
Adjusted R^2 (%)	51		54		24		11	

*p<0.05; †p<0.10.
‡n=138, Caucasian males only, aged between 30 and 65.
§Never smoked as reference group.
¶General population as reference group (n=972), Caucasian males only, aged between 30 and 65.
FEV_1, forced expiratory volume in 1 s; FEV_1/FVC, forced expiration ratio; FVC, forced vital capacity; PEF, peak expiratory flow.

Compared to a minimally irritant exposed internal reference group, cast-house workers in the group with the highest exposure to irritants reported significantly more eye symptoms during their work and workers in the moderate exposed group reported significantly more chest tightness symptoms when waking up. No differences in spirometric values were found between exposure groups.

Cast-house workers who reported work-related airway symptoms reported significantly more asthma attacks compared to workers without work-related airway symptoms. The majority of cast-house workers who reported job change due to their symptoms reported asthma.

The average daily mean exposure to inhalable dust, metals, HF, fluoride salts and sulphur dioxide was relatively low compared to reference values. However, peak emissions of HF and fluoride salts occurred in the cast-house area when aluminium was poured from transport ladles into the furnaces. Normal airflow patterns in the workplace were disturbed on a regular base and, as a result, emissions from transport ladles with high concentrations of HF and fluoride salts spread into the workplace. So, peak exposures to HF and fluoride salts are very likely but were difficult to measure due to their unpredictable nature.

Measurements showed that peak exposures to chlorine gas can occur as a result of specific production process disturbances. This was confirmed by workers during walk-through surveys and during medical interviews with workers who changed job due to symptoms. Thus, intermittent exposures to irritants are relevant to cast-house workers. In particular, exposures to fluorides were not restricted to certain tasks or jobs but depended on weather conditions and airflow patterns in the workplace and as a result were quite homogeneous for all cast-house workers within the cast-house area.

In their study among 30 cast-house workers and 17 controls, Godderis et al found no significant difference in any of the respiratory questionnaire categories or in spirometry results between cast-house personnel and referents and concluded that there was no indication for respiratory health problems in cast-house personnel compared to the referent population.[15]

In our study we also found no significant differences in any of the respiratory questionnaire categories or in the spirometry results between cast-house personnel and internal referents. In addition, spirometry results were not associated with duration of employment as a proxy for cumulative exposure to irritants (data not shown).

However, cast-house workers do have respiratory health problems compared to a general population sample and these problems are likely to be underestimated.

Godderis et al concluded that exposure levels in cast houses seemed to be acceptable but that peak exposure to fumes could not be excluded. Our study shows that exposures measured in the workplace are on average within acceptable limits but that peak exposures to respiratory irritants occurred on a regular basis as a result of disturbances in the airflow pattern and more intermittent exposures to chlorine gas.

Our study suggests that these peak exposures to irritants may explain the respiratory health effects in exposed cast-house workers in comparison to the general population.

In an internal comparison of groups exposed to irritants, the highest exposed group reported significantly more eye symptoms during their work and workers in the moderate exposed group reported significantly more chest tightness symptoms when waking up. These symptoms may be a result of irritation by fluorides and/or chlorine.[26 27] The homogeneous character of

exposures among cast-house workers may explain why we did not find more differences in respiratory symptoms among exposure groups.

Furthermore, cast-house workers who reported work-related airway symptoms reported significantly more asthma attacks compared to workers without work-related airway symptoms and most of those who reported job change due to their symptoms also reported asthma.

Most workers with physician diagnosed asthma reported they had no asthma symptoms when they started working at the plant. These findings may be an indication that exposures in cast-house workers either caused or aggravated symptoms of asthma. Indeed, exposure to irritants can aggravate or probably cause asthma.[28] Kipen et al reported cases of non-sensitisation adult-onset asthma in settings of exposure to noticeable but distinctly 'tolerable' levels of inhalation irritants and Taiwo et al demonstrated a significant relationship between mean gaseous fluoride exposure and the incidence rate of asthma but were unable to show any significant association between short-term HF exposure and asthma incidence in their study population.[10 29] Furthermore, Simonsson et al showed acute and long-term airway hyper-responsiveness in a case series of aluminium-salt exposed workers with nocturnal asthma.[30]

Whether cast-house workers with asthma had 'potroom asthma' as described in aluminium potroom workers[1] cannot be concluded from this study because cases were not further evaluated. But even then, although the bronchial responsiveness in aluminium potroom workers reporting work-related asthmatic symptoms appeared to be related to plasma levels of fluoride, the causative agent of potroom asthma has still not been elucidated.[2] However, Burge et al raised the possibility, in a case report, that potroom asthma is the result of a response to aluminium fluoride.[31]

The study population was small, and this limited statistical power in internal comparisons, especially after adjusting for confounding variables in multiple regression modelling.

Information was collected in a standard manner and exposure was assigned blind to the questionnaire and test results. As a result, misclassification will likely to be non-differential and exposure—response relationships might have been underestimated.

Cast-house workers reported significantly more respiratory symptoms and showed significantly lower spirometric values compared to the Dutch ECRHS population. However, overestimation of symptoms in workers cannot be excluded, and recall bias may have affected comparisons with the general population. Nevertheless, the workers also showed significantly lower spirometric values which are a more objective outcome. Reversibility in FEV_1 was not measured, so it was not possible to evaluate the nature of the spirometric changes.

The general population data were obtained using the same procedure and device, with the same age and distribution, but were not restricted to a working subpopulation. The general population sample also included non-active workers who were not fit enough to be active in the workforce; therefore, the differences in respiratory status between exposed workers and the general population are likely to be underestimated.

The healthy worker effect is a potential source of bias in cross-sectional studies when restricted to actively employed workers. Leaving employment or job transfer to lower exposure as a result of disease may have led to underestimation of the effects of exposure.[32 33]

Job transfer may have led to an underestimation of exposure—response relationships in this study, because 14 workers reported they had changed job during their employment at this plant as a result of work-related airway symptoms. The company

initiated several control measures after the study. Filling pipes in the ovens were shortened to avoid the situation whereby liquid metal in the oven closes off the filling pipe thus increasing the emission of heat and fumes at the oven inlet. In addition, local ventilation is being installed above oven inlets. Both measures aim to reduce the emission of fumes and gasses to the cast-house area, although the effectiveness has not been measured at this time.

In conclusion, this epidemiological study suggests cast-house workers in the aluminium industry are exposed to respiratory risk. Although an exposure—response relationship could not be demonstrated, this study supports preventive measures in the working environment of cast-house workers with a focus on (peak) exposures to irritants. Exposure should be minimised and health surveillance should be offered to exposed workers.

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