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Pulmonary function in aluminium smelters

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ABSTRACT Two studies were conducted at an aluminium smelter employing 113 male workers in the smelting process. Twenty one of the 111 men in the first study experienced chest tightness more often than once a week and had a higher prevalence of cough, dyspnoea, and nasal symptoms but not of positive skin test responses than symptomless men. Lung function in these men did not differ significantly from that in the symptomless men at the beginning of the working week and only marginal deterioration occurred over the week. In the second study serial spirometric measurements were obtained over several shifts in a subset of 31 men from the first study. Impairment of ventilatory function on exposure to smelting fumes was demonstrated in 18 men. Analysis of all data from the 31 subjects revealed that ventilatory function varied significantly in association with heavy exposure to potfumes and a history of recurrent chest tightness. The findings of these two studies indicate that aluminium smelting fumes can cause bronchoconstriction in susceptible individuals. The reaction is dose dependent and is more severe in those with a history of recurrent chest tightness.

Asthma occurring in workers exposed to aluminium smelting fumes was first reported in English by Midttun,[1] who also reviewed the earlier Norwegian papers. Further studies in Scandinavia,[2] Australia,[3] and Yugoslavia[4 5] have confirmed the original observations. Two studies in the United States[6 7] have failed to demonstrate significant respiratory impairment either by questionnaire or by spirometric measurement, but these studies were concerned with chronic respiratory disease and were not designed to detect the transient changes of asthma. A recent Canadian study failed to show a greater decrease in FEV_1 or other spirometric indices in potroom workers than in control workers over the course of a workshift.[8] The present study was undertaken to investigate the short term variation in respiratory function of employees of an aluminium smelter from which four men had been referred to me with symptoms consistent with occupational asthma.

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Description of the smelter

Aluminium is produced by the electrolytic reduction of alumina (aluminium oxide) in a bath of the fused fluorides of aluminium and sodium ("cryolite"). The electrolytic process generates very high temperatures, which maintain the bath in a molten state. The electrolytic cells in which the aluminium is produced are known in the industry as "pots." Alumina is spread in a layer on the surface of the molten cryolite in the pot; the aluminium produced during electrolysis settles to the bottom of the pot and is periodically siphoned into a large crucible. Several carbon anodes are suspended in each pot. They are gradually consumed by reaction with the oxygen released during the reduction of alumina and must be replaced periodically by a group of men assigned to this task.

The pot emissions consist of gases and particulates. The physical and chemical composition of these two components at the high temperatures at which they are evolved have not yet been defined precisely. The major gaseous constituents are hydrogen fluoride, carbon monoxide, carbon dioxide, sulphur dioxide, and oxides of nitrogen. The particulates comprise mainly alumina and fluoride with traces of many elements, including vanadium and nickel. Polycyclic aromatic hydrocarbons have also been detected.

The smelter in which the present study was conducted was situated in a semirural area of New South Wales, Australia, and had been in operation for two years. The pots were aligned end to end in two parallel rows in a building about 800 metres long. Access to individual pots was by a broad central corridor between the two potlines and by two narrower corridors between each potline and the wall of the building. The potroom was ventilated by an efficient flow through system, air entering through gratings in the floor and being taken out through exhausts in the roof. The individual pots were covered by lids, which were raised for routine procedures such as anode changing, metal tapping, and adding alumina. High volume exhaust ventilation was provided on all pots so that appreciable contamination of the potroom environment occurred only when the covers were raised.

An environmental study conducted immediately prior to the survey found that the levels of total fluoride, particulate fluoride and gaseous fluoride, in the general potroom atmosphere and in the breathing zone of employees working on the pots, were all less than the recommended maximum allowable concentrations for these substances. However, peak exposures were not recorded. Detailed analyses of the pot emissions were not undertaken.

Design of survey

Two studies were conducted at the smelter over a period of 12 months. The first established the prevalence of respiratory symptoms in the work force and examined the changes in respiratory function over the working week. The second investigated the variation in respiratory function over an eight hour work shift, particularly in relation to procedures causing a greater than average exposure to pot fumes.

The work force at the smelter was unusually stable and most men had been employed there for the full two years of its operation. Although no figures were provided, labour turnover was stated to be trivial owing to the depressed economic conditions in the area and the high wages paid to potline employees. Eleven employees had been transferred from the potline to other duties. The population for the first study was defined as those men currently employed in the potroom or previously employed there and now working elsewhere in the plant. One hundred and thirteen men were eligible by these criteria.

The men worked a rotating roster based on three eight hour work periods—morning, afternoon, and night. All three work periods were included in the study, tests being conducted throughout the 24 hours. Each man had tests of respiratory function on two occasions: the first immediately prior to the first shift of his working week before he had entered the potroom or changed into his working clothes, and the second during the last shift of his working week. Four men worked some overtime on the potline during their rostered days off preceding the first testing session.

A respiratory symptom questionnaire was administered and skinprick tests, to assess atopic state, were performed at a convenient time during the working week.

Two men were lost to the study because of sickness unrelated to their employment. Three men were excluded from the lung function analysis because of incomplete data.

The second study was confined to men working on the central third of the potline so that employees would not have to walk an unreasonable distance for their tests. The operation of the pots in this section did not differ from the remainder of the potline and there is no reason to believe that the environment was unrepresentative of the potroom as a whole. Thirty three men were employed on the central section at the time of the study. Five declined to participate. Four men from other sections of the potline volunteered and were transferred to the central section for the duration of the study. The final sample therefore comprised 32 men.

The study was conducted over nine days in 12 testing sessions divided equally between the three work periods. The design permitted each man in the sample to be studied during three shifts.

Procedures which exposed employees to a greater than average concentration of pot fumes were nominated for special study. All required raising of the covers on the pots. Environmental measurements indicated that anode changing was associated with a heavier exposure to pot fumes than any of the other nominated procedures.

Spirometry was performed on all men at the beginning of the shift. They were instructed to present themselves for further measurements before starting a nominated procedure and at specified intervals during the procedure and after its completion. With certain procedures it was not possible to anticipate the start of the operation. In these cases the employees presented for the first time as soon as possible after finishing the procedure.

It proved difficult for employees to adhere strictly to the specified times and some latitude had to be allowed. Although intervals between measurements tended to be irregular, the required number of measurements was usually obtained. In general, individual data for each shift proved adequate in all but a few instances.

Methods

FIRST STUDY

Questionnaires on respiratory symptoms and smoking habits, based on the British Medical Research Council's Respiratory Symptom Questionnaire, were administered to all men. The symptom questionnaire included a technique whereby cough frequency is uniquely ranked on a 10 point scale, increasing in severity from score 1 to 10.[9] The men were classified into three groups according to their response to the questions "Does your chest ever feel tight or your breathing become difficult?" and "Does your chest feel tight or your breathing become difficult as often as once a week?" Those who had never experienced chest tightness or difficulty in breathing were assigned to category A, those who experienced it less often than once a week to category B, and those who experienced it more often than once a week to category C.

Breathlessness on exertion was assessed by the question "Are you able to keep up with others of your own age walking up hills or stairs at an ordinary pace?"; dyspnoea at rest was identified by the question "Do you ever get short of breath at rest?" and nasal symptoms by the question "Do you often sneeze or get an itchy, running nose?"

Smokers were defined as men who regularly smoked one or more cigarettes a day at the time of the survey or who had ceased smoking less than three months before the survey. All but four men in this group smoked 10 or more cigarettes a day. Non-smokers were defined as men who had never regularly smoked one or more cigarettes per day. Ex-smokers were defined as men who had ceased smoking cigarettes three months or more before the survey. All ex-smokers in this group had in fact ceased smoking more than 12 months before the survey.

The presence of a productive cough was assessed by ear from a single requested cough.[10]

Skin testing by the "prick" method was performed with four allergens: rye grass; cocksfoot and wild oats; house dust; aspergillus. Coca's solution was used as a control. Reactions were scored as follows: 0—no palpable weal; +—palpable weal less than 4 mm in diameter; ++—palpable weal 4 mm or more and including weals with pseudopodia. The total score for the individual was given by the sum of the scores for each allergen (+ scoring as 1 and ++ as 2).

Chest radiography was performed on all men during the two months after the survey. Lung function tests were performed in a specially equipped mobile laboratory[11] located in the open, adjacent to the potroom. The same tests were performed on all subjects at the first and second testing sessions.

The one second forced expiratory volume (FEV_1) was measured with a wet spirometer (Collins, 9 litres). Transfer factor (TL) was measured by the single breath method, the procedure being automated by the use of a Resparameter Mark IV (PK Morgan). The inspiratory vital capacity (VC) was measured immediately before the breath holding procedure. The following conditions were standard for all measurements of TL: inspired volume equal to vital capacity less 0·2 litres; dead space rejection, 0·7 l; collected volume 0·6 l. Corrected breath holding time was automatically displayed. The composition of the inspired gas was 0·4% carbon monoxide, 21% oxygen, 5% neon, and the balance nitrogen. Gas analysis was performed by gas chromatography (Varian Aerograph, series 2700) with helium as the carrier gas. Functional residual capacity (FRC) was measured with the subject seated in a pressure corrected volume displacement body plethysmograph (Emerson) by the method of Du Bois *et al.*[12] Signals were displayed on a storage cathode ray oscilloscope (Tektronix 564 B) and recorded on polaroid film. Inspiratory capacity was recorded immediately after the measurement of functional residual capacity. Total lung capacity (TLC) was obtained from the sum of the functional residual capacity and the inspiratory capacity. Residual volume (RV) was derived by subtracting the vital capacity measured with the wet spirometer from the total lung capacity.

The maximum expiratory flow at 50% TLC ($Vmax_{50}$) was derived from maximum expiratory flow-volume curves obtained plethysmographically with a Fleisch No 4 pneumotachograph. Closing capacity (V_{cc}) was measured by the single breath oxygen technique, expired volume being recorded plethysmographically. The method was a modification of that recommended by the working party of the National Heart and Lung Institute in 1973. Total respiratory resistance (R_{rs}) was obtained by the forced oscillation technique[13] at an applied frequency of 5 Hz. The resistance was measured at peak inspiratory flow during quiet breathing.

Histamine challenge was performed with a standard solution of histamine diphosphate (1 mg/ml), delivered by a De Vilbiss 40 nebuliser using compressed air at 138 kPa (20 lb/in^2) as a propellant. The aerosol was inhaled during quiet breathing for one minute. Single measurements of FEV_1 were made at 1½ minutes, 2½ minutes, and 4 minutes after commencing inhalation. Bronchial reactivity to histamine (ΔFEV_1 hist) was estimated as the difference between the mean of the three control values and the mean of the three postinhalation values. Subjects with a recent history of asthma or wheezing were excluded from this test.

All tests were performed in duplicate at each testing session except for FEV_1 and histamine challenge. Triplicate measurements of FEV_1 were obtained; histamine challenge was performed only once at each session. Closing capacity and total respiratory resistance records were measured independently by two observers to minimise the influence of subjective bias on these measurements. The means of all replicate measurements were used in the subsequent statistical analyses.

SECOND STUDY

FEV_1 and peak expiratory flow rate (PEFR) were measured with a digital electronic spirometer (Virgulto). The technical quality of the forced expiratory manoeuvre was monitored on an X-Y recorder (Brush), which provided a continuous record of expiratory flow against expired volume. The spirometer was located in an air conditioned office adjacent to one of the central entrances to the potroom. The ambient temperature was recorded whenever a measurement of function was made.

The approximate forced vital capacity was noted on each occasion as a check on technique, but an accurate measurement of vital capacity was not attempted since repeated expirations to residual volume proved a strain on the subjects' cooperation. Two technically satisfactory measurements were required each time an employee presented for testing. Usually three records were obtained; if all were technically satisfactory, the two highest values were recorded for both FEV_1 and PEFR.

The spirometer was calibrated immediately before the start of each shift. Calibration for flow was performed in the expiratory direction at flows of approximately 5 and 2 litres per second, a set of standard constricted orifice tubes being used in association with a motor blower. Volume calibration was performed at about 5 l and 2·5 l ATP with a Collins 9 litre spirometer. The digital readout was adjusted at the higher calibration level to display true flow and volume at ambient temperature. The calibration of both flow and volume was checked at the two levels on completion of each shift and the observed digital values for flow and volume were recorded. Usually the calibration was also checked on one or more occasions during a shift and the observed digital values were recorded.

Linear regressions of the observed digital values of flow and volume on the true values were fitted to each set of calibration data, the regressions being constrained to pass through the origin. The mean regression coefficients for both flow and volume did not differ significantly from unity and the coefficient of variation of the individual regression coefficients about the mean was 3% in both instances.

The mean temperature in the test room was 20·2°C with a standard deviation between work shifts of 0·75°C and during a shift of 0·36°C. In view of the small temperature variation ATPS values are given.

Results

FIRST STUDY

Of the 111 men in the first study, 60 denied ever experiencing chest tightness or difficulty in breathing (category A), while 30 experienced these symptoms less often than once a week (category B) and 21 once a week or more (category C). Table 1 shows the smoking habits and the prevalence of symptoms and skin test reactions in the three categories. The smoking habits were similar in all the categories, about two thirds of the work force being regular cigarette smokers. When a test of trend[14] was aplied there was a significant progression in the prevalence of dyspnoea on exertion through the three categories ($p < 0·01$). Dyspnoea at rest occurred only in category C. The prevalence of nasal symptoms increased significantly with chest tightness from category A to category C ($p < 0·05$). There was no difference in the prevalence of a loose cough. About half of the men had negative reactions to all four skin test allergens. Scores greater than 1 were infrequent. No significant difference in the skin test scores for the three categories was found. Most category A men had low cough frequency scores. Category B showed a distinct bimodal distribution,

Table 1 *Study 1: prevalence of cigarette smoking and respiratory symptoms by chest tightness category in 111 men*

	% of each category		
	A (n = 60)	*B (n = 30)*	*C (n = 21)*
Smokers	65·0	73·3	71·4
Non-smokers	25·0	20·0	19·0
Ex-smokers	10·0	6·7	9·5
Dyspnoea on exertion	1·7	10·0	19·0
Dyspnoea at rest	0·0	0·0	19·0
Nasal symptoms	18·3	36·7	38·1
Loose cough	33·3	36·7	42·9
Skin test score			
0	50·0	50·0	61·9
1	40·0	33·3	28·6
2–6	10·0	16·7	9·5
Cough frequency score			
1–2	56·7	50·0	0·0
3–5	28·3	10·0	52·4
6–9	15·0	40·0	47·6

while all subjects in category C admitted to some degree of regular cough. No man had a score of 10. The increase in cough frequency with chest tightness from category A to category C was significant ($p < 0{\cdot}001$).

The chest radiographs were read by a single experienced chest physician. All were considered to be within normal limits except one, which showed an apical opacity consistent with a healed tuberculous lesion.

Respiratory function in the three chest tightness categories at the beginning of the week is shown in table 2. The data have been adjusted to the mean age and height of the study population by the use of coefficients derived by linear regression analysis. The small differences in R_{rs}, $Vmax_{50}$, and V_{cc} between categories A and B did not reach conventional levels of significance and there was no consistent trend from category A to category C. In one man in category B phase 3 was too abnormal to define the onset of phase 4. Mean lung function did not differ significantly between categories A and C. The standard deviation of bronchial reactivity to histamine was considerably greater in category C than in category A despite the exclusion of six men with a recent history of wheezing or asthma, but there was no significant difference between the categories in either the mean or the median values.

Changes in lung function over the working week in the 90 men who worked exclusively in the potroom were minor and showed no consistent trends. Closing capacity increased by 4·6% TLC in category C ($p < 0{\cdot}05$) but was not accompanied by any detectable change in other indices of airway function.

Table 2 *Study 1: mean age, height, and pulmonary function* by chest tightness category in 108 men*

	Mean (SD)		
	A (n = 59)	*B (n = 29)*	*C (n = 20)*
Age (y)	33·6 (8·4)	33·7 (5·8)	32·5 (8·4)
Height (m)	1·72 (0·08)	1·75 (0·07)	1·75 (0·08)
FEV_1 (l)	3·78 (0·45)	3·69 (0·43)	3·68 (0·68)
VC (l)	4·79 (0·51)	4·85 (0·63)	4·62 (0·68)
TLC (l)	6·45 (0·71)	6·51 (0·89)	6·47 (0·87)
RV (l)	1·66 (0·46)	1·66 (0·57)	1·85 (0·55)
R_{rs} (cm l^{-1} s^{-1})	2·90 (0·69)	3·31 (1·72)	2·89 (0·95)
$Vmax_{50}$ (l s^{-1})	2·91 (1·74)	2·50 (1·39)	3·16 (1·72)
Vcc (% TLC)	37·8 (8·8)	41·7 (7·3)	37·6 (6·8)
TLCO ml min^{-1} mm Hg^{-1}	29·5 (5·0)	30·9 (6·0)	29·7 (4·4)
$\Delta FEV_{1\,hist}$ (l)	0·08 (0·17)	0·10 (0·22)	0·22† (0·38)

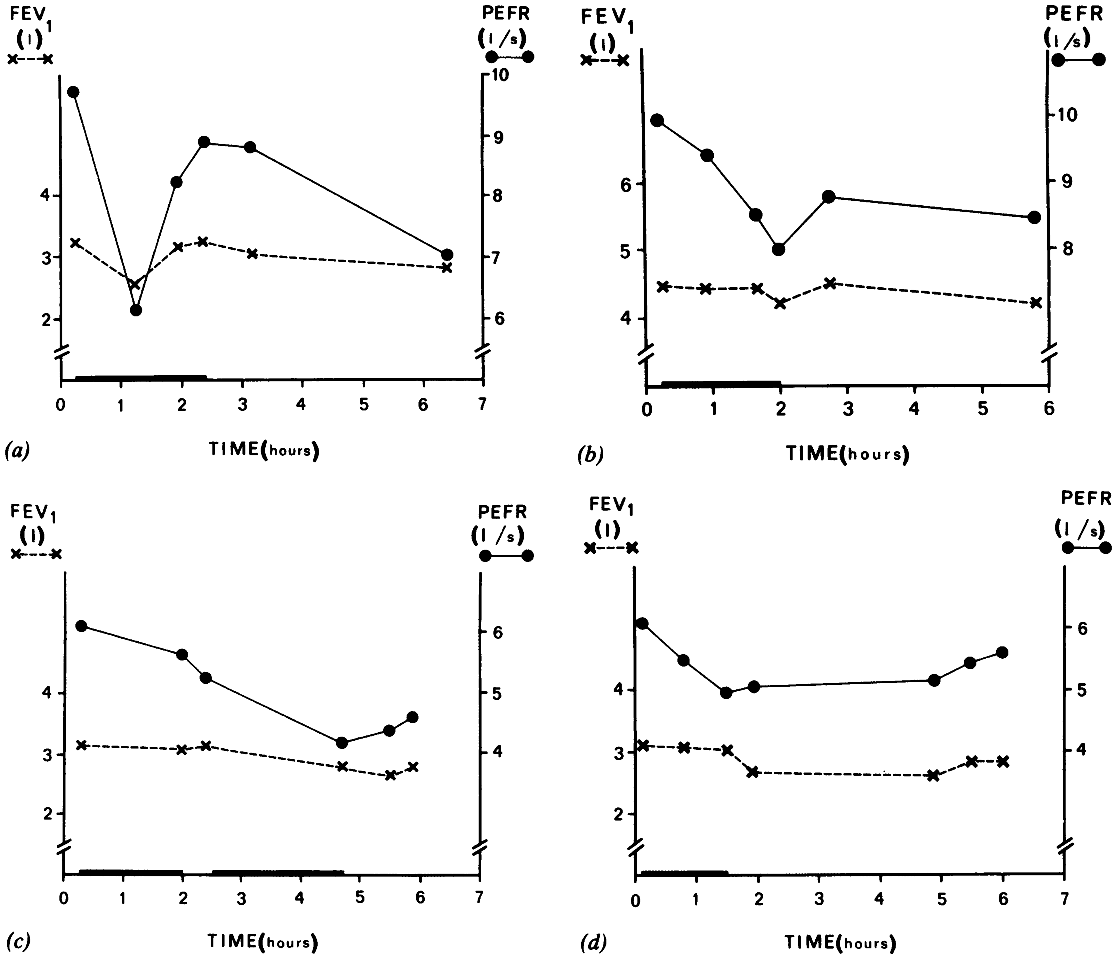
*Adjusted for age and height.
†n = 14 for category C.
VC—vital capacity; TLC—total lung capacity; RV—residual volume; R_{rs}—total respiratory resistance; $Vmax_{50}$—maximum expiratory flow at 50% of TLC; Vcc—closing capacity; TLCO—transfer factor; $\Delta FEV_{1\,hist}$—fall in FEV_1 after inhalation of histamine (1 mg/ml for 1 min).
Conversion: traditional to SI units—Rrs: 1 cm l^{-1} s^{-1} = 0·1 kPa l^{-1} s^{-1}; TLCO: 1 ml min^{-1} mm Hg^{-1} = 0·334 mmol min^{-1} kPa^{-1}.

SECOND STUDY

Satisfactory data for FEV_1 and PEFR were obtained in 31 of the 32 employees in the second study. One man was consistently unable to perform an adequate forced expiratory manoeuvre despite repeated attemps; his data have been excluded from the analyses. One man was studied over four shifts, five over two shifts, and two over only one shift. Of the 31 men, 19 were from category A, 9 from category B, and 3 from category C. The relatively low proportion of category C men employed on the central section of the potline did not differ significantly from the proportion in the workforce overall.

Inspection of individual data showed no consistent trends in FEV_1 or PEFR over the course of a single shift but some men showed considerably greater variation in ventilatory function than others during the shift. Decreases in ventilatory function occurred in two of the three category C men in immediate relation to procedures giving relatively heavy exposure to pot fumes. The figure (*a*) illustrates the type of response seen in these two men in four of the six shifts studied. The third man sustained only minor exposure to pot fumes in his three shifts. Bronchoconstriction occurring during anode changing in a category A employee is also depicted in the figure (*b*); the response of another category A employee during the addition of alumina to pots and the siphoning of aluminium from pots is shown in (*c*) and (*d*). Similar decreases in ventilatory function in relation to a nominated procedure occurred in 18 of the 31 men, six showing a fall in PEFR of 2 l s^{-1} or more on at least one occasion.

A hierarchical analysis of variance was performed on the pooled data of the 31 men. This analysis divides the total variation in ventilatory function into the variation between duplicate measurements, between observations recorded during a single shift, between shifts, and between men. It is postulated that a response to the environment will show itself as an increase in the variability between measurements made at different times during a shift. Two measurements were made on each occasion; the variability between these duplicates therefore represents the repeatability of the measurements at a given time. Provided that the variability between duplicates is uninfluenced by the environment the variability between measurements at different times during a shift, which will include the duplicate variability, can be compared for different groups. For all 31 men the standard error of the mean of duplicate measurements of PEFR was 0·19 l s^{-1} and of FEV_1 0·05 l. The variation between observations taken at



Serial measurements of PEFR and FEV$_1$ (a) in a category C employee and (b) in a category A employee during a shift that included a period during which they were engaged in anode changing (indicated by bars); (c) in a category A employee during a shift that included periods during which he was engaged in adding alumina to the pots (bars); and in the employee shown in (c) during a shift that included a period during which he was engaged in siphoning aluminium from the pots (bar).

different times during a shift was significantly greater than the variation between duplicates ($p < 0{\cdot}01$).

In table 3, the data have been analysed in terms of chest tightness category. The duplicate mean square did not differ between categories for either PEFR or FEV$_1$. The variation between times within shifts was similar in categories A and B but was significantly greater in category C ($p < 0{\cdot}01$), indicating a greater variability in ventilatory function during a shift in this group.

An analysis of the changes in ventilatory function associated with anode changing was performed on the data from men who had been studied during shifts in which they did and did not do anode changing. Fourteen employees fulfilled this criterion. In table 4 separate analyses are shown for the "anode changing" and "no anode changing" shifts. Each man is represented in each group but the contribution of shifts from each man is not necessarily the same for each group. The analysis does not take into account the fact that the same men were included in each group; the significance levels may therefore be conservative. The duplicate mean square was the same for the two groups but the variation between

Table 3 *Study 2: variation in pulmonary function by chest tightness category*

	Mean square (degrees of freedom)		
	A (n = 19)	*B (n = 9)*	*C (n = 3)*
PEFR ($l\ s^{-1}$)			
Between times within shifts	0·26 (382)	0·29 (178)	0·83 (78)*
Between duplicates	0·07 (435)	0·08 (202)	0·08 (88)
FEV_1 (l)			
Between times within shifts	0·023 (382)	0·029 (178)	0·05 (78)*
Between duplicates	0·006 (435)	0·007 (202)	0·006 (88)

*The "between times" mean square is significantly greater ($p < 0·01$) in category C than in the pooled categories A and B.
PEFR—peak expiratory flow rate.

times within shifts for the "anode changing" shifts was significantly greater than that for the "no anode changing" shifts ($p < 0·01$).

Cigarette smokers showed a significantly greater variation during a shift than non-smokers in PEFR ($p < 0·05$) but not in FEV_1.

A systematic trend in ventilatory function over the working week was sought by examining the data for each of the three shifts, ordered in relation to the start of the working week. Only those men employed in jobs giving moderately heavy exposure to pot fumes were included in the analysis. Twenty one men met this requirement. The mean PEFR for each of the three shifts was 7·94, 7·97, and 7·95 $l\ s^{-1}$ respectively and the mean FEV_1 3·46, 3·53, and 3·52 l respectively. A similar result was obtained when the chest tightness categories were considered individually. The variation in ventilatory function between times within a single shift also showed no significant trend over consecutive shifts.

Discussion

Chest tightness has proved to be the most consistent and distinctive symptom of occupational asthma[15] and it was for this reason that it was chosen for the present studies. Although figures for the prevalence of symptoms assessed by questionnaire must be considered with some caution in industrial work forces, it is worth noting that the observed prevalence of chest tightness in this survey was some three times greater than in surveys conducted by this department where no bronchoconstrictor agent has been present in the environment. The association of cough, dyspnoea, and nasal symptoms with chest tightness is suggestive of an asthma like syndrome. The high prevalence of cough was particularly notable as the technique used to score this symptom was better able to detect false positive responses than are conventional questionnaire methods. The similarity of smoking habit in the three chest tightness categories and the fact that sputum production, as judged by the loose cough sign, did not increase in prevalence through the categories implies that cigarette smoking was not responsible for the high prevalence of cough in men complaining of chest tightness.

There was no significant difference in lung function between the three chest tightness categories at the start of the working week and no progressive deterioration over the course of the week was detected in either study. Nevertheless, the occurrence of bronchoconstriction in some employees while they were working in the potroom was beyond question. In the examples shown in the figures the decrease in ventilatory function far exceeded the variation between duplicate measurements and was at least three times the standard deviation of observations within a shift recorded for the whole sample. The analysis of the data for category C employees in the second study indicates that the variation in ventilatory function in this group was considerably greater than in either category A or category B. There is no reason to suppose that this was due to different conditions existing in the potroom when these men were studied. They were drawn from different roster groups and the type of work in which they were employed did not differ from that of their fellows. Thirty per cent of the category C shifts included anode changing compared with 25% in the other categories. The greater variation of ventilatory function in category C must therefore reflect special characteristics of the men making up this group rather than differences in their work environment. The characteristic defining the group was a high incidence of episodic chest tightness. It therefore seems that men with a history of recurrent chest tightness are more susceptible on average to bronchoconstriction on exposure to pot fumes than other potroom workers. The data do not, however, indi-

Table 4 *Study 2: variation in pulmonary function in relation to anode changing*

	Mean square (degrees of freedom)	
	Anode changing (n = 14)	*No anode changing (n = 14)*
PEFR ($l\ s^{-1}$)		
Between times within shifts	0·61 (132)†	0·31 (165)
Between duplicates	0·08 (151)	0·08 (186)
FEV_1 (l)		
Between times within shifts	0·052 (132)†	0·032 (165)
Between duplicates	0·008 (151)	0·008 (186)

†The "between times" mean square is significantly greater ($p < 0·01$) in the "anode changing" group than in the "no anode changing" group.
PEFR—peak expiratory flow rate.

cate whether chest tightness is caused by pot fumes. It is unlikely that the variation in respiratory function in this group reflected asthmatic bronchoconstriction unrelated to aluminium smelting and that the association with work in the potroom was coincidental. Such an interpretation would be difficult to reconcile with the clearly defined decreases in ventilatory capacity in two members of this group during procedures giving relatively heavy exposure to pot fumes.

The comparison between shifts in which anode changing was performed and those in which it was not provides convincing evidence that exposure to pot fumes was responsible for the observed variations in ventilatory function. The assumption implicit in this analysis, that the inhalation of pot fumes can cause only a deterioration in ventilatory function and not an improvement, is a reasonable one and is supported by the records of individual employees. Shifts concerned with anode changing did not differ in any other way from the usual shift routine. Environmental measurements indicated that, of the nominated procedures, anode changing was associated with the highest total particulate concentration in the atmosphere. The choice of this procedure as a basis for assessing the respiratory effect of pot fumes was therefore justified by data independent of ventilatory function. The results show that anode changing was associated with a greater variation in ventilatory function than the other nominated procedures. The significance of this finding is enhanced by the relatively crude subdivision of shifts into "anode changing" and "no anode changing." Individual reactions during other nominated procedures indicate that anode changing was not the only procedure accompanied by decreases in ventilatory function. The comparison between the two types of shifts therefore reflects the additional effect of anode changing over that of other nominated procedures. The true magnitude of the reaction to anode changing is probably better estimated by comparison of the variation between times within shifts with the duplicate variation on the assumption that the between times variation in ventilatory function was minimal when no reaction to the work environment occurred.

The greater variation in ventilatory function over the course of a shift in cigarette smokers was only just detectable in these studies. It may simply have reflected the effect of smoking during working hours but the possibility that the reaction to pot fumes was enhanced in smokers cannot be excluded. There were too few subjects to determine whether the magnitude of this effect increased with cigarette consumption.

These studies indicate that inhalation of the fumes liberated during the routine procedures carried out in aluminium smelting caused bronchoconstriction which was dose dependent. The effect was greatest in men with a history of regular chest tightness but was not confined to them and it seems unlikely that a clear division into "reactors" and "non-reactors" can be made. An allergic mechanism cannot be excluded but the absence of objective evidence of atopy, as judged by skin testing, in susceptible individuals does not support such a mechanism. The wide range of individual susceptibility, with some men showing no detectable impairment of airway function when exposed to pot fumes and others showing significant bronchoconstriction after a similar exposure, implies that the action on the bronchial tree is not primarily an irritant one. This conclusion is supported by the histories of the four severely affected individuals who had been referred for clinical evaluation. All were able to work initially in the fumes without developing respiratory symptoms and it was only after a latent period of several months or longer that they developed characteristic symptoms of cough and chest tightness.

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