Two year follow up of pulmonary function values among welders in New Zealand

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Abstract

Objectives—To examine whether welding is a risk factor for an accelerated decline in pulmonary function.

Methods—2 Year follow up of pulmonary function and respiratory symptoms among 54 welders and 38 non-welders in eight New Zealand welding sites.

Results—There were no significant differences in age, height, smoking habits, ethnicity, or total time in industrial work between welders and non-welders. No overall differences were noted in the changes of pulmonary function variables between the two study groups. However, when the comparison was restricted to smokers, welders had a significantly greater ($p=0.02$) annual decline (88.8 ml) in FEV₁ than non-welders, who had a slight non-significant annual increase (34.2 ml). Also, welders without respiratory protection or local exhaust ventilation while welding had a greater annual decline both in forced vital capacity (FVC) and forced expiratory volume in one second (FEV₁) than welders with protection ($p=0.001$ and 0.04 , respectively). Among welders a significant association was found between the acute across shift change and the annual decline in FEV₁. Chronic bronchitis was more common among welders (24%) than non-welders (5%). Only one welder (2%) but eight non-welders (21%) reported having asthma.

Conclusions—Welders who smoked and welders working without local exhaust ventilation or respiratory protection have an increased risk of accelerated decline in FEV₁.

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Exposure to welding fumes is known to be a risk factor for respiratory disorders. Welding fumes may cause acute respiratory effects including airway irritation, acute bronchitis, metal fume fever, and, less commonly, hypersensitivity pneumonitis or occupational asthma.¹ Welders are also known to have a higher risk for chronic respiratory disorders—such as pneumoconiosis,¹ chronic bronchitis,¹ and lung cancer.²

Several studies have shown a small acute decline in lung function during welding work,³⁻⁵ although this effect has not been noted in all studies.^{6,7} The long term significance of

this acute decline is still unclear, although it is possible that repeated acute declines could result in the development of chronic respiratory impairment. Knowledge of the chronic effect of welding fumes on lung function is mainly based on cross sectional studies of current workers.^{1,8-10} Only a few longitudinal studies have been published,¹¹⁻¹³ with conflicting results. Chinn *et al*¹¹ found an irreversible effect of welding on forced expiratory volume in one second (FEV₁) and forced vital capacity (FVC) in a 7 year follow up of welders and caulker/burners, and they also noted an interaction between the effects of smoking and welding. Beckett *et al*¹³ did not find any effect of welding on the annual decline of lung function in a 3 year follow up.

In 1996 a cross sectional survey was conducted in eight different New Zealand engineering sites and found that an acute decrease in FEV₁ relative to work was more prevalent among welders than among non-welders.¹⁴ In that study welders had a mean 2.8% fall from baseline FEV₁ after 15 minutes of work compared with a 1.0% increase in non-welders. The purpose of the present survey was to study the same workers 2 years after the previous study and to examine whether welders also had an accelerated chronic decline in lung function.

Subjects and methods

A 2 year follow up visit was performed at the same eight New Zealand engineering sites studied in the first survey in 1996.¹⁴ All sites were known to regularly involve welding as part of their industrial process. Most of the welders studied worked with mild steel or mild steel and stainless steel as a base metal, with either gas tungsten arc welding (TIG) or gas metal arc welding (MIG) techniques.

QUESTIONNAIRE

As in the previous study, the questionnaire included demographic data, current smoking habits, questions about work related respiratory symptoms, and selected questions from the European Community Respiratory Health Survey.¹⁵ Reports of current or recent cough, phlegm, wheeze, chest tightness, and shortness of breath were recorded, along with whether these symptoms were related to work (defined as a symptom reported to be worse at work or improving on rest days or holidays).

Smoking was divided into two categories: smokers included all current smokers during study 1 (it includes four smokers who stopped smoking between the two studies), and non-

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smokers included both never smokers and long term ex-smokers. Chronic bronchitis was defined as regular phlegm production at any time during the day or night for ≥ 3 months of the year and for ≥ 2 years.

CURRENT WELDING EXPOSURE

The current job type and the duration of employment were recorded both in the first and the second survey, but the basic definitions were based on the welding status at the time of study 1. A worker was classified as a welder if he had been an active welder (welding $\geq 5\%$ of the working day) in study 1 and had continued in that job between the two surveys (this includes seven welders who stopped welding between study 1 and study 2 with a mean stopping date of 4 months before study 2). Non-welders were defined as all workers who had never worked as welders and workers who were ex-welders at the time of the study 1 or at that time did only minimal welding ($\geq 5\%$ of the working day) and had not been active welders between the two surveys.

PREVIOUS WELDING EXPOSURE

Similarly, welding history was recorded at both surveys but the basic definitions were based on the welding history at the time of study 1. All workers were asked to describe their previous lifetime exposure in terms of sequential periods spent in differing jobs, and the associated proportion of the day spent welding in each of these posts. The effective exposure in years (per job) was calculated as the product of these two variables, and the cumulative measure (years) was calculated by summing all the individual exposures for each job. This estimate is subsequently referred to as the total exposure index.¹⁴

PULMONARY FUNCTION

All workers in the study were asked to perform pulmonary function tests with one of the two calibrated portable spirometers (Alpha Spirometer, Vitalograph) used in the first survey. Otherwise the protocol was the same as in study 1.¹⁴ Pulmonary function measurements, carried out according to the guidelines set by Quanjer *et al.*,¹⁶ were taken before the shift, 15 minutes after the start of welding work (or at a corresponding time for workers not welding) and again 7 hours into the workshift. All preshift values were recorded before any exposure to welding fumes on the study day and was at least 14 hours since any previous welding work. Forced expiratory volume in one second (l), forced vital capacity (l) and forced midexpiratory flow (FEF₂₅₋₇₅ l/s) were measured, with the best value of three forced expiratory manoeuvres in the standing position.

All variables were also converted into the percentage predicted value for each person with the equations integral in the spirometer,¹⁶ including adjustment for ethnicity (Polynesian and non-Polynesian).

The two spirometers used in the study 1 differed from each other with a mean difference of 4% in the FEV₁ measurements after adjust-

ment for age, sex, and height. Because only one of these spirometers was used in the second study, the analysis was adjusted for which spirometer was used in the first study. Thus, for the 23 welders and 21 non-welders who used one spirometer (A) in the first study but the other spirometer (B) in the second study, their pulmonary function measurements for study 1 were adjusted to account for the difference in mean FEV₁ measurements between the two spirometers (controlling for age, sex, height, and ethnicity). The other 20 welders and 14 non-welders used the same spirometer (B) in both studies.

DATA ANALYSIS

The statistical analysis system (SAS)¹⁷ was used for all regression analyses. The mean pulmonary function values were adjusted for age and height as a continuous variable, spirometer, smoking habit in three groups (current, ex-smoker and non-smokers), and ethnicity in two groups (European and non-European—which includes both Maori and other Polynesians) in an analysis of covariance (ANCOVA). This calculates what the mean values would have been if the age, height, smoking, ethnicity, and spirometer distributions were the same in the groups being compared—for example, welders and non-welders.

Continuous variables were compared between groups—for example, welders and non-welders—by estimating the mean (SEM) and the associated unpaired *t* test. Categorical variables were compared between groups with the standard χ^2 test.

The annual changes in pulmonary function values were calculated from the preshift values for each person as the difference between their pulmonary function values in study 1 and study 2 divided by the time between the two measurements (about 2 years) with the adjusted mean values. Linear regression was used to measure the change in annual decline in pulmonary function values (ml) for a 1% acute decline in FEV₁ measured across the shift in study 1.

All workers in this study gave written informed consent to take part and the study was approved by the Wellington ethics committee.

Results

Of the 137 workers studied in 1996, 96 (70%) participated in this second survey, of whom two were retired, two were on sick leave, one was unemployed, and six had changed job; these 11 workers were visited at home or at their new place of work. Only four women participated in the study; they were all non-welders and were excluded from the analysis. Forty one workers could not be included in the second study (mostly because they could not be contacted), however, those 21 welders and 20 non-welders who did not participate did not differ from those who participated in terms of mean age or pulmonary function values. The response rates were 54/61 (89%) in male welders and 38/70 (54%) in male non-welders.

Table 1 Demographic characteristics and welding and smoking history of the welders and non-welders

	Welders (n=54)		Non-welders (n=38)		p Value
	Mean	SD	Mean	SD	
Age (y)	40.1	11.6	41.4	13.6	0.6
Height (cm)	176.5	7.8	177.8	8.0	0.5
Total exposure index	7.9	6.8	0.9	2.1	0.0001
Total time in industry	17.4	10.5	15.5	14.4	0.5
	n	%	n	%	
Current smokers	24	44.4	13	34.2	0.3
Ex-smokers	10	18.5	10	26.3	0.4
Non-smokers	20	37.0	15	39.5	0.8
European	36	66.7	31	81.6	0.1

All data based on study 1, except age in study 2.

Table 2 Asthma, atopy, chronic bronchitis, work related and general respiratory symptoms in welders and non-welders at the time of study 2

	Welders (n=54)		Non-welders (n=38)		p Value
	n	%	n	%	
Asthma	1	1.9	8	21.1	0.002
Nasal allergies	17	31.5	14	36.8	0.6
Skin allergies	13	24.1	10	26.3	0.8
Chronic bronchitis	13	24.1	2	5.3	0.02
Work related symptoms:					
Cough	7	13.0	4	10.5	0.7
Phlegm	12	22.2	5	13.2	0.3
Wheezing	6	11.1	2	5.3	0.3
Shortness of breath	1	1.9	2	5.3	0.4
Chest tightness	7	13.0	5	13.2	1.0
Any work related symptom	16	29.6	9	23.7	0.5
Respiratory symptoms:					
Persistent cough	9	16.7	7	18.4	0.8
Any chest tightness	17	31.5	13	34.2	0.8
Chest tightness just with colds	4	7.4	1	2.6	0.3
Wheeze or whistle in past 12 months	18	33.3	15	39.5	0.5
Wheezing only with colds	11	20.4	6	15.8	0.6
Shortness of breath grade 1	6	11.1	7	18.4	0.7

Table 3 Adjusted* pulmonary function values in study 1 and study 2, and the annual change among welders and non-welders

	Welders		Non-welders		p Value
	Mean*	SE	Mean*	SE	
Study 1	n = 48		n = 37		
FVC (l)	4.85	0.11	4.94	0.13	
FEV ₁ (l)	3.83	0.08	3.85	0.09	
FEF ₂₅₋₇₅ (l/s)	3.46	0.15	3.36	0.18	
Study 2	n = 43		n = 35		
FVC (l)	4.75	0.11	4.83	0.12	
FEV ₁ (l)	3.78	0.08	3.81	0.09	
FEF ₂₅₋₇₅ (l/s)	3.59	0.18	3.71	0.21	
Annual change	n = 43		n = 35		
FVC (ml)	-64.6	38.9	-65.0	45.0	
FEV ₁ (ml)	-26.4	21.3	-33.1	24.6	
FEF ₂₅₋₇₅ (ml/s)	78.0	62.1	162.9	71.8	
	Mean	95% CI			
Annual change welders v non-welders:					
FVC (ml)	0.4	-107.4 to 108.1			0.99
FEV ₁ (ml)	6.7	-52.3 to 65.7			0.82
FEF ₂₅₋₇₅ (ml/s)	-84.8	-256.8 to 87.2			0.33

* Adjusted for age, height, smoking (current smokers, ex-smokers, and non-smokers), spirometer used, and ethnicity (European and non-European).

Table 1 shows the demographic details and smoking status of the study groups. The 54 welders did not differ significantly from the 38 non-welders in terms of age, height, total time in the industry, smoking habits, and ethnicity. The mean total exposure index was 7.9 years among welders and 0.9 years among non-welders (some of these were longtime ex-welders or had done minimal welding).

Table 2 shows the prevalence of asthma and respiratory symptoms at the time of study 2 in welders and non-welders. Only one welder but eight non-welders reported having asthma.

Chronic bronchitis was much more common among welders (24%) than among non-welders (5%). Four of the 20 (20%) welders who had never smoked had chronic bronchitis compared with none of the 15 non-welders who had never smoked. Of the work related symptoms only phlegm production and wheezing were more often reported by welders (22% and 11%) than non-welders (13% and 5%), but these differences were not significant. Many of the general respiratory symptoms were more common among non-welders, presumably because of the eight asthmatic workers in that group.

Spirometry values of 78 workers were included to the analysis; two others declined to be tested, six were excluded as they had been welding during the preceding 14 hours (before baseline was measured at the start of the working day), four measurements did not reach the reproducibility criteria and from three workers we obtained only the questionnaire data as they were only interviewed by telephone. The response rates for spirometry were 43/61 (71%) in male welders and 35/70 (50%) in male non-welders.

The mean (SD) percentage of the predicted pulmonary function values did not differ significantly between the welders and non-welders. These were: FVC 102.8 (13.5) in welders and 105.0 (15.8) in non-welders; FEV₁ 98.4 (13.7) and 98.7 (14.3); and FEF₂₅₋₇₅ 80.2 (23.6) and 83.0 (26.7).

The annual decline in pulmonary function did not differ significantly between welders and non-welders (table 3). However, when the analysis was restricted to smokers, welders had a significantly (p=0.02) greater annual decline in FEV₁ than non-welders (table 4); the difference in the annual decline in FEF₂₅₋₇₅ also tended to be greater among welders who smoked than non-welders who smoked, but this difference was not significant (p=0.08). The findings were similar after adjusting for pack-years of smoking. Among non-smokers the result was the reverse; non-welders had a steeper annual decline in FEV₁ than welders (p=0.05). The high number of asthmatic workers among the non-smoking non-welders did not explain this pattern as excluding them from the analysis did not significantly change the findings; there were also some (n=3) ex-smokers and ex-welders in the group of non-smoking non-welders but excluding them did not change the findings.

At the time of the first survey, 27 (50%) of the 54 welders had used either a personal respirator or local exhaust ventilation, or both while welding; 20 used a mask, four used an air purifier, and 13 had a local exhaust ventilation. Welders without any personal protection used while welding had a significantly steeper annual decline in FEV₁ and FVC than welders with protection (table 5). As the decline was noted both in FVC and FEV₁, it was therefore partly related to volume. Welders who smoked and worked without protection had the steepest (144 ml) decline in FEV₁ whereas welders with protection who did not smoke had a slight

Table 4 Adjusted* pulmonary function values in study 1 and study 2, and the mean annual change by smoking status in welders and non-welders

	Smokers				Non-smokers			
	Welders Mean*	SE	Non-welders Mean*	SE	Welders Mean*	SE	Non-welders Mean*	SE
Study 1:								
n	20		12		28		25	
FVC (l)	4.79	0.18	4.84	0.23	4.87	0.14	5.00	0.17
FEV ₁ (l)	3.77	0.14	3.77	0.18	3.83	0.09	3.85	0.11
FEF ₂₅₋₇₅ (l/s)	3.51	0.26	3.47	0.34	3.43	0.19	3.29	0.23
Study 2:								
n	17		11		26		24	
FVC (l)	4.59	0.18	4.73	0.22	4.74	0.15	4.83	0.17
FEV ₁ (l)	3.66	0.15	3.87	0.18	3.79	0.09	3.68	0.11
FEF ₂₅₋₇₅ (l/s)	3.46	0.34	4.27	0.41	3.70	0.20	3.33	0.24
Annual change:								
n	17		11		26		24	
FVC (ml)	-166.7	84.0	-28.8	103.2	-49.0	40.6	-96.1	48.5
FEV ₁ (ml)	-88.8	29.8	34.2	36.6	4.3	28.1	-75.8	33.6
FEF ₂₅₋₇₅ (ml/s)	-36.0	118.2	315.9	145.1	178.3	69.1	60.2	82.6
	Mean	95% CI		p Value	Mean	95% CI		p Value
Annual change welders v non-welders:								
FVC (ml)	-137.9	-423.4 to 147.6	0.33		47.1	-67.9 to 162.1	0.41	
FEV ₁ (ml)	-123.0	-224.2 to -21.7	0.02		80.2	0.5 to 159.8	0.05	
FEF ₂₅₋₇₅ (ml/s)	-351.9	-753.4 to 49.7	0.08		118.1	-77.8 to 314.0	0.23	

*Adjusted for age, height, smoking habit (current, ex-and non-smokers), spirometer, ethnicity (European and non-European).
SE = standard error.

annual increase (12 ml) in FEV₁ (not shown in tables).

Welders who showed the most acute decline in FEV₁ across the shift in study 1 also had a greatest annual decline in FEV₁ but not in FVC or FEF₂₅₋₇₅ (table 6).

Table 5 Pulmonary function values in study 1 and study 2, and the annual change separately in welders with and without respiratory protection or local exhaust ventilation in use while welding

	Protection		No protection	
	Mean*	SE	Mean*	SE
Study 1:				
n	27		21	
FVC (l)	4.61	0.14	5.19	0.16
FEV ₁ (l)	3.74	0.10	3.95	0.11
FEF ₂₅₋₇₅ (l/s)	3.51	0.20	3.39	0.23
Study 2:				
n	26		17	
FVC (l)	4.68	0.13	4.85	0.17
FEV ₁ (l)	3.78	0.10	3.78	0.12
FEF ₂₅₋₇₅ (l/s)	3.70	0.22	3.41	0.28
Annual change:				
n	26		17	
FVC (ml)	26.6	45.2	-215.0	57.4
FEV ₁ (ml)	6.6	25.9	-80.7	32.8
FEF ₂₅₋₇₅ (ml/s)	65.7	77.9	98.3	98.8
	Mean	95% CI		p Value
Annual change welders with v without protection:				
FVC (ml)	241.6	99.1	384.0	0.001
FEV ₁ (ml)	87.3	5.7	168.8	0.04
FEF ₂₅₋₇₅ (ml/s)	-32.6	-278.0	212.8	0.79

*Adjusted for age, height, smoking habit (current smokers, ex-smokers, and non-smokers), spirometer, ethnicity (European and non-European).

Table 6 Change in annual decline in pulmonary function values (ml) /1% acute decline in FEV₁ across the shift in study 1

	FVC	FEV ₁	FEF ₂₅₋₇₅
Welders:			
n	42	42	42
Annual decline /1% acute decline in study 1*	-0.9	4.4	3.6
SE	3.5	1.8	4.1
p Value	0.8	0.02	0.4
Non-welders:			
n	34	34	34
Annual decline per 1% acute decline in study 1*	11.7	3.1	-5.0
SE	5.4	2.9	10.9
p Value	0.04	0.3	0.7

* Adjusted for age, height, smoking (current smokers, ex-smokers and non-smokers), spirometer, ethnicity (European and non-European).

Discussion

In this 2 year follow up no significant overall differences were noted in the annual changes in pulmonary function variables between welders and non-welders. However, when the comparison was restricted to smokers, welders had a significantly steeper annual decline in FEV₁ than non-welders. Chronic bronchitis was more common among welders (24%) than non-welders (5%), and especially notable was the difference in the presence of chronic bronchitis in lifetime non-smokers: 20% in welders and 0% in non-welders. Only one welder (2%) but eight non-welders (21%) reported having asthma.

Our findings should be treated with caution because of the lack of an overall difference between welders and non-welders in annual changes in pulmonary function variables, and because of the number of comparisons that were made. Nevertheless, our findings in smokers are consistent for those of several cross sectional studies^{8 10 18} and of one longitudinal study.¹¹ Cotes *et al*¹⁰ found that FEV₁ was reduced relative to the average welding exposure among current and ex-smokers but not among non-smokers. Cross sectional studies by Hunnicutt *et al*⁸ and Özdemir *et al*¹⁸ found significantly impaired pulmonary function among welders who smoked compared with controls who smoked but not among non-smokers. In a 7 year follow up of 488 shipyard workers by Chinn *et al*¹¹ welders who smoked had nearly twice the annual decline in FEV₁ (50 ml) than welders who did not smoke (37 ml), and three times more than controls who did not smoke (16 ml).

Thus our findings, together with those from previous studies, strongly suggest that there is a synergistic relation between the effects of smoking and welding exposure, causing airway narrowing of both large and small airways and chronic bronchitis. The mechanism of this interaction is not exactly known, but the basic

pulmonary responses to both smoking and certain occupational exposures—for example, inorganic dust—are similar, both involving polymorphonuclear recruitment and alveolar macrophage activation. Thus, it is plausible that there could be a synergistic effect of smoking and exposures to welding fume.¹⁹

In our study, half of the welders did not have available or use any respiratory protection, and only a quarter had local exhaust ventilation, which is recommended. Welders without any protection while welding had a greater annual decline both in FVC and FEV₁ than welders with protection. The steepest annual decline in FEV₁ was found in welders who smoked and did not have any respiratory protection.

The relation between respiratory protection and pulmonary function values among welders has rarely been reported in previous studies. In the study by Beckett *et al*¹³ all welders had proper preventive measures and they could not find any evidence for chronic irreversible effects on lung function. Similarly, all workers studied by Chinn *et al*¹² in their second follow up had local exhaust ventilation. They classified welders by regular (100% of the time) and non-regular use of exhaust ventilation, and found that the annual decline in FEV₁ was smaller among the regular users.

We found a significant association between the acute and chronic effects of exposure to welding fume. Decline in FEV₁ across the shift was a significant predictor of annual decline in FEV₁. To our knowledge, none of the previous studies on welders have considered this question. However, studies among cotton²⁰ and grain workers^{21, 22} have found that acute responses to occupational exposure, measured as changes in FEV₁ across the shift, are a significant determinant of annual change in FEV₁. Furthermore, it is biologically plausible that recurrent acute obstructive changes lead to chronic airways obstruction.²³

The main limitations of our study are that the number of workers was small, especially in subgroup analysis, and that the follow up period, 2 years, was short for assessing the effect of exposure to welding on pulmonary function changes. Nevertheless, even in that short period there was a significant difference in annual decline in FEV₁ between welders and non-welders who smoked.

As our study was longitudinal all workers could serve as their own controls and we avoided in part some of the typical problems in cross sectional studies including the healthy worker effect. We also attempted to study workers who had left their workplace or who had retired to reduce the healthy worker effect. However, only 11 were surveyed at home or in a new workplace and 41 workers could not be studied, mostly because they had changed work and could not be found. Thus, there was still some dropout from the study population and our findings may therefore still have been affected by the healthy worker effect to some extent.

In our study non-smoking non-welders had an unexpectedly steep decline in FVC and FEV₁, steeper than that in smoking non-

welders or non-smoking welders. The reasons for these inconsistent findings are unclear, and it was not explained by the number of asthmatic subjects in that group, nor by the presence of some ex-smokers and ex-welders in that group; however, the most likely explanation is that it was a chance finding due to the small numbers of workers in this subgroup analysis.

We grouped non-welders and ex-welders together because the ex-welders had stopped welding before study 1 and it was assumed that the effect of welding fumes on decline in lung function does not continue after the end of exposure. There were also some non-welders who had done minimal welding. A similar classification was used for smoking: workers who were ex-smokers during the study 1 were classified as non-smokers because the decline in FEV₁ among smokers has been shown to normalise to the same level with never smokers after the end of smoking.²⁴ However, if pulmonary function variables continue to decline after exposure to tobacco or after the end of welding, or if they decline just due to occasional, minimal welding, then our method of categorisation would lead to an underestimation of the true difference between welders and non-welders (and between smokers and non-smokers) and could not account for the differences that we have found.

In conclusion, despite the short follow up period and the few workers in our study, smoking welders and welders welding without local exhaust ventilation or respiratory protection had significantly increased risks for accelerated decline in FEV₁. Even though no significant difference was noted among non-smokers, it should be stressed that effective preventive measures should be available for all welders. The use of masks and negative pressure respirators has been found to be unfeasible because of heat, moisture and discomfort.^{25, 26} Thus, local exhaust ventilation is the most practical method to avoid exposure to welding fumes, and is highly recommended, as is stopping smoking.

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