The rate of decline of FEV_1 in aluminium production workers in a smelter in Australia - a retrospective study of longitudinal spirometry data using FEV1 as the dependent variable

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Aluminium Production

- $2Al_2O_3+3C=4Al+3CO_2$
- $2Al_2O_3+3C$ (in a coal tar pitch-bound anode)$+Na_3AlF+AlF_3= 4Al+3CO_2+SO_2+F(HF)+NO_2$
- Occurs in a primary aluminium production smelter.
  - **In reality its a high temperature electrolytic reaction of alumina (aluminium oxide) with carbon to produce free molten aluminium metal and carbon dioxide**
  - Occurs in large, carbon-lined steel pots which acts as the cathode
  - **The chemical constituents are dissolved in a cryolite bath solution**
  - The carbon anode block is suspended in the bath and gets consumed in the process

INTRODUCTION AND BACKGROUND

- **Aluminium smelter pot-room workers are exposed to various dusts and fumes**
- WHAT IS KNOWN/EMERGING RESEARCH
  - **Emerging research suggesting accelerated loss of lung function in metalliferous and non-metalliferous smelting (can lead to COPD)**
  - **A previous review of 2006-2009 data suggested higher than normal drop in lung function in two of three smelters**
- GAPS IN KNOWLEDGE
  - **No published prospective or longitudinal studies** in aluminium smelting
  - **Causative factors not known** therefore not possible to infer from other metalliferous smelting studies
- Reasons for the Study
  - **Routine review of surveillance data for trends**
  - Indirectly evaluate the impact of improvements (exposure reduction and respiratory protection)

RESEARCH QUESTIONS

- **The aim of this study was to investigate whether workers exposed to dust and fumes of aluminium smelting experience an accelerated decline in lung function**
- A secondary aim was to investigate other factors which might contribute to accelerated decline in lung function, AND
  - Variables were chosen based on local experiences and literature review

Objectives

- Describe the trends in lung function over time
- **Quantify the annual decline in lung function**
- **Identify the proportion of workers experiencing accelerated loss in lung function**
- Identify any workers whose lung function is significantly impaired or **meet the criteria for COPD or are below the LLN;**
- **Explore the relationship between any decline and occupational dust exposure**
- **Identify any other factors contributing to the decline** in lung function with particular focus on cigarette smoking, weight, tenure, previous respiratory disease, gender and age
- **Recommend ways to help in the early identification of at risk employees and strategies to eliminate this risk.**

METHODOLOGY

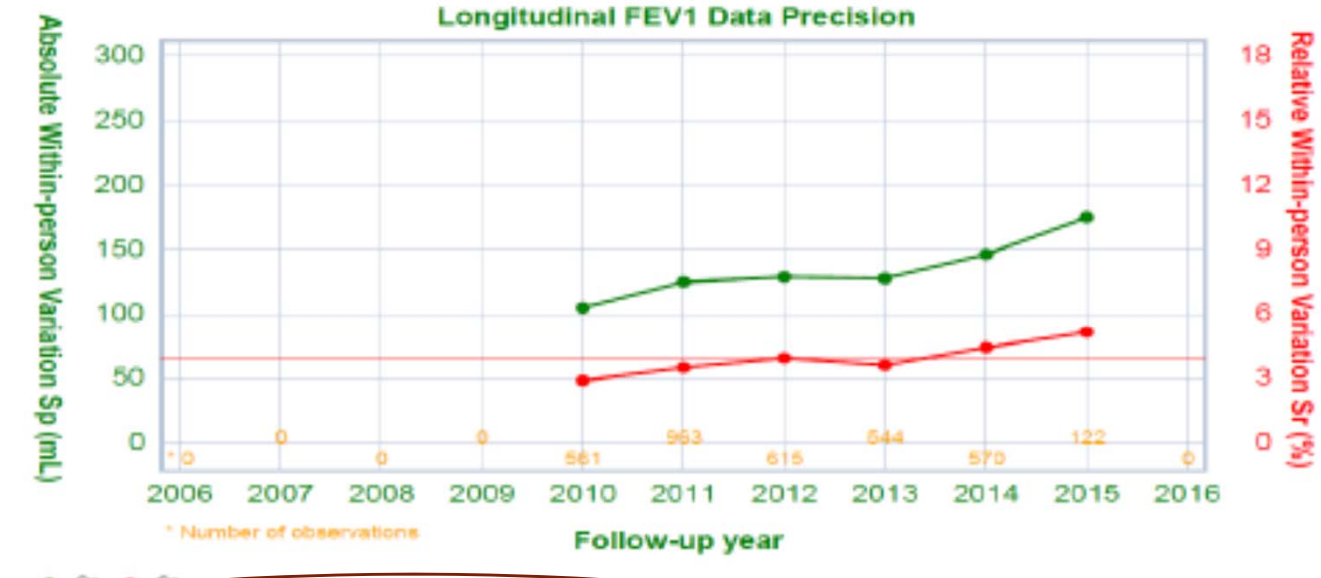
- STUDY TYPE
  - **Longitudinal spirometry data review: retrospective cohort**
    - An attempt was made to include data for all workers who had worked at the smelter between 2010 and 2015
    - 80%power with sample size of 800
- SETTING
  - High quality respiratory surveillance program
  - Large number of participants
  - Well-maintained spirometry data
- DATA ANALYSIS
  - **ANOVA**(comparing last test to first test)
    - All employees with a test done in2010 AND 2015 (150 employees excluded)
  - **SPIROLA** (Spirometry Longitudinal Data Analysis)- to analyze longitudinal data for group FEV1 means over time and measure the group mean annual decline in FEV1
    - Employees with at least 3 test results included (to enable drawing a line of best fit)

RESULTS

Data quality indices

- **Pairwise within person variation about 4%**
- **Absolute within person variation about 200ml**
- Z scores show no real difference between observed and expected

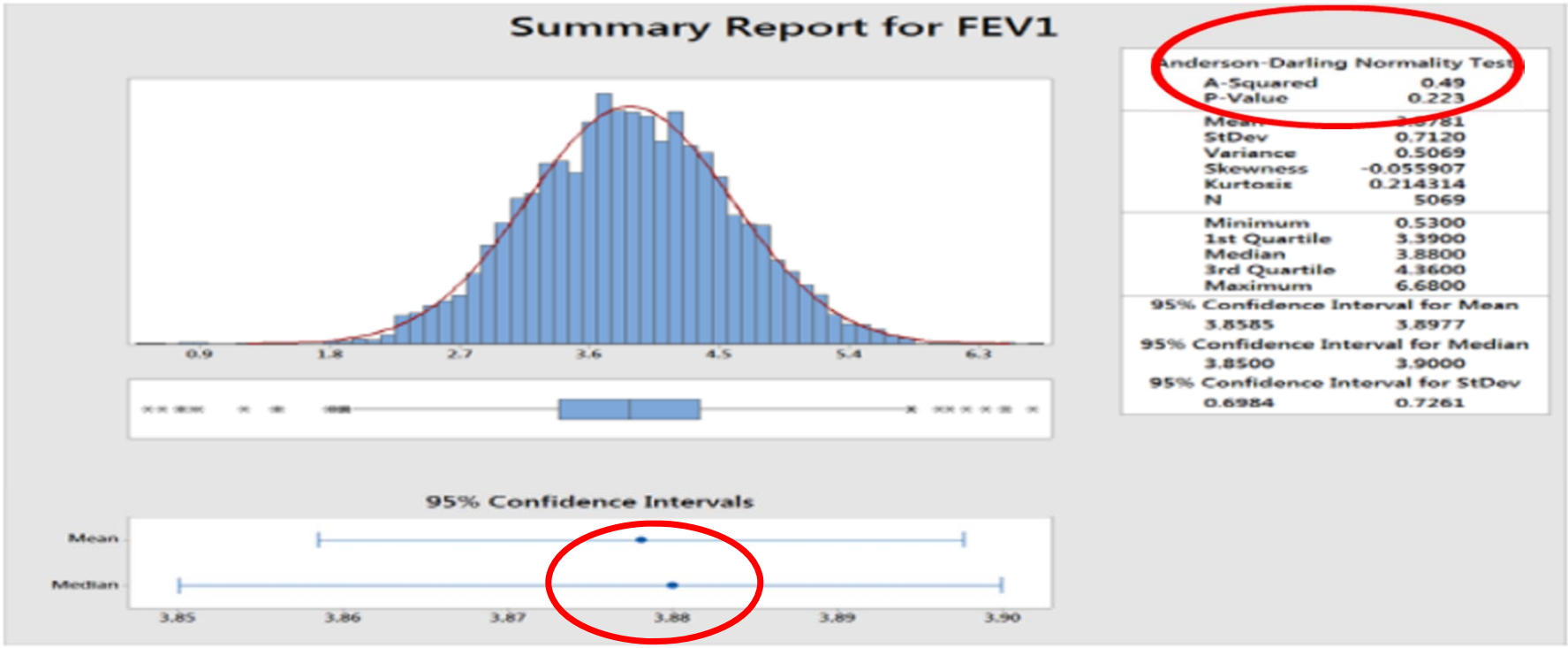
Figure 17- Group data precision



- The target for the program's variation should be Sr below 4%. If Sr is above 4% focus should be on improving spirometry quality.

Results: SAMPLE fev1 distribution

Figure 1- Distribution of FEV_1 data



Anderson-Darling Normality Test	
A-Squared	0.49
P-Value	0.223
Mean	3.8781
StDev	0.7120
Variance	0.5069
Skewness	-0.055907
Kurtosis	0.214314
N	5069
Minimum	0.5300
1st Quartile	3.3900
Median	3.8800
3rd Quartile	4.3600
Maximum	6.6800
95% Confidence Interval for Mean	
3.8585	3.8977
95% Confidence Interval for Median	
3.8500	3.9000
95% Confidence Interval for StDev	
0.6984	0.7261

Histogram of all test results showing that the FEV_1 data is normally distributed. The Confidence Interval for the mean and median are both narrow and the mean and median are almost identical making the distribution almost symmetrical.

Results: SAMPLE CHARACTERISTICS/ DEMOGRAPHICS

Total subjects	1041	89.6% male; 83.4% >28yrs
Mean age	**41 years**	Range (16-73)
Mean tenure	**12 years**	Range (3-37)
Dust exposure	**26.2% high, 40.2% mod**	33.6% low
Pot-room workers	468	45%
Ever smoked	**525**	**50.5%**
Current smokers	204	19.6%
Mean BMI	28.8	

FEV1	litres	
Mean	**3.88**	Range (3.02-4.03)
Male	3.95	
Female	3.12	
Ever smoked	**3.78**	
Never smoked	3.99	
Tenure >20 years	**3.47**	
High dust & >20 years	**3.26**	
High dust & >20 pack y	**3.29**	
High dust, >20 y & >20 pack years	**3.02**	

results: ANOVA

PERMANOVA ANALYSIS OF VARIANCE FOR DIFFERENCES BETWEEN FIRST TEST (2010) AND LAST TEST (2015)

Table 6- FEV_1 Correlations

		Correlation R	Sum of squares	df	Mean-Square	F-ratio	P
Age	Male	-0.516	575.228	1	575.228	1673.257	0.000
	Female	-0.421	21.063	1	21.063	98.467	0.000
Height	Male	0.484	506.783	1	506.783	1413.105	0.000
	Female	0.572	38.825	1	38.825	221.81	0.000
Weight	Male	0.029	1.868	1	1.868	3.991	0.046
	Female	0.171	3.458	1	3.458	13.699	0.000
Tenure	Male	-0.316	215.587	1	215.587	511.082	0.000
	Female	-0.172	3.502	1	3.502	13.877	0.000
Smoking Pack Years	Male	-0.31	205.505	1	205.505	483.533	0.000
	Female	-0.302	10.799	1	10.799	45.701	0.000

Results: 3 factor anova permutations

Table 7- FEV_1 Analyses in Permanova looking at the differences between the first test and the last test

Variables	Permutations	Sum of Squares	df	Mean- Square	F	P
Sex x Age x Weight	Sex	176.67	1	176.67	489.88	**0.001**
	Age	54.077	1	54.077	149.95	**0.001**
	weight	2.944	1	2.944	8.163	**0.003**
	Sex x Age	4.543	1	4.543	12.598	**0.001**
	Sex x weight	3.82E-02	1	3.82E-02	0.105	0.744
	Age x weight	1.89E-02	1		5.25E-02	0.822
	Sex x Age x weight	1.127	1	1.127	3.127	0.073
First test- last test x smoking x sex	First test- last test	2.001	1	2.001	4.564	**0.034**
	Smoking	7.632	2	3.816	8.705	**0.002**
	Sex	168.28	1	168.28	383.88	**0.001**
	First test- last test x smoking	0.112	2	5.60E-02	0.127	0.873
	First test- last test x sex	0.104	1	0.104	0.238	0.638
	Smoking x sex	4.797	2	2.398	5.471	**0.004**
	First test- last test x smoking x sex	6.86E-02	2	3.43E-02	7.82E-02	0.908
First test-last test x smoking status x Department	First test- last test	5.599	1	5.599	11.369	**0.003**
	Smoking status (current vs Ex vs Never)	41.677	2	20.839	42.312	**0.001**
	Department (Reduction lines vs other)	0.19	1	0.19	0.386	0.558
	First test- last test x smoking	1.16E-02	2	5.78E-02	1.17E-02	0.991
	First test- last test x Department	0.833	1	0.833	1.691	0.204
	Smoking x Department	2.834	2	1.417	2.877	0.065
	First test x Smoking x Department	0.981	2	0.49	0.996	0.374
First test- last test x dust rating x Department	First test- last test	1.406	1	1.406	2.789	0.102
	Dust rating	2.461	2	1.231	2.441	0.082
	Department	1.481	1	1.481	2.938	0.108
	First test- last test x dust rating	0.221	2	0.111	0.219	0.808
	First test- last test x Department	0.437	1	0.437	0.867	0.332
	Dust rating x Department	1.322	2	0.661	1.311	0.270
	First test- last test x Dust rating x Department	0.429	2	0.214	0.425	0.650
Smoking status x Dust rating x Department	Smoking	12.722	2	6.361	12.882	**0.001**
	Dust	2.56	2	1.28	2.593	0.073
	Department	0.585	1	0.585	1.185	0.292
	Smoking x dust	2.864	4	0.716	1.44	0.202
	Smoking x department	3.148	2	1.574	3.188	**0.034**
	Dust x department	1.462	2	0.731	1.48	0.239
	Smoking x dust x department	3.453	4	0.863	1.748	0.150

Results: Box plot analysis

Figure 5- Boxplot of FEV_1 by smoking pack years

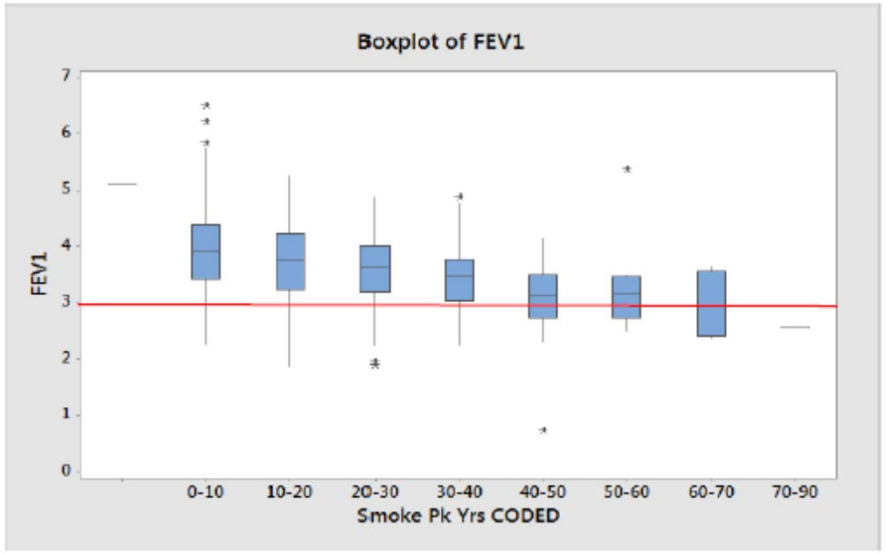
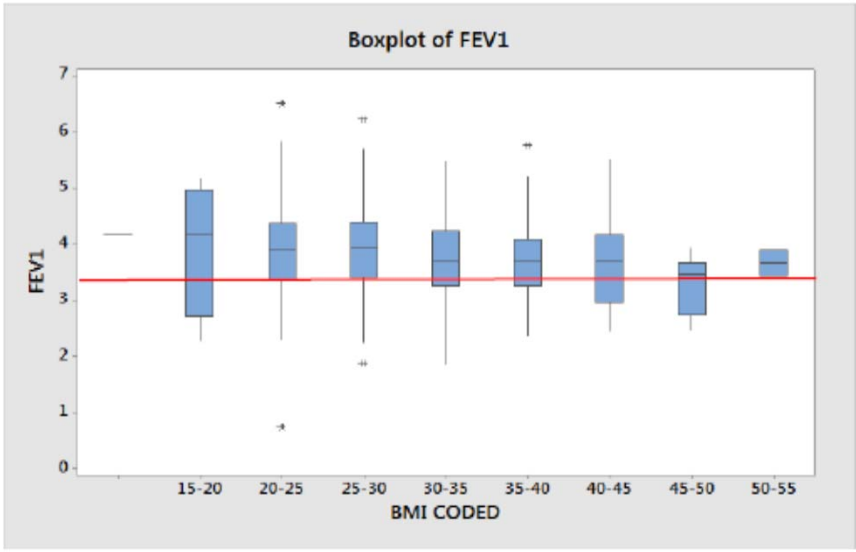


Figure 7- Boxplot of FEV_1 by BMI



Results: Spirola analysis- longitudinal decline in mean FEV_1

Table 8- Longitudinal Decline in Mean FEV_1

Category	FEV_1 (ml/year)	RMSE (ml)	RANK
Non-operational workers	32	101	27
Reduction Services	34	114	26
Reduction Line 3	34	88	25
Never smoked	34	103	24
Carbon	35	106	23
Previous respiratory condition	35	131	22
Male	37	103	21
Female	35	98	20
10-19 years in role	35	99	19
Moderate dust exposure	37	107	17
<9 years in role	37	107	16
All employees	37	101	15
No previous respiratory condition	38	98	14
>10 years in role	38	98	13
High dust exposure	39	100	12
20-29 years in role	39	90	11
All Reduction Lines	40	99	10
Ex-smoker	40	101	9
Low dust exposure	42	81	6
Maintenance	44	81	5
Reduction Line 1/2	46	106	4
Metal Products	50	89	3
Recent respiratory infection	56	138	2
>30 years in role	57	128	1

Table 9. Slope for employees with loss greater than 300mls or 500mls over 5 years

Category	FEV_1 (ml/years)	RMSE (ml)
Employees with >300ml decline from First test to last test	86*	112
Employees with >500ml decline from First test to last test	117*	138

Findings and Implications of the research

- **Negative correlation between FEV1 and smoking, age, tenure, dust exposure, BMI and respiratory infections (rate 1.5 to 2 times normal)**
  - **14.6 % with double rate, 2.9% accelerated loss (below Longitudinal Limit of Decline)**
  - **11.7% have FER < 70% or below LLN**
- **More work needs to be done to reduce the dust exposure in aluminium smelting**
- **SPIROLA offers an opportunity to better evaluate lung function data. SPIROLA provides an easy way of closely monitoring spirometry data and identifying individuals at high risk**

Limitations

- **Retrospective study**-limited ability to draw conclusions
- **Some key data such as SEG data was not available for individual work tasks**
- The hygiene data reports total exposure to dust **without specifying the dust type.**
- It is not certain whether the changes to lung function identified in this study are **permanent**
- **No attempt has been made to make a correlation between excessive loss in lung function and clinical symptoms**

DISCUSSION

Recommendation

- **Further follow up of affected workers to determine the clinical significance** of changes and the impact of ceasing exposure
- **Closer monitoring of smokers**, smoking cessation programs and potential to exclude smokers from potroom environment
- **Employees who have been identified as being higher risk need further study**. A closer review of individual employee results needs to be carried out to identify other factors which this study has not identified.
- The respiratory surveillance program needs to **change from department to SEG** to enable a better correlation between lung function changes and exposures in future studies.
- **Employees exposed to these dusts need better protection** including training, monitoring and appropriate respiratory protection
- **A cohort study with newer employees without legacy exposures**

Conclusion

- There is evidence of higher than normal annual decline in lung function in aluminium pot-room workers
- This loss is accelerated in less than 2.9% of the worker population with half of those affected working in the pot-room environment.
- **Potroom dust exposure in the presence of cigarette smoking is a significant risk factor** for accelerated loss of lung function in aluminium smelting.
- Future studies should use stricter SEG data to draw a better linkage with specific work tasks

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QUESTIONS

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