

Breathing at Work: Assessing Occupational Airborne Exposure and Respiratory Health Risks in Manufacturing Workers

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Abstract

Background: Occupational exposure to airborne dust and particulate matter may adversely affect respiratory health among manufacturing workers. This study assessed the relationship between occupational airborne exposure, respiratory symptoms, and pulmonary function among manufacturing workers in Lahore, Pakistan. **Methods:** An analytical cross-sectional study was conducted among 200 manufacturing workers. Occupational exposure was assessed using PM_{2.5}, PM₁₀, total dust, and respirable dust measurements. Participants were categorized into low-, moderate-, and high-exposure groups. Respiratory symptoms were assessed using a structured questionnaire, while pulmonary function was evaluated using spirometry. Associations between categorical variables were assessed using Pearson's chi-square test. One-way ANOVA with Tukey post-hoc testing was used to compare spirometric parameters across exposure groups. Pearson correlation was used to examine relationships between continuous exposure measurements and lung-function parameters. **Results:** Respiratory health impairment was significantly more prevalent among workers with higher exposure, increasing from 49.3% in the low-exposure group to 80.3% in the high-exposure group ($p=0.001$). Cough, phlegm, and wheezing were significantly associated with exposure category ($p=0.003$, $p=0.026$, and $p=0.011$, respectively). Mean FEV₁ and FEV₁/FVC were significantly lower among highly exposed workers ($p=0.002$ and $p=0.021$, respectively), whereas FVC did not differ significantly. PM_{2.5}, PM₁₀, total dust, and respirable dust were significantly and negatively correlated with FEV₁. **Conclusion:** Higher occupational airborne exposure was associated with increased respiratory symptoms, respiratory health impairment, and poorer pulmonary function. Strengthening workplace exposure controls, respiratory protection, and periodic respiratory health surveillance is warranted among manufacturing workers.

Keywords: Occupational exposure; Airborne dust; Manufacturing workers; Respiratory health; Spirometry

Introduction

Occupational exposure to airborne contaminants remains an important environmental and occupational health concern, particularly in manufacturing industries where workers may encounter dust, particulate matter, fumes, and process-specific contaminants. Repeated inhalation of these pollutants can contribute to respiratory symptoms, impaired pulmonary function, and longer-term

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occupational respiratory disease. Evidence from industrial populations indicates that exposure to dust and fumes is associated with increased respiratory symptoms and measurable deficits in lung function, including reductions in forced expiratory volume in one second (FEV₁) and FEV₁/FVC ratio [1,2]. A recent systematic review and meta-analysis among factory workers also reported a substantial burden of occupational respiratory symptoms, emphasizing the importance of workplace exposure control and respiratory protection [3].

The issue is particularly relevant in Pakistan, where manufacturing workers may be exposed to poorly controlled airborne contaminants. A recent Pakistani study among 498 textile workers demonstrated the feasibility of combining standardized respiratory questionnaires, spirometry, and workplace dust measurements to evaluate relationships between occupational dust exposure and respiratory health [4]. Earlier evidence from Pakistani cement manufacturing has likewise documented pulmonary illness among exposed workers, highlighting the need for effective occupational health strategies [5]. International evidence further suggests that occupational exposure to dusts and fibers represents an important contributor to the global burden of work-related disease [6].

Despite this evidence, assessment of occupational airborne exposure often focuses on either environmental measurements or health outcomes separately. An integrated assessment incorporating measured particulate exposure, respiratory symptoms, and objective spirometric parameters can provide a more comprehensive understanding of respiratory risks among manufacturing workers. Furthermore, examining both categorical exposure levels and continuous measures such as PM_{2.5}, PM₁₀, total dust, and respirable dust may help identify exposure–response patterns.

Therefore, the present study, “Breathing at Work: Assessing Occupational Airborne Exposure and Respiratory Health Risks in Manufacturing Workers,” was undertaken to assess airborne occupational exposure among manufacturing workers and determine its relationship with respiratory symptoms and pulmonary function. The study specifically evaluates exposure levels, respiratory health impairment, and spirometric parameters, including FEV₁, FVC, and FEV₁/FVC, to provide evidence for strengthening workplace respiratory health surveillance and preventive measures.

Methodology

Study design and setting

An analytical cross-sectional study was conducted among manufacturing workers in Lahore, Punjab, Pakistan. Lahore is a major industrial and manufacturing center where workers may be exposed to particulate matter, dust, fumes, and other process-related airborne contaminants. Previous occupational studies conducted in and around Lahore have documented respiratory health effects among industrial workers, including textile workers exposed to airborne endotoxin and dust [7,8]. Pakistani research has also demonstrated an association between occupational dust exposure and impaired lung function, supporting the use of workplace exposure assessment together with respiratory questionnaires and spirometry [9].

The study was conducted in selected manufacturing workplaces in Lahore representing a range of production activities, including processing, production, mixing, packaging, maintenance, grinding/cutting, welding, and quality control. Data collection incorporated worker characteris-

tics, occupational exposure information, respiratory symptoms, environmental exposure measurements, and pulmonary function assessment.

Study population and sample size

The sample size was based on a 56% expected prevalence of respiratory symptoms, derived from the Pakistan-based study by Sadia et al. [10]. Using a 95% confidence level and 7.5% precision, the calculated minimum sample size was 169 participants. After allowing for approximately 10% potential non-response, incomplete questionnaires, or unacceptable spirometry, the required sample increased to approximately 188 participants. Therefore, a final target sample of 200 manufacturing workers was selected, providing a small additional margin beyond the adjusted requirement and allowing participants to be distributed across low-, moderate-, and high-exposure categories. [10].

Eligibility criteria

Workers were eligible if they were 20 years of age or older, were currently employed in the selected manufacturing workplace, and had sufficient occupational exposure to participate in the assessment. Workers who were unable to complete the questionnaire or spirometric assessment were excluded. Participants with information required for the primary exposure or respiratory-health analyses missing were also excluded from the respective analyses.

Data collection

Data were collected using a structured questionnaire covering demographic characteristics, occupational history, working hours, duration of employment, smoking status, previous respiratory history, respiratory symptoms, workplace exposure characteristics, and use of respiratory protective equipment. Respiratory symptoms assessed included cough, phlegm, wheezing, shortness of breath, chest tightness, and breathing difficulty during work.

Occupational airborne exposure was assessed using measurements of $PM_{2.5}$, PM_{10} , total dust, and respirable dust, together with information regarding process-specific contaminants and workplace exposure conditions. Workers were subsequently categorized into low, moderate, and high environmental exposure groups based on the study's predefined exposure classification.

Spirometry

Pulmonary function was assessed using spirometry. The principal spirometric outcomes were forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and FEV_1/FVC ratio. Multiple spirometric trials were performed and the best recorded values were used for analysis. Spirometry has been widely used in occupational respiratory studies in Pakistan to assess the relationship between workplace dust exposure and pulmonary function [8,9].

Outcome assessment

The principal respiratory outcomes were respiratory symptoms and respiratory health impairment. Respiratory health impairment was classified according to the predefined study criteria incorporating the recorded respiratory health and spirometric findings. The analysis focused on dif-

ferences in respiratory outcomes across environmental exposure categories and relationships between continuous airborne exposure measurements and pulmonary function.

Statistical analysis

Data were analyzed using SPSS 26.0. Continuous variables were summarized using means and standard deviations, while categorical variables were presented as frequencies and percentages. Associations between categorical exposure groups and respiratory outcomes were assessed using the Pearson chi-square test. Differences in mean FEV₁, FVC, and FEV₁/FVC across the three exposure categories were evaluated using one-way analysis of variance (ANOVA). Where the overall ANOVA was statistically significant, Tukey's post-hoc test was used for pairwise comparisons. Pearson correlation coefficients were calculated to examine relationships between continuous airborne exposure measurements and lung-function parameters. Statistical significance was defined as $p < 0.05$, and all tests were two-tailed.

Ethical considerations

The study was conducted in accordance with established principles for research involving human participants. Participation was voluntary, and participants were informed about the purpose and procedures of the study before data collection. Written informed consent was obtained from participants, and confidentiality of individual information was maintained throughout the study. Participants were identified using study codes rather than names in the analytical dataset.

Results

Participant characteristics and occupational exposure

A total of 200 manufacturing workers were included in the analysis, with complete data available for all variables examined. The mean age of participants was 38.54 ± 7.33 years, with an age range of 20–59 years. The majority were male (162, 81.0%), while 38 (19.0%) were female. Participants had a mean BMI of 25.31 ± 4.18 kg/m² and had worked in their current employment for a mean of 6.30 ± 2.96 years. Mean daily working time was 8.54 ± 0.90 hours. The largest occupational department was production (22.5%), followed by processing (17.0%), packaging (15.5%), and mixing (14.5%).

The mean measured concentrations were 31.68 ± 14.60 µg/m³ for PM_{2.5}, 74.90 ± 35.33 µg/m³ for PM₁₀, 1.93 ± 0.95 mg/m³ for total dust, and 0.97 ± 0.55 mg/m³ for respirable dust. Mean FEV₁ was 4.12 ± 0.48 L, FVC was 5.17 ± 0.57 L, and FEV₁/FVC was 0.797 ± 0.054 . Workers were distributed almost equally across the predefined environmental exposure categories: 67 (33.5%) low exposure, 67 (33.5%) moderate exposure, and 66 (33.0%) high exposure.

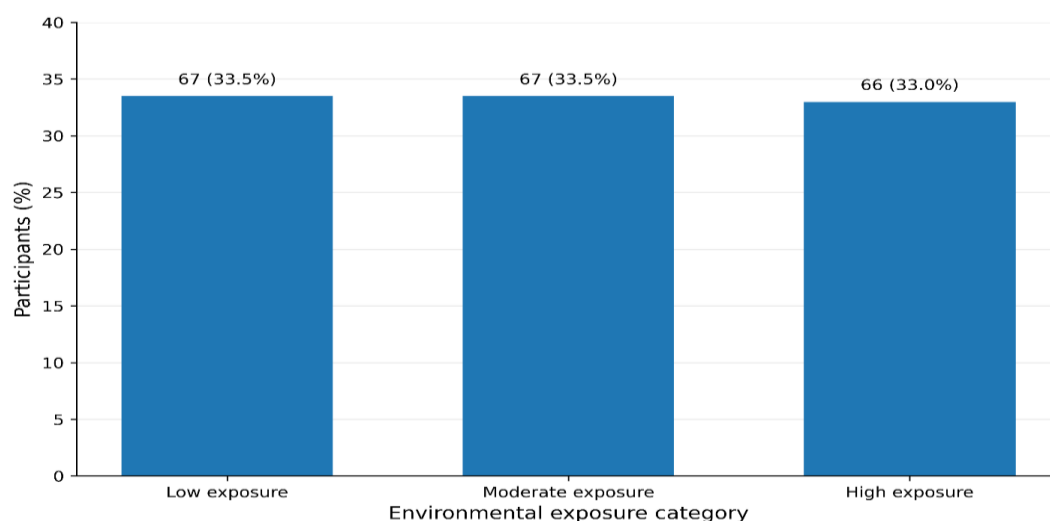
Table 1. Participant characteristics, occupational exposure measurements, and baseline respiratory parameters

Characteristic	Value
Participants, n	200
Age, years	38.54 ± 7.33
Age range, years	20–59
Sex, n (%)	Male 162 (81.0)

	Female	38 (19.0)
BMI, kg/m²		25.31 ± 4.18
Employment duration, years		6.30 ± 2.96
Working hours/day		8.54 ± 0.90
PM_{2.5}, µg/m³		31.68 ± 14.60
PM₁₀, µg/m³		74.90 ± 35.33
Total dust, mg/m³		1.93 ± 0.95
Respirable dust, mg/m³		0.97 ± 0.55
FEV₁, L		4.12 ± 0.48
FVC, L		5.17 ± 0.57
FEV₁/FVC		0.797 ± 0.054
PEF, L/s		5.20 ± 0.69
Environmental exposure category, n (%)	Low	67 (33.5)
	Moderate	67 (33.5)
	High	66 (33.0)

Values are mean ± SD unless otherwise indicated.

Figure 1. Distribution of workers according to environmental exposure category



Respiratory symptoms according to exposure category

Overall, 23.0% of workers reported cough during the preceding 12 months, while 20.0% reported phlegm, 12.0% wheezing, 15.5% shortness of breath, 11.0% chest tightness, and 16.5% breathing difficulty during work. There were no missing observations for these respiratory symptom variables. A significant association was observed between environmental exposure category and cough. Cough was reported by 31.8% of workers in the high-exposure group, compared with 28.4% in the moderate-exposure group and 9.0% in the low-exposure group ($\chi^2(2)=11.447$, $p=0.003$).

Similarly, phlegm was more frequently reported among highly exposed workers (30.3%) than among workers with moderate (17.9%) or low exposure (11.9%), with a statistically significant association ($\chi^2(2)=7.282$, $p=0.026$). Wheezing was reported by 21.2% of workers in the high-

exposure group, compared with 10.4% in the moderate-exposure group and 4.5% in the low-exposure group. This difference was statistically significant ($\chi^2(2)=9.047$, $p=0.011$). In contrast, no statistically significant association was observed between exposure category and shortness of breath ($\chi^2(2)=3.929$, $p=0.140$) or breathing difficulty during work ($\chi^2(2)=3.639$, $p=0.162$). Chest tightness was also not significantly associated with exposure category ($\chi^2(2)=1.734$, $p=0.420$).

Table 2. Respiratory symptoms according to environmental exposure category

Respiratory outcome	Low, n (%)	Moderate, n (%)	High, n (%)	χ^2 (df)	p-value
Cough	6 (9.0)	19 (28.4)	21 (31.8)	11.447 (2)	0.003
Phlegm	8 (11.9)	12 (17.9)	20 (30.3)	7.282 (2)	0.026
Wheezing	3 (4.5)	7 (10.4)	14 (21.2)	9.047 (2)	0.011
Shortness of breath	8 (11.9)	8 (11.9)	15 (22.7)	3.929 (2)	0.140
Chest tightness	6 (9.0)	6 (9.0)	10 (15.2)	1.734 (2)	0.420
Breathing difficulty during work	7 (10.4)	11 (16.4)	15 (22.7)	3.639 (2)	0.162

Percentages are calculated within exposure categories. Pearson chi-square tests were used.

Respiratory health impairment

Overall, 131 of 200 workers (65.5%) were classified as having respiratory health impairment. The prevalence increased progressively across exposure categories, from 49.3% in the low-exposure group to 67.2% in the moderate-exposure group and 80.3% in the high-exposure group. This association was statistically significant ($\chi^2(2)=14.308$, $p=0.001$).

Table 3. Respiratory health impairment according to environmental exposure category

Exposure category	No impairment, n (%)	Impairment, n (%)	Total
Low	34 (50.7)	33 (49.3)	67
Moderate	22 (32.8)	45 (67.2)	67
High	13 (19.7)	53 (80.3)	66
Total	69 (34.5)	131 (65.5)	200

Pearson $\chi^2(2)=14.308$, $p=0.001$.

Spirometric findings across exposure categories

Mean FEV₁ differed significantly across environmental exposure groups. Mean FEV₁ was 4.22 ± 0.42 L in the low-exposure group, 4.20 ± 0.45 L in the moderate-exposure group, and 3.96 ± 0.53 L in the high-exposure group. The overall one-way ANOVA was statistically significant ($F(2,197)=6.411$, $p=0.002$), while Levene's test indicated no significant heterogeneity of variance ($p=0.095$).

Tukey post-hoc testing demonstrated that the high-exposure group had significantly lower FEV₁ than both the low-exposure group (mean difference -0.263 L, $p=0.004$) and the moderate-exposure group (mean difference -0.241 L, $p=0.009$). No significant difference was observed between the low- and moderate-exposure groups ($p=0.963$).

In contrast, FVC did not differ significantly across exposure categories. Mean FVC was 5.26 ± 0.53 L in the low-exposure group, 5.20 ± 0.58 L in the moderate-exposure group, and 5.06 ± 0.60 L in the high-exposure group. The overall ANOVA was not statistically significant ($F(2,197)=2.122$, $p=0.123$), and Levene's test was also non-significant ($p=0.232$).

The FEV_1/FVC ratio also differed significantly across exposure categories. Mean values were 0.804 ± 0.045 in the low-exposure group, 0.805 ± 0.054 in the moderate-exposure group, and 0.782 ± 0.060 in the high-exposure group. One-way ANOVA demonstrated a significant overall difference ($F(2,197)=3.931$, $p=0.021$), with no evidence of unequal variances (Levene's $p=0.127$).

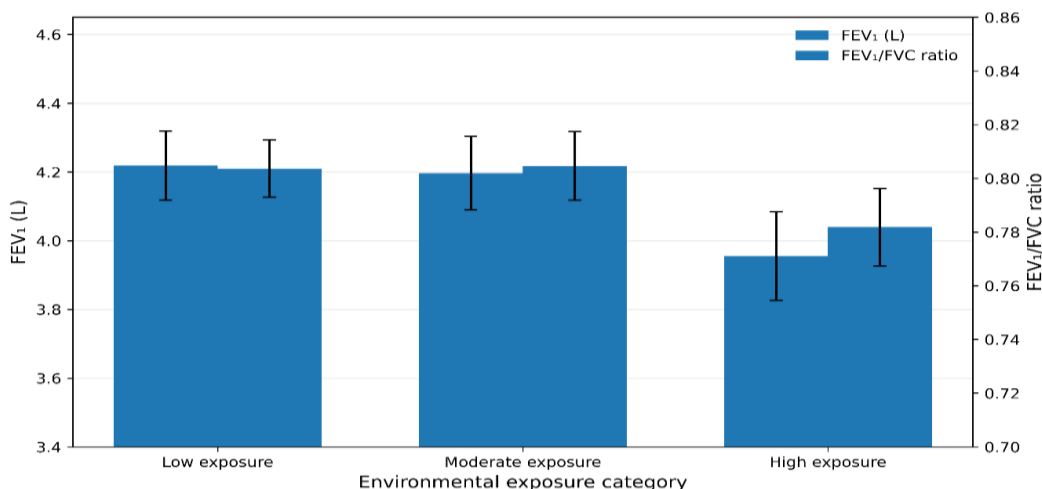
Tukey testing showed that the high-exposure group had a significantly lower FEV_1/FVC ratio than both the low-exposure group (mean difference -0.0218 , $p=0.049$) and moderate-exposure group (mean difference -0.0229 , $p=0.036$). The low- and moderate-exposure groups did not differ significantly ($p=0.992$).

Table 4. Spirometric parameters according to environmental exposure category

Parameter	Low exposure	Moderate exposure	High exposure	F (2,197)	p-value
FEV_1, L	4.218 ± 0.419	4.197 ± 0.448	3.956 ± 0.534	6.411	0.002
FVC, L	5.255 ± 0.529	5.197 ± 0.577	5.057 ± 0.599	2.122	0.123
FEV_1/FVC	0.804 ± 0.045	0.805 ± 0.054	0.782 ± 0.060	3.931	0.021

Values are mean $\pm$ SD. One-way ANOVA was used for overall comparisons.

Figure 2. Lung-function measures according to environmental exposure category



Bars represent mean values; error bars represent 95% confidence intervals. FEV_1 = forced expiratory volume in 1 second; FVC = forced vital capacity.

Correlation between measured airborne exposure and lung function

Correlation analyses demonstrated a consistent inverse relationship between measured airborne particulate/dust concentrations and FEV_1 . $PM_{2.5}$ was weakly negatively correlated with FEV_1 ($r=-0.206$, $p=0.003$). Similarly, PM_{10} ($r=-0.217$, $p=0.002$), total dust ($r=-0.245$, $p<0.001$), and respirable dust ($r=-0.247$, $p<0.001$) were all significantly and negatively correlated with FEV_1 .

For FEV₁/FVC, PM₁₀ demonstrated a weak negative correlation ($r=-0.143$, $p=0.043$), as did total dust ($r=-0.162$, $p=0.022$) and respirable dust ($r=-0.183$, $p=0.009$). The correlation between PM_{2.5} and FEV₁/FVC did not reach statistical significance ($r=-0.136$, $p=0.055$).

Table 5. Correlations between airborne exposure measurements and lung-function parameters

Exposure measure	FEV ₁ , r	p-value	FEV ₁ /FVC, r	p-value
PM _{2.5}	-0.206	0.003	-0.136	0.055
PM ₁₀	-0.217	0.002	-0.143	0.043
Total dust	-0.245	<0.001	-0.162	0.022
Respirable dust	-0.247	<0.001	-0.183	0.009

Pearson correlation coefficients; N=200 for all analyses.

Smoking status and other factors

Respiratory health impairment was reported in 73.3% of current smokers, 71.1% of former smokers, and 58.8% of never smokers. However, the association between smoking status and respiratory health impairment was not statistically significant ($\chi^2(2)=4.160$, $p=0.125$).

Smoking status also did not differ significantly across exposure categories ($\chi^2(4)=2.091$, $p=0.719$), with current smoking reported by 28.8%, 28.4%, and 32.8% of workers in the high-, low-, and moderate-exposure groups, respectively.

Employment duration showed a weak but non-significant inverse correlation with FEV₁ ($r=-0.112$, $p=0.113$). In contrast, age was significantly and negatively correlated with FEV₁ ($r=-0.231$, $p=0.001$).

Discussion

The present study demonstrates a consistent association between occupational airborne exposure and adverse respiratory health outcomes among manufacturing workers in Lahore. Workers in the high-exposure category had substantially greater prevalence of cough, phlegm, wheezing, and overall respiratory health impairment than those in the low-exposure category. These findings are consistent with the broader occupational literature, which identifies airborne dust exposure as an important determinant of respiratory symptoms among industrial workers. A 2023 systematic review and meta-analysis reported a pooled prevalence of approximately 55% for respiratory symptoms among factory workers exposed to occupational dust, while longer work experience, inadequate use of personal protective equipment (PPE), and prolonged working hours were identified as important associated factors [11].

The progressive increase in respiratory health impairment observed in the present study—from 49.3% among low-exposure workers to 67.2% among moderate-exposure workers and 80.3% among high-exposure workers—is particularly noteworthy. This pattern supports the biological plausibility of an exposure-related respiratory burden, although causality cannot be established because of the cross-sectional design. Similar concerns have been documented in Pakistan. A study of cement-factory workers reported significantly greater pulmonary illness among exposed

workers, emphasizing the importance of workplace exposure control in preventing occupational respiratory morbidity [12].

Objective lung-function findings further strengthened the observed relationship. FEV₁ was significantly lower among highly exposed workers, with post-hoc analysis demonstrating significant differences between the high-exposure group and both low- and moderate-exposure groups. Likewise, FEV₁/FVC was significantly lower in the high-exposure group, whereas FVC did not differ significantly between exposure categories. This pattern suggests that occupational airborne exposure may be more closely related to airflow limitation than to reductions in overall lung volume in this population. Previous research among dust-exposed industrial workers has similarly demonstrated reductions in FEV₁ and FVC, supporting the use of spirometry as an objective component of occupational respiratory surveillance [13].

An important strength of the present findings is the consistency between categorical exposure analyses and continuous exposure measurements. PM_{2.5}, PM₁₀, total dust, and respirable dust were all negatively correlated with FEV₁, while PM₁₀, total dust, and respirable dust were also significantly associated with lower FEV₁/FVC. This exposure–lung-function pattern provides additional support for a relationship between increasing airborne particulate burden and poorer respiratory function. The importance of occupational dust exposure is also reflected in the WHO/ILO evidence base, which recognizes substantial occupational exposure to hazardous dusts and their contribution to work-related disease [14].

Smoking did not differ significantly across exposure categories and was not significantly associated with overall respiratory health impairment in this sample. Nevertheless, smoking remains an important potential respiratory confounder and should continue to be considered in occupational health surveillance. Overall, these findings support strengthening workplace engineering controls, ventilation, dust suppression, PPE use, and periodic respiratory screening among manufacturing workers in Lahore.

Conclusion

This study found a clear association between occupational airborne exposure and respiratory health among manufacturing workers in Lahore. Higher exposure was associated with increased respiratory symptoms, particularly cough, phlegm, and wheezing, as well as greater overall respiratory health impairment. High-exposure workers also demonstrated significantly lower FEV₁ and FEV₁/FVC values. Increasing PM_{2.5}, PM₁₀, total dust, and respirable dust concentrations were negatively correlated with lung function. Although causality cannot be established from this cross-sectional study, the findings support stronger workplace ventilation, dust-control measures, respiratory protective equipment, worker training, and regular respiratory health surveillance.

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