


RESEARCH ARTICLE



## Impaired exercise capacity in electrostatic polyester powder paint workers

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### ABSTRACT

**Purpose:** Limited number of studies investigated the effects of Electrostatic powder paints (EPP) on human health. We investigated the effects of EPP exposure on lung function, exercise capacity, and quality of life, and the factors determining exercise capacity in EPP workers.

**Methods:** Fifty-four male EPP workers and 54 age-matched healthy male individuals (control group) were included. Lung function and respiratory muscle strength were measured. The lower limit of normal (LLN) cut-points for FEV<sub>1</sub> and FEV<sub>1</sub>/FVC were calculated. An EPT was used to evaluate bronchial hyperactivity. The handgrip and quadriceps muscle strength were evaluated using a hand-held dynamometer. An ISWT was used to determine exercise capacity. The physical activity level was questioned using the IPAQ. The SGRQ and NHP were used to assessing respiratory specific and general quality of life, respectively.

**Results:** Duration of work, FEV<sub>1</sub>, MIP, handgrip strength, and ISWT distance were significantly lower, and the change in FEV<sub>1</sub> after EPT and %HRmax were significantly higher in the EPP group compared to the control group ( $p < 0.05$ ). There were no subjects with a < LLN for FEV<sub>1</sub> and FEV<sub>1</sub>/FVC in both groups. In the EPP group, ISWT distance was significantly related to age, height, duration of work, FEV<sub>1</sub>, change in FEV<sub>1</sub> after EPT, MIP, MEP, handgrip strength, IPAQ, SGRQ, and NHP total scores ( $p < 0.05$ ). The change in FEV<sub>1</sub> after EPT, MIP, and duration of work explained % 62 of the variance in the ISWT distance ( $p < 0.001$ ).

**Conclusions:** Changes in lung function based on LLN for the FEV<sub>1</sub> and FEV<sub>1</sub>/FVC were not clinically relevant in EPP workers. Exercise capacity is impaired in EPP workers. Degree of exercise-induced bronchospasm, inspiratory muscle strength, and duration of work are the determinants of exercise capacity in EPP workers.

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### KEYWORDS

Lung function; occupational pulmonary disease; exercise capacity; inhalation toxicity; chemical agent

## Introduction

Diseases or disorders caused by work and workplace are called occupational diseases. Although there is no definitive statistical data, it is estimated that one in 1000 workers in the industrialized countries get a new occupational disease every year. These rates differ between business lines. The amount of the effect varies depending on the occupational and personal factors (Kuschner and Stark 2003).

Despite the use of ether and chloroform in the aerosol mixtures until the 1950s, hydrocarbons have been used in aerosol mixture products, including spray paints, in recent years, due to their ease in obtaining and low costs (Kamens et al. 2011). Hydrocarbon inhalation is known to have hepatic, cardiac, neurological, and renal side effects (Tormoehlen et al. 2014). However, there are few reports on respiratory complications and chronic pulmonary sequelae (Beckett 2000).

Electrostatic powder paints (EPP) contain polyester, which is a hydrocarbon. It is a polymer that is formed by melting at a high temperature of petroleum and produced 'terephthalic acid' and 'ethyl glycol,' and it is a carcinogenic

substance (Pang et al. 2016). Polyester is used in electrostatic paint production due to its electrostatic properties. Polyesters are known to cause various skin diseases (Meyers 2010). In addition, it decreases the progesterone ratio in pregnant women due to its electrostatic effect and causes miscarriage. In male subjects, the use of polyester underwear has been reported to reduce sperm count and quality. The inhalation of polyester, which has serious side effects even in contact with the skin, is hazardous (Dale et al. 2014). When animal experiments conducted to investigate the effectiveness of polyester are examined, it is seen that exposure to polyester causes damage to the lung tissue the most. At 13 weeks, it has been shown to cause an increase in the weight, the number of macrophages and inflammatory cytokines of the affected lung tissue (Katz et al. 1997). In addition to the polyester in powder paints, organic, metallic, and plastic pigments, binders, and thinners are used. Each of these may accumulate in the lungs as a result of inhalation and may cause occupational lung diseases (Meyers 2010).

Studies on occupational lung diseases revealed a decrease in quality of life, lung function, and exercise capacity due to pulmonary fibrosis (Scirha et al. 2019) and gas exchange problems (Schneider et al. 2014). Studies investigating occupational lung disease in EPP workers are minimal, and the effects of EPP on lung function have been investigated (Cartier et al. 1994). In a case study, acute changes in lung function after polyester exposure were examined. Due to the wide usage area of EPP, possible health problems due to exposure to EPP would threaten the lives of many EPP workers. Nevertheless, there is no study in the literature comparing lung function and exercise capacity of EPP workers with a healthy group. Since there is limited knowledge, we aimed to determine lung function, exercise capacity, and quality of life in EPP workers and compare their values with those of healthy individuals in this study. The factors determining exercise capacity were also investigated. In this way, it was thought to anticipate the risks that may arise due to exposure to EPP in this occupational group and to express an opinion on taking necessary precautions.

## Materials and methods

### Participants

Fifty-four EPP male workers (EPP group) and 54 age-matched male healthy subjects (control group) participated in this study. We calculated (G\*Power Version 3.1.9.4, Franz Faul, Universitat Kiel, Germany) power of 80% with 0.05 significance, a difference to be detected of 0.43 liters, and a standard deviation of 0.86 in forced expiratory volume in one second (FEV<sub>1</sub>) values (Alexandersson et al. 1987), generating a sample of 51 patients per group.

Age, body weight, and height were recorded for each subject. Body mass index (BMI) was calculated using the body weight/height<sup>2</sup> (kg/m<sup>2</sup>) formula (Kuczmarski et al. 1997). In order to determine the risk factors, information about occupational exposure, smoking history (recorded as pack-years), and family history of lung disease was recorded. The study included EPP workers, working in the same factory, who could cooperate with measurements and tests, without any orthopedic, neurological, and vestibular problems, who were older than 18 years, and who were willing to participate in the study. The control group included age-matched healthy individuals without any health problems, working in the same factory, without any exposure to occupational lung disease factors, and who were willing to participate in the study. Individuals with an orthopedic, neurological and vestibular disease may prevent the completion of the test; those with cardiovascular problems that may affect exercise capacity, those with congenital anomalies, regular medication, and acute upper respiratory tract infection (e.g., H. influenza) were excluded from the study. The study was approved by the decision of the Erciyes University Medical School Ethics Committee, numbered 2017/511. Written informed consent was obtained from all participants.

The daily working hours and workloads of the EPP group and the control group were similar. For example,

EPP group employees carried the materials to be painted to the paint boiler, while the control group employees carried materials of similar weight and size to the assembly line.

### Experimental protocol

Quality of life questionnaires and the International Physical Activity Questionnaire (IPAQ) were first administered to the individuals included in the study on the day of evaluation. In order not to be affected by fatigue, lung function test, respiratory muscle strength and peripheral muscle strength measurements were performed before the incremental shuttle walk test (ISWT). ISWT was performed last, and measurements were completed that day. The next week, only exercise provocation test (EPT) test was performed on the same individuals. Individuals in the EPP and control groups participated in the measurements in random order.

Tests and questionnaires to all participating individuals were conducted after the last working day of the week (Friday), where exposure and accumulation were the highest during the week. The factories and their leadership were visited, and then measurements were made by creating suitable conditions in the factory (Asgedom et al. 2019). The ISWT and EPT were held once on Fridays with a week break.

### Modified medical research council (MMRC) dyspnea scale

Shortness of breath was evaluated using the Modified Medical Research Council (MMRC) dyspnea scale. It is a categorical scale in which individuals choose the most appropriate of the five expressions of dyspnea, between 0 and 4 points, to define their dyspnea levels (Bestall et al. 1999).

### Lung function test

In order to evaluate lung function, spirometry (Cosmed Pony FX Spirometer, Milan, Italy) was used to measure FEV<sub>1</sub>, forced vital capacity (FVC), FEV<sub>1</sub>/FVC, peak expiratory flow rate (PEF), and forced expiratory volume from 25 to 75% (FEF<sub>25-75%</sub>) based on the European Respiratory Society/American Thoracic Society (ERS/ATS) criteria. The test was performed in the sitting position. At least three technically acceptable measurements were obtained between the two best-measured FEV<sub>1</sub> values with no more than a 5% difference, and the best FEV<sub>1</sub> value was selected for analysis. The lower limit of normal (LLN) for FEV<sub>1</sub> and FEV<sub>1</sub>/FVC were calculated for each subject (Quanjer et al. 1993).

### Exercise provocation test (EPT)

The EPT was performed to show sensitivity to exercise in airways and to evaluate whether there was hyperactivity in bronchi due to EPP exposure in paint workers. No drugs or chemicals were used during this test. The volunteers were told to wear casual clothing and sports shoes during the test and avoid intense exercise four hours before the test.

Initially, baseline FEV<sub>1</sub> was determined. The exercise was started at a low speed, and the maximum heart rate (220-age) reached 80–90% in the first 2–3 minutes, and at this rate, it was aimed to reach a total of 6–8 minutes of test time by continuing for at least 4 minutes. The test was terminated after exercising for at least 4 minutes at the intended intensity. The FEV<sub>1</sub> measurements were repeated at the 1st, 3rd, 5th, 10th, 15th, 20th, and 30th minutes after the exercise. Since FEV<sub>1</sub> measurements performed after EPT should be performed in a short time, only one measurement was performed, and the values were recorded. Due to the nature of EPT, choosing the best measurement among the three measurements performed during the lung function test could not be applied. The FEV<sub>1</sub> value, which is the most significant difference with the initial value, was taken for analysis. A 12% decline in FEV<sub>1</sub> was considered positive for bronchial hyperactivity (De Meer et al. 2004).

### Respiratory muscle strength

Respiratory muscle strength was measured using spirometry (Cosmed Pony FX Spirometer, Milan, Italy). For the measurement of maximum inspiratory pressure (MIP), maximum expiration was performed to the person, and immediately the respiratory tract was closed with a valve, and then the person was asked to perform maximum inspiration for 1–3 s. For maximum expiratory pressure (MEP), a maximal inspiration was performed, and then the person was asked to perform a maximal expiration of 2 s against the closed airway. At least three technically acceptable maneuvers were performed, with no more than a 5% difference between the two best-measured values (American Thoracic Society 1995).

### Peripheral muscle strength

Peripheral muscle strength was determined by measuring handgrip strength and quadriceps muscle strength using a digital dynamometer (Jtech Commander Muscle Tester, UT). The mean values of the right and left side measurements were obtained. Then, the measurements were recorded in Newton (N) using the averaging of each side's measurements (Harkonen et al. 1993).

### Incremental shuttle walk test (ISWT)

The ISWT was performed to assess the exercise capacity of individuals. The test is set to 10 m between two lines for testing. The individual walks the distance of 10 m as a round trip and runs as necessary. The test starts at a slow walking speed (0.5 m/s) and continues with increasing signals at a rate of 0.17 m/s. The individual can terminate the test because of tiredness or by his request. At the end of the test, the distance traveled by the individual is recorded (Singh et al. 1992). Heart rate, blood pressure, oxygen saturation (Cosmed Spiropalm 6MWT, Milan, Italy), respiratory rate, dyspnea, and fatigue level using the modified Borg Scale (Borg 1982) were evaluated before and after the ISWT.

### International physical activity questionnaire (IPAQ) short form

IPAQ short form was used to assess participants' physical activity levels. Severe, moderate-severe, and walking include seven questions that question the time elapsed while doing these. Sitting time is considered a separate question. Metabolic equivalence (MET-minute) score is obtained as a result of calculations. Total MET values are calculated, and those with a total MET value of <600 MET-min/week inactive, 600–3000 MET-min/week of minimum active, and >3000 MET-min/week are classified as very active (Saglam et al. 2010).

### St George respiratory questionnaire (SGRQ) and Nottingham health profile (NHP)

SGRQ and NHP for quality of life were used. The SGRQ is a disease-specific quality of life questionnaire consisting of 76 items, the symptoms part (29 items), the activity part (9 items), and the effect part (38 items) (Polatli et al. 2013). The NHP is a frequently used measurement to assess the perceived health status. Some problems that people may encounter in daily life are questioned in seven sub-categories: pain, emotional reactions, sleep, social isolation, physical activity, and energy consumption (Kucukdeveci et al. 2000).

### Statistical analysis

Statistical analyses and graphs were performed using SPSS Statistics 22.0 (IBM Inc., Armonk, NY) and GraphPad Prism 9.0.0 (GraphPad Software, San Diego, CA). Values were presented as the mean and related standard deviation, median values with minimum and maximum, frequencies, and percentages. Kolmogorov–Smirnov test was applied to determine the compatibility of the parametric data with the normal distribution. Student's *t*-test and Mann–Whitney U test were used to compare the measured values of EPP and control groups, as appropriate. Chi-square test (Pearson's Chi-square, Yates corrected Chi-square) was used to examine the relationship between the variables. Spearman's correlation analysis was performed to examine the relationship between numerical variables because the data were parametric. Multiple linear regressions with the stepwise method were performed to determine the factor explaining the ISWT distance. Variables (age, height, duration of work, FEV<sub>1</sub>, the change in FEV<sub>1</sub> after the EPT, MIP, MEP, handgrip strength, IPAQ, SGRQ, and NHP) were included if they had a significant correlation with the ISWT distance. The probability of error in statistical analysis was determined as  $p < 0.05$ .

## Results

### Participant characteristics

Participant characteristics are summarized in Table 1. Age, body weight, height, smoking history, and BMI were similar

**Table 1.** Physical and demographic characteristics and dyspnea in electrostatic powder paint workers and the control groups.

Parameter	EPP Group (n = 54) Mean ± SD	Control Group (n = 54) Mean ± SD	p Value
Age (years) <sup>b</sup>	30.11 ± 6.78	31.55 ± 6.85	0.274
Height (cm) <sup>b</sup>	177.03 ± 4.63	176.16 ± 4.99	0.350
Weight (kg) <sup>b</sup>	73.40 ± 6.86	74.51 ± 6.40	0.387
BMI (kg/m <sup>2</sup> ) <sup>a,c</sup>	23.37 (18.81–29.41)	23.45 (20.45–29.39)	0.147
Smoking exposure (pack-years) <sup>a,c</sup>	6 (0–36)	7 (0–25)	0.856
Duration of work (years) <sup>a,c</sup>	4 (1–11)	5 (1–25)	<b>0.021*</b>
MMRC score <sup>a,c</sup>	0 (0–1)	0 (0–1)	0.465

\*The bold values represents as statistically significant  $p < 0.05$  values.

<sup>a</sup>Expressed in median (min–max).

<sup>b</sup>Student's *t*-test,

<sup>c</sup>Mann–Whitney U test (Different tests were used due to distribution difference).

EPP: Electrostatic powder paint; BMI: Body mass index; MMRC: Modified Medical Research Council Dyspnea Scale.

between the EPP group and the control group ( $p > 0.05$ ). Of the volunteers in the EPP group, 34 (63.0%) were active smoker, six (11.1%) were former smoker, and 14 (25.9%) were nonsmoker. Of the subjects in the control group, 36 (66.7%) were active smoker, five (9.3%) were former smoker, and 13 (24.1%) were nonsmoker. There was no statistically significant difference between the two groups regarding smoking habits ( $p > 0.05$ , Table 1). The duration of the work of the EPP group was significantly lower than the control group ( $p < 0.05$ , Table 1). There was one person in the EPP group and 13 in the control group working for more than 10 years. However, we thought that this difference was not clinically significant since there was no polyester exposure in the control group. Although the working time was longer in the control group, the higher spirometer values compared to the EPP group supports this finding. The EPP group workers were using used half-face masks (3M™ Half Facepiece Reusable Respirators 6000 Series, MN) to reduce their exposure to paint.

### Lung function test

The pulmonary function test parameters are summarized in Figure 1. A statistically significant decrease in FEV<sub>1</sub> and FEV<sub>1</sub>/FVC was found in the EPP group ( $p < 0.05$ , Figure 1(A)). The FEV<sub>1</sub> of 32 (59.3%) EPP workers were lower than the 95% confidence interval of the controls (4.17–4.44 L). The LLN for FEV<sub>1</sub> (L) was  $3.41 \pm 0.38$  L and  $3.57 \pm 0.41$  L for the EPP and the control groups, respectively ( $p = 0.899$ ). The LLN for FEV<sub>1</sub>/FVC was  $71.81 \pm 1.08\%$  and  $71.70 \pm 1.19\%$  for the EPP and the control groups, respectively ( $p = 0.437$ ). There was no case in which FEV<sub>1</sub> and FEV<sub>1</sub>/FVC below the LLN, and therefore lung function was within the normal range.

### Respiratory muscle function

The MIP values of the EPP group were significantly lower than those of the control group ( $p < 0.05$ , Figure 1(B)). The MIP value of 36 (66.7%) EPP workers were lower than the 95% confidence interval of the controls (111.97–119.88 cmH<sub>2</sub>O). The MEP value of 32 (59.3%) EPP workers were lower than the 95% confidence interval of the controls (227.61–244.75 cmH<sub>2</sub>O) ( $p > 0.05$ ). The median value for

the MMRC score of both EPP and control groups was '0' ( $p > 0.05$ , Table 1).

### Exercise provocation test (EPT)

The change in FEV<sub>1</sub> after EPT was more significant in the EPP group than in the control group ( $p < 0.05$ , Figure 1(C)). Five (9.26%) EPP workers had a 12% decline in FEV<sub>1</sub> after the EPT, indicating a positive response for bronchial hyperactivity.

### Peripheral muscle strength

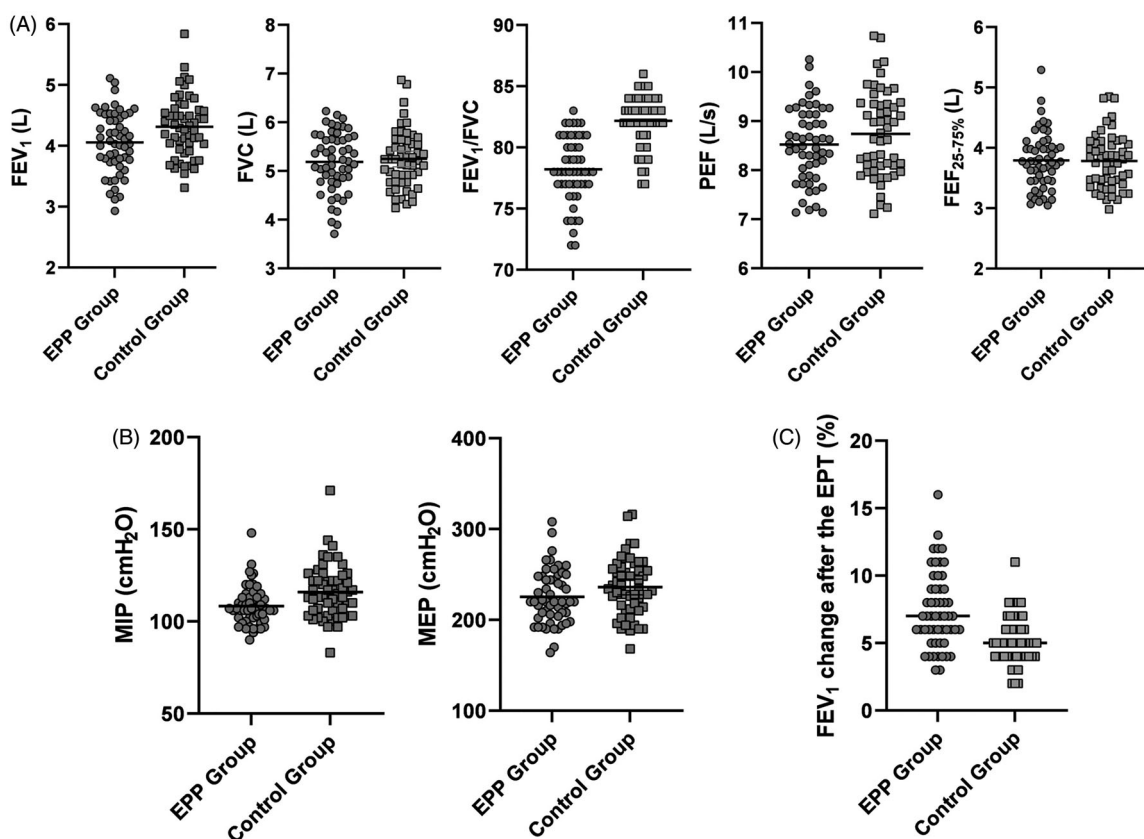
Handgrip strength in the EPP group was significantly lower than the control group ( $p < 0.05$ , Figure 2(A)). The handgrip strength value of 34 (63.0%) EPP workers were lower than the 95% confidence interval of the controls (342.56–364.35 cmH<sub>2</sub>O). No statistically significant difference was found in quadriceps muscle strength between the two groups ( $p > 0.05$ , Figure 2(B)).

### Incremental shuttle walk test (ISWT)

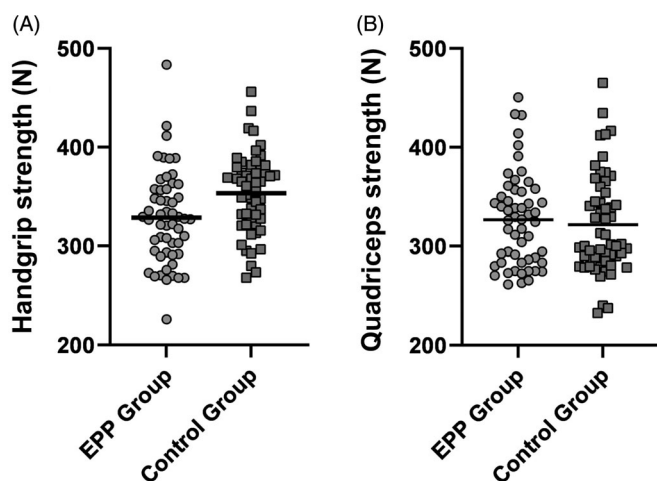
The ISWT distance of the EPP group was significantly lower than those of the control group ( $p < 0.05$ , Figure 3(A)). The ISWT distance of 39 (72.2%) EPP workers were lower than the 95% confidence interval of the controls (822.92–882.30 m). The percentage of maximal heart rate (%HRmax) reached at the end of the ISWT was significantly higher in the control group than the EPP group ( $p < 0.05$ , Figure 3(B)). Borg scores for dyspnea, leg fatigue, and general fatigue were significantly higher in the EPP group ( $p < 0.05$ , Figure 3(C)).

### International physical activity questionnaire (IPAQ) short form, St George respiratory questionnaire (SGRQ) and Nottingham health profile (NHP)

No significant differences were found in the IPAQ high and medium intensity scores, IPAQ walking and sitting score, and the IPAQ total score ( $p > 0.05$ , Table 2). The SGRQ symptom, activity, and impact scores, as well as total score, were similar ( $p > 0.05$ , Table 2). There were no significant differences in the NHP pain, emotional reactions, sleeping,



**Figure 1.** Comparison of (A) forced expiratory volume in one second (FEV<sub>1</sub>) ( $p = 0.009$ ), forced vital capacity (FVC), FEV<sub>1</sub>/FVC ( $p < 0.001$ ), peak expiratory flow (PEF) ( $p = 0.170$ ), forced expiratory volume from 25 to 75% (FEF<sub>25-75%</sub>) ( $p = 0.930$ ), (B) maximum inspiratory pressure (MIP) ( $p = 0.002$ ) and maximum expiratory pressure (MEP) ( $p = 0.066$ ), and (C), FEV<sub>1</sub> change after exercise provocation test (EPT) ( $p < 0.001$ ) between the Electrostatic Powder Paint (EPP) and Control Groups.



**Figure 2.** Comparison of (A) handgrip strength ( $p = 0.004$ ) and (B) quadriceps strength ( $p = 0.710$ ) between the Electrostatic Powder Paint (EPP) and Control Groups.

social isolation, physical activity, and energy subscale scores, and the NHP total score between the groups ( $p > 0.05$ , Table 2).

#### Relationship between ISWT distance and the measured parameters

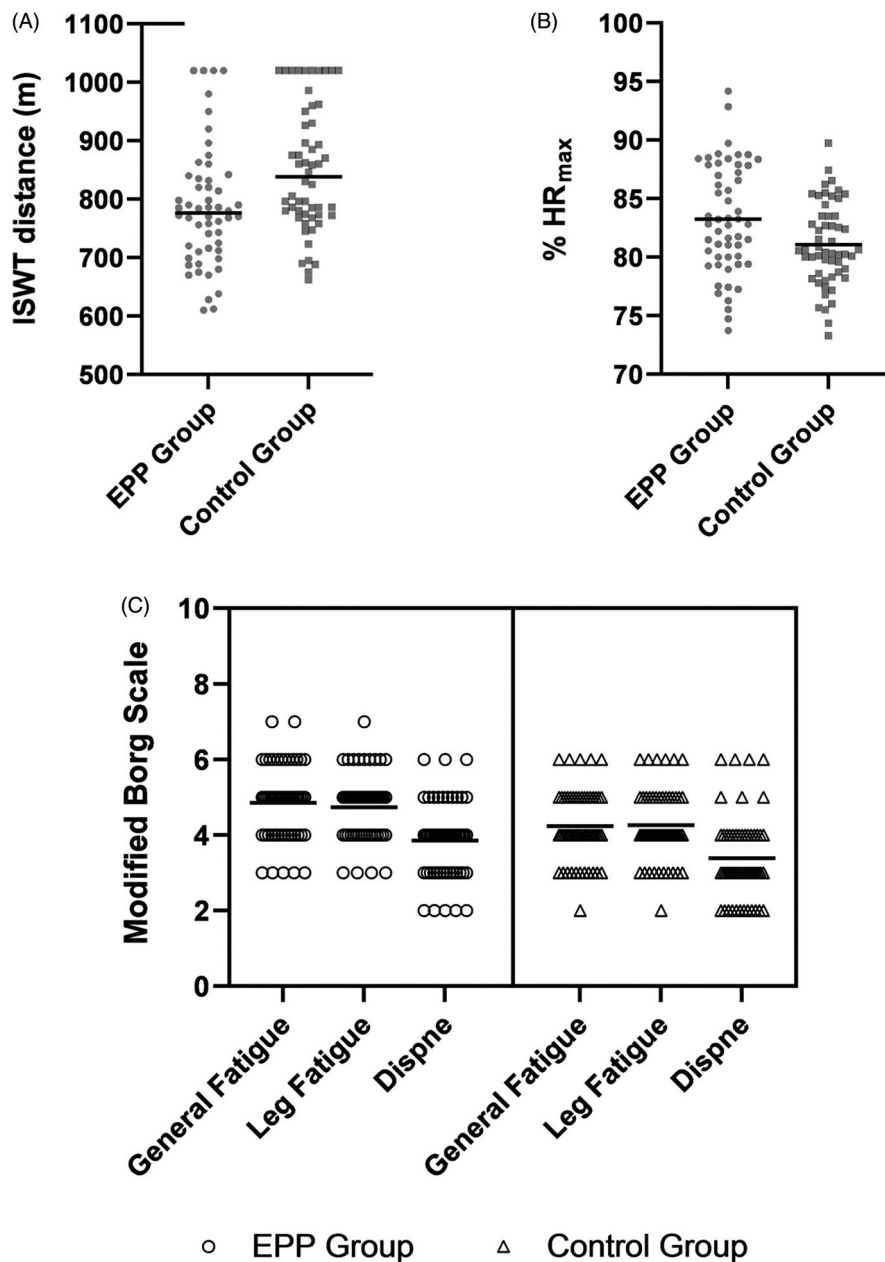
The ISWT distance was significantly associated with age ( $r = -0.628$ ,  $p < 0.001$ ), height ( $r = 0.307$ ,  $p = 0.024$ ), FEV<sub>1</sub>

( $r = 0.426$ ,  $p = 0.001$ ),  $\Delta$ FEV<sub>1</sub> after EPT ( $r = -0.750$ ,  $p < 0.001$ ), MIP ( $r = 0.544$ ,  $p < 0.001$ ), MEP ( $r = 0.342$ ,  $p = 0.011$ ), handgrip strength ( $r = -0.355$ ,  $p = 0.009$ ), duration of work ( $r = -0.674$ ,  $p < 0.001$ ), IPAQ total score ( $r = 0.387$ ,  $p = 0.004$ ), SGRQ total score ( $r = -0.385$ ,  $p = 0.004$ ), and NHP total score ( $r = -0.548$ ,  $p < 0.001$ , Figure 4(A-H)). Based on the multiple linear regression analysis, the change in FEV<sub>1</sub> after EPT, duration of work, and MIP accounted for % 62 of the variance in the ISWT distance ( $r = 0.788$ ,  $r^2 = 0.621$ ,  $F_{(1,50)} = 27.27$ ,  $p < 0.001$ , constant = 625.781, Table 3).

When FEV<sub>1</sub>/FVC, FEV<sub>1</sub> change after %EPT, MIP, and ISWT distance were compared between nonsmokers in both groups, a statistically significant difference was found in favor of the control group ( $p < 0.05$ , Table 4). In both groups, a statistically significant difference was found between the active smokers' FEV<sub>1</sub>, FEV<sub>1</sub>/FVC, FEV<sub>1</sub> change after EPT, and ISWT distance in favor of the control group ( $p < 0.05$ , Table 4).

#### Discussion

In this study, we showed that the EPP workers had impaired exercise capacity as compared with healthy counterparts, working at the same factory. Subjects in the EPP group reached 73.72% of the predicted ISWT distance. The determinants of exercise capacity are the degree of bronchoconstriction after the EPT, inspiratory muscle strength (MIP),



**Figure 3.** Comparison of (A) incremental shuttle walk test (ISWT) distance ( $p = 0.002$ ), (B) percentage of maximal heart rate (HR<sub>max</sub>) after the ISWT ( $p = 0.007$ ), and (C) general fatigue ( $p = 0.002$ ), leg fatigue ( $p = 0.008$ ), and dyspnea ( $p = 0.013$ ) between the Electrostatic Powder Paint (EPP) and Control Groups.

and duration of work, explaining 62% of the variance (Table 3).

When the test results were compared, it was observed that there was a statistically significant difference in FEV<sub>1</sub> and FEV<sub>1</sub>/FVC values between the groups (Figure 1(A)). None of the subjects had a reduced FEV<sub>1</sub> and FEV<sub>1</sub>/FVC below the LLN in the EPP and control group (Quanjer et al. 2012) indicating the difference is not clinically relevant. Therefore, the findings of the study support that there are no possible clinically detrimental effects of exposure to EPP on lung function.

Reduced exercise capacity has adverse health consequences (Tremblay et al. 2010). We found that exercise capacity in EPP workers impaired as compared to healthy counterparts, working at the same factory. Fifty per cent of the variance in exercise capacity was explained by the reduction in

FEV<sub>1</sub> after the EPT stating bronchial provocation. Previous studies have shown that polyester material causes extensive allergic reactions (Blomqvist et al. 2005), bronchial provocation, and occupational asthma (Cartier et al. 1994). In our study, five EPP workers had positive EPT. The use of masks by EPP workers may decrease the number of subjects having positive EPT tests. Studies assessing the potential results of exposure EPP were emphasized that a decline in exercise capacity caused by bronchial provocation (Cartier et al. 1994). Exposure to other paints without EPP was shown to cause bronchial provocation by the EPT. An increase even occurs in lung function and exercise capacity when the bronchodilator agent was medicined (De La Rocha et al. 1987). Evaporation occurs in the surface of the airway during exercise may result in dehydration and the cell shrinking in the airway (De Meer et al. 2004). Restorative cell volume

**Table 2.** Comparison of physical activity and quality of life in electrostatic powder paint and control groups.

Variables	EPP Group (n = 54) Median (min–max)	Control Group (n = 54) Median (min–max)	p Value
International Physical Activity Questionnaire <sup>a</sup>			
High intensity (MET-min/week)	0 (0–1440)	0 (0–1440)	0.978
Medium intensity (MET-min/week)	10800 (10800–10800)	10800 (10800–10800)	1.000
Walking score (MET-min/week)	1524 (762–3811)	1524 (722–4237)	0.605
Sitting score	4 (3–6)	4 (3–6)	0.519
Total score (MET-min/week)	12324 (11562–14809)	12324 (11522–16051)	0.672
St George Respiratory Questionnaire <sup>a</sup>			
Symptom	0 (0–1.40)	0 (0–1.40)	0.800
Activity	1.18 (0–1.18)	1.18 (1.18–1.18)	0.151
Impact	0 (0–1.55)	0 (0–1.55)	0.786
Total Score	1.18 (0–4.13)	1.18 (1.18–4.13)	0.653
Nottingham Health Profile <sup>a</sup>			
Pain	0 (0–0)	0 (0–0)	1.000
Emotional Reactions	12.01 (0–49.25)	12.01 (0–46.99)	0.599
Sleeping	7.98 (0–37.81)	15.97 (0–37.81)	0.855
Social Isolation	15.97 (0–58.11)	0 (0–36.1)	0.171
Physical Activity	0 (0–0)	0 (0–0)	1.000
Energy	0 (0–63.23)	0 (0–63.23)	0.222
Total Score	44.55 (0–150.25)	39.97 (0–123.86)	0.204

<sup>a</sup>Mann–Whitney U test.

EPP: Electrostatic powder paint.

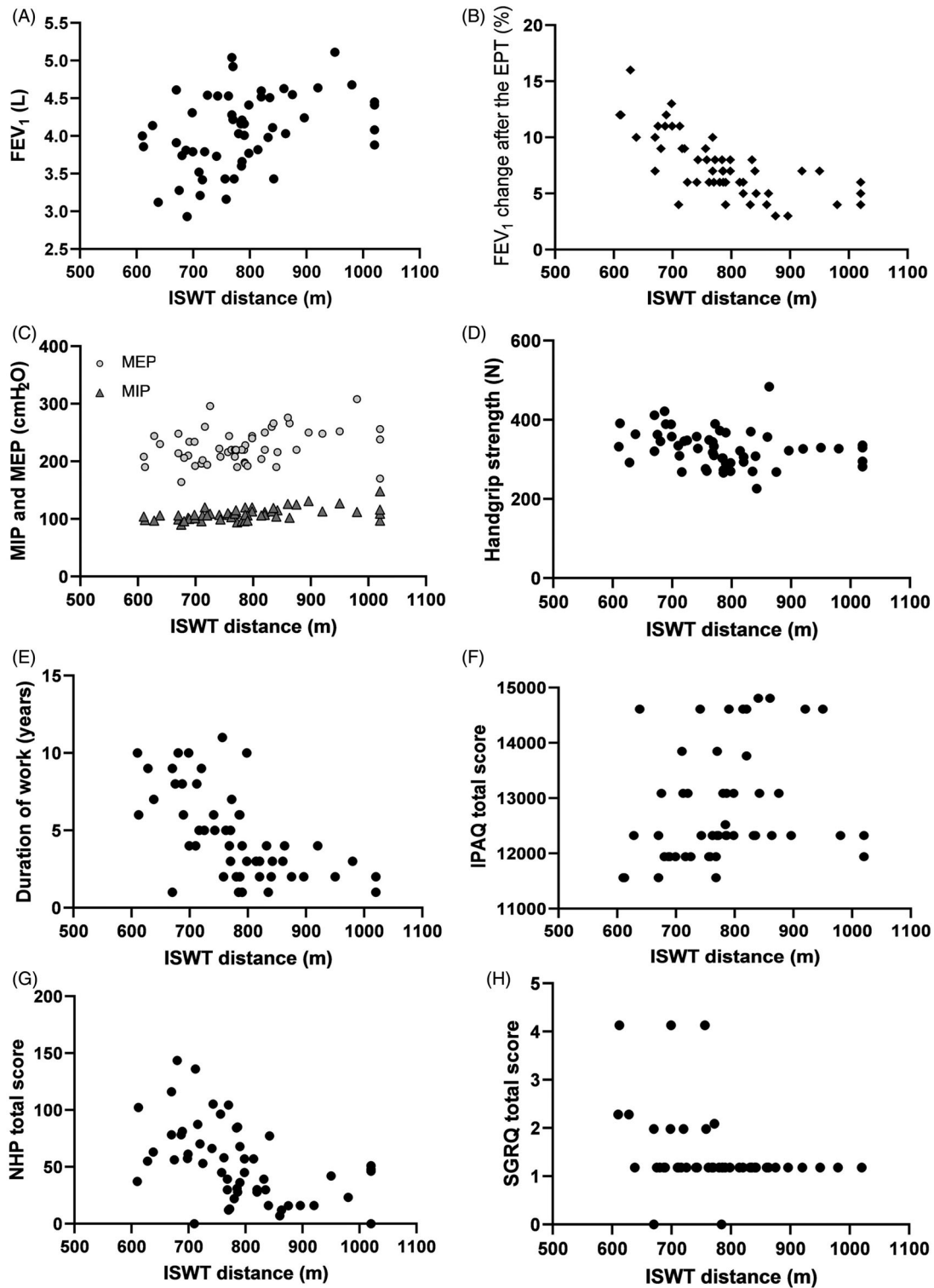
(mast cells, epithelial cells, sensor nerve cells) increases, causing bronchospasm and preventing enough ventilation in the lung (De Meer et al. 2004). Impaired ventilation-perfusion rates may prevent cells from getting enough oxygen. These mechanisms might have caused a decline in aerobic capacity and the ISWT distance in the EPP workers. Mechanism of diminished exercise capacity needs to be investigated to ensure a full picture of the effects of exposure on to EPP.

The MIP accounted for 7.7% of the variance in the ISWT distance, stating that low respiratory muscle strength may have reduced exercise capacity of the EPP workers (Table 3). The current study is the first study investigating respiratory muscle strength in EPP workers. Previously, chemical plant workers exposed to chemical substances have shown to be decreased inspiratory and expiratory muscle strength, especially those who worked for more than 10 years (Konieczny et al. 1999). The possible mechanisms have been proposed as the hyperinflation caused by inhaled chemicals, muscle structure and chemistry, and obstruction of the lungs (Horstman et al. 2005). The other reason might be the result of an ergoreflex from increased respiratory workload due to obstruction, increased oxygen consumption of respiratory muscles, and insufficient ventilation (Barđi et al. 2016). Fatigue in the inspiratory muscles stimulates ergoreflex, causing vasoconstriction and thereby diminished blood flow to peripheral tissue (active muscle) (Barđi et al. 2016). We did not investigate the effect of the polyester substance contained in EPP on the metabolism and structure of muscles. Therefore, it is not possible to say that respiratory muscle strength loss has developed due to this effect of the polyester substance. Further study on this subject is needed.

Duration of work, an indicator of EPP exposure (Neghab et al. 2011), was related to the ISWT distance in EPP workers in our study and explained 4.2% of the variance in the ISWT distance (Table 3). While the mean working time of EPP workers was four years, there was only one EPP worker working over 10 years. Lung function, including FEV<sub>1</sub>,

deteriorates as the exposure time increases (Neghab et al. 2011). One could think that statistically lower FEV<sub>1</sub> values in the EPP group might support this finding (Figure 1(A)). However, based on LLN of FEV<sub>1</sub> and FEV<sub>1</sub>/FVC (Quanjer et al. 1993), we showed that the EPP workers in this study did not have clinically relevant lung function impairment. We did not measure diffusion capacity; therefore, further study is warranted to investigate the possible effects of reduced diffusion capacity (Cartier et al. 1994) on exercise capacity in the EPP workers. Hydrocarbon inhalation has been known to be associated with cardiac and central nervous system dysfunction, muscle weakness, and metabolic acidosis (Tormoehlen et al. 2014). We found increased heart rate response to incremental exercise and reduced handgrip strength in the EPP workers. These findings warrant further investigation of possible cardiac function, neuromuscular or metabolic adaptations by EPP exposure that may affect exercise capacity.

Univariate analyses showed that the ISWT distance was associated with age, height, FEV<sub>1</sub>, MEP, handgrip strength, IPAQ, SGRQ, and NHP total scores (Figure 4). The ISWT distance was found to be related to age in EPP workers since exposure to the agent causes bronchial provocation, which reduces exercise capacity (De La Rocha et al. 1987). Height was the other factor that was related to the ISWT distance because the ISWT distances of the tall individuals were found to be higher (Itaki et al. 2018). The univariate relationship between FEV<sub>1</sub> and the ISWT distance is probably due to the association of lung function and maximum oxygen consumption, index of aerobic capacity as shown by a previous study on asymptomatic subjects (Babb et al. 1997). The MEP was found to be related to ISWT because expiratory muscle strength loss is associated with the aerobic capacity (Giua et al. 2014). However, we found no difference in MEP between the EPP workers and controls (Figure 1(B)). We thought that bronchospasm was resistant to inspiration, and expiration was mostly passive (McConnell and Romer 2004). Fatigue of respiratory muscles causes



**Figure 4.** Correlation of the incremental shuttle walk test (ISWT) distance with (A) forced expiratory volume in one second (FEV<sub>1</sub>) ( $p = 0.001$ ), (B) FEV<sub>1</sub> change after the exercise provocation test (EPT) ( $p < 0.001$ ), (C) maximum inspiratory pressure (MIP) ( $p < 0.001$ ) and maximum expiratory pressure (MEP) ( $p = 0.011$ ), (D) handgrip strength ( $p = 0.009$ ), (E) duration of work ( $p < 0.001$ ), (F) the International Physical Activity Questionnaire (IPAQ) total score ( $p = 0.004$ ), (G) the Nottingham Health Profile (NHP) total score ( $p < 0.001$ ), and (H) the St. George Respiratory Questionnaire (SGRQ) total score ( $p = 0.004$ ) in electrostatic powder paint Workers.

vasospasm in the peripheral arterioles (Bargi et al. 2016). We found that lower handgrip strength is related to the shorter ISWT distance in EPP workers (Figure 4(D)). Low handgrip strength is a predictor of physical decline (Bohannon 2008). Handgrip strength was associated with exercise capacity. It is due to the neuromechanical

dysfunction of the respiratory muscles (diaphragm and accessory muscles) and changes in lung volume during activities involving the upper extremities (Kaymaz et al. 2018). We found no study evaluating muscle strength in the EPP workers. The individuals in the EPP group worked on their feet during the day and did not perform any more

handgrip work; therefore, their muscles were not actively used.

In our study, the IPAQ scores showed that both the EPP and control groups include physically active individuals (Table 2). Being physically active are associated with better health outcomes. Although the IPAQ scores were associated with the ISWT distance in the EPP group (Figure 4(F)), physical activity was not an independent determinant of the distance. Since ISWT is a test that evaluates exercise intolerance, we could say that individuals who are active in the EPP group have a higher aerobic capacity. In addition, ISWT distances were higher in the control group (Figure 3(A)). Therefore, our findings revealed exercise intolerance in the EPP workers. These findings also revealed that exercise capacity measured using the ISWT distance, which has a high correlation with peak oxygen consumption (Puentes-Maestu et al. 2016), and physical activity determined using the IPAQ, a subjective measure, have different construct.

When the cigarette consumption of both groups was compared, there was no difference between the groups (Table 1). However, as being an active smoker can affect test results, groups were compared as active smokers and nonsmokers. Hu et al. examined the effect of smoking on oxygen consumption in their study on rats in 2014. As a result of the study, they emphasized that smoking significantly reduced resistance to fatigue and aerobic capacity (Hu et al. 2014). Sato et al. stated in their controlled study that the FEV<sub>1</sub>/FVC ratios significantly decreased with

smoking (Sato et al. 2018). In our study, when nonsmokers in both groups were compared, it was observed that there was a statistically significant decrease in pulmonary function and exercise capacity in the EPP group. Similarly, in the comparison of active smokers in both groups, respiratory function tests and exercise capacity were found to be low in the EPP group (Table 4). However, since EPP and smoking effect are together in these results, the comparison of nonsmokers show the main effect due to EPP.

We found that disease-specific (SGRQ) and general (NHP) health-related quality of life was related to the exercise capacity in EPP workers (Figure 4(G,H)). High exercise capacity with less fatigue during daily life would increase the quality of life (Callegari et al. 2019). The questionnaires used were not specific to occupational exposure. There may be a need for the questionnaire that could be selective in subjects with progressive functional impairment.

We were unable to perform diffusion capacity to evaluate any other component, such as interstitial lung diseases, which is common in occupational exposures (Lopes et al. 2012). We could not measure respiratory mechanics during the exercise test and used a standardized maximal field test since all of the evaluations were performed in the workplace. The use of cardiopulmonary exercise testing might have additional information related to the components of impaired exercise tolerance. In addition, if we perform spirometric measurements using a bronchodilator, we could obtain additional information on exposure. The lack of difference in the quality of life between the groups may be because the quality of life assessment questionnaires we used was not specific to this group. More selective quality of life questionnaires could be used for the EPP group in future studies. In our study, we performed measurements on Fridays, predicting that exposure would be higher on the last day of the week. However, to see if this assumption was correct, we need to measure and compare on the first working day of the week. The inclusion of the pretest in further study may show the exposure-related effects of during workdays.

**Table 3.** Regression analysis of the clinical variables with the incremental shuttle walk test (ISWT) distance as the dependent variable.

Variables in the model	Adjusted r <sup>2</sup>	β	F	p Value
FEV <sub>1</sub> change after the EPT (%)	0.492	-0.398	52.246	<0.001*
MIP (cmH <sub>2</sub> O)	0.562	0.299	9.333	0.004*
Duration of work (years)	0.598	-0.280	5.582	0.022*

The bold values represents as statistically significant  $p < 0.05$  values.  $r = 0.788$ ,  $r^2 = 0.621$ ,  $F_{(1,50)} = 27.27$ ,  $*p < 0.001$ , constant = 625.781

Dependent variable: ISWT. Independent variables: age, height, duration of work, FEV<sub>1</sub>, change in FEV<sub>1</sub> during EPT, MIP, MEP, handgrip strength, IPAQ, SGRQ, and NHP.

**Table 4.** Comparison of parameters showing a statistically significant difference between active smokers and nonsmokers in the Electrostatic Powder Paint (EPP) and Control groups.

Variables	Nonsmokers			Active smokers		
	EPP Group (n = 20) Mean ± SD	Control Group (n = 18) Mean ± SD	p Value	EPP Group (n = 34) Mean ± SD	Control Group (n = 36) Mean ± SD	p Value
Lung Function <sup>b</sup>						
FEV <sub>1</sub> (L)	4.13 ± 0.55	4.35 ± 0.58	0.235	4.00 ± 0.47	4.28 ± 0.46	0.015*
FEV <sub>1</sub> /FVC	78.50 ± 2.89	82.00 ± 2.27	<0.001*	78.02 ± 2.61	82.25 ± 2.04	<0.001*
Exercise provocation test <sup>a,c</sup>						
FEV <sub>1</sub> change after EPT (%)	6.5 (4 – 12)	5 (2 – 11)	0.017*	7 (3 – 16)	5 (2 – 8)	<0.001*
Respiratory muscle strength <sup>b</sup>						
MIP (cmH <sub>2</sub> O)	108.43 ± 8.24	121.64 ± 16.03	0.003*	108.15 ± 11.93	113.07 ± 12.95	0.104
Incremental shuttle walk test <sup>a,c</sup>						
ISWT distance (m) <sup>a</sup>	770 (612 – 1020)	900 (675 – 1020)	0.011*	782 (610 – 1020)	827 (662 – 1020)	0.046*

\*The bold values represents as statistically significant  $p < 0.05$  values.

<sup>a</sup>Expressed in median (min–max).

<sup>b</sup>Student's *t*-test,

<sup>c</sup>Mann–Whitney U test, based on normality.

EPP: Electrostatic powder paint; FEV<sub>1</sub>: Forced expiratory volume in one second; MIP: Maximum inspiratory pressure; EPT: Exercise provocation test; ISWT: Incremental shuttle walk test.

In conclusion, we have demonstrated decreased exercise capacity in EPP workers. The exercise capacity was related to EPP exposure based on the univariate analysis. Degree of bronchial reactivity, inspiratory muscle strength, and duration of work, were the independent determinants of the exercise capacity in EPP workers. Giving the adverse effects of reduced exercise capacity on health, the EPP workers should be followed, and appropriate exercise interventions may be needed to be employed. The effects of worked based exercise training interventions warrant further investigation.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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