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REGULAR ARTICLE

Work-related respiratory symptoms and lung function among solderers in the electronics industry: a meta-analysis

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Abstract

Objective Research on the respiratory effect of exposure to solder fumes in electronics workers has been conducted since the 1970s, but has yielded inconsistent results. The aim of this meta-analysis was to clarify the potential association.

Methods Effect sizes with corresponding 95% confidence intervals (CIs) for odds of respiratory symptoms related to soldering and spirometric parameters of solderers were extracted from seven studies and pooled to generate summary estimates and standardized mean differences in lung function measures between exposed persons and controls.

Results Soldering was positively associated with wheeze after controlling for smoking (meta-odds ratio: 2.60, 95% CI: 1.46, 4.63) and with statistically significant reductions in forced expiratory volume in 1 s (FEV1) (−0.88%, 95% CI: −1.51, −0.26), forced vital capacity (FVC) (−0.64%, 95% CI: −1.18, −0.10), and FEV1/FVC (−0.35%, 95% CI: −0.65, −0.05). However, lung function parameters of solderers were within normal ranges [pooled mean FEV1: 97.85 (as percent of predicted), 95% CI: 94.70, 100.95, pooled mean FVC: 94.92 (as percent of predicted), 95% CI: 81.21, 108.64, and pooled mean FEV1/FVC: 86.5 (as percent), 95% CI: 78.01, 94.98].

Conclusions Soldering may be a risk factor for wheeze, but may not be associated with a clinically significant impairment of lung function among electronics workers.

Keywords Electronics workers · Soldering · Rosin · Asthma · Lung function

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Introduction

The electronics industry involves a wide variety of processes that include the assembly of printed circuit boards (PCB) by soldering. The latter is a method of joining metals using a filler metal (solder) with a melting point below 800°F (425°C) and soldering flux [1–4]. The solder is commonly a lead/tin alloy because of its low melting point. The flux used to provide flow for the solder joint and non-tarnished surfaces for bonding consists of organic or inorganic materials, but the most common type in the electronics industry is the rosin type of organic flux [1]. Rosin, also called colophony, is a natural product derived from pine resin and is based on a mixture of several diterpene acids. It consists of 90% of abietic acid and 10% of pimaric acids [5, 6].

The potential of colophony to cause respiratory diseases has been reported since the 1970s. However, studies among electronics workers involved in soldering have yielded inconsistent results. Ross et al. [7] reported that 5% of occupational asthma incident cases in the United Kingdom were due to colophony. Palmer and Crane [8] and Burge et al. [9] found the risk of developing occupational asthma symptoms to be significantly higher in electronics workers exposed to soldering in comparison to those not exposed.

On the other hand, Courtney and Merrett [10], in a study including exclusively 1611 female electronics workers, and Lee et al. [11] found no excess of respiratory symptoms in solderers compared to controls. The mechanisms by which colophony could induce respiratory disorders are still unclear. Nor is it known whether resin acids or their breakdown products are the cause of asthma attributed to colophony [12, 13]. Inhalation exposure to colophony comes from heating of the material, which is a mixture of resin acids and decomposition products, but occupational asthma due to unheated colophony has been reported [14]. Possible asthma due to colophony has been suggested to have the features of a sensitizing reaction [15]. Elms et al. [16] investigated the interaction of colophony with immune cells and suggested that reactive oxygen species may be induced in vivo and oxidize colophony to resin acid epoxides and hydroperoxides that initiate immune responses.

Given the inconsistency of the existing epidemiological studies, we performed the present meta-analysis to examine the odds of respiratory symptoms among electronics workers involved in soldering and their lung function. This study adds in a unique manner to the existing literature by quantitatively and systematically synthesizing studies on the topic. It will help increase the effect size precision of potential associations and better estimate lung function parameters of solderers.

Methods

Data sources and searches

A search of MEDLINE, Highwire, the Cumulative Index to Nursing and Allied Health Literature (CINAHL), and The Cochrane Library for studies containing information to estimate the odds of asthma or asthma symptoms among electronics workers was conducted using the terms electronics workers, asthma; electronic industry, asthma; colophony fume, asthma; solder/soldering/solderer, asthma, up to December 2010. The search strategies in the different databases were as follows:

- In MEDLINE ("electronics" [MeSH Terms] OR "electronics" [All Fields]) AND ("manpower" [Subheading] OR "manpower" [All Fields] OR "workers" [All Fields]) AND ("asthma" [MeSH Terms] OR "asthma" [All Fields]), using the keywords 'electronics workers, asthma'; ("electronics" [MeSH Terms] OR "electronics" [All Fields] OR "electronic" [All Fields]) AND ("industry" [MeSH Terms] OR "industry" [All Fields]) AND ("asthma" [MeSH Terms] OR "asthma" [All Fields]) with the keywords 'electronic industry, asthma'; ("rosin" [Supplementary Concept] OR "rosin" [All Fields]) OR "colophony" [All Fields)] AND fume [All Fields] AND ("asthma" [MeSH Terms] OR "asthma" [All Fields]) using the keywords 'colophony fume, asthma'; and (solder [All Fields] AND ("asthma" [MeSH Terms] OR "asthma" [All Fields]), soldered [All Fields] AND ("asthma" [MeSH Terms] OR "asthma" [All Fields]), soldering [All Fields] AND ("asthma" [MeSH Terms] OR "asthma" [All Fields]) with the keywords 'solder/soldering/solderer, asthma'.
- In Highwire: 'electronics workers, asthma' or 'electronic industry, asthma' or 'colophony fume, asthma', or 'solder*, asthma' (all words in title or abstract).
- In CINAHL: 'electronics workers AND asthma' or 'electronic industry AND asthma' or 'colophony fume AND asthma', or 'solder* AND asthma'.
- In The Cochrane Library: 'electronics workers, asthma' or 'electronic industry, asthma' or 'colophony fume, asthma', or 'solder*, asthma' (title, abstract, or keywords).

In addition to the database search, we screened the lists of references in previous reviews and selected papers to identify additional relevant studies.

Study selection

Studies that met the following criteria were included in the meta-analysis: (1) Studies published in English or those that had an abstract available in English; (2) studies that reported or contained data to calculate the odds of work-related respiratory symptoms with corresponding 95% confidence intervals (CIs), or data on % predicted values for forced expiratory volume in 1 s (FEV1), forced vital capacity (FVC), and/or FEV1/FVC in solderers from electronics industries and controls. All references were independently screened by two authors (A.M. and C.D.) according to selection criteria. Differences of opinion on whether or not to include a study were resolved by agreement, while disagreements on data extraction or the reporting quality of a study were resolved through mutual discussion and, if needed, by consulting a third author (J.G.). The initial selection after the removal of duplicates from records identified through database search was based on title and abstract screening. The final selection was done using full texts. The studies to be excluded after title and abstract screening were:

- Articles published in a language other than English which did not have an abstract in English encompassing enough data for the present meta-analysis.
- Reviews, case reports, and animal and immunological studies.

In the final selection, based on full-text screening, the criteria for exclusion were the following:

- Ineligible exposures: exposures other than soldering in an electronics industry setting.
- Ineligible outcomes: outcomes other than respiratory symptoms and spirometric parameters.

Data extraction and quality assessment

Using a data extracting sheet, two of the authors (A.M. and C.D.) independently retrieved from full-text articles data on references (first author, year of publication), study design, country where the study was conducted, age of participants, duration of exposure, asthma symptoms, effect size and corresponding 95% confidence interval, lung function measurements, and the covariates adjusted for (Table 1). If data were duplicated in more than one study, the most recent one was included in the analysis.

The following methodological quality components of studies were assessed: size of the population, study design, definition and duration of exposure to soldering allowing detection of respiratory effects, assessment of respiratory symptoms and lung function, potential confounders' measure and control, and statistical methods used in individual papers. The quality of the reporting was evaluated using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement checklist for cohort, case–control, and cross sectional studies, version 4 [17]. The studies were classified into the following three categories—A: more than 80% of STROBE criteria fulfilled, B: 50–80% of STROBE criteria fulfilled, and C if less than 50% of STROBE criteria were fulfilled.

Analysis

For each respiratory symptom, the extracted or calculated effect sizes with corresponding 95% confidence intervals were combined by means of weighted average of effects to generate summary estimates. Each study was weighted by its inverse effect size variance [18]. To evaluate the pulmonary function of solderers, the mean values and standard deviation of FEV1, FVC, and/or FEV1/FVC were combined to generate pooled means. The differences in spirometric parameters between exposed and nonexposed participants was calculated using DerSimonian and Laird random-effects meta-analyses, based on standardized mean difference with effect size estimator Hedges' adjusted g. The random-effects analysis not only weights each study by its inverse variance, but additionally includes the within- and between-studies variances. It is more conservative than fixed-effects models, providing wider confidence intervals when there is between-study heterogeneity; therefore, it is preferable to fixed-effects models [19]. Hedges' adjusted g provides an effect size measure with a correction factor for small sample bias [20].

We tested for heterogeneity in results across studies using a Cochran Q statistic. The Cochran Q test for heterogeneity computes the sum of the squared deviation of each study effect size from the overall effect estimate. It follows a χ^2 distribution with an $N - 1$ degree of freedom (N being the number of studies) and has a low power, so its statistical significance is conventionally defined as $p < 0.10$ instead of the usual level of 0.05. The I^2 was used to quantify the extent of true heterogeneity. It computes the division of the difference between the result of the Q test and its degrees of freedom by the Q value itself, multiplied by 100 [21].

An assessment of publication bias (studies less likely to be published because of the size or statistical significance of their effect size) was performed with the Egger test, based on the funnel plot and the regression of the standardized effect estimate on a measure of precision [22, 23]. We investigated the influence of each individual study on the overall estimates through a sensitivity analysis which computes summary estimates after omitting each study in turn. A study was considered to significantly change the overall estimate if, after its omission, the 95% confidence interval of the summary estimate did not overlap with that of the overall effect size. All analyses were performed in STATA (Version 11; Stata Corporation, College Station, TX, USA) and a p value of <0.05 was considered to be statistically significant.

Results

The steps of our literature search are shown in Fig. 1. Briefly, a total of 112 articles were identified. The search yielded 44 articles from PubMed, 48 from CINAHL, 20 from Highwire, no article from The Cochrane Library, and no new citation from reference screening. Finally, 7 studies were included in the meta-analysis [8–11, 24–26].

Studies' characteristics

The 7 studies that met our inclusion criteria were published between 1979 and 1997. They were conducted mainly in the United Kingdom [8–10, 24], but also in the United States [26], India [25], and Singapore [11]. Five studies were cross-sectional [8, 10, 11, 25, 26], one was a case control [9], and one was a cohort [24]. Three studies fulfilled more than 80% of the STROBE criteria [8, 9, 26], two fulfilled between 50 and 80% of the criteria [11, 25], and two fulfilled less than 50% of the criteria [10, 24].

Table 1 Individual studies' characteristics

Study ID (reporting quality)	Study design	Country	Number of participants	Age (years)	Exposed	Controls	Outcome	Duration of exposure (years)	Variables adjusted for
Burge et al. [9] (A)	Case control	UK	58	Mean age: 46.5 (±10.9) for workers without symptoms and 39.4 (±11.4) for cases	Solderers and ex-solderers	Never soldered	Respiratory symptoms, lung function	Mean duration: 10.1 years (±4.3) for workers without symptoms and 6.7 (±5.1) for cases	No adjustment
Burge et al. [24] (C)	Cohort	UK	45	Range: 25–62	Solderers	No control group	Lung function	Not available	No adjustment
Greaves et al. [26] (A)	Cross-sectional	USA	104	Mean age: 41.2 (±14.3)	Solderers, mostly "hand solderers"	No control group	Lung function	Mean duration: 3.7 years (±3.6)	No adjustment
Courtney and Merrett [10] (C)	Cross-sectional	UK	1611	Mean age: 51 for exposed. Standard deviation and age of non-exposed not available	Female solderers and ex-solderers	Female non-solderers	Respiratory symptoms and lung function	No mean duration available. Participants were divided according to whether the duration of exposure was more or less than 6 years	No adjustment
Gupta et al. [25] (B)	Cross-sectional	India	197	Mean age: 34.8 (±0.85) in exposed males, 35.2 (±0.42) in exposed females, 34.4 (±1.05) in male control group, and 32.9 (±0.14) in female control group	Solderers	Participants never involved in soldering	Respiratory symptoms and lung function	Mean duration: 13.3 years (±0.4)	Smoking, atopy
Lee et al. [11] (B)	Cross-sectional	Singapore	202	Mean age: 29.2 (±6.4) in exposed and 28.5 (±5.9) in controls	Full-time "hand solderers"	Administrative staff in industry with no present or past exposure to soldering	Respiratory symptoms and lung function (expressed in liter)	Not available. Participants were divided according to whether the duration of exposure was more or less than 5 years	Smoking
Palmer et al. [8] (A)	Cross-sectional	UK	152	Mean (range): 35.6 (17–63)	Full-time solderers (≥37 h/week)	Part-time solderers (≤20 h/week)	Respiratory symptoms	Median: 5 years	Smoking, atopy

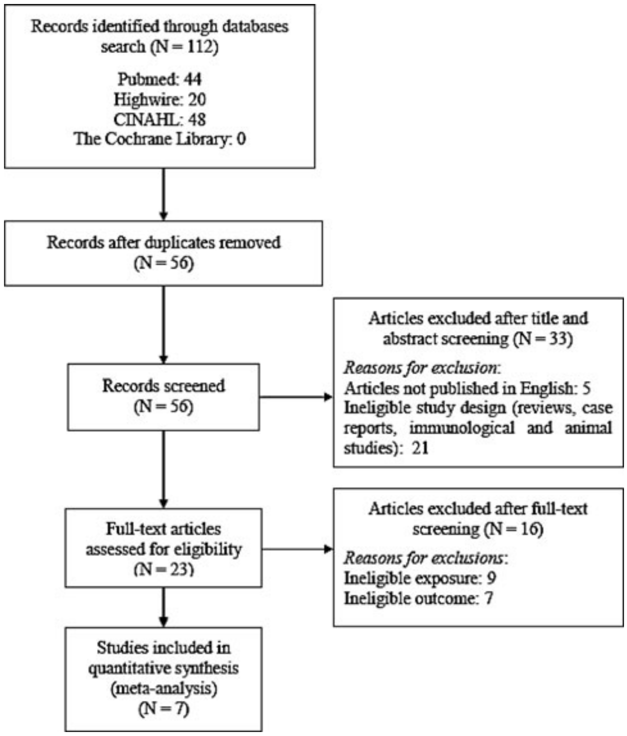

Fig. 1 Flow chart of study selection

Respiratory symptoms

Five studies examined the odds of respiratory symptoms [8–11, 25]. Tests for heterogeneity indicated high consistency in studies (Q test p value: 0.69, I^2 null for dyspnea, Q test p value: 0.44, I^2 null for wheeze, and Q test p value: 0.31, I^2: 17% for cough). Egger tests for publication bias were not significant for any of the analyses (p: 0.32 for dyspnea, 0.99 for wheeze, and 0.17 for cough).

The summary odds ratios (ORs) showed that exposure to soldering in the electronics industry was associated with respiratory symptoms in general (meta-OR: 2.18, 95% CI: 1.23, 2.77 for dyspnea, 2.67, 95% CI: 1.63, 4.38 for wheeze, and 1.59, 95% CI: 1.01, 2.51 for cough) (Fig. 2). In the meta-analysis of studies that adjusted for smoking [8, 10, 11], soldering was associated solely with wheeze (meta-OR: 2.60, 95% CI: 1.46, 4.63) (Fig. 3). In the sensitivity analysis, no study that was omitted significantly changed the summary estimates (Table 2).

Lung function

Five studies were pooled to generate the mean FEV1, FVC, and FEV1/FVC of solderers [8, 11, 24–26]. Three studies were combined to determine the standardized mean difference in spirometric parameters between exposed and unexposed persons [8, 11, 25].

Table 2 Influence analysis of individual studies

Study omitted	FEV1 (95% CI)	FVC (95% CI)	FEV1/FVC (95% CI)	Odds ratio (OR) unadjusted (95% CI)			OR adjusted for smoking (95% CI)		
				Wheeze	Dyspnea	Cough	Wheeze	Dyspnea	Cough
Burge et al. [9]	–	–	–	2.13 (0.67, 6.77)	1.54 (0.93, 2.54)	1.78 (0.96, 3.31)	–	–	–
Burge et al. [24]	98.04 (94.90, 101.18)	94.37 (79.42, 109.33)	–	–		–	–	–	–
Greaves et al. [26]	97.09 (92.14, 102.04)	93.53 (77.26, 109.79)	86.50 (78.01, 94.98)	–		–	–	–	–
Courtney and Merrett [10]	97.83 (94.70, 100.95)	94.92 (81.21, 108.64)	–	3.56 (1.81, 7.03)	3.05 (1.48, 6.29)	2.14 (1.12, 4.06)	4.50 (1.68, 12.02)	2.65 (0.73, 9.65)	1.53 (0.59, 3.93)
Gupta et al. [25] (males)	97.91 (94.78, 101.05)	100.38 (88.72, 112.04)	88.13 (78.79, 97.47)	–	1.61 (0.94, 2.74)	1.38 (0.93, 2.06)	–	–	–
Gupta et al. [25] (females)	98.08 (94.93, 101.22)	99.90 (88.11, 111.69)	86.98 (78.16, 95.80)						
Lee et al. [11]	97.49 (93.67, 101.31)	93.57 (76.58, 110.56)	81.81 (69.55, 94.08)	2.41 (0.99, 5.97)	1.90 (1.05, 3.46)	1.61 (1.00, 2.60)	2.65 (1.48, 4.75)	1.54 (0.71, 3.34)	1.19 (0.69, 2.08)
Palmer and Crane [8]				1.56 (0.89, 2.73)	1.88 (0.99, 3.59)	1.92 (1.01, 3.67)	1.88 (0.95, 3.76)	1.37 (0.57, 3.31)	1.25 (0.65, 2.39)

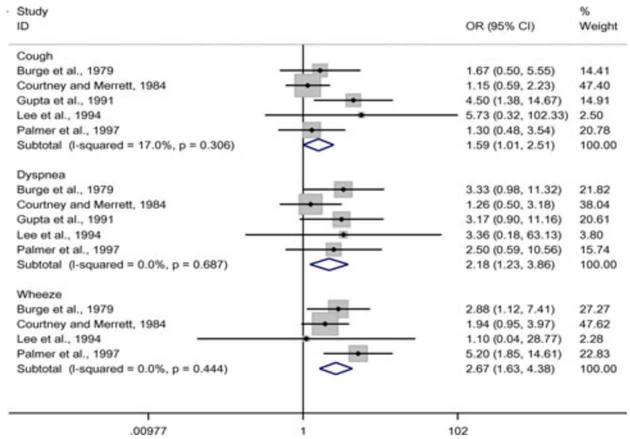

Fig. 2 Forest plot of the association between solder flux exposure in electronics industries and respiratory symptoms, using a random-effect model. *OR* odds ratio, *CI* confidence interval

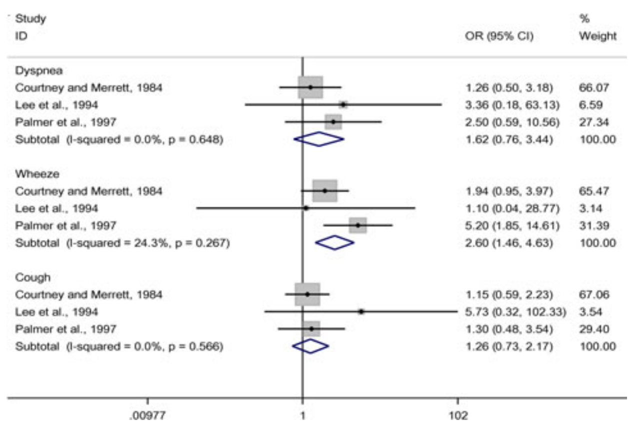

Fig. 3 Forest plot of the association between solder flux exposure in electronics industries and respiratory symptoms after adjustment for smoking, using a random-effect model

The pooled mean FEV1 was 97.85 (as percent of predicted), 95% CI: 94.70, 100.95 (*Q* test *p* value: 0.525, I^2 null). The pooled mean FVC was 94.92 (as percent of predicted), 95% CI: 81.21, 108.64 [*Q* test significantly heterogeneous (*p* value: 0.06), I^2: 52.2%]. The pooled mean FEV1/FVC was 86.5 (as percent) [95% CI: 78.01, 94.98 (*Q* test *p* value: 0.74, I^2 null)] (Table 3). Egger tests for publication bias were not significant (*p* 0.86 for FEV1, 0.98 for FVC, and 0.87 for FEV1/FVC) and no study that was omitted significantly changed the summary estimates in the sensitivity analysis (Table 2).

The standardized mean differences (SMD) in lung function test results between solderers working in electronics factories and controls were statistically significant [SMD: −0.88% for FEV1 (95% CI: −1.51, −0.26), −0.64% for FVC (95% CI: −1.18, −0.10), and −0.35% for FEV1/FVC (95% CI: −0.65, −0.05)] (Table 3).

Table 3 Lung function of solderers and standardized mean differences (SMD) in spirometric parameters compared with controls

Study ID	FEV1		FVC		FEV1/FVC	
	Mean (±SD)	Mean difference (95% CI)	Mean (±SD)	Mean difference (95% CI)	Mean (±SD)	Mean difference (95% CI)
Burge et al. [24]	74.8 (±16.5)	–	95.2 (±30)	–	84.6 (±9)	–
Greaves et al. [26]	99 (±17)	–	98 (±16)	–	–	–
Gupta et al. [25] (males)	85.4 (±19.2)	−0.92 (−1.3, −0.6)	78.5 (±13.2)	−1.27 (−1.62, −0.93)	78.7 (±10.4)	−0.58 (−0.90, −0.25)
Gupta et al. [25] (females)	81.6 (±12.9)	−0.81 (−1.1, −0.5)	75.5 (±15.1)	−0.90 (−1.22, −0.58)	80.4 (±15.9)	−0.41 (−0.73, −0.10)
Lee et al. [11]	102.3 (±12.7)	−0.07 (−0.4, 0.3)	96 (±12.7)	−0.07 (−0.39, 0.26)	90.8 (±6)	−0.05 (−0.38, 0.27)
Palmer and Crane [8]	98.3 (±1.6)	−1.77 (−2.2, −1.3)	107.8 (±1.6)	−0.33 (−0.71, 0.04)	–	–
Pooled mean and SMD	FEV1		FVC		FEV1/FVC	
	Mean (95% CI)	SMD (95% CI)	Mean (95% CI)	SMD (95% CI)	Mean (95% CI)	SMD (95% CI)
	97.85 (94.70, 100.95)	−0.88 (−1.51, −0.26)	94.92 (81.21, 108.64)	−0.64 (−1.18, −0.10)	86.5 (78.01, 94.98)	−0.35 (−0.65, −0.05)

FEV1 forced expiratory volume in 1 s, *FVC* forced vital capacity, *SD* standard deviation, *95% CI* 95% confidence interval, *SMD* standardized mean difference

Discussion

The results of our meta-analysis indicate that exposure to solder fumes in the electronics industry was associated with wheeze after adjustment for smoking. The mean lung function values were within normal ranges in exposed workers, and the differences with controls were statistically, but not clinically significant.

Among studies included in our meta-analysis, Palmer and Crane [8] found occupational wheeze to be associated with the weekly number of hours of exposure to solder flux, but did not find a relationship with dyspnea and cough after adjusting for smoking, history of atopy, and age. Lee et al. [11] did not report significant differences in work-related respiratory symptoms or lung function parameters between solderers and controls, nor were there significant differences between those exposed to solder fumes for less than 5 years and those exposed for 5 years or more. They surprisingly noted that solderers did not have increased diurnal variations in peak expiratory flow rate (PEFR) compared to controls.

Gupta et al. [25], for their part, found exposure to soldering to be associated with mild restrictive ventilator disturbance (FVC between 70 and 79% predicted). However, they did not observe that workers who had more than 10 years of exposure to solder fumes had a greater impairment of lung function compared to the others. The differences in spirometric parameters found between exposed and nonexposed persons may be related to a higher prevalence of smokers among workers exposed to solder fumes, as suggested by Courtney and Merrett [10], who concluded that discrepancies in lung function parameters between short-term (less than 6 years) and long-term (6 years or more) solderers and ex solderers in their study were more likely due to smoking habits than to the exposure to solder fumes. This hypothesis is supported by previous studies that found a higher prevalence of smokers among welders than in the general population (48 vs. 22%) [27]. However, in the one study that reported lung function parameters separately for smokers and non-smokers, Courtney and Merrett [10] found that, among smokers, solderers had lower FEV1 than non-exposed office workers, whereas no such difference was found among non-smokers. This may suggest that smoking and soldering exposure could have a synergistic effect in inducing an impairment of lung function.

The papers included in our meta-analysis had limits to their methodological quality. They all failed to explain how their population sample size was arrived at. One study [10] had a large number of participants (>1000, but its omission in the sensitivity analysis did not affect the summary estimates), 4 studies [8, 11, 21, 25] had between 100 and 250 subjects, and the remaining two [9, 24] included fewer than a hundred. With regard to the study design, six of the seven papers were prevalence studies, which do not allow for assessing the temporality between the respiratory symptoms and the exposure to solder fumes. The only cohort study did not aim to determine the incidence of asthma in electronics workers, but rather to follow the evolution of the affected patients [24]. Exposure was measured based on the number of years of soldering or weekly hours of work. In most of the studies the duration of exposure was more than 6 years, corresponding to the latent period between the first exposure and the first symptoms [15]. Respiratory symptoms were self-reported in all the papers. In some studies the measurements of lung function were performed before and after a working shift or in a single measure, which could be poor methods of assessing occupational asthma [9, 11, 24]. Most of the studies reported the proportions of smokers and atopic subjects, and the age of participants, but only one controlled for all of these factors in the analysis, while most did not control for any of them [9, 10, 24, 25].

Other limitations of our study need to be commented on. The most important one is the lack of quantitative measurement of exposure intensity or any other measure of dose in the individual studies. Also, our study is a meta-analysis; therefore, the potential biases of individual studies may have affected the summary effect sizes. The number of studies included in some analyses was small and may have biased some of the results, especially in the comparison of lung functions between solderers and controls. We only included papers published in English, which may not be representative of all the studies conducted on the topic. Also, an underestimation of occupational asthma was possible due to a selection bias: individuals may develop work-related respiratory symptoms and leave the occupation. The high turnover of employees in some electronics factories may have protected most workers from developing work-related respiratory symptoms [28].

In conclusion, there is an association between exposure to soldering in electronics workers and an increased risk of wheezing; however, it is still unclear whether soldering is associated with an impairment of lung function. Future cohort studies with the appropriate sample size are needed to assess the effect of soldering flux on respiratory symptoms, lung function, and risk for asthma and other lung diseases. Importantly, given the small detected differences in lung function, other relevant measures, such as asthma-related quality of life or asthma morbidity should be evaluated.

Conflict of interest The authors report no conflict of interest.

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