Annals of Work Exposures and Health, 2022, Vol. 66, No. 1, 5–13
doi: 10.1093/annweh/wxab044
Advance Access publication 13 July 2021
Original Article

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Silica Exposure Estimates in Artificial Stone Benchtop Fabrication and Adverse Respiratory Outcomes

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Submitted 26 February 2021; revised 22 April 2021; editorial decision 26 May 2021; revised version accepted 21 June 2021.

Abstract

Silicosis is being increasingly reported among young stonemasons in the artificial stone (AS) benchtop fabrication and installation industry. Respiratory health screening, which included a job and exposure history, a chest X-ray (CXR), a respiratory health questionnaire, and gas transfer testing, were offered to stonemasons in Victoria, Australia. Workers typically reported a variety of tasks, including cleaning and labouring, which made exposure assessment complex. We estimated the relative respirable crystalline silica exposure intensity of each job from the proportion of time using AS and the proportion of time doing dry work (work without water suppression). The relative average intensity of exposure for up to five jobs was calculated. Cumulative exposure was calculated as the sum of the duration multiplied by intensity for each job. Installers and factory machinists (other than computer numeric control operators) were the most likely to report dry work with AS, and so had a greater average intensity of exposure. Exposure intensity and cumulative exposure were associated with increased odds of an ILO (International Labour Organisation) CXR profusion major category of ≥1 and with dyspnoea. Exposure duration was also associated with ILO profusion category. In multivariate analyses of health outcomes, only job type was associated with the ILO profusion category. For both most recent and longest-duration job types, when compared to the lowest exposure group, factory machinists were more likely to have an ILO category ≥1. This suggests that intensity of exposure estimated from the proportion of time dry cutting and proportion of time working on AS can predict the risk of adverse respiratory outcomes for workers in this industry.

Keywords: artificial stone; exposure; silica

What's Important About This Paper?

Stonemasons in the benchtop industry, including young workers, experience silicosis, including accelerated silicosis. In this study, the percentage of time dry cutting and the percentage of time working on artificial stone (AS) was used to estimate relative exposure intensity to respirable crystalline silica among stonemasons making benchtops. These simplified determinants were used to predict exposure intensity and cumulative exposure which were associated with increased risk of adverse respiratory health outcomes, even in young men (median age 36) with a short period of exposure as a stonemason in the AS benchtop industry (median 6.8 years). Dry cutting of AS should be prohibited, so as to reduce exposure and risk of disease among stonemasons.

Background

Since the early 2000s, the use of artificial stone (AS) for fabrication of kitchen and bathroom benchtops has increased. AS is also known as engineered stone or reconstituted stone. AS usually has a very high silica content of 90% or more (Ophir *et al.*, 2016; Hoy *et al.*, 2018). Respirable crystalline silica (RCS) is generated when cutting, grinding, or polishing AS and can accumulate in the lungs of those who are exposed.

Silicosis among stonemasons in the AS benchtop fabrication and installation industry has been reported (Qi and Echt, 2016; Johnson *et al.*, 2017) with increasing frequency since 2011 (Leso *et al.*, 2019). Affected workers have been frequently reported to be young and still actively employed (Hoy *et al.*, 2018; Leso *et al.*, 2019; Martínez González *et al.*, 2019). In Australia, some of these young workers have been diagnosed with a rapidly advancing silicosis, *accelerated silicosis*, and have required lung transplant (Levin *et al.*, 2019; Newbigin *et al.*, 2019; Jones *et al.*, 2020).

Some work practices, in particular, tasks such as dry cutting and grinding of AS, have been reported to generate extremely high levels of exposure to RCS (Cooper *et al.*, 2015; Johnson *et al.*, 2017). However, as Phillips states 'workers alternated between tasks, such as sawing, grinding, or polishing, every 5–10 min or less' (Phillips *et al.*, 2013). Operators also spend time setting up and moving blocks, so task-based data do not easily translate to daily average exposure. Exposure during cutting can be many orders of magnitude above the 2020 Australian Workplace Exposure Standard of 0.05 mg/m^3 RCS 8-h time-weighted average exposure.

The cumulative exposure, the product of the intensity (average mg/m^3), and the duration (years) of exposure to RCS, is a likely predictor of the risk of development of silicosis (Leso *et al.*, 2019). It is unclear whether exposure rate is a risk factor, that is, whether long-term low exposure has the same effect as short-term high exposure where the cumulative exposure may be the same.

WorkSafe Victoria (WSV) funded respiratory health screening (RHS) for all past and present workers in benchtop fabrication businesses. Some preliminary silicosis findings from the first year of the registry have been published (Hoy *et al.*, 2020). This paper extends the earlier paper by looking at a larger group of workers. It investigates whether job category, and estimates of silica exposure duration, exposure intensity, and cumulative exposure, are associated with the specific adverse respiratory outcomes that are measured when screening silica-exposed workers.

Methods

The RHS was conducted by two occupational health providers (OHPs) The health screening data collected for each worker included a CXR (chest X-ray) read to ILO standards, by a NIOSH qualified B-reader, a respiratory health questionnaire from which a dyspnoea score was derived using a modified Rose Dyspnoea Scale, and respiratory function testing including Forced Expiratory Volume in 1 second (FEV_1), Forced Vital Capacity (FVC), and Diffusion Capacity of the Lung for Carbon Monoxide (DLCO). These data were reviewed by an occupational physician to determine whether there was a risk of silicosis. Those identified as 'at risk of silicosis' were referred to a respiratory physician for further evaluation including a high-resolution computed tomography (HRCT) chest scan. More details of the questionnaire and RHS methods are provided in an earlier paper (Hoy *et al.*, 2020).

Eligible workers who participated in the RHS were invited to contribute their data for research purposes. Study data were collected and managed using REDCap (Research Electronic Data Capture), a secure, web-based application designed to support data capture for research studies (Harris *et al.*, 2009), hosted and managed by Helix at Monash University.

Workers who attended the RHS, recorded up to five jobs, including start and end dates. Most non-office

Table 1. Decision tree for job classification.

Decision tree	Job category
1. ≥80% *time in 'Other' tasks:* more than 80% of the workers' time was not undertaking factory floor tasks or onsite tasks	
a) ≥80% of job history in 'Other' tasks	Other minimal secondary exposure
No personal hands-on exposure and <10% secondary exposure	
b) ≥80% of job history in 'Other' tasks	Other with some direct or secondary exposure
Some personal exposure and/or ≥10% time secondary exposure	
2. <*80% time 'Other' tasks*: usually called stonemason	
a) ≥40% installing	Installer
b) <40% installing	
(i)≥40% on CNC	Factory worker-CNC
(ii)<40% on CNC	Factory worker-Machinist

workers gave their job title as stonemason, so further information on their tasks was needed to group them into likely exposure categories. Stonemasons often work in small workplaces and undertake a variety of tasks. Therefore, study participants were asked, for each job, to identify tasks from a list and allocate a percentage of time to each. The tasks were: *Shaping*, e.g. with powered hand tools, *Sawing*, e.g. with a bridge saw, *Using CNC (computer numeric control) machine*, *Polishing/Finishing*, *General labouring*, *Maintenance*, *Cleaning* the tools, surfaces and/or workspace, *Onsite installing* and *Other*, e.g. template maker, manager, supervisor, office worker.

Self-reported task information was used to create job categories as detailed in Table 1. Job titles in the 'Other' category included general manager, estimator, administration, accounts clerk, director, and template maker. Workers categorized as 'Other' were separated into those who undertook 'hands-on' tasks and/or reported significant bystander exposure and those who did not. All remaining workers were then grouped as 'Installers' or 'Factory workers'. The latter group were divided into 'Factory worker-CNC operator' or 'Factory worker-(other) machinist' based on the highest percentage of time spent in the relevant tasks. Jobs, where practices have changed, were recorded as two jobs to accurately capture job-level information before and after processes changed.

For each recorded job, the start and end dates (month and year) were used to calculate job duration. For current jobs, duration was calculated using the screening date as the end date. For the longest job, the duration of time spent in each job category was calculated by adding all durations in the relevant job category.

Exposure to RCS from AS dust can be reduced by using wet processing methods. It was thought that the major determinants of exposure intensity were likely to be the proportion of time working on AS, the proportion of dry processing, the ventilation, and the use of respiratory protective equipment (RPE). For each job, the participants were asked to estimate the proportion of time on AS (>50% or <50%) or 0% if only natural stone was handled and to identify the type(s) of ventilation and RPE used (if any). Workers were also asked about the *proportion of time spent doing dry work* and the *proportion of time spent near someone else doing dry work* for each job, with the following options available: Never 0%, Rarely 1 to <10%, Sometimes 10 to <25%, Frequently 25 to <50%, Very frequently 50 to <100%, Always 100%; see Supplementary Table S1.

Only the type of stone and proportion of time doing dry work were used to derive intensity of exposure which was used to weight duration of exposure as shown in Table 2. The ventilation and RPE were not included in the exposure metric.

The values used to weight the exposure estimate by intensity of exposure were chosen *a priori*. We used a 10-fold weighting for dry versus wet work (Table 2) as suggested by the UK Health and Safety Executive (2001). Data from four workplaces where granite was being cut showed that changing from dry to wet cutting reduced 8-h TWA exposure by approximately an order of magnitude (Simcox *et al.*, 1999). A similar 10-fold reduction in exposure was seen between wet and dry cutting of AS (Cooper *et al.*, 2015).

A weighting factor of 0.3 was used to account for the difference between all natural stone and all AS work. AS typically contains over 90% silica content compared to granite typically 30% silica and marble of about 2% silica.

Weighted cumulative exposure was calculated by multiplying job exposure intensity values by duration for each job and then adding together the results of all jobs. Averaged exposure intensity was calculated by dividing the weighted cumulative exposure by the duration of exposure summed over all reported jobs.

To investigate whether installers were at increased risk of adverse respiratory outcomes compared to workers who had not been installers, an ever/never analysis was undertaken separating workers into the following groups:

- *Ever installer:* workers who reported doing installation work in any reported job.
- *Never installer:* workers who have not reported doing any installation work across any of their reported jobs.

To assess whether workers who did not undertake significant hands-on work are at risk, an analysis using the following groups was completed:

- *Other* only includes workers who only have jobs in the *Other* category across all reported jobs, which includes either *other minimal secondary exposure* and/or *other with some direct or secondary exposure*.
- *Ever factory or installation* includes workers who have at least one job in the installation or factory category (includes factory CNC and factory machinists).

Statistical analysis

All participants with workplace history data were included in the analyses. Descriptive statistics including counts, percentages, medians, and interquartile ranges (IQR) were used to summarize the demographic and exposure characteristics of the cohort. The Kruskal-Wallis test was used to assess associations between most recent and longest-duration job category and job intensity.

Respiratory outcomes were dichotomized for analysis: CXR as ILO profusion major of 0 (normal) or categories ≥1 (abnormal), dyspnoea as none or present, and the respiratory function parameters as above and below the lower limit of normal (LLN), as determined by the Global Lung Initiative normal values (Quanjer *et al.*, 2012).

Multivariate Firth logistic regression was used to investigate associations between workplace silica exposure variables and the binary respiratory outcomes. This model was chosen as it can handle the problem of data separation (zero cell counts).

All models were adjusted for relevant potential confounding factors identified *a priori* by the researchers, based on Directed Acyclic Graphs. Analyses for the respiratory outcomes of CXR and dyspnoea were adjusted for age, gender, and smoking. Models for lung function were adjusted for smoking only, as age and gender and had been incorporated into the LLN calculations. All analyses were conducted using Stata/IC V16 (StataCorp, College Station, TX, USA) with the level of significance set at 5%.

Ethical approval was granted by the Monash University Human Research Ethics Committee.

Results

A total of 557 workers participated in the WSV RHS, of these 407 (73%) agreed to contribute their data for research. Of the 407 consented workers, Monash University received 324 complete participant records (80%) from the OHP. Ten participants did not have CXR results and 69 did not have complete respiratory function data, most as a result of COVID-19 restrictions.

Table 3 shows the demographic details of the workers in the program. The majority (300) were men, the participants had a median age of 36 years and 45% had never smoked. They had worked for a median of 6.8 years in the industry. Most of the workers were in small workplaces, 89% were from workplaces with fewer than 50 workers, 40% from workplaces with fewer than 10 workers.

Participants typically reported a variety of tasks, most reported some cleaning and labouring tasks. When categorized by most recent job, almost half of the participants were factory machinists, 23% of workers were in installation and 9% worked as CNC machinists. Analysis by longest job category had similar findings.

Table 3 also shows the adjusted odds ratios (ORs) for the six respiratory outcomes by demographic and

Table 2. Weighting factors for exposure intensity based on proportions of dry work and type of stone (no units).

Dry work	All artificial (1)	≥50% artificial (0.75)	<50% artificial (0.5)	All natural (0.3)
Never (1)	1	0.75	0.5	0.3
Rarely 1 to <10% (2)	2	1.5	1	0.6
Sometimes 10 to 25% (4)	4	3	2	1.2
Frequently 25 to <50% (6)	6	4.5	3	1.8
Very frequently 50 to <100% (8)	8	6	4	2.4
Always 100% (10)	10	7.5	5	3

exposure variables. Exposure intensity and cumulative exposure were associated with increased odds of an ILO category of ≥1 and with dyspnoea, and exposure duration was associated with an ILO category ≥1. Duration and intensity were not associated with any of the respiratory function parameters. The relationship between respiratory outcomes and exposure duration, intensity, and cumulative exposure is shown in Fig. 2.

Importantly, in multivariate analyses, significant associations with job type were only identified for ILO categories. For both most recent and longest-duration job types, workers with some direct or secondary exposure and installers had lower odds of an ILO category ≥1 compared to factory machinists. Workers who had left the industry within 1 year of the RHS, had higher odds of reporting dyspnoea compared to those still working. These participants also had higher odds of having respiratory function values <LLN than those who were still working. Working status was not a predictor of having an ILO category of 1 or more.

For dyspnoea, the size of workplace was significant for workplaces of 10–50 compared to less than 10, but not for other workplace sizes. No other outcomes showed significant associations with workplace size (see Supplementary Table S1).

No associations with the health outcomes were identified when comparing those who had only ever had 'Other' jobs (n = 47) with those who had ever been and factory workers or installers (n = 277); or when comparing those who had never been an installer (n = 119) with those who had ever been an installer (n = 205) (see Supplementary Table S1).

The duration of exposure for workers by longest job category is shown in Supplementary Figure S1. CNC operators had the shortest median duration of exposure of 3.7 years. Workers categorized as having minimal secondary exposure (i.e. do not undertake hands-on work) had a similar median work duration to installers and factory machinists of 6.7, 5.0, and 7.3 years, respectively. Workers who have occasional hands-on or bystander exposure ('Other with some direct or secondary exposure') had the longest median duration of 9.0 years and also the largest duration range.

The intensity score varies with the job. Installers and factory machinists were the most likely to report dry work with AS, hence have a greater intensity of exposure (Fig. 1). The intensity of exposure for CNC operators was low, probably because CNC operators reported mainly wet cutting in addition CNC machines are usually enclosed reducing the dust emitted. Table 4 shows that installers and factory machinists had the highest median job intensity for both most recent and longest-duration jobs, and there was statistically significant variation in the intensity of exposure between job categories. Weighted cumulative exposure by longest job category is shown in Supplementary Figure S2.

Supplementary Table S2 shows the shift in percentage of time dry processing across jobs, with workers' spending the least amount of time dry processing in their most recent job. For the earliest reported jobs, 74% of workers recorded dry processing 50% of time or more, which is substantially higher than the most recent job where only 16% of workers were dry processing more than 50% of the time. For the group as a whole, the proportion of time spent dry processing has gradually declined from earliest job to the most recent job.

RPE was not included as a determinant of exposure, as only a minority of workers reported always wearing it and data were not available about fit testing. Supplementary Table S3 shows the proportion of time wearing RPE for each job recorded. Only 24% of the 29 workers with data for five jobs wore RPE for more than 50% of the time in their earliest job recorded, with a gradual increase in the proportion from job to job, increasing to 52% in the most recent job for the 316 workers with available data. The proportion of reported time spent wearing RPE did not change substantially over successive jobs, however, it should be noted that some workers reported stopping the use of RPE recently after wet processing was introduced.

Supplementary Table S4 shows the type of ventilation used for each reported job. The majority of workers indicated that in their most recent job, the ventilation was an open window, door, or in the ceiling, i.e. unlikely to be removing the dust before it entered the breathing zone. The use of *on the tools* ventilation was higher at 15%

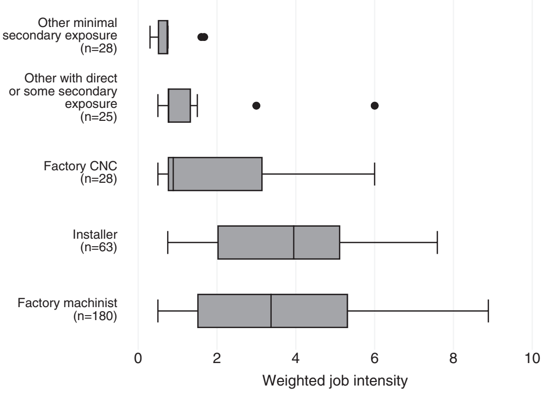

Figure 1. Weighted intensity of exposure mean and 95% confidence intervals for longest-duration job.

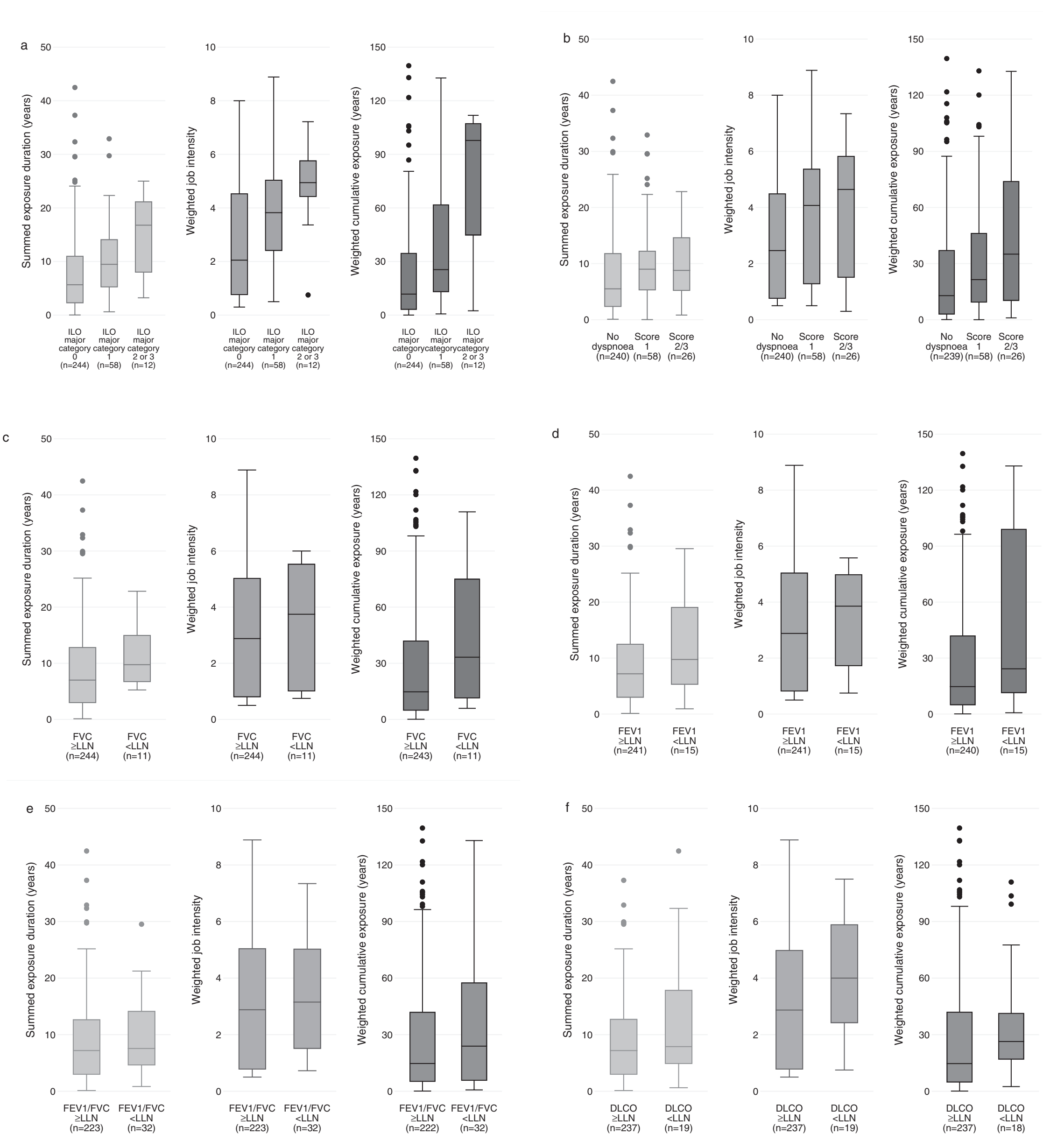

Figure 2. Exposure duration, intensity, and cumulative exposure by respiratory outcomes[a].

[a]All weighted cumulative exposure figures exclude one worker with a very high value.

for the most recent job compared to all other jobs where only 5–8% of workers used *on the tools* ventilation.

Discussion

The relative intensity score is associated with the adverse respiratory outcomes of an ILO major profusion category ≥1 and dyspnoea (Fig. 2). For the ILO category, duration of exposure was also an important variable, probably reflecting the time it takes to develop detectable fibrosis.

The intensity score depended on two questions for each job, the portion of time doing dry work (or near someone doing dry work) and the percentage of time working on AS. Despite the reductionist nature of these questions, the resulting score predicted risk.

Table 3. Multivariate Firth logistic regression for association between demographic and exposure variables and respiratory outcomes.

	All workers, *N* (%)	Chest X-ray[a] ILO 0 versus ILO ≥1	Dyspnoea[a] No versus Yes	$FVC^b \geq LLN^c$ versus <LLN	$FEV_1{}^b \geq LLN$ versus <LLN	$FEV_1/FVC^b \geq LLN$ versus <LLN	$DLCO^b \geq LLN$ versus <LLN
Male	300 (92.6)	Reference	Reference				
Female	24 (7.4)	0.26 (0.05, 1.43)	2.09 (0.86, 5.09)				
Age (years)	36 (29, 46)[d]	**1.03 (1.00, 1.06)**	1.02 (0.99, 1.04)				
Never smoker	147 (45.4)	Reference	Reference				
Former smoker	75 (23.1)	**2.38 (1.15, 4.95)**	1.67 (0.86, 3.23)				
Current smoker	102 (31.5)	**3.35 (1.72, 6.53)**	1.66 (0.91, 3.03)				
Time since first exposure years	9 (3, 14)[d]	**1.05 (1.01, 1.09)**	1.03 (1.00, 1.07)	**1.07 (1.01, 1.14)**	1.06 (1.00, 1.11)	1.02 (0.98, 1.07)	**1.07 (1.02, 1.13)**
Age at first exposure years	25 (20, 34)[d]	**0.96 (0.92, 0.99)**	0.97 (0.94, 1.01)	1.02 (0.96, 1.08)	1.02 (0.97, 1.07)	**0.93 (0.88, 0.98)**	1.00 (0.94, 1.05)
Summed job duration years	6.8 (2.9, 12.5)[d]	**1.05 (1.00, 1.10)**	1.03 (0.99, 1.08)	1.04 (0.97, 1.12)	1.05 (0.99, 1.12)	1.02 (0.97, 1.07)	1.06 (1.00, 1.12)
Weighted job intensity	2.9 (0.8, 5.0)[d]	**1.19 (1.04, 1.36)**	**1.28 (1.13, 1.45)**	1.07 (0.82, 1.40)	1.05 (0.83, 1.33)	1.04 (0.88, 1.23)	1.21 (0.97, 1.51)
Weighted cumulative exp median years	14.7 (4.5, 41.3)[d]	**1.01 (1.00, 1.02)**	**1.01 (1.00, 1.02)**	1.01 (1.00, 1.02)	1.01 (1.00, 1.02)	1.00 (1.00, 1.01)	1.01 (1.00, 1.02)
Most recent job							
Other minimal 2° exp	40 (12.3)	0.63 (0.19, 2.02)	0.54 (0.19, 1.56)	0.94 (0.15, 5.85)	1.23 (0.28, 5.36)	0.53 (0.13, 2.12)	0.73 (0.12, 4.38)
Other some direct or 2° exp	21 (6.5)	**0.05 (0.00, 0.92)**	1.22 (0.43, 3.46)	0.39 (0.02, 7.18)	0.29 (0.02, 5.26)	0.42 (0.07, 2.36)	0.25 (0.01, 4.51)
Factory CNC	29 (9.0)	1.21 (0.49, 2.98)	0.43 (0.13, 1.38)	2.04 (0.45, 9.25)	0.82 (0.14, 4.83)	0.32 (0.06, 1.78)	1.03 (0.23, 4.55)
Installer	73 (22.5)	**0.47 (0.22, 0.98)**	1.38 (0.75, 2.54)	0.44 (0.07, 2.63)	0.54 (0.13, 2.23)	0.65 (0.26, 1.67)	0.39 (0.10, 1.58)
Factory machinist	161 (49.7)	Reference	Reference	Reference	Reference	Reference	Reference
Longest-duration job							
Other minimal 2° exp	28 (8.6)	0.65 (0.18, 2.33)	0.77 (0.26, 2.30)	0.44 (0.02, 8.12)	1.23 (0.20, 7.56)	0.56 (0.10, 3.19)	1.46 (0.23, 9.37)
Other some direct or 2° exp	25 (7.7)	**0.05 (0.00, 0.81)**	0.77 (0.27, 2.23)	1.05 (0.18, 6.33)	0.88 (0.15, 5.20)	0.69 (0.17, 2.76)	0.21 (0.01, 3.81)
Factory CNC	28 (8.6)	1.09 (0.43, 2.78)	0.62 (0.21, 1.82)	1.19 (0.19, 7.27)	1.00 (0.17, 5.97)	0.74 (0.18, 3.02)	1.47 (0.32, 6.63)
Installer	63 (19.4)	**0.22 (0.09, 0.57)**	1.30 (0.68, 2.48)	0.52 (0.09, 3.07)	0.73 (0.17, 3.01)	0.88 (0.34, 2.29)	0.28 (0.05, 1.59)
Factory machinist	180 (55.6)	Reference	Reference	Reference	Reference	Reference	Reference
Industry status							
Still working	297 (91.7)	Reference	Reference	Reference	Reference	Reference	Reference
Recently left	17 (5.2)	1.90 (0.66, 5.47)	**3.74 (1.40, 9.96)**	4.49 (0.70, 28.93)	2.98 (0.48, 18.59)	**6.23 (1.66, 23.40)**	4.63 (0.89, 24.15)
Not working	10 (3.1)	0.69 (0.14, 3.32)	2.59 (0.74, 9.05)	**9.01 (1.73, 46.87)**	**6.11 (1.24, 30.13)**	1.57 (0.26, 9.61)	**6.84 (1.24, 37.88)**

Bold values show statistically significant differences. 2° exp, secondary exposure.

[a]Adjusted for gender, age, and smoking, CXR data missing for 10 participants.

[b]Adjusted for smoking (age and gender are accounted for the LLN calculations) spirometry data missing for 68 participants (another missing FVC and FEV_1/FVC).

[c]Lower limit of normal.

[d]Interquartile range.

Table 4. Relative exposure intensity by job.

	N (%)	Intensity, median (IQR)	*P*-value[a]
Most recent job			
Other minimal secondary exposure	40 (12.3)	0.8 (0.6, 0.8)	<0.001
Other with some direct or secondary exposure	21 (6.5)	1.0 (0.8, 1.5)	
Factory CNC	29 (9.0)	1.0 (0.8, 3.8)	
Installer	73 (22.5)	3.2 (2.1, 5.3)	
Factory machinist	161 (49.7)	3.5 (1.5, 5.3)	
Longest-duration job, *n* (%)			
Other minimal secondary exposure	28 (8.6)	0.8 (0.5, 0.8)	<0.001
Other with direct or secondary exposure	25 (7.7)	0.8 (0.8, 1.3)	
Factory CNC	28 (8.6)	0.9 (0.8, 3.2)	
Installer	63 (19.4)	3.9 (2.0, 5.1)	
Factory machinist	180 (55.6)	3.4 (1.5, 5.3)	

[a]Kruskal–Wallis test.

The proportion of time on different tasks, the proportion of dry work, and the proportion of AS work were very variable between participants in our study and also over time. As identified by Phillips *et al.*, the participants carried out a variety of cutting and shaping tasks and spending time setting up, moving blocks, etc. (Phillips *et al.*, 2013). There is a paucity of data in the literature about the average daily exposure to RCS during dry work in the AS benchtop industry. Most of the available data are task-based and measured over 20–30 min (Cooper *et al.*, 2015; Qi and Echt, 2016; Johnson *et al.*, 2017). The attribution of measured exposure data to predict each individual's mean daily exposure would have been very complex and speculative. The recent move from dry to wet processing means that recently collected exposure data are not applicable to many jobs prior to about 2018.

The findings suggest that the job category did not strongly predict the odds of adverse respiratory outcomes apart from a lower risk of a high ILO score for installers and 'Other' workers compared to factory machinists. Many of the 'Other' workers had early jobs as a machinist, for example, but later became supervisors and managers, so they may have longer exposure but recent exposure was likely to have been lower.

The low exposure score for CNC workers in our metric correctly reflects the low proportion of time dry cutting for those who spend at least 40% of their time as CNC operators. This provides some face validity for the time spent dry cutting to be a major driver of risk. Exposure to RCS was usually measured as 0.02–0.03 mg/m^3 during the CNC cutting of granite and other materials (Phillips *et al.*, 2013).

Installers are likely to experience high exposure over a short amount of time when dry cutting on site but because they spend time setting up and doing the installation, they will have a comparatively low time-weighted average exposure. Installation workers' average RCS exposure was measured at around 0.01 mgm^3 but with very short-term high exposures to total dust from dry work have been recorded in Australia (Gaskin *et al.*, 2018).

The limitations of the study include incomplete capture of job history. A maximum of 5 stonemason jobs were described, so job histories may have been truncated. However, only 31 (<10%) participants reported five jobs, and 75 (23%) (Supplementary Table S2) reported four jobs, so the majority of participants' working time has been included.

There was limited use of RPE and we had no data on how well fitted the RPE was, when it was used. Field studies of the achieved protection from RPE suggest that the protection often is less than expected (Tannahill *et al.*, 1990; Brouwer *et al.*, 2001). The low rates of on the tool ventilation suggest that this factor was unlikely to have reduced exposure for most participants. Thus, it seems unlikely that neither the RPE nor the ventilation would have greatly reduced exposure for many participants.

Conclusion

Workers in the AS benchtop industry are often in small workplaces and carry out a variety of different tasks. These data suggest, however, that job duration, proportion of time dry cutting, and proportion of time working on AS correlate with the reported tasks, e.g. CNC workers have a lower predicted exposure than other machinists.

Job intensity, as determined by time spent dry processing and the proportion of AS, was found to be a predictor of adverse respiratory health outcomes, even in young men (median age 36) with a short period of exposure as a stonemason in the AS benchtop industry (median 6.8 years). This is a much shorter time period than expected for workers with natural stone.

A ban on dry cutting should greatly reduce exposure for factory machinists, but some dry cutting may still occur during site installation. When dry cutting is eliminated, the effectiveness of the ventilation system and the cleaning processes and the use of RPE may become more important determinants of exposure.

Exposure assessments in respect to RCS should include previous jobs and consider time spent dry cutting and proportion of AS used.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

Funding

This study was funded by WorkSafe Victoria (WSV) (Australia).

Disclaimer

The authors declare no conflict of interest relating to the material presented in this article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

Data Availability

Data cannot be shared for ethical and privacy reasons.

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