Quartz and Respirable Dust in the Dutch Construction Industry: A Baseline Exposure Assessment as Part of a Multidimensional Intervention Approach

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ABSTRACT

Quartz exposure can cause several respiratory health effects. Although quartz exposure has been described in several observational workplace studies, well-designed intervention studies that investigate the effect of control strategies are lacking. This article describes a baseline exposure study that is part of a multidimensional intervention program aiming to reduce quartz exposure among construction workers. In this study, personal respirable dust and quartz exposure was assessed among 116 construction workers (bricklayers, carpenters, concrete drillers, demolishers, and tuck pointers). Possible determinants of exposure, like job, tasks, and work practices, use of control measures, and organizational and psychosocial factors, were explored using exposure models for respirable dust and quartz separately. Stratified analyses by job title were performed to evaluate the effect of control measures on exposure and to explore the association between control measures and psychosocial factors. Overall, 62% of all measurements exceeded the Dutch occupational exposure limit for quartz and 11% for respirable dust. Concrete drillers and tuck pointers had the highest exposures for quartz and respirable dust (0.20 and 3.43 mg m^{-3}, respectively). Significant predictors of elevated quartz exposure were abrasive tasks and type of material worked on. Surprisingly, in a univariate model, an increased knowledge level was associated with an increase in exposure. Although control measures were used infrequently, if used they resulted in approximately 40% reduction in quartz exposure among concrete drillers and tuck pointers. Only among concrete drillers, the use of control measures was associated with a higher score for social influence (factor 1.6); knowledge showed an inverse association with use of control measures for concrete drillers, demolishers, and tuck pointers. In conclusion, the detailed information on determinants of exposure, use of control measures, and constraints to use these control measures can be used for the determination and systematic prioritization of intervention measures used to design and implement our intervention strategy. This study underlines the need for multidisciplinary workplace exposure control strategies although larger study populations are necessary to determine a possible causal association between organizational and psychosocial factors and psychosocial factors and control measures.

INTRODUCTION

Occupational exposure to quartz, used to mean respirable crystalline silica, results in a substantial disease burden in terms of excess occupational disease occurrence and excess mortality (Fedotov and Eijkermans, 2007; Brun *et al.*, 2009). Diseases associated with quartz exposure are chronic respiratory diseases like chronic obstructive pulmonary disease (Rushton, 2007), silicosis including the progressive type (Tjoe Nij *et al.*, 2003; Brown, 2009; Ehrlich *et al.*, 2011), and lung cancer (Vida *et al.*, 2010). In the Netherlands, approximately 300 000 workers were employed in the construction industry in 2009, of whom almost 60% were potentially exposed to quartz (Lumens *et al.*, 2009). In previous studies, several jobs and tasks within the Dutch construction industry showed exposure levels well above the Dutch occupational exposure limit (OEL) for quartz of 0.075 mg m^{-3} (Lumens and Spee, 2001; Tjoe Nij *et al.*, 2003). Similar findings of excessive quartz exposure in the construction industry were reported in other countries in the European Union (Maciejewska, 2008) and in the USA (Yassin *et al.*, 2005).

Information is available that describes the efficacy of control measures for (silica) dust under experimental conditions, either in a laboratory or under controlled conditions at the workplace (Fransman *et al.*, 2008). However, under actual workplace conditions, organizational and psychosocial factors also contribute to the effectiveness of prevention and management of occupational exposures (Heederik and van Rooy, 2008). The importance of organizational engagement is generally acknowledged (LaMontagne *et al.*, 2005), and a study focused on exposure determinants in a range of jobs suggested the importance of psychosocial factors on the exposure variability (Kromhout and Vermeulen, 2001). Occupational hygiene studies have paid much less attention to the role of these factors in controlling occupational exposures.

Hence, well-designed, multidimensional intervention studies should integrate technical (i.e. engineering), organizational, and psychosocial measures, in order to facilitate intervention strategies adopted in the workplace (Goldenhar *et al.*, 2001; Lazovich *et al.*, 2002; Kristensen, 2005; Seixas *et al.*, 2011; Heederik *et al.*, 2012).

The study described in this article forms the basis of a multidimensional intervention study aimed at reducing quartz exposure in the construction industry. The aim of this article is to provide baseline estimates of quartz exposure levels and obtain insight into the most important determinants associated with quartz exposure in the construction industry, including engineering and organizational and psychosocial aspects. This information will be used to develop and implement a multidimensional intervention program to reduce respirable dust and quartz exposure.

METHODS

Study population

The study population consisted of construction workers from eight construction companies, recruited via branch organizations. Companies were relatively specialized and had a limited number of job titles present. All companies and individual workers gave oral and written informed consent to participate. Relevant job categories were selected based on exposure levels identified in previous studies (Flanagan *et al.*, 2003; Lumens *et al.*, 2009), and in a pilot study, in which we visited a small selection of building sites and performed some exploratory measurements. Besides potential exposure levels, the size of the population was considered, resulting in the selection of the following jobs: bricklayers, carpenters, concrete drillers, demolishers, and tuck pointers. Although carpenters were expected to have lower quartz exposure, this category was included because it is assumed that they may be affected by bystander exposure. A more detailed task description per job category is provided in Table 1.

Management questionnaire focused on organizational factors

Employers were asked to fill in a questionnaire to get insight into the occupational safety and health policy of the company. This questionnaire was adapted from the Occupational Health and Safety Assessment Series (OHSAS) norm for health and safety management by selecting all questions focusing on hazardous

Table 1. Description of included job categories in relation to main activities performed

Job category	Job description with most important tasks[a]
Bricklayer	Mainly pointing mortar between bricks; several times per day, only for few minutes, involved in preparing mortar
Carpenter	Performs several tasks, predominantly framing and embedding concrete; handling of (contaminated) materials
Concrete driller	Mainly involved with drilling or sawing concrete or lime–sandstone (usually with integrated water suppression serving as control measure); chopping out concrete using jackhammer; recess milling of concrete or lime–sandstone; handling of (contaminated) materials
Demolisher	Performs several tasks, including demolishing concrete objects/building (parts) using jackhammer or demolishing crews; tidying the workplace by using bobcat/shovels; handling of (contaminated) materials
Tuck pointer	Mainly involved with chasing out of mortar between bricks with pneumatic chipping hammers or hand-held grinders (usually without integrated ventilation serving as control measure)

[a] Tasks with potential (high) exposure to respirable quartz dust.

substances (Anonymous, 2007). OHSAS is an audit evaluation system to assess whether organizations have a safety management system, documented and working in practice.

Among others, the questionnaire was focused on dust-reducing practices and included topics such as (i) presence and compliance of work procedures and workplace instructions; (ii) training of employees; (iii) management support of proactive health and safety culture (e.g. toolbox meetings on a fixed and regular schedule to stimulate discussion between employers and employees); and (iv) communication and feedback with equipment contractors to improve services.

Personal exposure assessment and assessment of engineering factors

Full-shift personal air samples (mean sampling time 7.3 h) were taken from 116 construction workers between November 2011 and February 2012, of whom 22% were sampled repeatedly to enable the evaluation of the within worker variance. Respirable dust samples were collected using Dewell–Higgins cyclones mounted with a PVC filter (Millipore, pore size: 5.0 μm, diameter: 25 mm), connected to a calibrated Gillian GilAir pump with an airflow of 2 l min^{-1}.

The amount of dust on filters was determined gravimetrically by pre- and post-weighing of filters on an analytical balance (Mettler) in a conditioned room. Filters were acclimatized at least 24 h prior to weighing (Health and Safety Executive (HSE), 2000). Quartz was determined by infrared spectroscopy and X-ray diffraction (Health and Safety Executive (HSE), 2005). None of the samples collected had values below the limit of detection (LOD) for respirable dust of 0.15 mg, assessed as the average weight difference of the blank filters plus thrice the standard deviation. Seven samples (5%) had values below the analytical LOD for quartz, which was 0.01 mg.

Throughout their shift, workers were observed using a structured walk-through survey to obtain detailed information on work activities (including task time), workspace, work practices, the type of tools used, type of material worked on, use of dust-reducing techniques (i.e. control measures), and respiratory protective equipment (RPE).

Worker questionnaire focused on psychosocial factors

To explore the possible role of psychosocial factors, employees were asked to fill in a questionnaire on psychosocial factors potentially related to respirable dust

and quartz exposure. Psychosocial factors covered topics like knowledge and beliefs regarding effectiveness of controls, risk perception, social influence, and motivation. A detailed description of these factors is given in Table 2. Knowledge of workers was assessed using a questionnaire with specific quartz dust–related questions. Adapted formats of existing standardized scales were applied to assess motivation, beliefs regarding effectiveness of controls, risk perception and social influence (Ajzen 1991; Geer *et al.*, 2007), and risk propensity (Meertens and Lion, 2008). All psychosocial variables that were considered had a Cronbach value ≥ 0.7, 'acceptable' based on the rules of thumb provided by George and Mallery (2010). Cronbach's alpha is a measure of internal consistency for different items that form a composite variable (Gliem and Gliem, 2003). A few psychosocial factors were included in the assessment (e.g. self-efficacy) but excluded in this analysis because of unreliable scales, i.e. low Cronbach value. All psychosocial variables were measured on a ratio scale with a range, as indicated in Table 2. Two separate questions addressed factors that may be (perceived as) a constraint or facilitator for a worker to perform dust-reducing work practices. In order to gain insight into the feasibility and reliability of the questionnaire, it was tested in a pilot study among 25 workers not involved in the next study phases.

Statistical analyses

All statistical analyses were performed using SAS v9.3 (SAS Institute Inc.). Samples below the analytical LOD of quartz were assigned a value of two thirds of the detection limit. All exposure data showed a skewed distribution, requiring the exposure data to be log transformed prior to statistical analysis. Descriptive statistics were calculated per job category. Spearman correlations between respirable dust and quartz concentrations were calculated. Determinants of exposure to respirable dust and quartz were explored using mixed effects models (PROC MIXED) in order to correct for possible correlation between repeated measurements (Rappaport *et al.*, 1999). Worker was considered as random effect, whereas job category, task, work characteristics (e.g. worker-source orientation and worker-source distance), and organizational and psychosocial factors were introduced as fixed effects. Fixed effects were included as dichotomized variables, except psychosocial factors that were

included as continuous variables. Variances were estimated as between-worker and within-worker variance components.

Model building comprised two steps. In the first step, univariate analyses were used to explore which determinants were associated with exposure to respirable dust and/or quartz. In the second step, determinants that were significantly associated with exposure were introduced stepwise into the model. For model building purposes, the level of significance for inclusion in the model was set at $P < 0.10$.

Separate analyses were conducted to evaluate the effect of control measures, stratified by job category, because the use of specific control measures varied by job category. In addition, associations between psychosocial factors and the use of control measures were explored by job category using linear regression models (PROC REG).

RESULTS

Population characteristics

The study population consisted of male construction workers only (Table 3). Concrete drillers and tuck pointers were generally younger and had less work experience than workers in the other job categories. Carpenters had received vocational training most frequently, whereas concrete drillers were least often vocationally trained (86 versus 13%, respectively).

Organizational factors

Participating companies in this study employed mainly permanent employees. Five out of eight companies stated that compliance with work procedures and workplace instructions regarding dust-reducing practices was supervised by their management. Two companies actively provided training regarding dust-reducing work practices to their personnel. Within three companies, management-supported proactive health and safety culture focused on dust-reducing practices. Five companies consulted with their equipment contractors on improving their services regarding dust-reducing practices.

Personal exposure levels

In total, 149 full-shift personal samples were collected from 116 workers. Table 3 shows the average exposure levels for each job category. Exposure to respirable

Table 2. Description of psychosocial factors

Scale	N^a	Based on (references)	Type	Cronbach value	Scale	Description	Examples of questions
Beliefs	10	Adapted existing questionnaire (Ajzen, 1991)	Likert 5[b]	0.75	1–5	Indication of an individual's beliefs in the effectiveness of various exposure controls and dust-reducing work practices	• Ventilation systems or wetting techniques are effective in reducing quartz dust • Dust-reducing work practices are effective in reducing quartz dust
Knowledge	8	Self-developed	[c]	n.a.[d]	0–1	Estimation of an individual's knowledge regarding exposure sources, controls, substances, routes of exposure, and short- and long-term effects of quartz dust	• Which task causes excessive quartz dust emission? • Which products contain the highest percentage of quartz? • Which long-term health effects may occur when you are exposed to quartz dust (for prolonged periods)?
Motivation	11	Adapted existing questionnaire (Ajzen, 1991)	Likert 5[b]	0.92	1–5	Indication of an individual's intention (or motivation) to use exposure controls and dust-reducing work practices	• To what extent are you planning to use dust-reducing work practices during cleaning of your workplace? • To what extent are you planning to use dust-reducing practices during your work?
Risk perception	6	Adapted existing questionnaire (Ajzen, 1991; Geer *et al.,* 2007)	Likert 5[b]	0.70	1–5	Indication of an individual's perception of risk of quartz dust and susceptibility to short- or long-term health effects	• How risky is quartz? • In your opinion, what are the chances that you will develop health complaints in the short term when working with quartz?

Table 2. continued

Scale	N^a	Based on (references)	Type	Cronbach value	Scale	Description	Examples of questions
Risk propensity	6	Adapted existing questionnaire (Meertens and Lion, 2008)	Likert 5[b]	0.68	1–5	Estimate of an individual's inclination to seek or avoid general (health) risks	• Health is everything for me • I preferably avoid risks • I take risks regularly
Social influence	3	Adapted existing questionnaire (Ajzen, 1991)	Likert 5[b]	0.67	1–5	Indication whether an individual is influenced by co-workers or supervising personnel to use exposure controls and dust-reducing work practices	• My colleagues regularly remind each other of dust-reducing work practices • I only use dust-reducing work practices when my supervisor is in the neighbourhood

[a]N = number of questions per scale.

[b]Questions using Likert-type scales comprised statements concerning the psychosocial factor of interest using five response possibilities, e.g. ranging between agree and disagree, likely and unlikely. All question outcomes were scaled in the same direction, depending on the type of question. Response categories were adjusted if statement was asked inversely.

[c]Knowledge scale consisted of dichotomous questions (true/false) and multiple choice, which were transformed into a ratio scale.

[d]A Cronbach value is not useful for the knowledge scale where diverse topics are evaluated.

dust was highest among tuck pointers, whereas concrete drillers were exposed to the highest quartz levels. The overall geometric mean (GM) was 0.88 mg m^{-3} for respirable dust [geometric standard deviation (GSD) 4.23] and 0.10 mg m^{-3} for quartz (GSD 3.84). The overall correlation coefficient (r) between respirable dust and quartz was 0.76 (range 0.24–0.84 for different job categories), with the largest association for concrete drillers. The full-shift exposure measurements showed quartz concentrations exceeding the Dutch OEL for quartz (0.075 mg m^{-3}) in 62% of the measurements, whereas the Dutch OEL for respirable dust (5.00 mg m^{-3}) was exceeded in 11% of the measurements.

Psychosocial factors

The questionnaire regarding psychosocial factors was administered to all 116 workers. However, eighteen workers did not fill in the questionnaire because of language barriers ($n = 2$) or lack of interest. Among all workers who completed the questionnaire, two main reasons were mentioned to use control measures and/

or to perform dust-reducing work practices if possible: 'It is better for my own health' (89%) and 'It is less inconvenient for my eyes or my airways' (67%). Ergonomically poorly designed tools that adversely affected their productivity were mentioned as the most important constraint to apply dust-reducing work practices.

Overall, carpenters had the highest score for knowledge regarding dust exposure and its possible health effects (0.8 on a scale of 0 to 1). Tuck pointers had the lowest scores for risk perception, beliefs regarding effectiveness of controls, social influence, and motivation compared with other job categories, whereas concrete drillers and demolishers had the highest scores. Psychosocial factor scores are presented in Table 3. Because we hypothesized that the way a company deals with their occupational safety and health policy may affect psychosocial aspects of the workers, we investigated the association between organizational and psychosocial factors. Concrete drillers were present in three companies. All of these three companies offered training on dust reduction practices to their employees,

Table 3. Population characteristics, mean exposure to respirable dust, and quartz and psychosocial factors by job category

	Job category					Overall
	Bricklayer	Carpenter	Concrete driller	Demolisher	Tuck pointer	
Population characteristics						
Age (years)[a]	46 (24–58)	37 (19–58)	37 (20–48)	41 (20–56)	39 (16–54)	39
Work experience (years)[a]	27 (7–42)	18 (3–44)	15 (3–28)	19 (3–39)	17 (1–36)	18
Received vocational training (%)	78	86	13	67	50	55
Exposure measurements						
k	2	1	3	2	3	8
n	9	21	38	32	16	116
r	3	0	7	9	7	26
N	12	21	46	45	25	149
Respirable dust (mg m^{-3})						
GM (GSD)[b]	0.22 (2.10)	0.22 (2.97)	0.86 (3.05)	1.17 (3.80)	3.43 (3.02)	0.88 (4.23)
Range	0.04–0.59	0.03–4.67	0.02–10.86	0.09–33.76	0.36–17.04	0.02–33.76
Quartz (mg m^{-3})						
GM (GSD)[b]	0.02 (1.73)	0.02 (2.30)	0.20 (2.75)	0.12 (2.86)	0.18 (2.18)	0.10 (3.84)
Range	0.01–0.04	0.01–0.09	0.01–1.36	0.01–0.91	0.02–0.80	0.01–1.36
Exceedance OEL respirable dust (%)	0	0	4	11	40	11
Exceedance OEL quartz (%)	0	5	97	71	92	62
Psychosocial factors						
Beliefs	3.6 (2.7–4.8)	3.8 (3.1–4.8)	3.9 (2.6–4.9)	4.1 (2.5–5.0)	3.3 (1.8–4.3)	3.8
Knowledge	0.6 (0.3–0.9)	0.8 (0.5–1.0)	0.7 (0.4–0.9)	0.7 (0.3–0.9)	0.7 (0.4–0.9)	0.7
Motivation	3.9 (2.3–5.0)	3.8 (2.6–4.9)	3.9 (2.9–5.0)	4.2 (3.0–5.0)	3.2 (1.9–4.1)	3.9
Risk perception	3.6 (2.2–4.7)	3.6 (2.5–4.5)	3.7 (2.7–4.7)	3.6 (2.5–5.0)	3.5 (2.5–4.7)	3.6
Risk propensity	3.6 (2.7–4.3)	3.6 (2.7–4.3)	3.6 (2.7–4.3)	3.6 (2.7–4.3)	3.4 (2.7–4.2)	3.5
Social influence	2.9 (2.2–3.7)	3.0 (1.4–4.2)	3.5 (2.2–4.6)	3.6 (2.2–5.0)	3.1 (2.0–5.0)	3.3

k = number of companies per job category; n = number of subjects per job category; r = number of subjects with repeated measurements per job category; N = total number of personal air samples per job category.
[a]Average (min–max).
[b]Geometric mean (geometric standard deviation).

Table 4. Estimates of model variables in final mixed effects models of the log-transformed exposure to respirable dust and quartz

Model variables (fixed effects)	n^a	Respirable dust		Quartz	
		β	*P* value	β	*P* value
Intercept[b]		−4.18	***	−5.98	***
Job category					
Carpenter	21	1.42	0.12****	1.27	0.14****
Concrete driller	46	2.39	0.01*	3.54	**
Demolisher	45	1.82	0.05*	2.81	**
Tuck pointer	25	3.02	***	2.63	***
Bricklayer	12	Ref.			
Tasks					
Demolishing	24	1.05	0.01*		
Drilling	38			0.29	0.15****
Handling	89	−0.32	0.02*	−0.39	0.01*
Milling	4	1.24	**		
Sanding	4	1.52	**	1.06	0.01*
Location					
Indoors	93	1.57	***	1.54	***
Outdoors	56	Ref.			
Distance to source					
Near field	60	0.54	**		
Far field	87	Ref.			
Work orientation					
Shoulder level	100	0.46	**		
Product					
Cement	36	2.08	0.02*	2.08	0.01*
Ceramics	11	0.99	**		
Control measure					
Integrated LEV	15	−0.62	0.02*	−0.53	0.03*
Stationary extraction unit	8	0.55	0.12****		
Integrated water suppression	34			−0.36	0.10****
Spraying water	9			−0.46	0.09*
Var_b$_w$ (CI)[c]		0.38 (0.24–0.69)		0.27 (0.14–0.66)	

Table 4. continued

Model variables (fixed effects)	n[a]	Respirable dust		Quartz	
		β	P value	β	P value
Var_w_w (CI)[d]		0.23 (0.14–0.43)		0.31 (0.20–0.55)	
Total explained variability		71%		71%	

[a]Number of observations with factor present.
[b]The intercept gives the exposure level working as a bricklayer, working outside, far field, not working on shoulder level, not performing any of the tasks, not working with the mentioned products, and not using any of the control measures included in the multivariate model.
[c]Variance component between workers (confidence interval).
[d]Variance component within workers (confidence interval).
Significant at *$P < 0.10$; **$P \leq 0.005$; ***$P \leq 0.0001$; ****borderline significant $0.10 \leq P \leq 0.20$.

probably resulting in a similar score (0.7 on a scale of 0 to 1) for knowledge of their employees. One company employing concrete drillers did not supervise on compliance of work procedures and workplace instructions, which may be indicative for the lower score on social influence (3.5 on a scale of 1–5) compared with concrete drillers with supervision in two other companies (4.2 and 4.3 on a scale of 1–5). A similar indicative, but weak association was found when comparing tuck pointers among three companies with regard to social influence. None of these associations were statistically significant (data not shown).

Determinants of exposure

Table 4 shows the final mixed effects models for respirable dust and quartz exposure. Concrete drillers had on average a 40 times higher exposure to quartz than the reference group, 'bricklayers'. Working indoors resulted in approximately 4.5 times higher exposure to respirable dust and quartz. The activities sanding and drilling were significantly associated with elevated respirable dust and quartz exposure (factors ranging from 1.5 to 4.5). Exposure to respirable dust increased when working at shoulder level or near-field worker-source distance. Integrated water suppression and the spraying of water resulted in almost 1.5 times lower exposure to quartz, whereas integrated local exhaust ventilation (LEV) reduced exposure to respirable dust and quartz by a factor 2. Use of a stationary extraction unit was not significantly associated with exposure. All determinants [e.g. task, product, work practices (i.e. worker-source orientation and worker-source distance), and control measure] by job category as well as their association with exposure in the univariate

models are presented in the Supplementary data, available at *Annals of Occupational Hygiene* online.

Organizational factors did not show any relation with exposure, in both the univariate and multivariate models. The psychosocial factors also were not associated with exposure in the multivariate models. However, the univariate models did show some significant associations. Because we were explicitly interested in psychosocial factors, the results for the univariate associations are shown in Table 5. Only for one of the psychosocial factors, i.e. knowledge, there were indications for an association with respirable dust ($P = 0.03$) and quartz ($P = 0.07$) exposure in a univariate model, with increasing exposure levels when the knowledge level increased. Larger social influence seemed associated with increased quartz exposure levels only ($P < 0.01$). The final models explained 72 and 83% of the between-worker variance, and 69 and 22% of the day-to-day variability for respirable dust and quartz, respectively.

Control measures

Because the use of control measures was correlated with job category, we separately analysed the effect of control measure on exposure by job category. Control measures were particularly used during abrasive tasks among certain job categories, i.e. concrete driller, demolisher, and tuck pointer. The effect of control measures by job category is shown in Table 6. Examples of the control measures that were available during the field study are shown in Fig. 1. Concrete drillers used control measures more frequently (83%) than demolishers (38%) and tuck pointers (28%). Tool-integrated water suppression, used by concrete drillers during drilling and sawing and characterized

Table 5. Psychosocial factors and associations with respirable dust and quartz exposure as estimated in a mixed model

Scale	Respirable dust		Quartz	
	β	*P* value	β	*P* value
Beliefs	−0.30	0.19	−0.06	0.80
Knowledge	−2.22	0.03*	−1.69	0.07*
Motivation	−0.18	0.37	0.03	0.88
Risk perception	−0.09	0.73	−0.05	0.84
Risk propensity	−0.49	0.13***	−0.30	0.32
Social influence	0.15	0.39	0.51	**

Significant at *P < 0.10; **P ≤ 0.005; ***borderline significant 0.10 ≤ P ≤ 0.20.

Table 6. Effect of identified control measures on exposure to respirable dust and quartz by job category

Job category	N	Control measure of interest (n)	Effect on exposure (*P* value)	
			Respirable dust	Quartz
Concrete driller	46	Integrated LEV (7)	2.2 (0.12)**	0.9 (0.86)
	46	Integrated water suppression (31)	1.0 (0.96)	0.6 (0.17)**
Demolisher	45	Stationary extraction unit (8)	9.5 (0.00)*	0.9 (0.70)
	45	Spraying water (9)	0.5 (0.10)**	0.7 (0.18)**
Tuck pointer	25	Integrated LEV (7)	0.4 (0.11)**	0.6 (0.11)**

N = total number of measurements per job category; n = number of measurements where this control is used for the given job category.
Significant at *P < 0.10; **borderline significant 0.10 ≤ P ≤ 0.20.

by a hose connection on the tool, resulted in a nonsignificant 40% reduction in quartz exposure (P > 0.10). For tuck pointers, the use of industrial vacuum cleaners fitted to a centralized extraction ventilation system showed a borderline significant exposure reduction of 60% for respirable dust and 45% for quartz (P = 0.11). Demolishers using a stationary extraction unit had a 9-fold higher exposure to respirable dust compared with demolishers not using this type of control measure. Spraying water as control measure demonstrated a borderline significant reduction in exposure to respirable dust (P = 0.10) among demolishers.

Psychosocial aspects and use of control measures

We explored whether the use of control measures was associated with psychosocial factors by job category because this association might explain why psychosocial factors were not significantly associated with exposure in the final multivariate model. Surprisingly, concrete drillers, demolishers, and tuck pointers with a higher knowledge level less often used control measures (factor 0.3–0.8; P > 0.10). Only among concrete drillers, a higher score for social influence from colleagues or supervisors seemed to result in a significant 1.6 increase (P < 0.001) in the use of control measures (data not shown).

DISCUSSION

This is the first study documenting the potential role of organizational and psychosocial determinants in relation to underlying exposure to respirable dust and quartz. Together with the baseline exposure assessment, this information will be integrated into an
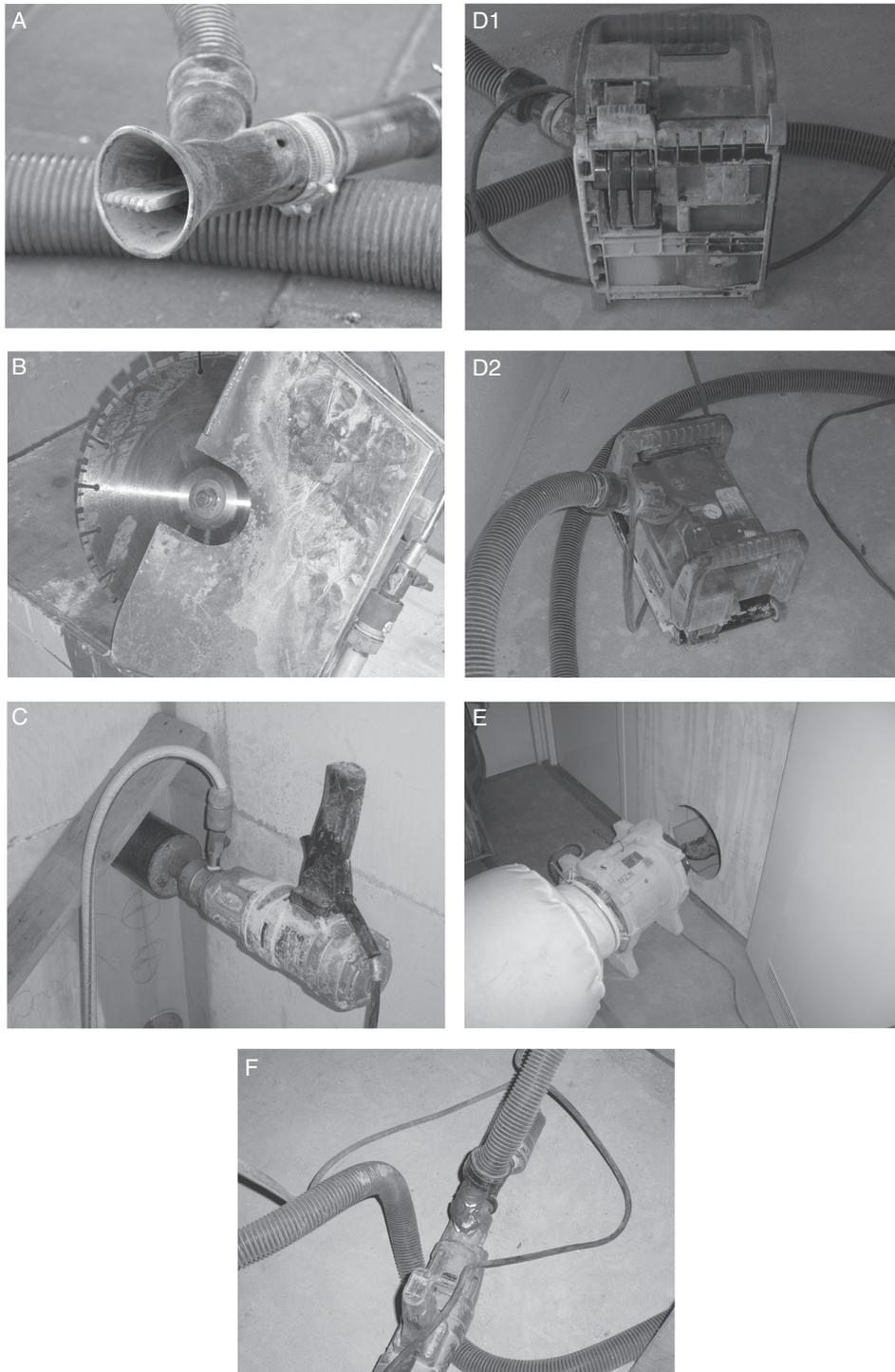
1   Illustrations of identified control measures during the baseline exposure assessment. (A) Tool-integrated local exhaust ventilation (LEV) applied to a pneumatic chipping hammer; (B) Tool-integrated water suppression applied to a circular hand saw; (C) Tool-integrated water suppression applied to a hand drill; (D) Tool-integrated LEV applied to an electric milling machine (D1: bottom view; D2: top view); (E) Stationary extraction unit; and (F) Tool-integrated LEV applied to a hand drill.

intervention strategy that will be evaluated in a post-intervention measurement study. This will eventually provide some first insight in the actual effectiveness of several of the identified control measures as well as the importance of several of the factors identified. It is foreseen that future studies can use this information and will also provide new information strengthening the knowledge on the role of different factors (technical, organisational, and psychosocial) and their interaction with respect to effective interventions.

Exposure concentrations for concrete drillers and demolishers were lower than those found in other studies in the Netherlands (Lumens and Spee, 2001; Tjoe Nij *et al.*, 2004), and exposure levels for tuck pointers were lower than the levels reported in US construction studies (Flanagan *et al.*, 2003; Yasui *et al.*, 2003). These differences may be due to differences in sampling strategies (i.e. task-based versus full-shift sampling) or different exposure circumstances. This and the previous studies demonstrate that exposure levels as observed for concrete drillers, demolishers, and tuck pointers can be, to a large extent, explained by the activities performed and the control measures used. The results of this study indicate that psychosocial factors (e.g. knowledge and social influence, described in Table 2) as well as the presence or absence of constraints when using control measures are associated with the use of control measures. The proactive engagement of the employer in controlling dust exposure could not clearly and consistently be associated with exposure to respirable dust and quartz.

Exposure models generated in this study explained a considerable part of the within- and between-worker variability. The explained day-to-day variability is substantially lower for quartz compared with respirable dust although respirable dust and quartz exposure levels are strongly correlated. The difference in within-worker variability for respirable dust and quartz was also shown by a previous study (Tjoe Nij *et al.*, 2004) and might be explained by the fact that quartz exposure is mostly related to the type of material worked on and the task performed (Tjoe Nij *et al.*, 2004; Flanagan *et al.*, 2006).

Several determinants (e.g. sanding, working indoors, and using tool-integrated LEV) were associated with respirable dust and quartz exposure in our final multivariate models. Among others, demolishing, milling, and worker-source orientation and worker-source distance were associated with higher respirable

dust levels only, whereas drilling and using tool-integrated water suppression were associated with higher quartz exposure levels. Correlation between the different determinants likely explains why some determinants are absent in our final exposure models, while an association was found in univariate models.

For instance, this study confirmed that performing abrasive tasks (e.g. drilling, sawing, jackhammering, and/or tuck pointing) increases exposure levels for respirable dust and quartz. These tasks were also identified as high exposed activities in previous studies (Akbar-Khanzadeh *et al.*, 2002; Echt *et al.*, 2003; Flanagan *et al.*, 2003; Yasui *et al.*, 2003; Croteau *et al.*, 2004; Yassin *et al.*, 2005). However, tasks are strongly job related, and in the final model some tasks did explain additional variability. Intercorrelations likely also explain why several determinants expected to predict respirable dust and quartz exposure, based on literature and earlier study findings, did not show any association with exposure in the multivariate model. Frequency and time spend on activities, likely sources of day-to-day variability in previous studies (Burstyn *et al.*, 1999), were not associated with exposure to respirable dust or quartz. Equipment used appeared not to be associated with exposure although literature shows that hand-operated equipment results in higher exposure levels compared with heavy equipment (Linch, 2002; Rappaport *et al.*, 2003). Materials with a high percentage of quartz, i.e. concrete and lime–sandstone, increased quartz exposure in a univariate model. However, because these materials were strongly correlated with job category, these determinants were absent in the multivariate model.

The effects of control measures were studied per job category. Limited numbers of observations per job category hampered these analyses for some jobs. However, most controls identified in this study appeared effective at reducing exposure. As can be expected, engineering control measures are less strongly associated with a significant reduction in the average exposure level over a full working day compared with task-based (peak) exposures (Rappaport *et al.*, 2003; Tjoe Nij *et al.*, 2003; Fransman *et al.*, 2008). Increased respirable dust levels for demolishers, using a stationary extraction unit as control measure, are remarkable, and this relationship might be confounded by their work area. As observed in

the walk-through survey, demolishers only used this control measure when jackhammering in a small enclosed and separated area where high dust loads could be expected (Flanagan *et al.*, 2006). Exposure levels in the same situation without this control measure could not be estimated due to the cross-sectional nature of this study. One can assume that the use of control measures is, at least to some extent, dependent on expected exposure levels. For RPE, this may also be the case. Interestingly, concrete drillers who were not using control measures wore RPE less frequently. On the other hand, tuck pointers more frequently wore RPE when not using control measures. These findings will be taken into account to optimize and evaluate the intervention and when the exposure data are being used to estimate exposure for an individual in a job title, performing a task under certain circumstances.

Besides indications arising from the questionnaire, observations resulted in some anecdotal reports that the presence of constraints can hinder workers who are motivated to use control measures. For example, a demolisher intended to use integrated water suppression as control measure. However, the worksite had no water supply available. Another concrete driller intended to use tool-integrated LEV when working on the 18th floor. However, the contractor gave no permission to use the elevator for this purpose. Thus, contextual factors determine the use of control measures as well.

Several studies have stressed the importance of psychosocial factors. Analyses of large databases have shown that worker behaviour is likely to explain between-worker variability and potentially also part of the within-worker variability (Kromhout and Vermeulen, 2001). Furthermore, personal factors and working techniques (i.e. work practices) might play an important role in worker's exposure, and these factors will also be important in exposure control, possibly even more than engineering controls (Rappaport *et al.*, 1999; Burdorf, 2005). To our knowledge, this is the first study exploring the effect of psychosocial factors in relation to occupational exposure to airborne substances. The questionnaire focused on psychosocial factors was based on existing questionnaires but was not validated. As a result, misclassifications could partly explain the relatively weak association. Nevertheless, some interesting indications were

observed but need confirmation in a larger study. With regard to the psychosocial factors, only knowledge showed a relation with exposure overall, with more knowledge resulting in lower exposure (univariate analysis). This might be due to training resulting in better use of control measures, but may also be due to confounding by other factors. For example, carpenters have the highest knowledge level, but they also naturally perform the lowest exposed activities. Larger social influence from co-workers and supervisors was expected to have a positive effect on exposure. This association was only observed among concrete drillers.

The use of control measures was associated with an individual's beliefs, risk perception, and/or motivation regarding the effectiveness and use of exposure controls and dust-reducing work practices. In general, interesting and somewhat unexpected associations (e.g. workers with higher knowledge levels less often used control measures, even within job categories) were found between some psychosocial factors and the use of control measures. Because these associations may be confounded by other factors, detailed contextual information is needed to interpret some of these associations. Many of these findings seem to be plausible, but more research is needed in a larger population to establish the causal role of the psychosocial factors taking into account potential confounding factors.

CONCLUSION

In conclusion, we identified determinants of respirable dust and quartz exposure in the construction industry that are relevant for designing an intervention strategy. Although a larger study population is required to determine relations between organizational and psychosocial factors univocally, and between psychosocial aspects and the use of control measures, this study did give indications that psychosocial factors, i.e. knowledge and social influence, may play a role in quartz exposure levels in the construction industry. In the intervention phase of this study, the focus will be directed towards the interplay between technical, organizational, and psychosocial factors. In general, the influence of constraints impeding and factors that facilitate the use of control measures, whether on an individual, work environment, or organizational level, will be optimized.

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