Ann. Occup. Hyg., 2015, Vol. 59, No. 8, 959–971
doi:10.1093/annhyg/mev037
Advance Access publication 8 June 2015

Effectiveness of a Multidimensional Randomized Control Intervention to Reduce Quartz Exposure Among Construction Workers

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Submitted 6 January 2015; revised 21 April 2015; revised version accepted 21 April 2015.

ABSTRACT

There is little evidence with respect to the effectiveness of intervention programs that focus on the reduction of occupational quartz exposure in the construction industry. This article evaluates the effectiveness of a multidimensional intervention which was aimed at reducing occupational quartz exposure among construction workers by increasing the use of technical control measures. Eight companies participating in the cluster randomized controlled trial were randomly allocated to the intervention (four companies) or control condition (four companies). The multidimensional intervention included engineering, organizational, and behavioural elements at both organizational and individual level. Full-shift personal quartz exposure measurements and detailed observations were conducted before and after the intervention among bricklayers, carpenters, concrete drillers, demolishers, and tuck pointers ($n = 282$). About 59% of these workers measured at baseline were reassessed during follow-up. Bayesian hierarchical models were used to evaluate the intervention effect on exposure levels. Concrete drillers in the intervention group used technical control measures, particularly water suppression, for a significantly greater proportion of the time spent on abrasive tasks during follow-up compared to baseline (93 versus 62%; $P < 0.05$). A similar effect, although not statistically significant, was observed among demolishers. A substantial overall reduction in quartz exposure (73 versus 40% in the intervention and control group respectively; $P < 0.001$) was observed for concrete drillers, demolishers, and tuck pointers. The decrease in exposure in the intervention group compared to controls was significantly larger for demolishers and tuck pointers, but not for concrete drillers. The observed effect could at least partly be explained by the introduced interventions; the statistically significant increased use of control measures among concrete drillers explains the observed effect to some extent in this job category only. Sensitivity analyses indicated that the observed decrease in exposure may also partly be attributable to changes in work location and abrasiveness of the tasks performed. Despite the difficulties in assessing the exact magnitude of the intervention, this study showed that the structured intervention approach at least partly contributed to a substantial reduction in quartz exposure among high exposed construction workers.

KEYWORDS: cluster randomized controlled trial; construction industry; exposure assessment; intervention study; quartz; technical control measures

INTRODUCTION

Occupational exposure to respirable crystalline silica, which is often called quartz in its most common form, is remarkably high among a large proportion of construction workers. Previous studies showed exposure levels well above the relevant occupational exposure limits (OELs) (which range between 0.025 and 0.10 mg m^{-3} in the different countries) during specific activities, such as drilling, sawing, and/or tuck pointing (Yassin *et al.*, 2005; Flanagan *et al.*, 2006; Sauvé *et al.*, 2013). In a recent survey among construction workers, we reported similar findings of excessive quartz exposure levels when comparable activities were performed (van Deurssen *et al.*, 2014). Occupational quartz exposure is associated with several potential health risks, e.g. silicosis (Leung *et al.*, 2012), lung cancer (Vida *et al.*, 2010), and chronic obstructive pulmonary disease (COPD) (Möhner *et al.*, 2013). Since a large number of workers are employed in the construction industry (Economisch Instituut voor de Bouw, 2013), there is a need for effective interventions to reduce or prevent occupational quartz exposure and thereby the prevalence and incidence of chronic respiratory diseases (Heederik and van Rooy, 2008; Brun *et al.*, 2009; Hutchings *et al.*, 2012).

Although several studies describe the efficacy of specific technical control measures to reduce hazardous substances in an experimental setting (Flynn and Susi, 2003), studies evaluating the effectiveness of these measures under real working conditions are scarce (Fransman *et al.*, 2008). In practice, organizational (Lamontagne *et al.*, 2005) and behavioural factors (Kromhout and Vermeulen, 2001) also determine the effectiveness of control measures (Heederik and van Rooy, 2008; Heederik *et al.*, 2012; Robson *et al.*, 2012). So far, a very limited number of intervention studies that focused on the reduction of hazardous substances in the occupational setting have been published. A well-known example is the Minnesota Wood Dust study that evaluated the effectiveness of an intervention comprising training of workers, technical assistance, and written recommendations in small woodworking shops (Lazovich *et al.*, 2002). Another more recent study among South-African bakery workers evaluated the effectiveness of an intervention comprising the implementation of different technical control measures in combination with dust control and risk-awareness training (Baatjies *et al.*, 2014). Both studies illustrate that structured interventions, conducted under real working conditions and integrating technical, organizational, and behavioural factors are the key to gain insight in effective prevention.

A comprehensive intervention program for the construction industry was therefore developed using the Intervention Mapping approach, which describes a process for developing theory- and evidence-based intervention programs (Bartholomew *et al.*, 2006). Baseline measurements and workplace observations (van Deurssen *et al.*, 2014) were combined with input from stakeholders and empirical findings from the literature to tailor the intervention strategy to the needs of the target population (Oude Hengel *et al.*, 2014). The aim of this study was to evaluate the effectiveness of this intervention on the increase in the use of technical control measures in order to reduce quartz exposure levels.

METHODS

Study design

A detailed description of the study design and the methods have been described elsewhere (Oude Hengel *et al.*, 2014). The effectiveness of the intervention was assessed in a cluster randomized controlled trial (cluster RCT). Companies rather than individuals were randomized since the intervention components were mostly administered at the organizational level (i.e. company) rather than at the individual level. Moreover, randomization at the organizational level minimized the risk of intervention group contamination (Christie *et al.*, 2009).

Randomization, blinding and sample size

Cluster randomization took place at the company level after the baseline survey. All eight companies were randomly assigned to either an intervention (n = 4) or control condition (i.e. no intervention; n = 4) using an electronic randomization tool (www.randomizer.org.). Construction workers, managers, and the research team could not be blinded to the allocation. Before the intervention took place, sample size calculations were performed assuming an 30% reduction in exposure, based on a comparable study in the wood processing industry (Lazovich *et al.*, 2002). We assumed an alpha of 5% and a power of 80%, as well as a long-term downward trends of 3% annually for two years in both the control and intervention group (Kromhout and Vermeulen, 2000) and a loss-to-follow-up of 20%. Based on these calculations, it was estimated that 60 construction workers for both the intervention and control group were required at baseline and during follow-up, resulting in a group of 120 workers. Since we aimed to conduct repeated measurements among 25% of the workers, we aimed to collect 150 personal samples in 120 workers during both baseline and follow-up.

Study population

Details about the study population are described elsewhere (van Deurssen *et al.*, 2014). The following job categories were included: bricklayer, carpenter, concrete driller, demolisher, and tuck pointer.

Companies were recruited through sector organizations. All construction workers within the participating companies who were permanently employed at the start (November 2011) and who had sufficient Dutch language skills, were eligible to participate. Because of the large number of workers eligible to participate, a random sample of these eligible workers per company was included in the baseline measurements (i.e. pre-intervention) (van Deurssen *et al.*, 2014). After the baseline measurement, participating companies were randomly allocated to an intervention or control group.

Follow-up measurements (i.e. post-intervention) were aimed at reassessing exposure in individuals included in the baseline random sample. However, some workers could not be included again during follow-up for practical reasons: they were working at inaccessible worksites or they were unemployed at the time of the follow-up measurements. These workers were replaced by other workers within the company with similar job titles and performing similar tasks in order to obtain an equal number of workers and measurements as in the baseline survey. All participating construction workers signed a written informed consent. The study is not part of the judgement of the Central Committee of Research Involving Human Subjects, meaning that no medical ethic approval was required for this study. The study has been executed according to the Dutch Data Protection Law.

Intervention

More details on the development and content of the intervention have been described elsewhere (Oude Hengel *et al.*, 2014). In short, the 6-month intervention program was developed according to the Intervention Mapping protocol (Bartholomew *et al.*, 2006), and consisted of engineering, organizational, and behavioural elements at both organizational (managers) and individual (construction workers) level. The intervention consisted of two plenary sessions and accompanying intervention materials. All permanent employees from a company were invited for the plenary sessions. The first plenary session for all employees (managers and construction workers) at the company comprised a presentation by the principal researcher (EvD) and an occupational physician, accompanied by a documentary about health risks of quartz exposure, and PIMEX videos [i.e. method to visualize the impact of good work practices, e.g. proper use of local exhaust ventilation or water suppression techniques, and poor work practices, e.g. no use of shielding dusty locations or compressed air cleaning, on exposure]. The second individual session was organized at the worksite and aimed to teach construction workers how to use technical control measures, including the discussion about constraints and possible solutions. Simultaneously with these worksite visits, a separate meeting was organized for the managers to give them more insight in the availability of state-of-the-art technical control measures. During the last plenary session at the company, all employees discussed with the principal researcher key solutions to overcome the main constraints when using technical control measures. Additionally, a labour inspector explained the policy of the labour inspection regarding quartz exposure during this session.

Outcome measures

This study investigated the effectiveness of the intervention on personal quartz exposure levels and the use of technical control measures [e.g. tool-integrated local exhaust ventilation (LEV) and water suppression techniques]. Follow-up measurements were conducted ~24 months after the baseline survey, 6 months after the implementation of the intervention. Population characteristics were obtained from the questionnaire administered to the construction workers (van Deurssen *et al.*, 2014).

Full-shift personal quartz samples were taken 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} (van Deurssen *et al.*, 2014). Quartz content of the filters was determined by infrared spectroscopy and X-ray diffraction, according to MDHS 101 (HSE, 2005). The analytical limit of detection (LOD) of quartz was 0.01 mg (HSE, 2005).

Use of technical control measures was assessed through observation of the workers throughout their shift, using a structured walk-through survey to obtain detailed information on the duration and type of technical control measures used (van Deurssen *et al.*, 2014).

Statistical analyses

Samples below the analytical LOD of quartz were assigned a value of two thirds of the detection limit. The quartz exposure distribution was highly skewed. Therefore, exposure data were log transformed prior to statistical analyses. Potential differences in population characteristics between construction workers in the intervention and control group, such as age, education level and baseline exposure levels, were tested using unpaired *t* tests (continuous variables) and Pearson Chi-square tests (dichotomous variables).

The statistical analyses used to evaluate the intervention effect followed a stepwise approach. First, descriptive statistics were generated for all job categories to gain insight in differences in quartz exposure levels between different groups over time. Second, hierarchical models were used to evaluate the intervention effect, defined as the difference in change in quartz exposure (natural logarithm of the quartz concentration (mg m^{-3}) as dependent variable) from baseline to follow-up between the intervention and control group. Bayesian models were used because these are particularly suited to cope with the unbalanced structure of the dataset (i.e. absence of both a baseline and follow-up measurement for part of the subjects). On job category level, i.e. concrete driller, demolisher and tuck pointer, an effect was estimated of occasion (pre- or post-intervention), condition (control or intervention), and the occasion*condition interaction term (the intervention effect). A random intercept for subject was included to adjust for correlations between repeated measures on the same worker. The hierarchical model was estimated using a Bayesian approach with Markov chain Monte Carlo (MCMC) methods, primarily for computational reasons (i.e. good convergence properties given the relatively few observations to estimate some of the random effects). Pearson Chi-square tests were generated to investigate the difference in duration of use of control measures by job category between baseline and follow-up among the control and intervention condition. Use of control measures was expressed as fraction of the time that abrasive tasks (e.g. drilling, sawing, jackhammering, tuck pointing) were performed, since it was observed that control measures were used only during abrasive tasks.

Bayesian estimation was performed using R (version 3.1.2; R Foundation for Statistical Computing, Vienna, Austria), while the remaining analyses were performed using SAS v9.3 (SAS Institute Inc., Cary, NC, USA). A $P < 0.05$ was considered as statistically significant. The code for the Bayesian analyses programmed in RStan (version 2.5.0; Stan Development Team) is presented in the Supplementary data, available at *Annals of Occupational Hygiene* online.

RESULTS

Participant flow and population characteristics

In total, a selection of 13 companies was approached to participate. Five companies were excluded because they employed too few permanent construction workers or because they had insufficient work supply during the period of the baseline survey. Hence, 62% (8 companies) were enrolled in the intervention study (Fig. 1). These eight companies employed in total 404 eligible construction workers (177 in the control group and 227 in the intervention group). Company size varied between 15 and 103 construction workers.

Personal full-shift exposure measurements were collected from 116 construction workers (n = 149 measurements) during the baseline survey (van Deurssen *et al.*, 2014), and 104 construction workers (n = 133 measurements) during follow-up (Fig. 1). In total, 68 construction workers had at least one measurement on both occasions. At baseline a higher percentage of the intervention group only followed secondary school ($P < 0.05$), while a higher percentage of the control group followed medium or high education ($P < 0.05$) (Table 1). Workers lost-to-follow-up had a lower level of education ($P < 0.05$) than the remaining workers measured at baseline, whereas no differences were observed between new entrants and workers measured at baseline.

Intervention effects and quartz exposure

The study demonstrated an overall reduction in quartz exposure in both the control and intervention group. This reduction was larger in the intervention group (73% compared to 40% in the control group; $P < 0.001$). The intervention effect could only be estimated for concrete drillers, demolishers, and tuck pointers, as the model provided unreliable estimates when all job categories were included. This was due to the absence of carpenters in the intervention group and the low exposure levels at baseline for both bricklayers and carpenters, which left very little potential for improvement (van Deurssen *et al.*, 2014). The difference in reduction in exposure was significant for demolishers and tuck pointers (P = 0.005 and P = 0.008, respectively), but not for concrete drillers (P = 0.15) (Fig. 2).

The reduction in exposure was also reflected in the number of measurements above the OEL. In the three high exposed job categories, 75 and 86% of the baseline measurements exceeded the Dutch OEL for quartz (0.075 mg m^{-3}) in the intervention group and control group, respectively. During follow-up, this was reduced to 40% of the measurements in the intervention group versus 60% of the measurements in the control group (Table 2).

The intervention aimed to establish an increase in the use of technical control measures in order to reduce occupational quartz exposure. Such an increased use of control measures was observed for concrete drillers in particular, even though there was no statistically significant effect of the intervention on exposure within

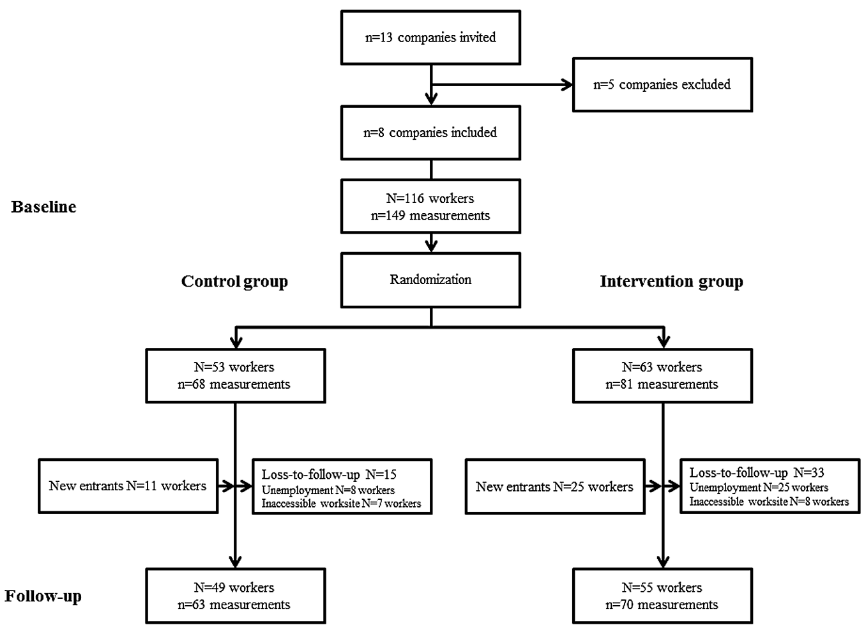

Figure 1 Flow diagram of study participants.

Table 1. Population characteristics, separated for occasion (baseline or follow-up) and condition (intervention or control).

	Baseline		Follow-up	
	Control group ($N = 53$; $n = 68$)	Intervention group ($N = 63$; $n = 81$)	Control group ($N = 49$; $n = 63$)	Intervention group ($N = 55$; $n = 70$)
Individual characteristics				
Age (years) (SD)	39.2 (11.7)	39.3 (9.7)	40.5 (11.2)	42.7 (9.5)
Missing		$N = 16$	$N = 5$	$N = 1$
Job category				
Bricklayer	4% ($N = 2$)	11% ($N = 7$)	8% ($N = 4$)	22% ($N = 12$)
Carpenter[a]	34 % ($N = 18$)	0	39% ($N = 19$)	0
Concrete driller	21% ($N = 11$)	48% ($N = 30$)	12% ($N = 6$)	31% ($N = 17$)
Demolisher	30% ($N = 16$)	25% ($N = 16$)	27% ($N = 13$)	13% ($N = 7$)
Tuck pointer	11% ($N = 6$)	16% ($N = 10$)	14% ($N = 7$)	34% ($N = 19$)
Smoking	43% ($N = 23$)	44% ($N = 28$)	39% ($N = 19$)	51% ($N = 28$)
Education level[b]				
No	12% ($N = 6$)*	7% ($N = 3$)*	4% ($N = 2$)	8% ($N = 4$)
Low	28% (N=14)*	41% (N=19)*	29% ($N = 14$)	27% ($N = 13$)
Medium/high	60% (N=30)*	52% (N=24)*	64% ($N = 29$)	65% ($N = 32$)
Missing	$N = 3$	$N = 17$	$N = 4$	$N = 6$
Graduated vocational training	65% ($N = 31$)	45% ($N = 19$)	64% ($N = 21$)	79% ($N = 34$)
Missing	$N = 5$	$N = 21$	$N = 16$	$N = 12$

N = number of subjects, n = number of measurements, [a]No carpenters in intervention group.
[b]No education considered only primary school, low education considered only secondary school, and medium or high education considered (secondary) vocational education.
*$P < 0.05$.

this job category. Concrete drillers in the intervention group used control measures for a significant greater proportion of time spent on abrasive tasks during follow-up, compared to baseline ($P < 0.05$; Table 3). This increase in use of control measures was attributable to an increase in the use of water suppression techniques. Although not statistically significant, demolishers and tuck pointers in the intervention group also tended to use water suppression techniques for a greater proportion of time spent on abrasive tasks during follow-up compared to baseline. No clear differences in use of LEV could be observed between the control and intervention group.

To test if the observed intervention effects for the various job categories could be explained by the increased use of control measures, we adjusted the intervention effect for the change in usage of control measures by job category by adding control measure as an explanatory variable into the model. This resulted in a diminished change in exposure for concrete drillers (not statistically significant). Although the effect was not statistically significant prior to adding control measures as an explanatory variable, this may indicate that the increased use of control measures among concrete drillers is at least partially responsible for the decrease in exposure observed in this job category.

Table 2. Mean exposure to quartz (mg m^{-3}) by job category, separated for occasion (baseline or follow-up) and condition (intervention or control).

Job category	Occasion	*n*	GM (GSD)[a]	Range	Exceedance OEL quartz (%)	Condition	*n*	GM (GSD)[a]	Range	Exceedance OEL quartz (%)
Bricklayer	Baseline	12	0.02 (1.73)	0.01–0.04	0	Control	3	0.02 (1.91)	0.01–0.04	0
						Intervention	9	0.02 (1.71)	0.01–0.04	0
	Follow-up	22	0.01 (2.06)	0.01–0.19	5	Control	8	0.01 (3.27)	0.01–0.19	13
						Intervention	14	0.01 (1.31)	0.01–0.02	0
Carpenter	Baseline	21	0.02 (2.30)	0.01–0.09	5	Control	21	0.02 (2.30)	0.01–0.08	5
						Intervention	0	n.a.	n.a.	n.a.
	Follow-up	23	0.01 (1.28)	0.01–0.02	0	Control	23	0.01 (1.28)	0.01–0.02	0
						Intervention	0	n.a.	n.a.	n.a.
Concrete driller	Baseline	46	0.20 (2.75)	0.01–1.36	80	Control	11	0.19 (2.14)	0.06–0.61	82
						Intervention	35	0.20 (2.96)	0.01–1.36	80
	Follow-up	25	0.12 (3.24)	0.01–0.86	60	Control	7	0.15 (5.21)	0.01–0.76	71
						Intervention	18	0.11 (2.65)	0.02–0.86	56
Demolisher	Baseline	45	0.12 (2.86)	0.01–0.91	71	Control	19	0.15 (3.14)	0.01–0.71	79
						Intervention	26	0.11 (2.67)	0.03–0.91	65
	Follow-up	25	0.04 (4.77)	0.01–0.44	40	Control	13	0.08 (3.60)	0.01–0.44	54
						Intervention	12	0.02 (4.19)	0.01–0.22	25
Tuck pointer	Baseline	25	0.18 (2.18)	0.02–0.80	92	Control	14	0.23 (1.86)	0.07–0.80	100
						Intervention	11	0.13 (2.39)	0.02–0.32	82
	Follow-up	37	0.05 (4.40)	0.01–0.66	42	Control	12	0.12 (3.77)	0.01–0.66	58
						Intervention	26	0.03 (3.97)	0.01–0.25	35

n.a., not applicable; *n*, number of measurements.
[a]Geometric mean (geometric SD).

Table 3. Mean duration of use of control measure per job category[a] as fraction of the time performing abrasive tasks[b], by occasion (baseline or follow-up) and condition (intervention or control).

Job category	Concrete driller				Demolisher				Tuck pointer			
Control measure	Control group		Intervention group		Control group		Intervention group		Control group		Intervention group	
	Baseline (n = 11) (%)	Follow-up (n = 7) (%)	Baseline (n = 35) (%)	Follow-up (n = 18) (%)	Baseline (n = 19) (%)	Follow-up (n = 13) (%)	Baseline (n = 26) (%)	Follow-up (n = 12) (%)	Baseline (n = 14) (%)	Follow-up (n = 12) (%)	Baseline (n = 11) (%)	Follow-up (n = 26) (%)
CM	64	69	62*	93*	38*	0*	48	63	14	4	38	20
LEV	6	30	6	11	21	0	32	6	14	4	38	9
Wetting	58	39	57	82	17	0	16	57	0	0	0	11

CM, control measure use (whether construction used a control measure in general, not specified for LEV or wetting; LEV, local exhaust ventilation.
[a]These analyses were performed within the sub-population of concrete drillers, demolishers and tuck pointers, since the remaining job categories (i.e., bricklayers and carpenters) did not use technical control measures.
[b]Abrasive tasks considered tasks such as drilling, sawing, jackhammering, sanding, and/or tuck pointing.
*$P < 0.05$.

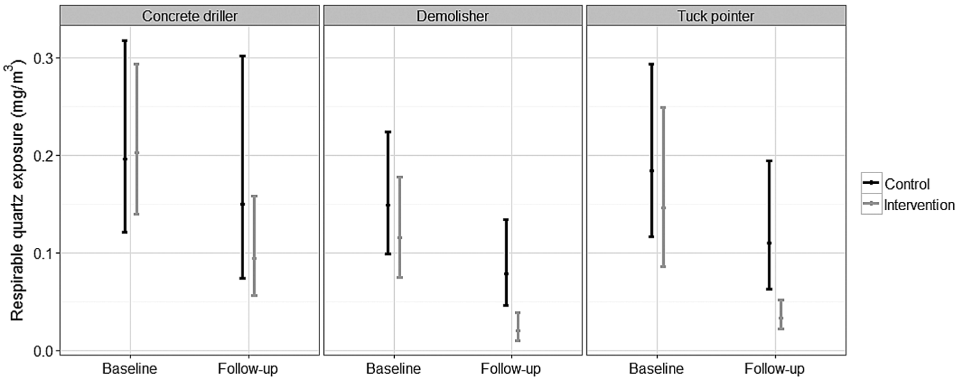

Figure 2 Baseline and follow-up geometric mean (95% confidence intervals) respirable quartz exposure levels (mg m^{-3}) per job category for the intervention group and control group. The *P* values for the intervention effect were $P = 0.005$, $P = 0.008$, and $P = 0.15$ for demolishers, tuck pointers, and concrete drillers, respectively.

The change in exposure remained similar with the addition of the control use variable for demolishers and tuck pointers although the significance level decreased (Table 4). Since the use of control measures was only slightly increased for demolishers and even slightly decreased for tuck pointers in the intervention group during follow-up (both not statistically significant), it is not likely that the change in exposure in these groups was caused by an increased use of control measures among these two job categories.

Several other variables potentially influencing exposure, which were not directly the part of intervention program, changed over time. These variables were selected if they changed over time, if they were not related to the primary intervention, and if they were associated with exposure. Due to colinearity and limited statistical power, some of these variables representing (almost) similar determinants were merged into composite variables. As these composite variables may have confounded the estimated intervention effect (in subgroups), sensitivity analyses were performed by job category. Work location and time spent on abrasive tasks were selected as composite variables, since it was observed that construction workers in the intervention group performed less abrasive tasks and were more often working outside during the follow-up measurements compared with the baseline measurements. The results of the sensitivity analyses showed that the intervention effects differed by job category (Table 4). Changes in work location attenuated the intervention effect for tuck pointers, although this was not statistically significant. However, for concrete drillers and demolishers the intervention effect disappeared or even was reversed when adjusting for changes in work location. A similar analysis with adjustment for time spent on abrasive tasks showed that in general the intervention effect remained visible for each of the job categories although the effect was almost halved for the demolishers.

DISCUSSION

This is the first study that evaluated the effectiveness of a randomized, multidimensional intervention aimed at the reduction of quartz exposure in the construction industry. This study demonstrated a substantial reduction in quartz exposure under workplace conditions among three high exposed jobs in both the control and intervention group. Overall, this effect was significantly larger in the intervention group than in the control group. However, we observed that factors that were not an element of the intervention strategy (the fraction of time spent outdoors and the fraction of time spent on abrasive tasks), changed over time as well. Adjustment for these factors either explained the intervention effect almost entirely (in case of the fraction of time spent outdoors) or reduced the intervention effect substantially, although, not for all of the job categories. Therefore, it cannot be ruled out that the reduction in exposure, for several job categories or within subgroups, is potentially attributable to other factors. Other observations support a potential intervention effect. Concrete drillers in the intervention

Table 4. Intervention effects for the different job categories adjusted for different specific interventions and other variables[a] which changed over time.

			Unadjusted			Adjusted for use of control measures			Adjusted for work location			Adjusted for fraction of time performing abrasive tasks			'Outside' only (stratified)			'Inside' only (stratified)		
Job category	Condition	Occasion	Average exposure (95% CI)[b]	Δ (%)[c]	Effect (%)[d]	Average exposure (95% CI)[b]	Δ (%)[c]	Effect (%)[d]	Average exposure (95% CI)[b]	Δ (%)[c]	Effect (%)[d]	Average exposure (95% CI)[b]	Δ (%)[c]	Effect (%)[d]	Average exposure (95% CI)[b]	Δ (%)[c]	Effect (%)[d]	Average exposure (95% CI)[b]	Δ (%)[c]	Effect (%)[d]
Concrete driller	Control	Baseline	0.20 (0.12–0.33)	−25%	−30%	0.26 (0.13–0.52)	−20%	−23%	0.07 (0.04–0.14)	−43%	23%	0.10 (0.05–0.21)	−20%	−24%	0.06 (0.02–0.16)	−50%	0%	0.29 (0.16–0.52)	−28%	−4%
		Follow-up	0.15 (0.07–0.30)			0.21 (0.09–0.51)			0.04 (0.02–0.10)			0.08 (0.04–0.19)			0.03 (0.01–0.13)			0.21 (0.10–0.43)		
	Intervention	Baseline	0.20 (0.14–0.29)	−55%		0.28 (0.17–0.49)	−43%		0.05 (0.03–0.10)	−20%		0.09 (0.04–0.20)	−44%		0.04 (0.01–0.10)	−50%		0.25 (0.17–0.35)	−32%	
		Follow-up	0.09 (0.06–0.16)			0.16 (0.07–0.35)			0.04 (0.02–0.07)			0.05 (0.03–0.11)			0.06 (0.03–0.12)			0.17 (0.09–0.31)		
Demolisher	Control	Baseline	0.15 (0.10–0.23)	−47%	−36%	0.16 (0.10–0.26)	−50%	−35%	0.03 (0.01–0.06)	−67%	17%	0.09 (0.05–0.16)	−56%	−19%	0.02 (0.01–0.07)	−50%	20%	0.19 (0.12–0.31)	−58%	0%
		Follow-up	0.08 (0.05–0.13)			0.08 (0.05–0.14)			0.01 (0.01–0.03)			0.04 (0.02–0.10)			0.01 (0.001–0.08)			0.08 (0.05–0.14)		
	Intervention	Baseline	0.12 (0.07–0.18)	−83%		0.13 (0.08–0.20)	−85%		0.02 (0.01–0.04)	−50%		0.08 (0.05–0.13)	−75%		0.01 (0.002–0.08)	−30%		0.12 (0.08–0.18)	−58%	
		Follow-up	0.02 (0.01–0.04)			0.02 (0.01–0.04)			0.01 (0.004–0.02)			0.02 (0.01–0.03)			0.01 (0.003–0.02)			0.05 (0.02–0.11)		
Tuck pointer	Control	Baseline	0.19 (0.12–0.30)	−42%	−38%	0.20 (0.12–0.32)	−45%	−35%	0.21 (0.13–0.34)	−52%	−25%	0.06 (0.03–0.13)	−17%	−43%	0.22 (0.12–0.38)	−50%	−23%	n.a.[e]	n.a.[e]	n.a.[e]
		Follow-up	0.11 (0.06–0.20)			0.11 (0.06–0.20)			0.10 (0.06–0.18)			0.05 (0.02–0.10)			0.11 (0.06–0.20)			n.a.[e]		
	Intervention	Baseline	0.15 (0.08–0.25)	−80%		0.15 (0.08–0.28)	−80%		0.13 (0.07–0.22)	−77%		0.05 (0.02–0.10)	−60%		0.12 (0.07–0.23)	−73%		n.a.[e]	n.a.[e]	
		Follow-up	0.03 (0.02–0.05)			0.03 (0.02–0.05)			0.03 (0.02–0.05)			0.02 (0.01–0.03)			0.03 (0.02–0.05)			n.a.[e]		

[a]Fraction of time spent on abrasive tasks comprised all abrasive tasks that were included as dichotomized variables; work location was included as dichotomized variable, i.e. inside and outside.
[b]Average quartz exposure levels (mg m^{-3}) and 95% confidence intervals.
[c]Difference in quartz exposure from baseline to follow-up per job category per condition (i.e. control or intervention group).
[d]Intervention effect defined as the difference in change in quartz exposure from baseline to follow-up between the intervention and control group.
[e]Model estimates for tuck pointing outdoors are not identical to the estimates for the unadjusted model for tuck pointers because the nested structure of the data used for the Bayesian models.

group used technical control measures, particularly water suppression, for a significant greater proportion of the time spent on abrasive tasks during follow-up compared to baseline. A similar effect, although not statistically significant, was observed among demolishers and tuck pointers. It is our interpretation that the intervention effect seems at least partly to be explained by the introduction of the intervention measures, although results are variable.

The shift from using ventilation systems to water suppression techniques might be most likely explained by the fact that the intervention focused on changing behaviour towards a preferred use of water suppression techniques, as we demonstrated in the baseline study that the use of these techniques was associated with a decrease in quartz exposure (van Deurssen *et al.*, 2014). In addition, a changed management support towards using technical control measures and applying dust-reducing work practices might have contributed to an increased use of control measures among construction workers. It was observed that companies initiated the development of dust-reducing technical solutions for work practices during follow-up, supported by the industry associations and equipment contractors. For instance, one company particularly involved with tuck pointing developed a water spray system over the chisel with manual water pumping in order to wet the surface.

Investigating the effectiveness of our intervention in a cluster RCT design, according to certain quality standards (Campbell *et al.*, 2004), and using randomization and a control group (West *et al.*, 2008) was a clear strength of this study. In addition, the study included detailed observations during all measurements to identify determinants of exposure during a working day under actual workplace conditions. These key features of the study enabled accurate interpretation of the effectiveness of the intervention and detailed analyses of the impact of different intervention components and possible confounding factors. Detailed observations of compliance with the intervention, i.e. use of control measures, diminished the potential risk of bias due to social desirable answers linked to only having self-reported information. Sampling was conducted during the same period of the year in order to avoid seasonal influence. The construction industry is a dynamic industry with workers changing jobs regularly. Inter-worker variability was kept to a minimum by reassessing almost 60% of the workers that were assessed at baseline during follow-up. We found that 52% of workers in the intervention group were not present anymore during the follow-up survey. This percentage was lower for controls (28%). However, most workers in the intervention group followed at least one educational intervention session (58%) (van Deurssen *et al.*, 2015). As a result, it seems unlikely that differential lost-to-follow-up contributed to dilution of the intervention effect.

Although a cluster RCT has been shown to be appropriate to prove the effectiveness of an intervention (Bonell *et al.*, 2011; Sanson-Fisher *et al.*, 2007), the application of such a design in this occupational setting with quartz exposure as outcome was rather challenging and some difficulties were encountered. Inherent to (occupational) intervention research, some measurement bias might be induced due to the so called 'Hawthorne effect'. The Hawthorne effect implies that compliance occurs with intervention recommendations because workers know they are being observed (Berthelot *et al.*, 2011; Haessler, 2014). Although this form of bias was controlled by completing comparable observations and measurements on both intervention and controls sites, complete blinding is not possible in the context of so called pragmatic intervention studies. To limit the association between the post-intervention exposure measurements and the intervention, these measurements were performed by fieldworkers whom were not involved in the development and implementation of the intervention. However, construction workers in both intervention and control sites knew that they were observed as part of the intervention study and the fieldworkers could not be blinded to intervention status since intervention materials (like a poster or information brochures) may have been present at the worksites. Furthermore, during the observations construction workers may have given away information on participation in the intervention. At the time of this study, the Dutch labour inspectorate started specific surveys with the intention to reduce exposure. Inspection visits were announced to the entire construction industry, starting just before the interventions for this study were implemented (van Deurssen *et al.*, 2015). These surveys were a likely explanation for the overall reduction in exposure that was observed in the control group also. Besides this industry-wide cointervention, the continuously changing and complex context of the construction industry resulted in worksites which all differed between the first and second measurement campaign. Interpretation of the results was complicated by these factors that changed over time and were difficult to control. Controlling for these underlying (and intercorrelated) variables proved to be difficult; variables that may have confounded the estimated intervention effect could only be considered in simple bivariate but not multivariate models. This was supported by the fact that model parameters became less reliable due to the small number of observations or large variability in the frequency of potential explanatory variables among job categories.

Other intervention studies in the wood processing industry (Lazovich *et al.*, 2002) and in bakeries (Baatjies *et al.*, 2014) encountered similar methodological issues due to a dynamic environment which were impossible to control. Since these methodological issues seem inevitable when performing this type of studies in occupational settings, some suggestions for conducting effective future intervention studies in the construction industry under real working conditions can be made based on our experiences and observations. For instance, it is important to perform a detailed full-shift exposure assessment gaining insight in (underlying) exposure determinants, to be able to assess potential confounding. Furthermore, a homogeneous study population comprising a small number of potential high exposed job categories is recommended, even though this will complicate generalizability of the study findings to the entire construction industry.

CONCLUSION

This study demonstrates a substantial reduction in quartz exposure among high exposure job categories (i.e. concrete drillers, demolishers and tuck pointers) in the construction industry. However, the exact magnitude of the intervention is difficult to assess. The intervention effect for several job categories or within subgroups is likely attributable to other factors that changed over time and that were not an element of the intervention. On the other hand, the study provides some evidence that introduction of intervention measures at least partly contributes to the observed reduction in exposure; a shift from using ventilation systems to water suppression techniques was observed.

SUPPLEMENTARY DATA

Supplementary data can be found at http://annhyg.oxfordjournals.org/.

FUNDING

The Netherlands Organization for Health Research and Development (ZonMw) (20802002).

ACKNOWLEDGEMENTS

The authors first of all thank all the managers and construction workers from the companies who participated in the study. Furthermore, the authors thank Neleida Marrufo Valenzuela and Ana Mafalda Rodrigues Pires Gomes for their support during data collection. We also acknowledge Rinke Klein Entink for his valuable advice on the statistical analysis.

DISCLAIMER

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

REFERENCES

Baatjies R, Meijster T, Heederik D *et al.* (2014) Effectiveness of interventions to reduce flour dust exposures in supermarket bakeries in South Africa. *Occup Environ Med*; 71: 811–8.

Bartholomew LK, Parcel GS, Kok G *et al.* (2006) *Planning health promotion programs: an intervention mapping approach*. San Fransisco, CA: Jossey-Bass.

Berthelot JM, Le Goff B, Maugars Y. (2011) The Hawthorne effect: stronger than the placebo effect? *Joint Bone Spine*; 78: 335–6.

Bonell CP, Hargreaves J, Cousens S *et al.* (2011) Alternatives to randomisation in the evaluation of public health interventions: design challenges and solutions. *J Epidemiol Commun Health*; 65: 582–7.

Brun E, Op dB, van Herpe S *et al.* (2009). Expert forecast on emerging chemical risks related to occupational safety and health. Luxembourg: European Agency for Safety and Health at Work, 1–198. ISBN: 978-92-9191-171-4.

Campbell MK, Elbourne DR, Altman DG; CONSORT group. (2004) CONSORT statement: extension to cluster randomised trials. *BMJ*; 328: 702–8.

Christie J, O'Halloran P, Stevenson M. (2009) Planning a cluster randomized controlled trial: methodological issues. *Nurs Res*; 58: 128–34.

Economisch Instituut voor de bouw (EIB). (2013) Bouw in beeld 2012–2013, pp 1–76. Available at http://www.eib.nl/pdf/Bouw-in-beeld-2012-2013.pdf. Accessed 13 February 2014.

Flanagan ME, Seixas N, Becker P *et al.* (2006) Silica exposure on construction sites: results of an exposure monitoring data compilation project. *J Occup Environ Hyg*; 3: 144–52.

Flynn MR, Susi P. (2003). Engineering controls for selected silica and dust exposures in the construction industry--a review. *Appl Occup Environ Hyg*; 18: 268–77.

Fransman W, Schinkel J, Meijster T *et al.* (2008) Development and evaluation of an exposure control efficacy library (ECEL). *Ann Occup Hyg*; 52: 567–75.

Haessler S. (2014) The Hawthorne effect in measurements of hand hygiene compliance: a definite problem, but also an opportunity. *BMJ Qual Saf*; 23: 965–7.

Health and Safety Executive (HSE). (2005) Methods for the determination of hazardous substances (MDHS) 101–crystalline silica in respirable airborne dusts, pp. 1–16. ISBN 0-7176-2897-3. Available at http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs101.pdf. Accessed 27 December 2010.

Heederik D, van Rooy F. (2008) Exposure assessment should be integrated in studies on the prevention and management of occupational asthma. *Occup Environ Med*; 65: 149–50.

Heederik D, Henneberger PK, Redlich CA; ERS Task Force on the Management of Work-related Asthma. (2012) Primary prevention: exposure reduction, skin exposure and respiratory protection. *Eur Respir Rev*; 21: 112–24.

Hutchings S, Cherrie JW, Van Tongeren M *et al.* (2012) Intervening to reduce the future burden of occupational cancer in britain: what could work? *Cancer Prev Res (Phila)*; 5: 1213–22.

Kromhout H, Vermeulen R. (2000) Long-term trends in occupational exposure: Are they real? what causes them? what shall we do with them? *Ann Occup Hyg*; 44: 325–7.

Kromhout H, Vermeulen R. (2001) Temporal, personal and spatial variability in dermal exposure. *Ann Occup Hyg*; 45: 257–73.

Lamontagne AD, Stoddard AM, Youngstrom RA *et al.* (2005) Improving the prevention and control of hazardous substance exposures: a randomized controlled trial in manufacturing worksites. *Am J Ind Med*; 48: 282–92.

Lazovich D, Parker DL, Brosseau LM *et al.* (2002) Effectiveness of a worksite intervention to reduce an occupational exposure: the Minnesota wood dust study. *Am J Public Health*; 92: 1498–505.

Leung CC, Yu IT, Chen W. (2012) Silicosis. *Lancet*; 379: 2008–18.

Möhner M, Kersten N, Gellissen J. (2013) Chronic obstructive pulmonary disease and longitudinal changes in pulmonary function due to occupational exposure to respirable quartz. *Occup Environ Med*; 70: 9–14.

Oude Hengel KM, van Deurssen E, Meijster T *et al.* (2014) ‘Relieved Working’ study: systematic development and design of an intervention to decrease occupational quartz exposure at construction worksites. *BMC Public Health*; 14: 760. doi:10.1186/1471-2458-14-760.

Robson LS, Stephenson CM, Schulte PA *et al.* (2012) A systematic review of the effectiveness of occupational health and safety training. *Scand J Work Environ Health*; 38: 193–208.

Sanson-Fisher RW, Bonevski B, Green LW *et al.* (2007) Limitations of the randomized controlled trial in evaluating population-based health interventions. *Am J Prev Med*; 33: 155–61.

Sauvé JF, Beaudry C, Bégin D *et al.* (2013) Silica exposure during construction activities: statistical modeling of task-based measurements from the literature. *Ann Occup Hyg*; 57: 432–43.

van Deurssen E, Pronk A, Spaan S *et al.* (2014) Quartz and respirable dust in the Dutch construction industry: a baseline exposure assessment as part of a multidimensional intervention approach. *Ann Occup Hyg*; 58: 724–38.

van Deurssen EH, Pronk A, Meijster T *et al.* (2015) Process evaluation of an intervention program to reduce occupational quartz exposure among dutch construction workers. *J Occup Environ Med*; 57: 428–35.

Vida S, Pintos J, Parent ME *et al.* (2010) Occupational exposure to silica and lung cancer: pooled analysis of two case-control studies in Montreal, Canada. *Cancer Epidemiol Biomarkers Prev*; 19: 1602–11.

West SG, Duan N, Pequegnat W *et al.* (2008) Alternatives to the randomized controlled trial. *Am J Public Health*; 98: 1359–66.

Yassin A, Yebesi F, Tingle R. (2005) Occupational exposure to crystalline silica dust in the United States, 1988-2003. *Environ Health Perspect*; 113: 255–60.