Quartz!?
A randomized controlled quartz exposure intervention in the construction industry

Kwarts!?
Een gerandomiseerd gecontroleerd interventieonderzoek naar kwartsstofblootstelling in de bouwnijverheid

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht op gezag van de rector magnificus, prof.dr. G.J. van der Zwaan, ingevolge het besluit van het college voor promoties in het openbaar te verdedigen op donderdag 29 oktober 2015 des middags te 4.15 uur

door

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geboren op 25 oktober 1987 te Sittard

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The study presented in this thesis was funded by the Netherlands Organization for Health Research and Development (ZonMw), project 208020002.

Contents

Chapter 1

General introduction

Occupational exposure to hazardous substances

The World Health Organization (WHO) has shown that respiratory diseases, e.g. lung cancer and chronic obstructive pulmonary diseases, are in the top 10 causes of mortality in 2008, accounting for 9.5 million deaths worldwide. In Europe, respiratory diseases attribute almost 1.0 million annual deaths.[1] According to a recent report from the International Labour Office (ILO) it has been estimated that 1.9 million workers worldwide annually die from work-related diseases, of whom nearly 900.000 die because of exposure to hazardous substances which are attributed to work.[2] Similar statistics for European Union member states, described by the European Agency for Safety and Health at Work, show that almost 160.000 workers die as a consequence of work-related diseases each year, with as many as 74.000 of these deaths attributable to exposure to hazardous substances at the workplace.[3] Work-related mortality data are not available in the Netherlands, but the Netherlands Centre for Occupational Diseases has estimated that the incidence of occupational diseases in 2013 amounts 267 cases per 100.000 employees per year.[4]

Next to the relatively high number of deaths attributable to occupational exposure, also the total burden of disease is strongly affected by occupational exposure to chemical substances.[5,6] This holds in particular for chronic respiratory diseases, which are ranked as second most important cause of disability-adjusted life years (DALYs) lost worldwide.[1,7] In the Netherlands a similar trend can be observed, as respiratory health effects contribute almost twice as much to the total burden of disease than accidents at work and symptoms which result from low back pain.[8] This large effect on the burden of disease is in particular applicable to the construction industry, in which exposure to a variety of dangerous substances is the cause of the high prevalence of chronic respiratory diseases, associated health care costs and mortality.[8,9]

Occupational quartz exposure in the construction industry

Different specific exposures may explain the disease burden in the construction industry. Besides diesel exhaust, epoxy resins and wood dust, respirable crystalline silica, which is often called quartz in its most common form, is an important hazardous substance to which construction workers might be exposed.[10] Almost a decade ago, a study by Tjoe Nij et al. (2003) has suggested an elevated risk of radiographic abnormalities indicative of pneumoconiosis among high-exposed construction workers.[11,12] Occupational exposure to quartz can result in silicosis,[12-14] chronic obstructive pulmonary disease (COPD)[15] and lung cancer.[16,17] In the Netherlands almost 25% of all 320.000 people employed in the construction industry in 2013 might be potentially exposed to quartz.[18] However, the number of Dutch construction workers is variable and has almost been halved over the last five years as a result of the economic crisis. Not all construction workers are at risk for quartz exposure, because of differentiation in job categories, tasks (e.g. drilling, sawing, jackhammering or removal of dusts by dry sweeping) and materials worked with (e.g. concrete or lime-sandstone).[19] International studies[20-23] and studies in the Dutch construction industry[24,25] show that there is a high likelihood of excessive quartz exposure levels among high exposed job categories well above the occupational exposure limit (OEL).

Importance to reduce occupational quartz exposure

Occupational quartz exposure is a universal problem; quartz exposure is still relevant in the construction industry and a large number of workers are employed in the construction industry.[26,27] Crystalline silica has been classified as a Group 1 human lung carcinogen[28] and it has been listed among the top ten emerging health risks in Europe.[3] Therefore, the WHO in conjunction with the ILO are managing a global program to eliminate silicosis since 1995,[19,29] while the European Union published in 2006 in its official journal a good practices guide for handling crystalline silica.[30] Also in the Netherlands the necessity has been recognized, as the Dutch Ministry of Social Affairs and Employment recently selected silica as a high-risk agent in the construction industry. Consequently, inspection visits by the Dutch labour inspectorate were initiated[31] and several contractors signed a letter of intent regarding dust-reducing work practices.[32] Nevertheless, these initiatives did not seem to have resulted in effective reduction and elimination of occupational quartz exposure over the last years. Thus, workers in this sector are still at risk for developing a variety of adverse respiratory effects.

As such, the employers' and employees' organization for occupational health and safety in the Dutch construction industry, in collaboration with the Netherlands Expertise Centre for Occupational Respiratory Disorders, initiated a health surveillance program. For this purpose a diagnostic model was developed which predicts the probability of silicosis.[33] Construction workers at high risk (based on the sum score threshold of 5.25 or higher) were invited for medical evaluation, including a low-dose high resolution

CT scan of the lungs. The results showed that 22% of the 295 high risk workers were diagnosed with (an early stage of) silicosis.[34] Many of these workers also showed considerable comorbidity, including COPD. These study outcomes imply that early detection is required in order to prevent worsening of silicosis.[34]

Studies investigating quartz exposure reduction

Considering the observed health risks and the (global) importance, there is a need for evidence-based approaches to reduce or prevent occupational quartz exposure and thereby the prevalence and incidence of chronic respiratory diseases.[3,35,36] Focal point of most observational studies aimed at reducing occupational quartz exposure have been the instalment of technical control measures, such as (tool-integrated) local exhaust ventilation (LEV) systems[37-39] and (tool-integrated) water suppression techniques.[39] Fransman et al. (2008) evaluated the body of evidence on the efficacy of technical control measures. They demonstrated that these technical control measures can show a wide variety in efficacy in practice.[40] However, the efficacy was in most cases determined under experimental conditions, either in a laboratory or under controlled conditions at the workplace. The number of studies evaluating the effectiveness of technical control measures under real working conditions are scarce, which is most likely explained by the complexity of designing and performing a good intervention study in real life occupational situations.[41-44] Especially in the construction industry, work force mobility and the transient nature of some construction sites contribute to the complexity and dynamic organization.

How to design a study in order to reduce quartz exposure?

Few studies demonstrate that several control measures have already been implemented in the construction industry.[25,45] The fact that quartz exposure still remains excessively high prioritizes the need for intervention studies under actual workplace conditions. Intervention studies which only focus on the implementation of technical control measures do not explicitly take into account the contextual aspects of workplace conditions such as the organizational work environment[46] and workers' behaviour.[47,48] These aspects determine the extent to which available control measures are actually used in an effective way.[35,49,50] Multidimensional studies, which integrate technical (i.e. engineering), organizational and individual/behavioural factors, need to be well-designed and of a high methodological quality in order to provide convincing evidence on the effectiveness of interventions[41,44] and information on what (not) works.[51] Hence, intervention studies designed as randomized controlled trials (RCTs) are preferred over observational studies, because of randomization, a control group and the conclusive insights regarding causality due to its prospective design.[52,53] Although intervention studies are most commonly performed in clinical medicine, a literature review conducted in 2006 demonstrated a substantial number of intervention studies in occupational health.[41] The majority of occupational intervention studies focused on physical disorders (e.g. ergonomics and injuries)[54-56] and psychosocial demands (e.g. stress),[57] whereas intervention studies regarding exposure to hazardous substances are scarce and generally focus only on the effectiveness of technical (i.e. engineering) control measures.

So far, only two multidimensional studies focusing on exposure reduction to hazardous substances have been conducted: one in the bakery sector[58] and one in the wood processing industry.[59] This scarcity is likely explained by practical difficulties and financial constraints. Since both studies illustrate that integrating technical, organizational and behavioural factors might be considered as the key to gain insight in effective prevention and to facilitate intervention strategies adopted in the workplace,[58,59] accompanied with other findings in the literature,[43,44,49,60] such a multidimensional intervention study was conducted in the construction industry.

Aim and structure of the thesis

The current thesis aims to design, implement and evaluate an evidence-based multidimensional intervention program to reduce occupational quartz exposure in the construction industry. Following this general introduction, **Chapter 2** of this thesis provides baseline estimates of quartz exposure levels and focuses on the factors associated with quartz exposure as identified in the baseline survey. The Intervention Mapping approach was applied to systematically incorporate the findings from this baseline survey, empirical findings from the literature and input from different stakeholders into an intervention program tailored to construction workers. **Chapter 3** describes this systematic development of the intervention and the study design for the evaluation of the intervention. The intervention program was implemented and evaluated among almost 150 workers from eight companies in the Netherlands using a cluster randomized controlled design. The feasibility of implementing an intervention at different worksites in the construction industry, the reach and satisfaction with the worksite intervention, the intention to use the intervention in the future and the role of contextual factors is presented in **Chapter 4**. **Chapter 5** presents the effects of the intervention on exposure levels and use of technical control measures in the intervention and control group. Whether the intervention was successful in improving behavioural factors is described in **Chapter 6**. The final chapter, **Chapter 7**, discusses the lessons learned from this study and provides implications for practice and future research.

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Chapter 2

Quartz and respirable dust in the Dutch construction industry: a baseline exposure assessment as part of a multidimensional intervention approach

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Ann Occup Hyg 2014;58:724-738

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 mg/m^3 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.[1] Diseases associated with quartz exposure are chronic respiratory diseases like chronic obstructive pulmonary disease,[2] silicosis including the progressive type,[3] and lung cancer.[4] In the Netherlands, approximately 300.000 workers were employed in the construction industry in 2009, of whom almost 60% were potentially exposed to quartz.[5] 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.[6] Similar findings of excessive quartz exposure in the construction industry were reported in other countries in the European Union[7] and in the USA.[8]

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.[9] However, under actual workplace conditions, organizational and psychosocial factors also contribute to the effectiveness of prevention and management of occupational exposures.[10] The importance of organizational engagement is generally acknowledged,[11] and a study focused on exposure determinants in a range of jobs suggested the importance of psychosocial factors on the exposure variability.[12] 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.[13-17]

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,[5,18] 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 2.1.

Table 2.1 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.

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 substances.[19] 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. 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.[20] Quartz was determined by infrared spectroscopy and X-ray diffraction.[21] 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 2.2. 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,[22,23] and risk propensity.[24] All psychosocial variables that were considered had a Cronbach value ≥0.7, 'acceptable' based on the rules of thumb provided by George and Mallery.[25] Cronbach's alpha is a measure of internal consistency for different items that form a composite variable.[26] 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 2.2. 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.[27] 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.

Table 2.2 Description of psychosocial factors.

Scale	N[a]	Based on	Type	Cronbach value	Scale	Description	Examples of questions
Beliefs	10	Adapted existing questionnaire[22]	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[22]	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[22,23]	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?
Risk propensity	6	Adapted existing questionnaire[24]	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[22]	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] Number of questions per scale. [b] Questions using Likert-type scales are comprised of 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.

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 2.3). 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 2.3 shows the average exposure levels for each job category. Exposure to respirable 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).

Table 2.3 Population characteristics, mean exposure to respirable dust and quartz and psychosocial factors by job category.

		Job category					
		Bricklayer	Carpenter	Concrete driller	Demolisher	Tuck pointer	Overall
Population characteristics							
	Age (years)#	46 (24-58)	37 (19-58)	37 (20-48)	41 (20-56)	39 (16-54)	39
	Work experience (years)#	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)[1]	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)[1]	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	3.7 (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

Average (min-max). 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. [1] Geometric Mean (Geometric Standard Deviation).

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 2.3. 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, 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 2.4 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 2.5. 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.

Table 2.4 Estimates of model variables in final mixed effects models of the log transformed exposure to respirable dust and quartz.

Model variables (fixed effects)			Respirable dust		Quartz	
		n[a]	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)	
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 $p \leq 0.005$; [♯] $p \leq 0.0001$ and [*] $p < 0.10$. [‡] Borderline significant $0.10 \leq p \leq 0.20$.

Table 2.5 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 $p \leq 0.005$ and [*] $p < 0.10$. [‡] Borderline significant $0.10 \leq p \leq 0.20$.

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 2.6. Examples of the control measures that were available during the field study are shown in Figure 2.1. 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 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 ninefold 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.

Table 2.6 Effect of identified control measures on exposure to respirable dust and quartz by job category.

Job category	N[a]	Control measure of interest (n)[b]	Effect on exposure	
			Respirable dust (p value)	Quartz (p value)
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)[‡]

[a] Total number of measurements per job category. [b] 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.

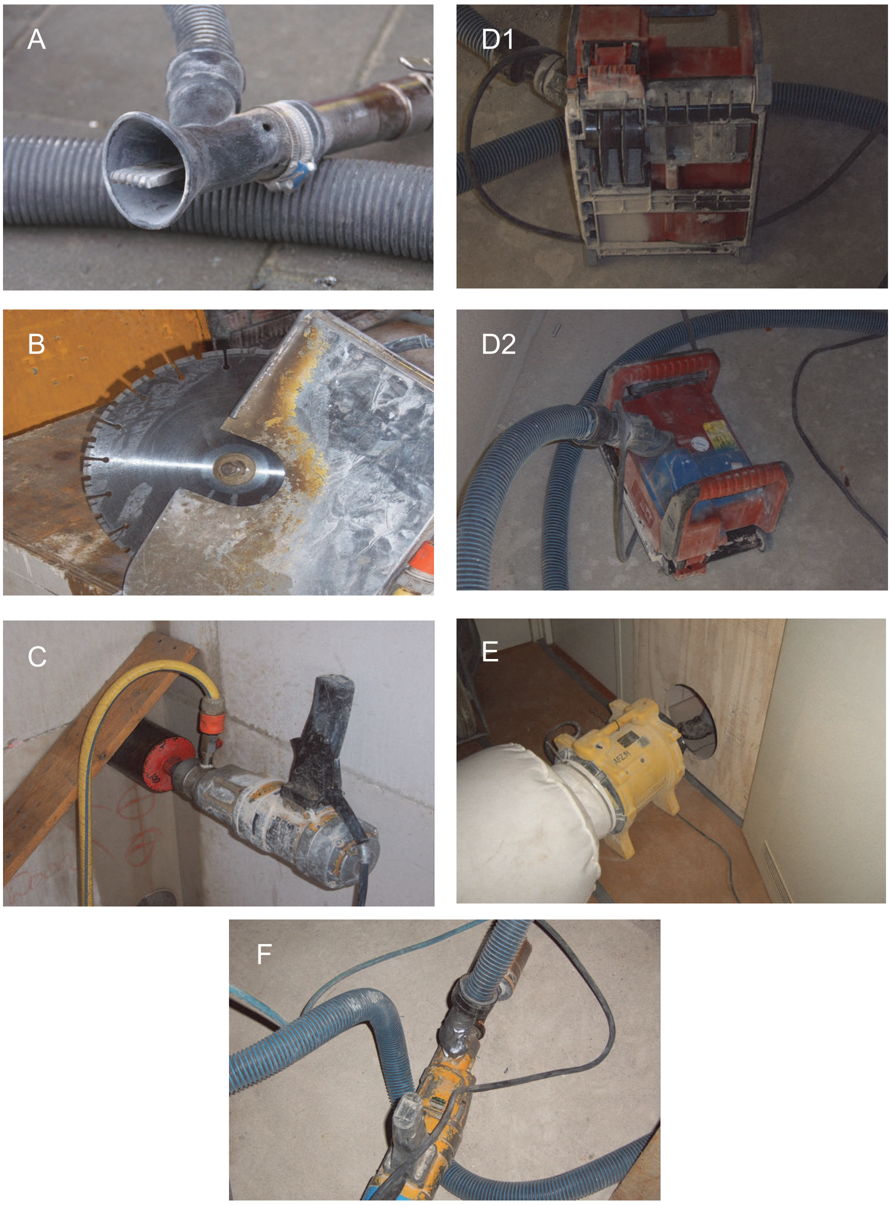

Figure 2.1 Illustrations of identified control measures during the baseline exposure assessment. (A) Tool-integrated local exhaust ventilation (LEV) applied to a pneumatic chipping hammer; (B) Tool-integrated water suppression applied to a circular hand saw; (C) Tool-integrated water suppression applied 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.

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 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, organizational 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,[6,28] and exposure levels for tuck pointers were lower than the levels reported in US construction studies.[18,29] 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 2.2) 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[28] and might be explained by the fact that quartz exposure is mostly related to the type of material worked on and the task performed.[28,30]

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.[8,18,29,31-33] 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,[34] 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.[35,36] 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.[9,35,37] 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.[30] 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 eighteenth 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.[12] Furthermore, personal factors and working techniques (i.e. work practices) might play an important role in workers' exposure and these factors will also be important in exposure control, possibly even more than engineering controls.[27,38] 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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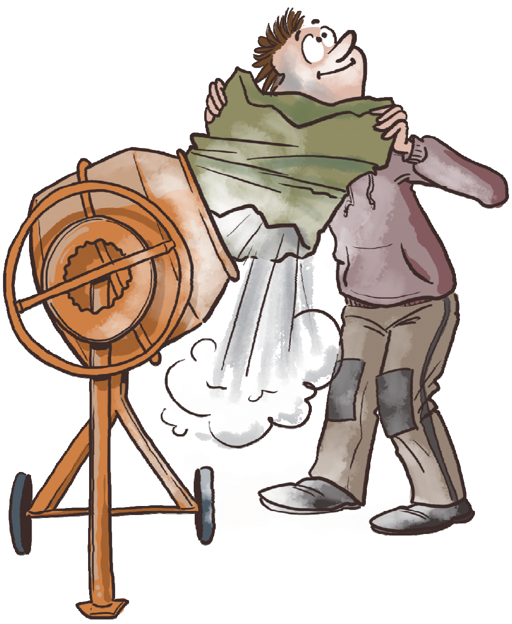
Chapter 3

'Relieved Working' study: systematic development and design of an intervention to decrease occupational quartz exposure at construction worksites



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BMC Public Health 2014;14:760

Abstract

Occupational quartz exposure continues to be a serious hazard in the construction industry. Until now, evidence-based interventions aimed at reducing quartz exposure are scarce. The aim of this study was to systematically develop an intervention and to describe the study to evaluate its effectiveness. The intervention was developed according to the principles of the Intervention Mapping protocol, meaning that evidence from the literature was combined with information collected from stakeholders (e.g. construction workers, managers and researchers). The intervention aimed to integrate technical, behavioural and organizational factors. The intervention consists of two plenary meetings for all employers within the company and individual visits at construction worksites, including specific intervention materials. Additionally, a demonstration session regarding control measures was organized for all managers. The effectiveness of the intervention will be evaluated in a cluster randomized controlled trial among eight construction companies, with measurements at baseline and follow-up. Outcome measures are personal respirable dust and quartz exposure by means of exposure assessment and behavioural and organizational determinants which will be assessed by means of questionnaires. Additionally, a process evaluation will shed light on whether the intervention (does not) works and, if so, the reasons for this. Applying Intervention Mapping in the development of an intervention to reduce occupational quartz exposure was useful, as different stakeholders provided input for the intervention as well as the implementation strategy. Therefore, the feasibility of the intervention has been enhanced, as it appeals to construction workers and managers and will not unduly interfere with the ongoing construction work.

Background

Occupational exposure to respirable dust containing quartz continues to be a serious hazard in the construction industry, as it experiences high quartz exposure levels during specific activities.[1-6] This is illustrated by previous studies which showed exposure levels well above the occupational exposure limits (OELs) for quartz among several jobs and tasks in the construction industry.[1,3,5-7] These high exposure levels could be explained by the fact that construction workers regularly work with building materials such as concrete and lime-sandstone, of which quartz is a major constituent.

As quartz exposure seems inevitable in construction work, construction workers could face potential health risks, mainly lung diseases such as silicosis and chronic obstructive pulmonary disease (COPD),[4,8-10] due to chronic occupational quartz exposure at an elevated level.[11,12] Quartz has been classified as a carcinogen and silica exposure also contributes to lung cancer morbidity and mortality.[13,14] Considering these potential health risks for construction workers, the need for evidence-based approaches to reduce occupational exposure has been recognized within the political system in the Netherlands.[15] To date, technical control measures with local exhaust ventilation (LEV) or wet suppression and personal respiratory protective equipment are most common to prevent occupational quartz exposure among construction workers.[16] Although experimental studies showed a reduction of quartz exposure when using these technical control measures properly,[17,18] there are few studies on the effectiveness of technical control measures under real working conditions. It could be hypothesized that it is more challenging to use technical control measures properly in practice, as construction worksites are temporary and mobile and variable in regard to job tasks and workspace.[19,20] Thus, to implement effective interventions to reduce occupational exposure at worksites, interventions should not only focus on the implementation of technical control measures, but also take into account workers' behaviour and the organizational work environment.[21]

The current study aimed to systematically develop an intervention targeting the integration of technical, behavioural and organizational factors in order to reduce occupational quartz exposure in the Dutch construction industry, through an application of the Intervention Mapping protocol.[22] The Intervention Mapping protocol was applied to systematically incorporate empirical findings from the literature and input from all stakeholders (i.e. workers, managers and researchers) into an intervention tailored to the construction workers. This paper describes Phase I of the study, the systematic development of the intervention and the evaluation study regarding the effectiveness of this program (Phase II).

Methods

The present study is divided in two phases. In the first phase, an intervention was systematically developed based on the Intervention Mapping approach, which describes a process for developing theory- and evidence-based intervention programs.[22] The second phase of this study involves the description of the evaluation of the intervention.

Phase I: Intervention development

Intervention Mapping facilitates a stepwise process to guide researchers through the development and planning of interventions by combining scientific knowledge and opinions from stakeholders (Figure 3.1). Intervention Mapping involves a systematic process that prescribes six steps: (i) needs assessment; (ii) performance objectives and determinants; (iii) selection of methods and strategies; (iv) design of the intervention program; (v) development of a plan for implementation and (vi) evaluation. The completion of these steps serves as a blueprint for the intervention in the current study.

Step 1: Needs assessment

In step 1 of the Intervention Mapping approach, insight into the underlying factors causing elevated levels of occupational quartz exposure was gained. Ultimately, this insight resulted in the formulation of the program objective. This objective specifies what changes are needed to decrease the elevated quartz exposure level.

Insight into the underlying factors was achieved by means of (i) a questionnaire and an exposure assessment survey among construction workers; (ii) a questionnaire among managers; (iii) a literature review and (iv) meetings with managers and sector organizations in the construction industry.

The main resource for step 1 was an assessment of the baseline characteristics of the study population. This assessment focussed on the role of behavioural and organizational factors in relation to quartz exposure among construction workers.[23] The questionnaire distributed among construction workers was completed by 116 eligible participants and produced insights in the behavioural factors. To explore the role of organizational factors, eight managers completed a questionnaire to obtain insight into the occupational safety and health policy of a company, using an adapted version from the Occupational Health and Safety Series (OHSAS) norm on hazardous circumstances.[24] Additionally, a literature search was conducted in Pubmed, using keywords relevant for the target population (e.g. 'construction workers', 'construction industry', 'concrete driller' and 'demolisher') and outcome measures (e.g. 'occupational exposure', 'quartz' and 'silica'). Furthermore, two focus groups were organized: one group with seven researchers and one focus group with three managers and three representatives of sector organizations. Three additional face-to-face interviews with managers of participating construction companies were also organized.

Step 1 Needs assessment	- Plan needs assessment - Assess physical environment, behavioural determinants and organizational factors - Establish program objectives
Step 2 Matrices of performance objectives	- Specify determinants - Specify performance objectives
Step 3 Theory-based methods and practical strategies	- Review program ideas with stakeholders - Identify theoretical methods - Choose program methods - Select or design strategies
Step 4 Program	- Consult with intended participants and implementers - Create program scope, sequence and material list - Develop documents and protocols - Review available materials
Step 5 Implementation plan	- Identify adopters and users - Specify adoption, implementation and sustainability - Create planning table - Write implementation plan
Step 6 Evaluation plan	- Develop an evaluation model - Develop effect and process evaluation questions - Develop indicators and measures - Specify evaluation designs
Implementation	

Evaluation

Figure 3.1 Intervention Mapping, source: Bartholomew et al. (2006).[22]

Factors related to occupational quartz exposure

Based on available resources, the factors that were associated with occupational quartz exposure were divided into work environmental factors, worker-related factors and organizational factors.

Firstly, work environmental factors were divided into technical control measures and work activities. Several types of technical control measures to reduce quartz exposure such as LEV or wet suppression are currently available for different job categories and job tasks in the construction industry.[6,17,25,26] The availability of technical control measures varies among job categories. Concrete drillers, demolishers and tuck pointers have more access to technical control measures than other construction workers. Although experimental studies showed a significant exposure reduction by using these technical control measures, the use of technical control measures varied among the construction workers in the current study. The baseline study illustrated that 'maintaining a good health' and 'inconvenience for eyes and airways' were mentioned by construction workers as reasons to work with these technical control measures.[23] Workers mentioned tools with poor ergonomic design, potentially resulting in a lower productivity, as constraints to work with technical control measures.[23] A previous study showed that using technical control measures with wet suppression resulted in wet materials or in a slippery working area.[25] Workers' opinions regarding the use of technical control measures were recognised by managers and sector organizations. Managers also mentioned the difficulties in using technical control measures, considering the variety in working tasks, which asked for different technical control measures. Additional to the technical control measures, specific work activities are associated with higher occupational quartz exposure. The baseline study showed that working inside and working with cement slots was associated with a higher exposure to both respirable dust and quartz, whereas determinants like near-field worker-source distance and work orientation at shoulder level were associated only with higher respirable dust exposure.[23] Working in the same workspace with another worker and the method of handling dusty rubbish were mentioned during the focus groups as risk factors for elevated exposure. Lastly, meteorological conditions such as rain and wind direction and speed, are also generally considered to be important determinants of inhalation exposure.[27,28]

Secondly, worker-related factors such as behavioural determinants influence whether construction workers use technical control measures. Previous studies showed that knowledge and theoretical competences about the proper use of technical control measures (e.g. connecting hoses and removing bags correctly, good sealing, maintenance and cleaning) are needed to maximize efficacy in controlling exposure.[29-31] Additionally, the baseline study showed that more peer pressure or presence of supervisors increased the use of technical control measures.[23] All participants in the focus groups mentioned that greater awareness and risk perception regarding the long-term health consequences of being exposed to dust and quartz potentially increases the use of technical control measures. They also emphasised improving the skills of construction workers to correctly implement these technical control measures.

Third, organizational factors include the responsibility of companies and sector organizations for reducing high levels of occupational quartz exposure. First, the availability of technical control measures at worksites is the responsibility of companies. However, the majority of managers face difficulties in collecting the relevant information about technical control measures from the different resources such as labour inspection and sector organization. They therefore recommend providing a clear overview of the newest technical control measures and their functionality. The majority of employers also mentioned the increasingly shorter lead times for construction processes and working with subcontractors led to tighter bids. This resulted in less time and investments to use technical control measures at construction worksites. Additionally, managers are responsible for organizing training sessions to educate their construction workers about quartz exposure and technical control measures. Education, procedures and training sessions at the worksites are of particular importance for the current study population, as most of them work without any professional education. The baseline study showed that only 25% of the managers offered this kind of training/education and five of eight (63%) companies stated that compliance with work procedures and workplace instructions regarding dust-reducing practices was supervised by their management.[23]

Program objective

Based on the needs assessment, the following program objective was formulated: establish an increase in the (proper) use of technical control measures in the construction industry by targeting both the workers' behaviour and organizational factors in order to significantly reduce occupational respirable dust and quartz exposure.

Step 2: Performance objectives and determinants

The performance objectives constitute the specific measurable objectives of the intervention program that are required from the target group (i.e. construction workers and managers) to achieve the program objective as described in the needs assessment. The results of the needs assessment showed that both the organization and workers' behaviour should be targeted adequately in order to increase the proper use of technical control measures at construction worksites. Three researchers of the project team (KOH, EvD and TM) discussed the results of the needs assessment and translated these into specific measurable performance objectives for both managers and construction workers to achieve during the intervention study. At the end, a list of performance objectives was constructed that fits the program objective of step 1. The final performance objectives were selected during an expert meeting with six researchers having broad experience in the field of occupational (quartz) exposure and/or implementation of interventions among blue collar workers (Table 3.1).

Table 3.1 Performance objectives for individual and environmental changes related to reducing occupational quartz exposure.

What construction workers will do to reduce occupational quartz exposure
1 Be aware of the risks and consequences of high occupational quartz exposure
2 Increase their knowledge on when they are exposed to occupational quartz exposure
3 Increase their knowledge about the causes and possible long-term risk of occupational quartz exposure
4 Identify solutions regarding the reduction of occupational quartz exposure at the worksites
5 Identify constraints for using technical control measures
6 Learn how to use technical control measures in a healthy and safe way
7 Discuss with colleagues their responsibility to reduce occupational quartz exposure
What managers will do to change the work environment in order to reduce occupational quartz exposure
1 Have a positive attitude towards reducing occupational quartz exposure
2 Incorporate knowledge and solutions regarding reducing occupational quartz exposure in their policies
3 Provide technical control measures for construction workers to reduce occupational quartz exposure
4 Increase their knowledge about the causes and possible risks of occupational quartz exposure
5 Be responsible for the usage of the technical control measures in their company

Besides the performance objectives, changeable determinants of the performance objectives were selected during the expert meeting to facilitate a change in the behaviour of construction workers and managers. As previously mentioned in the needs assessment, the following behavioural determinants at worker level were identified: knowledge, awareness, risk perception and skills. Knowledge and attitude were also defined as important behavioural determinants for managers. Additionally, social-cultural and economic determinants (e.g. investment in tools) were selected as organizational determinants. By defining the performance objectives and determinants, very specific intervention goals and materials could be developed in the next step of Intervention Mapping.

Step 3: Selection of methods and strategies

After defining performance objectives and determinants, appropriate theoretical methods were selected to monitor behavioural and organizational changes and to translate these into practical strategies.

Theory-based intervention methods

For each determinant defined in step 2, appropriate theoretical methods were identified from literature and from the guidelines published by Bartholomew et al. (2006).[22] A theoretical method describes the expected association between an intervention action and a change in identified individual and organizational determinants. Decisions regarding suitable theoretical methods were made, based on feedback from key contacts of the companies and sector organizations, as well as within the research group. Because the program outcomes and determinants are at individual and organizational level, theoretical methods were directed to both workers and managers. For example, as demonstrated in Table 3.2, scenario-based risk information was selected as a theoretical method to improve risk perception of both construction workers and managers in order to work with technical control measures.

Practical strategies

Theoretical methods were translated into practical strategies during two brainstorm sessions with the research team and fine-tuned during the meeting with the key contacts of the companies and sectors organizations. Specific tools and materials that fit the chosen determinants, theories and strategies were selected (Table 3.2). For instance, passive learning, modelling and stimulating communication were chosen as theoretical methods to increase the awareness of the consequences of occupational quartz exposure among construction workers and managers. Then, written information, role modelling and group discussion were selected as providing practical strategies that fit the population of construction workers and their managers. Specifically, visual program materials such as films and posters were developed for the study population in the current study, as it was mainly comprised of low-educated workers. Demonstrating and practicing with tools were chosen as the most suitable intervention session for managers to increase their knowledge.

Table 3.2 Theory based methods, practical strategies and selected tools and materials for the intervention to reduce occupational quartz exposure.

Determinants	Theory-based methods	Practical strategies	Selected training, tools and materials
Behavioural determinants			
Awareness	Passive learning	Providing (written) information	Personal letter to workers with information regarding the exposure levels of the baseline measurement
	Modelling	Role modelling	Poster for managers and workers
	Stimulating communication	Discussion	Interactive group sessions to exchange constraints/facilitators of using technical control measures
Knowledge	Passive learning	Providing (written) information	Tailored factsheets for workers Occupational physician will attend first meeting to explain health risks
	Active learning	Discussion	Interactive presentations including documentary and PIMEX videos[a] during sessions at the worksite
		Demonstration	Interactive group sessions at the worksite Discussion with labour inspector regarding the context of using technical control measures Tailored sessions for managers to demonstrate technical control measures
	Images	Providing verbal information/images	Video on long-term effects of occupational exposure
Risk perception	Scenario-based risk information	Recognizing invisible risks	Video on long-term consequences of occupational exposure Occupational physician will attend first meeting to explain health risks
		Recognizing behaviour	PIMEX videos[a]
Skills	Feedback	Feedback	Group discussions at the worksite
	Guided practice	Guidance sheet	Tailored factsheets Tailored sessions for managers to use technical control measures
	Modelling	Demonstration	PIMEX videos[a]
Organizational determinants			
Social-cultural	Shifting focus	Workers telling their stories	Video on long-term consequences of occupational exposure
	Building skills for resistance	Discussion	Defining skills and reasons for resistance
	Reinforcement	Remembrance through incentives	Posters
	Social support	Discussion	Managers and workers discuss about constraints and facilitators to use technical control measures
Economic	Availability	Approval	Manager approves training during working time Managers are willing to invest in technical control measures

[a] PIcture Mix EXposure, a video exposure monitoring method for exposure of hazardous materials to measure the impact of workplace practices and conditions at the same time.

Step 4: Design of the intervention program

The first intervention program was subjected to commentary during an expert meeting with researchers, managers from larger companies and representatives of sector organizations. Based on this meeting, a final version of the intervention program based on the tools and intervention materials from Table 3.2 was developed.

Program description

The intervention, so called 'Relieved Working' study, takes place during a six-month period and consists of plenary sessions and intervention materials (Figure 3.2).

The starting point of the six-month intervention is a personal letter to the construction workers in the intervention group, in which they are invited to the first plenary session and are notified for their exposure levels as obtained from the baseline survey. Employers receive a letter with company-specific average exposure levels, including an explanation regarding the intervention program and the role of managers.

Intervention program and materials

The first plenary session for all employees at the company (e.g. construction workers, managers and supervisors) was an interactive presentation by the principal researcher (EvD) and an occupational physician, consisting of the following elements: (i) showing a short documentary to increase risk perception and awareness of long-term health consequences; (ii) providing results of the baseline study, including both exposure and observed behaviour; (iii) providing information regarding the health risks; (iv) discussing situations with high quartz exposure; (v) teaching skills regarding the proper use of technical control measures by showing PIMEX videos (i.e. PIcture Mix EXposure, a video exposure monitoring method for exposure of hazardous materials to measure the impact of workplace practices and conditions at the same time); (vi) discussing constraints and facilitators to work with technical control measures and (vii) set tailored goals for the intervention period. At the end of this session, posters were distributed to companies and compact-sized factsheets are handed out to construction workers. For each job category, this tailored factsheet provides specific instructions on how to reduce quartz exposure at the worksite. These instructions are focused on (i) proper use of technical control measures; (ii) organizational factors such as asking the supervisor for technical control measures and using protective equipment and (iii) behavioural factors such as cleaning the workspace.

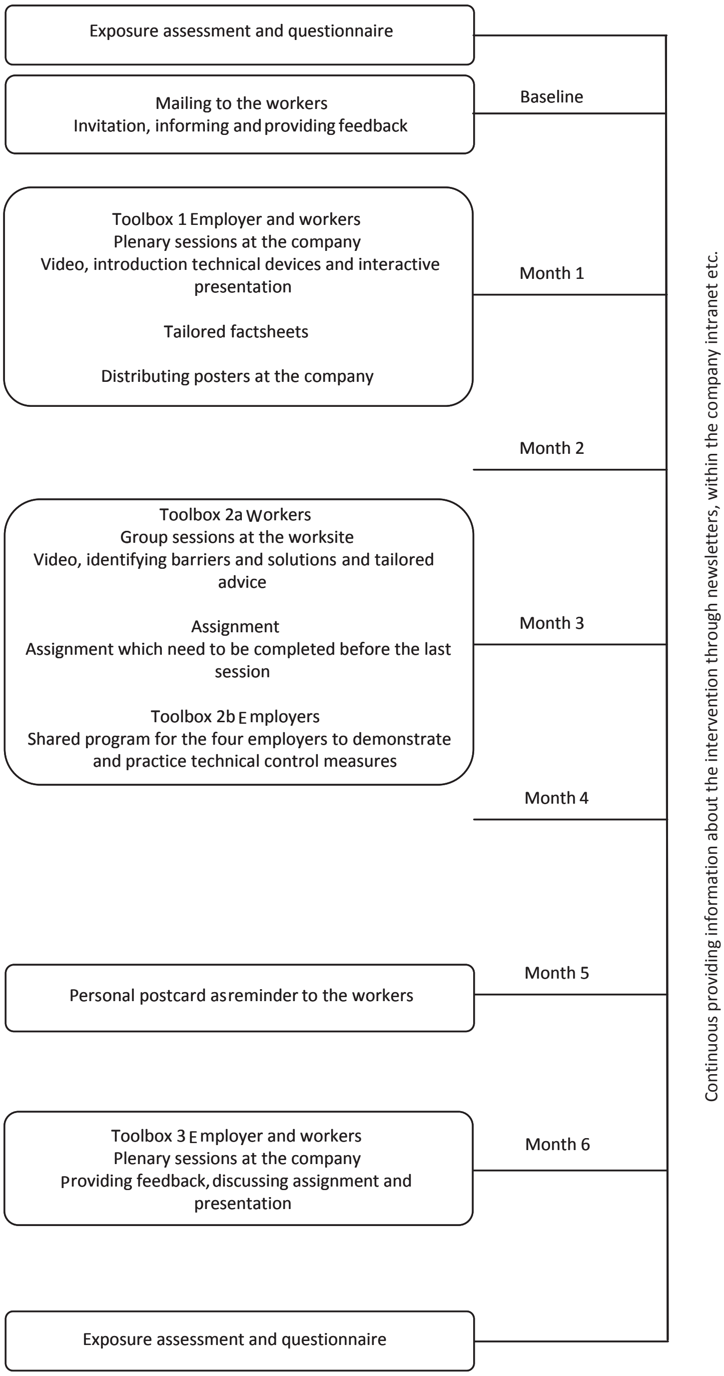

Figure 3.2 Flow chart of intervention program.

The second individual session is organized at the worksite and aims to teach workers how to use technical control measures in a proper and productive way. Therefore, the construction workers (i) define situations with high levels of exposure at their current worksite; (ii) learn how technical control measures should be used to reduce this exposure; (iii) discuss constraints for using technical control measures and (iv) define solutions to tackle these constraints. At the end, an assignment is given to the construction workers in which they are asked to photograph two situations at the worksite (i.e. a good and a bad practice) which serve as input for the last plenary sessions.

Simultaneously with the worksite visits, a meeting is separately organized for the managers to gain more insight in the availability of technical control measures. This meeting consists of a demonstration of the newest available technical control measures, their innovations and their possibilities. As this session is held at the lab within the research institute, the managers have the possibility to practice with technical control measures and to discuss possible constraints related to functionality.

During the last plenary session at the company, managers and workers discuss, evaluate and reconsider the goals and actions that are achieved. During an interactive presentation of the principal researcher, lessons learned and key solutions to overcome the main constraints are discussed. The assignment with photos serves to open this discussion regarding the good and bad practices across different worksites. Additionally, a labour inspector joins this session to give practical information on their policy regarding quartz exposure.

Step 5: Development of a plan for implementation

Researchers pay attention in step 5 to important preconditions that ensure optimal implementation and adoption of the 'Relieved Working' study. Firstly, as managers and supervisors play a key role in successful implementing an intervention at worksites,[32] they are encouraged to actively participate in the intervention. Managers are also invited for a session with all participating companies to share ideas and learn about new innovations of technical control measures. Secondly, as time, place and costs are important factors to successfully adopt and implement the program,[33,34] the three sessions are organized within the existing so-called 'toolbox education system' in the Dutch construction industry. The toolbox education system consists of at least ten obligatory health and safety training sessions for workers, which have to be organized by managers in the construction industry each year in order to obtain an official health and safety certificate. Thirdly, because the intervention is implemented across different companies, a protocol including an outline, time schedule and communication between all stakeholders was developed to standardize the intervention.

Phase II: Evaluation of the intervention

Step 6: Evaluation plan

Study design

The effectiveness of the intervention will be measured by performing a cluster randomized controlled trial (cluster RCT). Participants who have given informed consent are measured at baseline and will be measured after the intervention. Workers at the worksite allocated to the intervention group receive the worksite intervention program during a six-month period, while those allocated to the control group receive no intervention. The study protocol and measurements are not part of the judgement of the Central Committee of Research Involving Human Subjects, meaning no medical ethic approval is required for this study. The study has been executed according to the Dutch Data Protection Law.

Study population

The study population includes blue collar workers in the construction industry. These workers are recruited through eight companies specialized in either demolishing, concrete drilling, sawing and/or facade maintenance, which are all activities associated with relatively high silica exposure levels. Inclusion criteria for the construction workers are (i) available for the intervention period; (ii) sufficient competency in the Dutch language and (iii) having signed a written informed consent to participate.

Recruitment of the study population

Companies were recruited via a request by sector organizations, either by distributing e-mails, hard copy invitations, or by telephonic contact. Within the company, support is needed at the level of manager, supervisor and worker.[32] Therefore, at the start of the project, the senior management of the eight companies committed themselves to the project by signing a letter of intent. Additionally, they agreed that their workers (supervisors and blue collar workers) are allowed to participate in the program during working hours. The recruitment of workers was conducted by the principal researcher through the usual and available communication channels within the companies, e.g. intranet, a personal letter or verbally. Finally, the principal researcher (EvD) informed all workers at the worksites regarding study and distributed a letter with the content of the study.

Randomization and blinding

In order to avoid intervention group contamination, to obtain maximal cooperation of managers and construction workers and to enhance participants' compliance, cluster randomization at the level of the company is considered the best randomization strategy for this study. Randomization is performed by the principal researcher (EvD) using an electronic randomization tool (www.randomizer.org) after the baseline measurement. Because the intervention takes place at the worksites, participating workers, managers, supervisors, as well as researchers/trainers cannot be blinded to the group assignment.

Sample size

The sample size was calculated as the number of workers needed to identify an effect of the intervention on occupational exposure to quartz. A previous intervention study on occupational exposure to wood dust aimed to decrease the exposure by 30%.[35] Assuming alpha is 0.05 and a power of 80% with a possibility to detect at least a 30% change in exposure in our intervention group, a sample size of 42 workers is needed. Although no specific information about exposure trends exists, it is well known that most occupational exposures show long-term downward trends of a few percent annually over recent decades.[36] Assuming this is also the case for the Dutch construction industry, a decline in exposure in the control group over the course of this study was taken into account. Based on these calculations and taking into account a loss-to-follow-up of 20%, it was estimated that 60 construction workers are necessary in both the intervention and control group.

Co-interventions

Researchers emphasized to the managers that participation in other intervention studies or programs aimed at reducing occupational quartz exposure might influence the study results. Managers were therefore asked to not actively initiate other activities to decrease occupational exposure to quartz during the intervention period. After the intervention, managers are asked if any other intervention took place during the period of the current study.

Primary outcome measure

Respirable dust and quartz exposure are measured by collecting full-shift personal air samples from construction workers at different worksites.[23] These samples are 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. Cyclones are attached in the breathing zone of the worker. The amount of dust on filters is determined gravimetrically by pre- and post-weighing of filters on an analytical balance in a conditioned room.[37] Quartz is determined by infrared spectroscopy and X-ray diffraction.[38] Throughout their shift, workers are 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 and respiratory protective equipment.[23]

Secondary outcomes

Behavioural determinants

Behavioural determinants related to respirable dust and quartz exposure are assessed by means of a questionnaire.[23] Questions about beliefs, motivation, risk perception and social influence are formulated based on a structure of questions often applied in the assessment of behavioural determinants.[39] Belief is defined as the indication of an individual's belief in the effectiveness of various exposure controls and dust-reducing work practices and is assessed by ten questions with answers on a 5-point scale. Additionally, motivation is measured by eleven questions with answers on a 5-point scale. Motivation is described as the indication of an individual's intention (or motivation) to use exposure controls and dust-reducing work practices. Risk perception (six questions with answers on a 5-point scale) is defined as an indication of an individual's perception of risk of quartz exposure and susceptibility to short- or long-term health effects. Lastly, three questions on a 5-point answer scale are constructed for social influence (i.e. indication whether an individual is influenced by co-workers or supervising personnel to use exposure controls and dust-reducing work practices). An adapted format of an existing standardized scale is applied for risk propensity, which is an estimation of an individual's inclination to seek or avoid general health risks.[40] This scale consists of six questions with a range from 1 to 5. Knowledge is described as an estimation of an individual's knowledge regarding exposure sources, technical control measures, substances, routes of exposure and short- and long-term effect of quartz dust and is assessed by eight quartz dust-related questions which are specifically composed for the current study, with answers on a dichotomous scale.

<u>Organizational factors</u>

Managers of all participating companies receive a questionnaire in order to gain insight into the occupational safety and health policy.[23] This questionnaire is based on the Occupational Health and Safety Assessment Series (OHSAS) norm for health and safety management and specifically focuses on hazardous substances.[24] The following themes were included: (i) the presence and compliance of work procedures and workplace instructions; (ii) the extent to which training and education is offered to employees; (iii) the presence of management support towards a proactive health and safety culture (e.g. toolbox meetings on a fixed and regular schedule to stimulate discussion between managers and construction workers) and (iv) the method of communicating and providing feedback with equipment contractors to improve services.

<u>Technical control measures</u>

Observations of the workers are used to assess to what extent technical control measures are used. Construction workers from the intervention and control group are observed throughout their shift on their use of technical control measures and protective equipment.

<u>Other variables</u>

Socio-demographic data such as gender, age, education level, job category, job history and job experience are assessed at baseline measurement.

Evaluation
The 'Relieved Working' study will be evaluated by an effect evaluation and a process evaluation.

Effect evaluation

The potential difference between the baseline and follow-up values in the primary and secondary outcomes will be compared between the intervention group and the control group. Analyses of measurements at individual level (i.e. exposure assessment and questionnaire) will be performed by means of multilevel analyses taking clustering of observations of workers within the same company into account, as well as repeated measurements within one worker.[41] Due to randomization at company level, the data will be analyzed at three levels: time, worker and company. The multilevel analyses using the follow-up measurement as dependent variable will be adjusted for possible confounding factors, such as education level and job category. These variables will also be checked for effect modification.

Process evaluation

A process evaluation will be carried out to gain insight into the factors influencing the effectiveness of the intervention program of the 'Relieved Working' study. The process evaluation will assess seven aspects of the intervention, following the guidelines of Steckler and Linnan (2002): recruitment (sources and procedures used to recruit companies and construction workers), reach (attendance rates of construction workers), dose delivered (the amount of intervention components actually delivered), dose received (the extent to which construction workers use materials or components), fidelity (the extent to which the program was delivered as planned), satisfaction (extent to which the workers were satisfied with the overall content and the specific program components) and context (organizational and environmental characteristics that affect the intervention).[42,43] Reach and recruitment will be evaluated by data collected in logs from the commencement of the project. Two of the aspects, dose delivered and dose received, will be assessed by checklists completed by the principal researcher during the separate sessions in each company. Fidelity and satisfaction will be obtained by logs from the principal researcher and questionnaires at the end of the intervention for managers and construction workers. Contextual factors will be discussed in the project team and with the managers.

Discussion

In this paper, the development of the 'Relieved Working' study and the design of its evaluation are described. This multidimensional intervention aims to establish an increase in the (proper) use of technical control measures by targeting both the workers' behaviour and organizational factors in order to significantly reduce occupational respirable dust and quartz exposure in the construction industry.

To our knowledge, this is the first study that will evaluate a multidimensional intervention in the construction industry tailored to both construction workers and managers. Since developing complex interventions, as in the present study, is a considerable challenge,[44] Intervention Mapping was used to design an intervention which is not only tailored to the needs of the target population, but also to the abilities and opportunities of managers and implementers. A strength in applying Intervention Mapping in this study was that quantitative (i.e. baseline study) and qualitative information of construction workers was systematically collected and combined with scientific literature to tailor the intervention to their needs. By also involving managers in the development, it eventuated that managers played an important role in the availability of technical control measures at all worksites. An additional informative session is therefore organized for all managers. Involving all stakeholders in the development of the intervention was another strength, as it provided insight into the practical strategies. For example, the intervention is incorporated within the existing toolbox education system of the construction industry. Because this education system is obligatory, a high level of commitment is expected from senior management, supervisors and construction workers. Another strength of the study is the extensive evaluation in terms of both effect and process evaluation. The effect evaluation will include personal exposure assessment, as well as behavioural and organizational outcomes, which could provide meaningful results at worker, company and policy level (e.g. guidelines). A thorough process evaluation alongside a cluster RCT will provide more detailed information regarding the context and degree of the implementation of the intervention.[45] A process evaluation may help researchers distinguishing between interventions that are not effective due to their intervention protocol and underlying theories and those that are not implemented adequately.[45,46]

Some limitations also need to be considered with respect to the development and design of the study. Firstly, as already mentioned in previous intervention studies in the construction industry,[47,48] Intervention Mapping is a time-consuming process. To be efficient, qualitative data (interviews and focus groups) were combined with quantitative data (observation forms and questionnaires among construction workers and managers) in the current study. However, the development of the intervention was still time-consuming and step 3 of Intervention Mapping was not fully applied. Secondly, the construction companies who commit themselves to the project are probably early adopters when it comes to health and safety.[49] The participating construction workers and especially the managers, have more sympathy towards the program than is general shown throughout in the construction industry. Employers of these companies might therefore be more aware of the hazards in the construction industry. The third limitation is that the cluster RCT is two-armed (control versus intervention), whereas the intervention consists of several components. This design does not allow separate evaluation of each intervention component in terms of effectiveness. The process evaluation will focus on the different components and their working mechanism of the components in view of the entire program.

In conclusion, the 'Relieved Working' study was developed to establish an increase in the proper use of technical control measures in the construction industry by targeting both the workers' behaviour and organizational factors. Applying Intervention Mapping in the development of an intervention to reduce occupational quartz exposure was useful, as different stakeholders provide input for the intervention as well as the implementation strategy. Therefore, it is likely that this program fits the target population well and increases the likelihood of compliance and effectiveness. Alongside the development of the intervention, this paper also described the design of a cluster RCT to determine the effectiveness of this program. This insight can play an important role in the decisions of employers in regard to investing in such interventions in the future.

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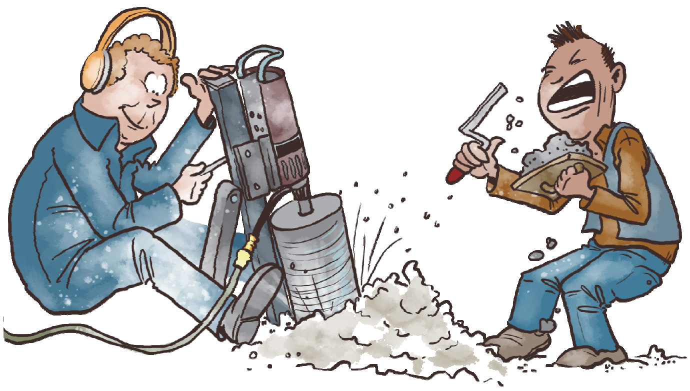
Chapter 4

Process evaluation of an intervention program to reduce occupational quartz exposure among Dutch construction workers



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J Occup Environ Med 2015;57:428-435

Abstract

The aim of this study was to evaluate the process of an intervention in the construction industry to reduce quartz exposure. In a cluster randomized controlled trial, data on seven process aspects (i.e. recruitment, reach, dose delivered, dose received, fidelity, satisfaction and context) were quantitatively collected on manager and worker level. Dose delivered was 95% for the plenary sessions and 20% for the plenary sessions. Although the protocol was mostly implemented as intended, dose received was lower than expected. Both managers and workers appreciated the intervention and recommended the intervention for future implementation. Workers attending all intervention sessions were most satisfied about the intervention. High rates for dose delivered and fidelity for the plenary sessions and relatively high satisfaction rates were achieved. Furthermore, continuous monitoring of contextual factors beforehand and alongside the implementation of interventions is recommended.

Background

The risks for construction workers to develop silicosis, lung cancer and chronic obstructive pulmonary disease (COPD) as a result of occupational quartz (i.e. silica) exposure are generally acknowledged.[1-6] Several jobs and tasks within the Dutch construction industry show quartz exposure levels well above the Dutch occupational exposure limit (OEL).[7-9] International studies show similar exposure levels for comparable activities.[10-14] Particularly because of the potential for high exposure levels and its serious health consequences, silica has recently been selected by the Dutch government as a high-risk agent in the construction industry.[15]

Despite the fact that construction workers often have access to technical control measures, such as tool-integrated local exhaust ventilation (LEV) and tool-integrated water suppression,[16,17] quartz exposure levels in the construction industry remain remarkably high.[18] Even though these technical control measures have been demonstrated to be effective in laboratory settings or under controlled workplace conditions,[19] the efficacy of these measures under actual working conditions appears to be lower. This can be explained by the fact that organizational factors, such as practical training of employees to use control measures properly,[20] and behavioural factors, such as motivation to use control measures,[21] also contribute to actual and effective use at worksites.[22] Therefore, intervention studies integrating technical, organizational and behavioural factors could be considered as effective when reducing occupational exposure.[23,24] Such a multidimensional worksite intervention program, called the 'Relieved Working' study, was developed to reduce quartz exposure in the Dutch construction industry.[25]

To date, intervention studies mainly focused on evaluating the effect(s) of the intervention rather than systematically evaluating the process to assess whether and why the intervention was successfully implemented or not.[26] Nevertheless, systematic process evaluations alongside randomized controlled trials (RCTs) are recommended to provide insight in the underlying causes of (un)successfulness of implementation or because of an inadequate implementation.[27-29] To what extent and how specific intervention components (e.g. plenary sessions, worksite visits and session for managers) are being delivered and to which extent these components are received and used (differently) by workers and managers, may provide insight how the implementation of the intervention might influence outcomes.[26,29-31] Additionally, a process evaluation provides more detailed information about the content and degree of implementation by many stakeholders across different companies and worksites.[26,27,29] Therefore, the aim of the current study is to evaluate the process of the 'Relieved Working' study among Dutch construction workers.

Methods

The process evaluation was performed alongside a cluster RCT on the effectiveness of an intervention to reduce occupational quartz exposure among Dutch construction workers. Detailed information on the baseline situation and intervention design has been published elsewhere.[9,25] No medical ethic approval was required for this study. The study has been executed according to the Dutch Data Protection Law.

Study population

The study participants consisted of construction workers and managers of eight companies, which were randomly allocated to the intervention group (n=4) or the control group (n=4). All construction workers and managers in the intervention group were included in this process evaluation.

Intervention program

The six-month lasting intervention program was developed using the Intervention Mapping approach.[32] Based on this, the following program objective was defined: establish an increase in the (proper) use of technical control measures in the construction industry by targeting both the workers' behaviour and organizational factors in order to significantly reduce occupational quartz exposure. Behavioural determinants that influence whether construction workers use technical control measures in a correct manner were assessed at individual level (i.e. awareness, knowledge, risk perception and skills) and at organizational level (i.e. social-cultural and economic). These determinants were translated into intervention sessions and intervention materials. By default, two plenary sessions at the companies were provided to both managers and construction workers. In these sessions, the principal researcher and the occupational physician or labour inspector (the first and second plenary session, respectively) gave an oral presentation and initiated several discussions with the target group to increase awareness, knowledge, risk perception and skills (Table 4.1). In addition, a separate workshop was organized for managers only and the principal researcher visited worksites for a supplementary session for construction workers measured at baseline. Baseline measurements (i.e. full-shift personal quartz exposure measurements, including detailed observations and a questionnaire on behavioural and organizational factors) involved a random sample of construction workers, since construction workers were measured based on work supply (relevant tasks with exposure) and allocation of construction workers per worksite.[9] Accompanying intervention materials, e.g. the documentary about potential health risks of occupational quartz exposure and the tailored factsheet, were introduced in one or more intervention sessions at the construction company (Table 4.1).[25]

Process evaluation

Based on the framework of Steckler and Linnan (2002),[33] seven process aspects were assessed in the current study. Six aspects (i.e. recruitment, reach, dose delivered, dose received, fidelity and satisfaction) measure the degree of implementation. The seventh aspect, context, maps the barriers and facilitators that affect implementation.[28,33] Except for recruitment and reach, all process aspects were collected for the intervention group at worker and management level.

Recruitment and reach

Recruitment was defined as the procedure used to approach construction companies to participate. Logs completed by the principal researcher were used to collect information on the process of recruitment.

Reach was defined as the number of construction workers who were eligible to participate in the intervention program, i.e. all construction workers employed by the four companies in the intervention group at the start of recruitment. Company records were used to collect data on reach.

Dose delivered and dose received

Dose delivered refers to the number of intervention components, i.e. two plenary sessions for construction workers and managers, an individual worksite visit for construction workers and a workshop for managers, that were actually delivered to the construction workers and managers. Data were collected using checklists and logs containing information about reasons for not delivering sessions or materials, completed by the principal researcher.

Table 4.1 Descriptive overview of the intervention components per determinant for each intervention session[e].

Intervention session	Intervention component	Behavioural determinants			Organizational determinants		
		Awareness	Risk perception	Skills	Knowledge	Social-cultural	Economic
Plenary session 1[b]	Documentary health consequences	x	x			x	
	PIMEX videos[e]	x	x	x			
	Tailored factsheet[f]	x			x		
	Posters	x					
	Quiz baseline survey[g]				x		
	Presentation occupational physician				x		
Workplace visit[c]	Assignment photographs	x					
	Discussion work practices	x		x			
	PIMEX videos[e]		x	x			
	Tailored advice control measures			x			
Plenary session 2[b]	Documentary health consequences	x	x				
	Discussion constraints/facilitators control measures[g]			x		x	
	Presentation labour inspector				x		x
Workshop[d]	Tailored demonstration control measures			x		x	
	Discussion constraints/facilitators control measures			x		x	
	Presentation availability and innovations control measures				x		x

[a] Different intervention components and intervention materials can affect multiple determinants; they are complementary to each other. [b] All construction workers eligible to participate in the intervention and managers were invited to attend the plenary sessions. [c] Construction workers measured at baseline were visited on site. [d] Managers were invited to attend the workshop. [e] PIMEX videos, i.e. PIcture Mix EXposure, a video exposure monitoring method for exposure of hazardous materials to measure the impact of good and poor workplace practices and conditions at the same time. [f] The tailored factsheet provides specific instructions on how to reduce quartz exposure at the worksite. [g] Presentations by the principal researcher (EvD).

Dose received at worker level was expressed as the proportion of construction workers that participated in the sessions (e.g. first and second plenary session, worksite visit) compared to the total number of construction workers who were eligible to participate in the intervention program (i.e. reach). For managers, dose received was expressed as the number of managers participating in each intervention session as the proportion of the total number of managers in the intervention group. Data were collected using attendance registration forms signed by the construction workers and the managers and registration forms completed by the principal researcher. Reasons for not attending one of the sessions were registered by the principal researcher.

Fidelity

Fidelity described the extent to which the intervention program was delivered according to the protocol. The protocol contained information about the outline and organization of the intervention including all specific sessions and materials. Moreover, the protocol described specific activities to be delivered by all implementers. Fidelity was examined by logs from the principal researcher, who attended all intervention sessions.

Satisfaction

Satisfaction was defined as the participants' satisfaction towards the intervention program and its specific components. Managers and construction workers were asked to evaluate the intervention and the specific sessions (i.e. plenary sessions, worksite visit and workshop) and materials (i.e. factsheet, documentary and PIMEX videos (i.e. PIcture Mix EXposure; video exposure monitoring method to visualize the impact of good and poor workplace practices)) by using a questionnaire after the intervention period. Construction workers who participated in an intervention session received the process questionnaire either from the principal researcher or manager, while managers received the questionnaire by e-mail. Satisfaction was measured by using a 10-point scale (ranging from 'very unsatisfied' to 'very satisfied'). Moreover, construction workers and managers were asked if they would recommend the intervention for future implementation. Reasons for (dis)satisfaction and suggestions for future implementation of the intervention (open-ended questions) were asked from managers.

Context

Contextual factors refer to factors and characteristics that either directly or indirectly may affect intervention implementation or study outcomes.[28,33] Three classes of contextual factors, as proposed by Fleuren et al. (2004),[34] were selected during data collection, i.e. individual, organizational and socio-political characteristics. Age and job category were selected as individual characteristics, based on the variety in exposure levels and use of control measures within the characteristics of the baseline survey,[9] and the impressions from the principal researcher that these subgroups' attitude differed during the intervention sessions. The extent to which a construction company already provided training programs in dust-reducing work practices before the baseline measurement was defined as organizational contextual factor. A co-intervention at socio-political level, i.e. inspection visits focused on quartz exposure by the labour inspection, occurred simultaneously alongside implementation. Since a previous study indicated that satisfaction was associated with compliance,[35] attendance rate was selected as contextual factor specifically for satisfaction.

Data analysis

Descriptive statistics (e.g. percentage, mean, standard deviation) were generated for the seven process aspects. Differences in the scores for satisfaction between the categories of each contextual factor were tested using Mann-Whitney U-tests and Kruskal-Wallis tests. Pearson Chi-square tests or Fisher's exact tests were performed to explore differences in the proportion of construction workers recommending the intervention and the proportion of construction workers attending the intervention sessions for each contextual factor. All statistical analyses were performed using SAS v9.3 (SAS Institute Inc.). Statistical significance was set at $p<0.05$.

Results

Recruitment and reach

Through sectorial organizations for concrete drillers, demolishers and facade maintainers (i.e. tuck pointers and bricklayers), a selection of companies (n=13) were approached to participate in the intervention. Five companies were excluded because they employed too few permanent employees or because they had insufficient work supply during the period of the baseline survey. Subsequently, the principal researcher visited the remaining companies (n=8; 62% of the invited companies) to provide information about the aims, content and design of the intervention, whereupon they all committed themselves to participate in the study. These eight companies were randomly assigned to an intervention (n=4) or control group (n=4). Within the four companies comprising the intervention group, 227 construction workers were eligible for the current study (i.e. reach).

Dose delivered and dose received

The first plenary session was delivered to all four companies (100%; dose delivered). This session was followed by 28% (n=63; dose received) of all construction workers (i.e. reach) (Table 4.2). The second plenary session was delivered to all four companies as well, attended by 54% of the construction workers (n=123). Main reasons for not attending the plenary sessions were unemployment at the time of the plenary sessions or time constraints due to work demands.

The worksite visit involved 20% (n=45) of all construction workers. However, only construction workers from the intervention group measured at baseline comprising the random sample (n=47) were eligible for a worksite visit. The worksite visit involved 55% (n=26) of this subpopulation. Reasons for not receiving a worksite visit for those construction workers representing the random sample were practical infeasibility for the principal researcher (n=11), unemployment (n=6) or absence of the construction workers due to holidays (n=4). Significant higher attendance rates were found in company II compared to the other companies. In total, 42% of all eligible construction workers followed none of the intervention sessions, whereas 58% followed at least one session and 11% followed all sessions (Table 4.2). All four managers attended the first and second plenary session at their company, as well as the workshop.

Fidelity

The first plenary session was delivered to all four companies as described in the protocol. According to the protocol, posters and factsheets were distributed within the company in order to reach all eligible construction workers, including those who did not attend the first intervention session. Based on the process questionnaire, 58% of these construction workers were aware of the poster and 54% of them received the tailored factsheet.

Table 4.2 Proportion of construction workers (% (N)) who received the intervention sessions for all construction workers and by company.

	Total (N)[a]	Company I (N)[a]	Company II (N)[a]	Company III (N)[a]	Company IV (N)[a]
Reach (N)[a,b]	227	81	26	54	66
Attendance per intervention session (%(N)); dose received)[c]					
Plenary session 1	28% (63)	23% (19)[*]	92% (24)[*]	17% (9)[*]	15% (10)[*]
Worksite visit	20% (45)	25% (20)	31% (8)	15% (8)	14% (9)
Plenary session 2	54% (123)	77% (62)[*]	96% (25)[*]	37% (20)[*]	17% (11)[*]
Number of attended intervention sessions (%(N))					
None	42% (95)	17% (14)[*]	0% (0)[*]	55% (30)[*]	77% (51)[*]
1 session	28% (64)	52% (42)[*]	8% (2)[*]	30% (16)[*]	6% (4)[*]
2 sessions	19% (43)	20% (16)[*]	6% (17)[*]	6% (3)[*]	11% (7)[*]
3 sessions	11% (25)	11% (9)[*]	27% (7)[*]	9% (5)[*]	6% (4)[*]
Process questionnaires	41% (93)	46% (37)	88% (23)	35% (19)	21% (14)

[a] Number of subjects, in total or per company. [b] At start of inclusion (November 2011). [c] All construction workers were invited for the plenary sessions, while only construction workers measured at baseline were eligible to receive a workplace visit. [*] Significant at $p<0.05$.

Accessible worksites were visited according to the protocol. The number of construction workers who received the advice at the worksite varied between one to five construction workers per worksite. Even though only the randomly selected sample of construction workers were planned to be visited by the principal researcher, additional colleagues at the worksite were also invited to participate in the worksite visit.

The second plenary session was not implemented as intended in all four companies as none of the construction workers fulfilled the assignment (i.e. taking photos of good and poor work practices which were planned to be used for discussion in the second plenary session), because the assignment was considered as not worth time investment. Alternatively, the principal researcher showed photos, taken during baseline survey, in which technical control measures were used (in)adequately. By presenting these pictures, discussion about the good and poor work practices was initiated in all four companies. Subsequently, the session continued by addressing all other prescribed elements.

The workshop for managers was organized according to protocol. Available technical control measures were introduced via an interactive web tool, where after managers had the opportunity to practice with all technical control measures and to discuss possible constraints when using these measures.

Satisfaction

In total, 93 construction workers who participated in the intervention (i.e. 70% of the construction workers that followed at least one intervention session) filled in the questionnaire. These construction workers were satisfied about the intervention (7.5) and its specific components (6.7-7.5; Table 4.3). Considering all scores above 7 as satisfactory, construction workers were only moderately satisfied about the tailored factsheet (6.7). Not practical at the workplace was reported as main reason for not using the factsheet.

The majority of the construction workers who filled in the questionnaire, 67%, recommended the intervention for future implementation. The main reason for recommendation was the insight into potential health risks of occupational quartz exposure. Of those construction workers who did not recommend the intervention, inevitability of occupational quartz exposure was their main reason.

Table 4.3 Satisfaction with the intervention and recommendation for future implementation among managers and construction workers in total and for each contextual factor.

Satisfaction (mean(SD))	Managers		Workers		Contextual factor											
					Providing training		Inspection visit		Age category		Job category				Attending all sessions	
		Total		Total	Yes	No	yes	no	≤45yrs	>45yrs	Bricklayer	Concrete driller	Demolisher	Tuck pointer	yes	no
		N=4		N=93[a]	N=51	N=42	N=23	N=70	N=52	N=37	N=34	N=15	N=18	N=23	N=25	N=68
Satisfaction with the intervention sessions																
Overall intervention	4	6.5 (1.7)	70	7.5 (1.6)	7.5 (1.8)	7.4 (1.5)	7.4 (1.4)	7.5 (1.8)	7.6 (1.7)	7.3 (1.6)	8.0 (1.6)	7.1 (1.2)	7.1 (2.0)	7.1 (1.9)	7.9 (2.0)	7.2 (1.4)
Plenary session 1	4	7.8 (0.5)	51	7.3 (1.5)	7.6 (1.3)	7.0 (1.6)	7.0 (1.4)	7.4 (1.5)	7.3 (1.4)	7.2 (1.7)	7.3 (1.4)	7.4 (1.4)	7.2 (2.3)	7.2 (1.3)	7.6 (1.6)	7.0 (1.3)
Workshop/visit[b]	4	7.0 (1.2)	44	7.2 (1.8)	7.3 (1.8)	6.9 (1.8)	6.9 (1.4)	7.3 (1.9)	7.7 (1.4)	6.5 (2.2)	7.4 (1.8)	7.1 (1.1)	7.1 (2.3)	7.1 (2.1)	7.8 (1.7)[*]	6.5 (1.6)[*]
Plenary session 2	4	6.5 (3.0)	86	7.0 (1.8)	6.9 (1.6)	6.5 (2.0)	6.8 (1.9)	6.7 (1.8)	6.6 (2.1)	7.0 (1.4)	7.3 (1.4)	7.3 (1.1)	6.0 (2.1)	6.1 (2.1)	7.7 (1.7)[*]	6.3 (1.7)[*]
Satisfaction with the intervention materials																
Tailored factsheet	3	7.3 (0.6)	50	6.7 (1.9)	6.7 (1.8)	6.7 (1.9)	6.6 (2.1)	6.8 (1.7)	6.5 (2.1)	7.0 (1.5)	7.5 (1.2)[*]	6.0 (1.1)[*]	7.4 (1.1)[*]	5.3 (2.5)[*]	7.1 (1.8)	6.4 (1.9)
Documentary	4	7.5 (0.6)	50	7.5 (1.6)	7.4 (1.8)	7.6 (1.4)	7.6 (1.6)	7.4 (1.6)	7.7 (1.8)	7.3 (1.2)	7.8 (1.5)	7.3 (1.1)	7.4 (0.9)	7.1 (2.3)	7.6 (1.8)	7.4 (1.4)
PIMEX	4	7.3 (1.0)	51	7.6 (1.4)	7.7 (1.6)	7.6 (1.3)	7.7 (1.5)	7.5 (1.5)	7.6 (1.6)	7.6 (1.1)	7.8 (1.5)	7.6 (1.0)	7.3 (0.8)	7.3 (2.1)	7.7 (1.8)	7.5 (1.1)
Recommendation for future implementation																
Overall intervention	4	100%	62	67%	69%	64%	83%	61%	71%	62%	65%	87%	39%	78%	96%[*]	56%[*]

[a] Data were obtained from construction workers (N=93) who completed a process questionnaire. [b] The workshop was organized for managers, while construction workers received the worksite visit. [*] Significant at $p<0.05$.

Managers were moderately satisfied with the intervention and the second plenary session (6.5), whereas they were highly satisfied with the first plenary session (7.8), the documentary (7.5) and the tailored factsheet and PIMEX videos (7.3). All managers recommended the intervention for future implementation, as it serves as a first step to force all other stakeholders in the construction industry (e.g. sectorial organizations, labour inspection and contractors) to cooperate in addressing the risks of occupational quartz exposure. In line with this comment, the managers emphasized the need to receive information about changes in legislation and about innovations regarding technical control measures regularly.

Context

Job category as contextual factor significantly influenced the satisfaction about the intervention sessions and materials (Table 4.3). More specifically, bricklayers were more positive about the intervention session and materials than other job categories; this difference in satisfaction was statistically significant for the tailored factsheet. Furthermore, construction workers who followed more intervention sessions (i.e. at least two sessions) were significantly more often satisfied with the intervention sessions and materials than their colleagues. Additionally, they more often recommended the intervention to colleagues for future implementation ($p<0.05$) (Table 4.3). Slightly higher satisfaction rates for the intervention sessions were found among construction workers working within a company which offered training in dust-reducing practices before the baseline measurement, construction workers who received an inspection visit and younger construction workers. However, these difference were not significant.

The association between each contextual factor and the attendance rates is presented in Table 4.4. Construction workers working within a company who received an inspection visit attended significantly more intervention sessions. Also construction workers followed more intervention sessions when they were working within a company which did not provide training in dust-reducing practices before the baseline measurement. However, this was not statistically significant. Job category influenced attendance rate, as concrete drillers, compared to other job categories, showed significantly lower attendance rates for the second plenary session.

Table 4.4 Proportion of construction workers (%(N))[a] who attended the intervention sessions for each contextual factor.

	Contextual factor[b]									
	Providing training		Inspection visit		Age category		Job category			
	Yes	No	Yes	no	≤45 yr	>45 yr	Bricklayer	Concrete driller	Demolisher	Tuck pointer
	N=93	N=55	N=26	N=122	N=77	N=60	N=52	N=28	N=26	N=33
Attendance per intervention sessions (%(N))										
Plenary session 1	31% (29)*	60% (33)*	92% (24)*	31% (38)*	45% (35)	38% (23)	50% (26)	43% (12)	27% (7)	39% (13)
Worksite visit	31% (29)	29% (16)	31% (8)	30% (37)	35% (27)	30% (18)	27% (14)	36% (10)	27% (7)	42% (14)
Plenary session 2	78% (73)	82% (45)	96% (25)*	76% (93)*	77% (59)	87% (52)	94% (49)*	39% (11)*	77% (20)*	97% (32)*
Number of attended intervention session (%(N))										
None	12% (11)	9% (5)	0% (0)*	13% (16)*	14% (11)	7% (4)	2% (1)	39% (11)	15% (4)	0% (0)
1 session	49% (46)	33% (18)	8% (2)*	51% (62)*	35% (27)	46% (28)	46% (24)	18% (5)	58% (15)	36% (12)
2 sessions	25% (23)	36% (20)	65% (17)*	21% (26)*	30% (23)	32% (19)	31% (16)	29% (8)	8% (2)	49% (16)
3 sessions	14% (13)	22% (12)	27% (7)*	15% (18)*	21% (16)	15% (9)	21% (11)	14% (4)	19% (5)	15% (5)

[a] Number of subjects. [b] Data from contextual factors were only obtained from those construction workers (N=148) who attended at least one intervention session, or who were measured at baseline or follow-up without attending at least one intervention session.* Significant at p<0.05.

Discussion

Recruitment through sectorial organizations resulted in a reach of 227 eligible construction workers among four companies in the intervention group. Dose delivered was more than 95% for the plenary sessions, while it was only 20% for the worksite visits. Dose received of the managers for all sessions was 100%, whereas this dose was 58% for the construction workers. As construction workers and managers were satisfied about the intervention, the majority of the construction workers (67%) and all managers (100%) recommended the intervention for future implementation. Contextual factors, e.g. working within a company which received an inspection visit or a company which did not provide training in dust-reducing practices before the baseline measurement, and job category (i.e. bricklayers) were significantly associated with higher attendance rates. Satisfaction was significantly higher among bricklayers and among construction workers attending all intervention sessions.

Strengths and weaknesses of the process evaluation

One of the main methodological strengths is the systematic data collection on all process aspects during all intervention sessions by using checklists, logs and questionnaires. Since these data were collected among both construction workers and managers, their responses towards the questionnaire are helpful to modify the intervention and their suggested recommendations will therefore be feasible for future implementation. Feasibility is also facilitated as contextual factors are measured beforehand and continuously alongside implementation.[28,36,37] Hence, interventions are more likely to be successful if these factors are assessed.[28]

Some methodological limitations of the present study must be considered as well. Although we considered the hierarchical structure of the study, i.e. cluster randomization took place at company level and data from individual construction workers within these companies were used for analyses, the limited amount of observations was the major reason why we were unable to perform multilevel analyses. Because companies were recruited by sector organizations, the participating companies were probably early adopters[38] when it comes to health and safety. This recruitment procedure might have induced selection bias, so caution should be taken when generalizing the results to the entire sector.[39] Another potential source of selection bias might have been introduced by the random sample of worksite visits. Construction workers measured at baseline who were working on a worksite which was inaccessible, were not able to attend all intervention sessions. Since attending all intervention sessions was associated with more positive satisfaction about the intervention, this source of selection bias may have affected satisfaction. Furthermore, absence of personal interviews with construction workers and managers limited interpretation of some of the process outcomes (e.g. fidelity, satisfaction and recommendation for future implementation). This information could have provided in-depth insights on facilitators and barriers alongside underlying reasons for implementation. The last limitation, which has been more often identified as general limitation of process evaluations,[28] was the absence of a defined definition and formula on the seven process aspects by Linnan and Steckler (2002)[33] to determine the success or failure of implementation. Therefore, no objective conclusion of the implementation grade of the current study can easily be provided.

Interpretation of the findings

Because no other process evaluations of interventions aimed at reducing dust exposure were published, our results were compared with process evaluations of two other studies[40,41] conducted in the construction industry which used a similar framework.

The commitment of companies to participate was higher compared to a previous study,[40] which could be explained by the close collaboration with sector organizations. In the current study, these organizations personally invited a selection of companies. All construction workers employed within these companies were defined as reach. Because ambiguous descriptions of several process outcomes in Steckler and Linnan's framework,[28] reach was differently defined across several studies which made comparison difficult.

Dose delivered of the plenary sessions was comparable with previous studies which found also rates above 90%.[40,41] Compared to these studies, dose delivered of worksite visits was lower because of the infeasibility to visit some worksites and because of the random selection of construction workers who were eligible for a worksite visit. In line with this, dose received was low. This means that 70% of the construction workers followed none or only one of the sessions, even though construction workers were personally invited,[39] the intervention was developed with construction workers,[25] and organized at the worksite[42,43] within working hours.[38,42,44,45] This lower than expected dose received might be explained because attendance of the plenary sessions was not always obligatory and because the required travel time from their worksite to the central office (i.e. place where the plenary sessions were held) was quite long for some construction workers. Contrary to the construction workers, all managers followed all three sessions.

Compared to previous studies,[40,41] fidelity was high as only the assignment was not completed by the construction workers. The aim of this assignment was twofold: (i) increasing the awareness and recognition of good and bad work practices at worksites and (ii) initiating a discussion during the last group session. This second aim was still achieved by showing alternative photos taken by the principal researcher. Showing these photos can be regarded as adaptability, which is an important facilitator for implementation compared to interventions that must be conducted 'as is'.[36]

Construction workers and managers who attended all sessions, showed comparable or even slightly higher satisfaction rates compared to previous studies.[40,41] Moreover, in the current study slightly more construction workers recommended the intervention for future implementation if they attended all sessions. Previous studies showed that active involvement of construction workers and managers during the development phase of the intervention probably enhanced these satisfaction rates.[25,32,46,47] Nevertheless, the second plenary session was less appreciated by construction workers and managers, because of repetition of several elements from the first plenary session and stereotyping the construction industry by the labour inspector. Additionally, higher attendance rates during the first plenary session among construction workers working within a company which did not provide training in dust-reducing practices before the baseline measurement indicates that initiatives addressing relatively unknown topics have enough support in the beginning.

As mentioned in previous studies,[28,44] contextual factors, among others, at social-political level, i.e. inspection visits, influenced implementation. For instance, the frequent and strict inspection visits by the Dutch labour inspection in some companies may explain the higher attendance rates of construction workers during the second plenary session.

Implications for future practice

For a successful large scale implementation of the intervention program, when effective, some lessons learned should be considered.

First, intervention sessions should be organized within working hours and within the obligatory toolbox education system or as elementary component within an already scheduled meeting at the central office in which multiple themes concerning the company's policy are addressed. This approach increased attendance rates in company II, whereas it was also considered to be effective in previous studies.[38,40,42-45]

Second, managers and construction workers recommended to increase awareness and risk perception by continuous repetition of the attention on potential health risks of quartz exposure and solutions to avoid exposure. Several stakeholders involved during the development of the intervention suggested active strategies (e.g. workshop, active presentation and worksite visits) and audio-visual intervention materials (i.e. documentary about potential health risks, PIMEX videos) as most promising techniques to disseminate this message because of the limited literacy skills of construction workers. Similar techniques among identical populations were also recommended in previous studies.[43,46] Since the intervention in the current study was implemented in only four companies, some intervention components, e.g. the documentary and tailored factsheet, need a revision. The main messages from the occupational physician and labour inspector should be incorporated in the documentary, as oral presentations during large scale implementation are practical infeasible. Additionally, because reading the factsheet was mentioned as not practical at the workplace (i.e. we observed at the worksites that the factsheet was not decisive enough to affect workers' behaviour), its content could be transferred into an application for mobile devices. Construction workers lacked photography, most likely because the assignment was announced once-only and because the construction workers were insufficiently accompanied by the principal researcher to complete the assignment. Therefore, the assignment could be transferred into the mobile application as well. Translation to visual materials would be recommended since the majority of the construction workers has a lower education level and because the relatively easy accessibility to mobile devices nowadays. Although increasing compliance to the assignment might be difficult through such an application, i.e. construction workers mentioned the assignment as not worth time investment, the application may enable dynamic between the intervention components and opportunities for the exchange of updated information for managers and other stakeholders.

Third, researchers and implementers need to be aware of contextual factors which can be identified beforehand and spontaneously running alongside implementation.[38] Based on the factors defined beforehand, previous studies recommend different implementation strategies to optimize the success of the implementation.[36] For example, in this study, participation might be enhanced if workers in each job category were approached differently; as bricklayers do not use control measures that often, tailored worksite visits and discussions about constraints and/or facilitators when using control measures could be replaced by other group sessions at the worksite aimed at, for instance, increasing awareness about tasks with potential (high) quartz exposure. Contextual factors can also take place spontaneously, such as the labour inspection visits during the current study. Monitoring these contextual factors is important as it helps the interpretation of the effectiveness. Additionally, integrating these unexpected events in the intended intervention strategy should be considered for future implementation in practice.

Conclusions

This process evaluation showed that dose delivered and dose received were high for the plenary sessions but lower for the worksite visits. Overall, the intervention was almost completely implemented according to the protocol and the intervention sessions and intervention materials were highly appreciated and recommended for future implementation by both managers (100%) and construction workers (67%). Contextual factors that positively influenced implementation were (i) working within a company which received an inspection visit, (ii) working within a company which did not provide training in dust-reducing practices, (iii) working as a bricklayer and (iv) attending all intervention sessions. The main lessons learned from this process evaluation is that an intervention in the construction industry especially should comprise audiovisual intervention components, which are implemented at the worksite.

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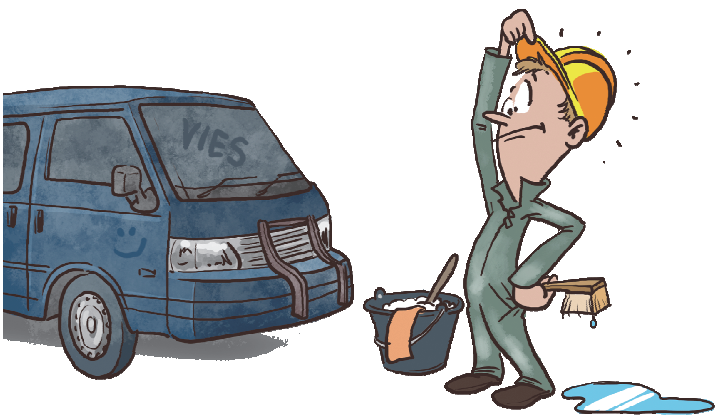
Chapter 5

Effectiveness of a multidimensional intervention program to reduce occupational quartz exposure among Dutch construction workers: results from a cluster randomized controlled trial



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Ann Occup Hyg 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.

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 mg/m^3 and 0.10 mg/m^3 in the different countries) during specific activities, such as drilling, sawing and/or tuck pointing.[1-3] In a recent survey among construction workers, we reported similar findings of excessive quartz exposure levels when comparable activities were performed.[4] Occupational quartz exposure is associated with several potential health risks, e.g. silicosis,[5] lung cancer[6] and chronic obstructive pulmonary disease (COPD).[7] Since a large number of workers are employed in the construction industry,[8] there is a need for effective interventions to reduce or prevent occupational quartz exposure and thereby the prevalence and incidence of chronic respiratory diseases.[9-11]

Although several studies describe the efficacy of specific technical control measures to reduce hazardous substances in an experimental setting,[12] studies evaluating the effectiveness of these measures under real working conditions are scarce.[13] In practice, organizational[14] and behavioural factors[15] also determine the effectiveness of control measures.[9,16,17] 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.[18] 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.[19] 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.[20] Baseline measurements and workplace observations[4] were combined with input from stakeholders and empirical findings from the literature to tailor the intervention strategy to the needs of the target population.[21] 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.[21] 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.[22]

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.[18] 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[23] 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.[4] 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).[4] 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.[21] In short, the six-month intervention program was developed according to the Intervention Mapping protocol,[20] 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, six months after the implementation of the intervention. Population characteristics were obtained from the questionnaire administered to the construction workers.[4]

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.[4] Quartz content of the filters was determined by infrared spectroscopy and X-ray diffraction, according to MDHS 101.[24] The analytical limit of detection (LOD) of quartz was 0.01 mg.[24]

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.[4]

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 (Figure 5.1). 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.

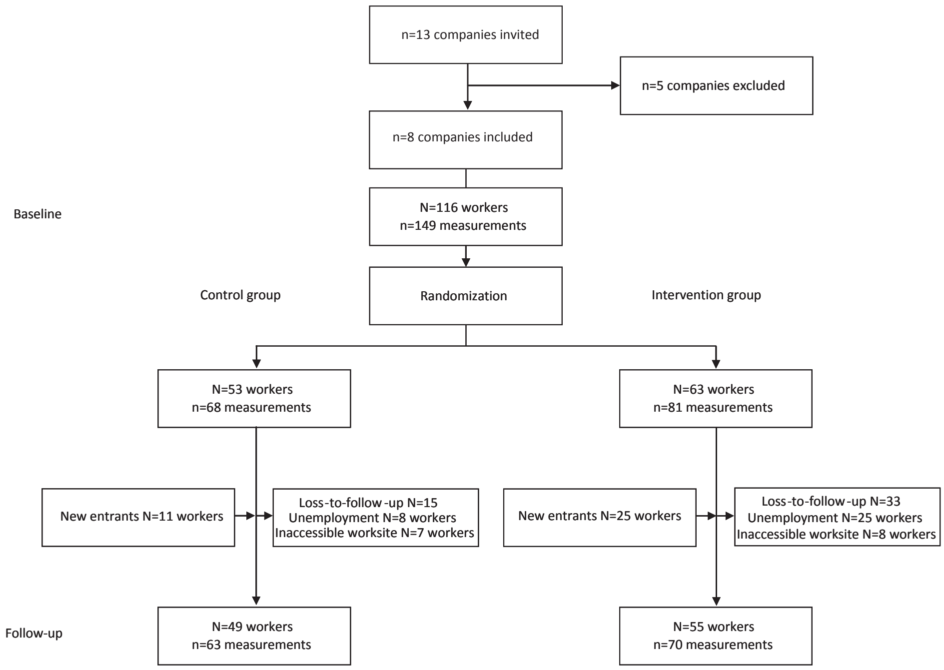

Figure 5.1 Flow diagram of study participants.

Personal full-shift exposure measurements were collected from 116 construction workers (n=149 measurements) during the baseline survey,[4] and 104 construction workers (n=133 measurements) during follow-up (Figure 5.1). 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 5.1). 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.

Table 5.1 Population characteristics, separated for occasion (baseline or follow-up) and condition (intervention or control).

	Baseline		Follow-up	
	Control group (N=53[a]; n=68[b])	Intervention group (N=63[a]; n=81[b])	Control group (N=49[a]; n=63[b])	Intervention group (N=55[a]; n=70[b])
Individual characteristics				
Age (yrs) (SD)	39.2 (11.7)	39.3 (9.7)	40,5 (11,2)	42,7 (9,5)
Missing	N=0	N=16	N=5	N=1
Job category				
Bricklayer	4% (N=2)	11% (N=7)	8% (N=4)	22% (N=12)
Carpenter[c]	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[d]				
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

[a] Number of subjects. [b] Number of measurements. [c] No carpenters in intervention group. [d] No education considered only primary school, low education considered only secondary school and medium or high education considered (secondary) vocational education. * Significant at p<0.05.

5

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.[4] 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) (Figure 5.2).

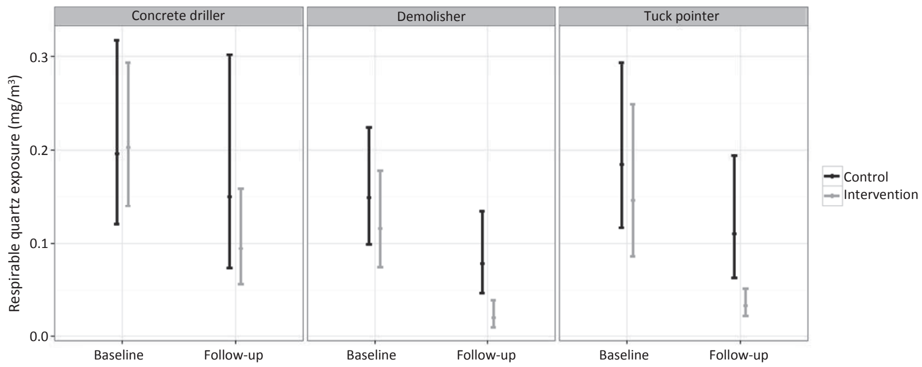

Figure 5.2 Baseline and follow-up geometric mean (95% confidence intervals) respirable quartz exposure levels (mg/m^3) per job category for the intervention group and control group. The *p* values for the intervention effect were *p*=0.005, *p*=0.008, and *p*=0.15 for demolishers, tuck pointers, and concrete drillers, respectively.

The 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 5.2).

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 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 5.3). 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 local exhaust ventilation LEV could be observed between the control and intervention group.

Table 5.2 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[b]	GM (GSD)[a]	Range	Exceedance OEL quartz (%)	Condition	n[b]	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.[c]	n.a.[c]	n.a.[c]
	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.[c]	n.a.[c]	n.a.[c]
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

[a] Geometric mean (geometric standard deviation). [b] Number of measurements. [c] Not applicable because absence of carpenters in 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. 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 5.4). 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 5.4). 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.

Table 5.3 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)[c]	Follow-up (n=7)[c]	Baseline (n=35)[c]	Follow-up (n=18)[c]	Baseline (n=19)[c]	Follow-up (n=13)[c]	Baseline (n=26)[c]	Follow-up (n=12)[c]	Baseline (n=14)[c]	Follow-up (n=12)[c]	Baseline (n=11)[c]	Follow-up (n=26)[c]
CM[d]	64%	69%	62%*	93%*	38%*	0%*	48%	63%	14%	4%	38%	20%
LEV[e]	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%

[a] These analyses were performed within the subpopulation 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. [c] Number of measurements. [d] Control measure use (whether construction used a control measure in general, not specified for local exhaust ventilation (LEV) or wetting). [e] Local exhaust ventilation. * Significant at $p<0.05$.

Table 5.4 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		
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]
Concrete driller	Control	Baseline	0.20 (0.12-0.33)	-25%		0.26 (0.13-0.52)	-20%		0.07 (0.04-0.14)	-43%	
		Follow-up	0.15 (0.07-0.30)		-30%	0.21 (0.09-0.51)		-23%	0.04 (0.02-0.10)		23%
	Intervention	Baseline	0.20 (0.14-0.29)	-55%		0.28 (0.17-0.49)	-43%		0.05 (0.03-0.10)	-20%	
		Follow-up	0.09 (0.06-0.16)			0.16 (0.07-0.35)			0.04 (0.02-0.07)		
Demolisher	Control	Baseline	0.15 (0.10-0.23)	-47%		0.16 (0.10-0.26)	-50%		0.03 (0.01-0.06)	-67%	
		Follow-up	0.08 (0.05-0.13)		-36%	0.08 (0.05-0.14)		-35%	0.01 (0.01-0.03)		17%
	Intervention	Baseline	0.12 (0.07-0.18)	-83%		0.13 (0.08-0.20)	-85%		0.02 (0.01-0.04)	-50%	
		Follow-up	0.02 (0.01-0.04)			0.02 (0.01-0.04)			0.01 (0.004-0.02)		
Tuck pointer	Control	Baseline	0.19 (0.12-0.30)	-42%		0.20 (0.12-0.32)	-45%		0.21 (0.13-0.34)	-52%	
		Follow-up	0.11 (0.06-0.20)		-38%	0.11 (0.06-0.20)		-35%	0.10 (0.06-0.18)		-25%
	Intervention	Baseline	0.15 (0.08-0.25)	-80%		0.15 (0.08-0.28)	-80%		0.13 (0.07-0.22)	-77%	
		Follow-up	0.03 (0.02-0.05)			0.03 (0.02-0.05)			0.03 (0.02-0.05)		

			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]
Concrete driller	Control	Baseline	0.10 (0.05-0.21)	-20%		0.06 (0.02-0.16)	-50%		0.29 (0.16-0.52)	-28%	
		Follow-up	0.08 (0.04-0.19)		-24%	0.03 (0.01-0.13)		0%	0.21 (0.10-0.43)		-4%
	Intervention	Baseline	0.09 (0.04-0.20)	-44%		0.04 (0.01-0.10)	-50%		0.25 (0.17-0.35)	-32%	
		Follow-up	0.05 (0.03-0.11)			0.06 (0.03-0.12)			0.17 (0.09-0.31)		
Demolisher	Control	Baseline	0.09 (0.05-0.16)	-56%		0.02 (0.01-0.07)	-50%		0.19 (0.12-0.31)	-58%	
		Follow-up	0.04 (0.02-0.10)		-19%	0.01 (0.001-0.08)		20%	0.08 (0.05-0.14)		0%
	Intervention	Baseline	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 (0.01-0.03)			0.01 (0.003-0.02)			0.05 (0.02-0.11)		
Tuck pointer	Control	Baseline	0.06 (0.03-0.13)	-17%		0.22 (0.12-0.38)	-50%		n.a.[e]	n.a.[e]	
		Follow-up	0.05 (0.02-0.10)		-43%	0.11 (0.06-0.20)		-23%	n.a.[e]		n.a.[e]
	Intervention	Baseline	0.05 (0.02-0.10)	-60%		0.12 (0.07-0.23)	-73%		n.a.[e]	n.a.[e]	
		Follow-up	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.

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 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.[4] 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,[25] and using randomization and a control group[26] 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%).[27] As a result, it seems unlikely that differential loss-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,[28,29] 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.[30,31] 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.[27] These surveys were a likely explanation for the overall reduction in exposure that was observed in the control group also. Besides this industry-wide co-intervention, 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[18] and in bakeries[19] 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.

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Chapter 6

An exploratory study of changes in outcomes of behavioural moderators related to occupational quartz exposure among construction workers

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Submitted

Abstract

There are hardly any studies in the occupational setting which investigate the relation between behaviour and exposure to hazardous substances, despite the fact that this may increase our understanding of how to change behaviour and increase the effectiveness of intervention programs consequently reducing worker exposure. The change in individual behaviour is affected by so called ‘behavioural moderators’, such as attitude, knowledge and risk perception. This study aimed to evaluate whether behavioural moderators changed as a result of the intervention and if so, if these have contributed to changes in work practices and exposure. Eight companies participating in a cluster randomized controlled trial were randomly allocated to the intervention or control group. The multidimensional intervention comprised technical, organizational and behavioural elements at both organizational and individual level. Behavioural moderators, i.e. knowledge, beliefs, motivation, risk perception, social influence and risk propensity, were assessed using a questionnaire, in which several questions specifically considered the content of the intervention for each moderator. The questionnaire was administered in both the control and intervention group, both during baseline and follow-up. Mean values for the behavioural moderators were compared to explore differences between baseline and follow-up. Pearson Chi-square tests were conducted to investigate differences in the percentage of ‘correct’ or ‘positive’ answers among workers using and not using technical control measures. There is a tendency that the scores for most of the behavioural factors are higher in the intervention group during follow-up compared to the control group. Furthermore, the percentage of workers who answered the questions that specifically considered the content of the intervention correctly at follow-up was larger in the intervention group compared to the control group ($p<0.05$). For knowledge, risk perception and motivation in particular, the workers who answered the questions that specifically considered the content of the intervention correctly used technical control measures more frequently ($p<0.05$). Scores on the behavioural moderators seemed to increase in the intervention group, partly as a result of the intervention. Knowledge, risk perception and motivation seemed to be associated with an increased use of technical control measures. The results indicate that these moderators of changing behaviour may be an integrated part of controlling exposures in the workplace.

Background

Although quartz exposure is strongly associated with several chronic respiratory diseases,[1-6] no studies were identified that evaluated the relationship between occupational quartz exposure and behavioural factors. Substantial reductions in quartz exposure partly as a result of an increased use of technical control measures have been observed recently.[7] However, the influence of behavioural moderators that drive the optimal use of these controls and constraints of effective use have not been taken into account yet.

The need to understand workers' behaviour is acknowledged due to analyses of several exposure databases.[8] Data suggest that worker behaviour is likely to account for much of the between-worker variability when performing similar work activities in similar conditions and potentially also for part of the within-worker variability.[8] This so-called 'human factor' in occupational hygiene is an interwoven concept that is both relevant for workers performing tasks on the work floor as well as for managers involved in decision-making. It seems reasonable to integrate these behavioural aspects into exposure assessment strategies in order to influence workers' attitude, knowledge and behaviour.[9,10] This might be a first step to gain insight in personal factors and the way work is performed (i.e. work practices) and to gain more understanding of how to change this behaviour if required.

Since the change in individual behaviour is affected by so called 'behavioural moderators', such as attitude, knowledge and risk perception,[11,12] the multidimensional intervention focussed on these moderators.[13] The aim of this paper was to explore whether these moderators indeed have changed as a result of the intervention and if so, if these changes might have contributed to changes in use of technical control measures and dust-reducing work practices.

Methods

Study design, randomization and study population

This study was a cluster randomized controlled trial (cluster RCT). Cluster randomization took place at company level after the baseline survey. All eight participating companies were randomly assigned to either an intervention program (n=4) or control condition (n=4). The study design has been described in detail elsewhere.[13]

The following job categories were included: bricklayer, carpenter, concrete driller, demolisher and tuck pointer. Because of the large number of eligible workers to participate, a random sample of these eligible workers per company was included in the baseline measurements.[14] Follow-up measurements were aimed at reassessing 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 was not evaluated by the Central Committee of Research Involving Human Subjects, since no medical ethic approval was required for this study. The study has been executed according to the Dutch Data Protection Law. Further details about the study population are described elsewhere.[14]

Outcome measures

As part of the exposure assessment, both at baseline and during follow-up, employees were asked to fill in a questionnaire on behavioural moderators potentially related to quartz exposure, i.e. beliefs, knowledge, motivation, risk perception, risk propensity and social influence (Table 6.1). These behavioural moderators were considered to have reliable scales, indicated by a Cronbach value ≥0.7.[15,16] The risk propensity scale was excluded for analyses, because of its too general nature. An additional argument was that the intervention did not directly address issues measured by this scale. Furthermore, a few behavioural moderators were included in the questionnaire, e.g. self-efficacy, but were excluded in the analyses because of unreliable scales, i.e. low Cronbach value. In order to get insight in the most important factors that may be (perceived as) facilitators or constraints for a worker to use technical control measures or to perform dust-reducing work practices, two separate questions were included in the questionnaire. These questions comprised multiple-choice questions. A more detailed description of the development of the questionnaire is described in.[14]

Each behavioural moderator comprised several underlying questions (Appendix 1). The knowledge questions consisted of dichotomous and multiple-choice questions of which the answers could be evaluated as ‘correct’ or ‘incorrect’. Multiple-choice questions with multiple correct answer options were considered as ‘correct’ only if all the correct options were filled in. The remaining scales comprised Likert-type (5-point Likert scale) questions, with responses ranging from totally disagree to totally agree. The responses to these subjective questions were evaluated as ‘positive’ when they were assumed to have a positive effect on the intervention, i.e. having a potential to contribute to an increased use, or more optimal use of dust-reducing control measures or best work practices (score ‘4’ or ‘5’ or a score of ‘1’ or ‘2’on the 5-point Likert scale depending on the formulation of the question).

For each moderator, several questions specifically considered the content of (components of) the intervention, for example the individual’s knowledge about potential long term health risks of quartz exposure. Workers were identified that gave the ‘correct’ or ‘positive’ answers on all the questions that specifically considered the content of the intervention by moderator.

Statistical analyses

All statistical analyses were performed using SAS v9.3 (SAS Institute Inc, Cary, NC). Exploratory analyses were conducted for those workers who filled in the questionnaire both during baseline and follow-up. To explore differences in behavioural moderators during baseline and follow-up, overall scores were compared using independent samples t-tests for the control and intervention group separately.

Equality of binominal proportions tests were performed to explore the difference between baseline and follow up in the proportion of construction workers who provided a ‘correct’ or ‘positive’ answer. These differences were evaluated for both the control and intervention group separately.

Furthermore, through Pearson Chi-square tests or Fisher exact tests it was explored whether workers that gave a 'correct' or 'positive' answer to all questions targeted in the intervention during follow-up more often used technical control measures during follow-up. Besides overall analyses, we stratified these analyses for intervention and control group, education level (construction workers with secondary education or less versus tertiary education and more) and for construction workers who had more or less than 20 years of experience in their current job. Since specific behavioural moderators were addressed in different intervention sessions,[13,19] it was also explored through Pearson Chi-square of Fisher exact tests whether workers who gave a 'correct' or 'positive' answer to all questions which specifically considered the content of the intervention during follow-up more often attended these intervention sessions (in the intervention group only).

As demonstrated during the baseline survey, workers' motivation to use exposure controls and dust-reducing work practices seemed associated with higher quartz exposure.[14] Therefore, separate Pearson Chi-square tests were conducted to evaluate the agreement between self-reported frequent use (answering 'almost always' or 'always' using local exhaust ventilation and/or water suppression techniques on a 5-point Likert scale) and observed (yes/no from observational checklist) use of technical control measures, both during baseline and follow-up. As only high exposed job categories, i.e. concrete driller, demolisher and tuck pointer[7,14] used technical control measures, these analyses were only performed among these job categories.

Results

Behavioural moderators

Questionnaires were available from 64 workers filled in the questionnaire both during baseline and follow-up. Overall, a large variability in the levels of all behavioural moderators was observed (Table 6.2). The scores for most of the moderators tended to be slightly higher during follow-up compared to baseline in the intervention group, especially for the differences for knowledge and motivation. Remarkably, the scores for social influence were higher during follow-up in both the intervention and control group.

Most important shifts between baseline and follow-up in the percentage of workers in the intervention group that gave a 'correct' or 'positive' answer to the questions that considered the content of the intervention were observed for knowledge and beliefs (Table 6.3). When considering the questions that specifically considered the content of the intervention per moderator (Table 6.4), more pronounced shifts between baseline and follow-up were observed for most of the moderators when comparing the control and intervention group. For instance, motivation showed a significant association.

Association between observed work practices and behavioural moderators

The observed use of water suppression techniques at follow-up was significantly higher among workers who answered the questions that specifically considered the content of the intervention as 'correct' for knowledge or as 'positive' for motivation and risk perception at follow up (p=0.02, p=0.001 and p=0.01, respectively). It was explored whether these associations were present in subgroups (e.g. workers with less experience in their current job), because the limited number of observations did not allow adjusted analyses.

Facilitators and constraints

Health concerns were the main reason mentioned by the construction workers why control measures were used and/or why dust-reducing work practices were performed (if possible). The most important constraint to apply dust-reducing work practices in the intervention group during follow-up comprised technical difficulties (Table 6.5).

Table 6.1 Description of behavioural moderators (adapted from van Deurssen et al. (2014)).[14]

Scale[a]	Based on	N[b]	Description
Beliefs	Adapted existing questionnaire[17]	10	Indication of an individual's beliefs in the effectiveness and constraints of optimal use of various exposure controls and dust-reducing work practices
Knowledge	Self-developed	8	Estimation of an individual's knowledge regarding exposure sources, controls, substances, routes of exposure and short- and long-term effects of quartz dust
Motivation	Adapted existing questionnaire[17]	11	Indication of an individual's intention (or motivation) to use exposure controls and dust-reducing work practices
Risk perception	Adapted existing questionnaire[17,18]	6	Indication of an individual's perception of risk of quartz dust and susceptibility to short- or long-term health effects
Social influence	Adapted existing questionnaire[17]	3	Indication whether an individual is influenced by co-workers or supervising personnel to use exposure controls and dust-reducing work practices

[a] Except knowledge scale, which consisted of dichotomous questions (true/false) and multiple-choice questions which on turn were transformed into a ratio scale, all other scales were measured on a ratio scale with a range. Questions using Likert-type scales comprised statements concerning the behavioural moderator 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. Other scales are excluded, e.g. the self-efficacy scale, due to an inadequate Cronbach value. [b] Number of questions per scale.

Table 6.2 Levels and differences in scores for behavioural moderators for individuals present at baseline and follow-up.

	Control group (N=35)[a]			Intervention group (N=29)[a]		
Scale	baseline (min-max)	follow-up (min-max)	Δ (min-max)	baseline (min-max)	follow-up (min-max)	Δ (min-max)
Knowledge	0.69 (0.28-0.92)	0.71 (0.49-0.91)	0.02 (-0.34-0.31)	0.71 (0.44-0.87)*	0.80 (0.61-1.00)*	0.09 (-0.14-0.34)
Beliefs	3.88 (2.50-5.00)	3.77 (2.38-5.00)	-0.11 (-1.88-1.38)	3.51 (1.75-4.75)	3.74 (1.29-4.88)	0.23 (-0.83-1.00)
Risk perception	3.68 (2.83-5.00)*	3.42 (2.17-4.50)*	-0.26 (-1.83-1.33)	3.52 (2.17-4.67)	3.73 (2.67-5.00)	0.20 (-1.17-2.33)
Social influence	3.22 (1.40-5.00)	3.52 (2.00-5.00)	0.31 (-1.15-1.80)	3.25 (2.20-5.00)	3.50 (2.40-4.80)	0.25 (-2.00-2.00)
Motivation	4.07 (2.36-5.00)	4.00 (2.09-5.00)	-0.07 (-1.27-1.55)	3.83 (1.55-5.00)	4.10 (1.82-5.00)	0.28 (-0.91-2.27)

[a] Number of subjects. * Significant at $p<0.05$ (percentage at baseline compared to follow-up for the control and intervention group).

Table 6.3 Percentage of workers who responded to the questions that specifically considered the content of the intervention with a 'correct' or 'positive' answer.[a]

	Control group (N=35)[b]			Intervention group (N=29)[b]		
Scale	baseline	follow-up	Δ	baseline	follow-up	Δ
Knowledge						
LEV and wetting are effective control measures in capturing dust at the source	40%	43%	3%	38%*	76%*	38%
Concrete contains a high percentage of quartz	83%	86%	3%	90%	97%	7%
Lime-sandstond contains a high percentage of quartz	83%	83%	0%	86%*	100%*	14%
There is no legal exposure limit for quartz in the air	49%	54%	5%	41%*	76%*	35%
Silicosis is a long-term health risk of quartz exposure	66%	63%	-3%	83%	90%	7%
Lung cancer is a long-term health risk of quartz exposure	94%	86%	-8%	72%*	93%*	21%
Beliefs						
I think that LEV and wetting can be effective to control dust	91%	89%	-2%	71%*	90%*	19%
I think that LEV and wetting take too much time and delay my work	23%	20%	-3%	52%	59%	7%
I do not feel comfortable if a colleague works carelessly and causes a lot of dust	69%	49%	-20%	41%*	72%*	31%
I feel I have to correct my colleagues if they do not use dust-reducing work practices	89%	80%	-9%	62%	76%	14%
Social influence						
How often do your colleagues apply dust-reducing work practices?	34%	31%	-3%	24%	55%	31%
My colleagues frequently correct each other to use dust-reducing work practices	46%	50%	4%	28%	45%	17%
My manager frequently points out that I should use dust-reducing work practices	40%	40%	0%	21%	34%	13
Motivation						
To what degree are you planning to apply dust-reducing work practices during your daily activities?	89%	83%	-6%	83%	90%	7%
To what degree are you planning to properly use and maintain LEV during abrasive tasks?	89%	77%	-12%	62%*	86%*	14%
To what degree are you planning to properly use and maintain wetting techniques during abrasive tasks?	63%	63%	0%	55%*	83%*	28%
To what degree are you planning to clean by using dust-reducing work practices?	74%	57%	-17%	51%	76%	25%
Risk perception						
In your opinion, how risky is quartz?	83%	91%	8%	76%*	96%*	20%
In your opinion, what is the chance that you will develop long term health complaints after being exposed to quartz dust?	63%	57%	-6%	38%	52%	14%
Do you have more or less chance of developing health complaints due to work with quartz compared to workers not employed in the construction industry?	80%	71%	-9%	90%	86%	-4%

[a] Assuming that 'positive' implies an answer within a scale that is associated with an increased or optimal use of controls or practices. [b] Number of subjects.
* Significant at $p<0.05$ (percentage at baseline compared to follow-up for the control and intervention group).

Table 6.4 Percentage of employees who provided a 'correct' or 'positive' answer to all the questions (per moderator scale) that specifically addressed the content of the intervention for individuals present at baseline and follow-up.

	Control group (N=35)[a]			Intervention group (N=29)[a]		
Scale	baseline	follow-up	Δ	baseline	follow-up	Δ
Knowledge[b]	20%	17%	-3%	3%	48%	45%
Beliefs[b]	14%	3%	-11%	14%	34%	20%
Social influence[b]	20%	20%	0%	7%	21%	14%
Motivation[b]	51%	46%	-5%	38%*	69%*	21%
Risk perception[b]	43%	40%	-3%	34%	45%	11%

[a] Number of subjects. [b] All employees who answered all the questions that specifically considered the content of the intervention 'correct' and/or 'positive'. * Significant at $p<0.05$ (percentage at baseline compared to follow-up for the control and intervention group).

Table 6.5 Percentage of workers who mentioned factors that were perceived as facilitators and constraints to use technical control measures or to perform dust-reducing work practices.

		Control group (N=35)[a]		Intervention group (N=29)[a]	
		baseline	follow-up	baseline	follow-up
Facilitator	Better for my own health	94%	89%	88%	86%
	Less inconvenient for my eyes and airways	3%	6%	0%	0%
	Manager or supervisor influence	3%	3%	12%	14%
Constraint	Technical difficulties	32%	47%	25%	41%
	Time consuming	17%	25%	21%	21%
	Measure is insufficient to reduce dust	23%	25%	25%	24%

[a] Number of subjects.

Discussion

In this study we explored differences in behavioural moderators between baseline and follow-up in an intervention study for which we previously demonstrated a substantial reduction in quartz exposure levels. The scores for most of the different behavioural moderators were tended to be higher at follow-up compared to baseline in the intervention group. This shift was most pronounced for those questions that specifically considered the content of the intervention for knowledge, beliefs and motivation, suggesting that these shifts may be attributable to information obtained during the intervention sessions. Since the use of technical control measures was associated with some of the behavioural moderators, e.g. knowledge and risk perception, the shift in behavioural moderators may explain the observed decreased exposure levels.

The intervention aimed to establish an increase in the proper use of technical control measures by targeting the workers' behaviour in order to reduce occupational quartz exposure.[13] Knowledge and risk perception were selected as important behavioural determinants, because most construction workers were not aware of quartz exposure and its potential health risks.[13,20] Reductions in exposure were demonstrated. However, due to factors that were not an element of the intervention strategy, the intervention effect for several job categories or within subgroups was potentially attributable to other factors that changed over time and that were not an element of the intervention.[7] The higher scores in the intervention group at follow-up for knowledge and risk perception, compared to scores at baseline in the intervention group and the increase in workers who could correctly (or positively) answer questions on topics that were specifically considered in the intervention sessions, suggests that the information presented during the intervention sessions has indeed contributed to the level of knowledge and risk perception. The fact that workers who correctly (or positively) answered the questions on these topics more often were observed to use technical control measures seemed to indicate that the intervention sessions have contributed to the increased of technical control measures that was demonstrated in the intervention study. Although this study focused on the individual behavioural moderators that might affect the use of technical control measures of workers in the workplace, organizational factors seemed to affect (optimal) use of technical control measures as well. For instance, encounters of the fieldworkers with the employers during follow-up seemed to indicate that employers tended to pay more attention towards the employees' knowledge about potential health risks of quartz exposure.

An important strength of this study was the useful insights that were generated in the facilitators and constraints for construction workers when using technical control measures. Nevertheless, several considerations need to be taken into account when interpreting the results. The questionnaire comprised specific parts of existing validated questionnaires but it was not validated itself. The development and the implementation of the non-validated questionnaire can be seen as rather experimental, despite the fact that the importance of human factor is well accepted. So far, understanding of human behaviour in the workplace is limited to the field of accidents or injuries[21] or muscoskeletal disorders.[22] Also the potential influence of the Hawthorne effect, which seems inherent to studies at the workplace, should be taken into account.[23,24] When completing the questionnaire, workers could have given social desirable answers. Workers could also have shown desired behaviour when they were observed at the workplace, but conversations at the workplace with close colleagues proved that this occurred very infrequently.

Several elements of our intervention strategy may have positively contributed to the observed changes regarding behavioural outcomes. Repetition of the intervention elements related to knowledge and risk perception, appeared to be effective when targeting these behavioural moderators. An increased knowledge and risk perception, at least to some extent, resulted in an increased rate of interaction between the employees and their employers about constraints to use technical control measures. This seemed to have contributed to the increased use of technical control measures among workers in the intervention group.

Conclusion

This study indicates that our strategy to focus the intervention on individual behaviour moderators to achieve an increased use of technical control measures seems partly successful. Scores on the behavioural moderators increased in the intervention group, likely at least to some extent as a result of the intervention. Knowledge, risk perception and motivation seemed to be associated with an increased use of technical control measures. Although the exact pathway cannot be established and causality cannot be proven on the basis of this study alone, useful insights were generated. Changing behaviour should be seen as an integral part of controlling exposures in the workplace, since behaviour, human error, organizational involvement and environmental factors contribute to the actual effectivity of control measures and interventions on the work floor.

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Appendix 1 Overview of all specific questions underlying the behavioural moderators

Knowledge	
	Which of the following is the most dusty task?
	Which two control measures are the most effective in capturing dust at the source? [a]
	Does concrete contain a high percentage of quartz? [a]
	Does lime-sandstone contain a high percentage of quartz? [a]
	A material safety data sheet (MSDS) gives, amongst others, information about health effects of a certain substance
	There is no legal exposure limit for quartz in the air [a]
	What is the main route of quartz exposure to the human body?
	Which of the following are short term health effects of quartz exposure?
	Is silicosis a long term health risk of quartz exposure? [a]
	Is lung cancer a long term health risk of quartz exposure? [a]
Beliefs	
	I think that LEV and wetting can be effective to control dust [a]
	I think that LEV and wetting are unpleasant and annoying to use [b]
	I think that LEV and wetting take too much time and delay my work [a,b]
	I think that wetting results in too much mess [b]
	I feel that respirators are unpleasant and annoying to use [b]
	I do not feel comfortable if a colleague works carelessly and causes a lot of dust [a]
	I feel I have to correct my colleagues if they do not use dust-reducing work practices [a]
	I do not think it is necessary to use dust-reducing measures in order to protect myself from quartz exposure
Social influence	
	My colleagues use control measures frequently
	How often do your colleagues apply dust-reducing work practices? [a]
	My colleagues frequently correct each other to use dust-reducing work practices [a]
	My manager frequently points out that I should use dust-reducing work practices [a]
Motivation	
	To what degree are you planning to apply dust-reducing work practices during your daily activities? [a]
	To what degree are you planning to apply dust-reducing work practices during abrasive tasks?
	To what degree are you planning to properly use and maintain LEV during abrasive tasks? [a]
	To what degree are you planning to properly use and maintain wetting techniques during abrasive tasks? [a]
	To what degree are you planning to use natural ventilation?
	To what degree are you planning to use mechanical ventilation?
	To what degree are you planning to use, maintain and store respirators as prescribed?
	To what degree are you planning to clean by using dust-reducing work practices? [a]
	To what degree are you planning to use curtains, dividers and shielding to reduce dust from containers and neighboring workplaces?
	To what degree are you planning to avoid dusty locations?
	To what degree are you planning to comply with personal hygiene measures?
Risk perception	
	In your opinion, how risky is quartz? [a]
	In your opinion, what is the chance that you will develop short term health complaints after being exposed quartz dust?
	In your opinion, what is the chance that you will develop long term health complaints after being exposed to quartz dust? [a]
	Compared with your colleagues, do you have more or less chance of developing health complaints when working with quartz?
	Do you have more or less chance of developing health complaints due to work with quartz compared to workers not employed in the construction industry? [a]
	Do you think that health complaints will disappear if you are not exposed to quartz anymore?

[a] These questions specifically considered the content of the intervention. [b] 'Positive' or 'correct' question outcome is 1 or 2 instead of 4 or 5.

Chapter 7

General discussion

General discussion

This thesis describes a novel randomized, multidimensional intervention study in the construction industry. This study has shown to be moderately effective in reducing occupational quartz exposure during typical workplace conditions. Detailed insight in the baseline situation with respect to technical, organizational and behavioural aspects and the needs perceived by the population was obtained. This information was gathered through a detailed exposure assessment, including a walk-through survey and a structured participatory approach in the developmental phase of the intervention. All these elements were thoroughly integrated in our study design **(Chapter 2 and 3)**. In terms of effectiveness, the reduction of exposure in the intervention group was at least partly attributable to the introduced intervention program that led to an increased use of control measures (i.e. more water suppression techniques) **(Chapter 5)**. Furthermore, companies initiated the development of dust-reducing technical solutions for work practices during follow-up. The intervention group tended to score higher for behavioural change compared to the control group during follow-up **(Chapter 6)**. The implementation of the intervention was evaluated positively by employees. Elements of the intervention study were recommended for future large-scale implementation by both employers and supported by employees **(Chapter 4)**. As it is important to extract lessons from this intervention study to improve future large scale intervention studies and to increase their effectiveness, this chapter discusses some of the main findings in the light of implications for (future) research and practice.

Is a randomized controlled trial a suitable design in the construction industry?

Very few multidimensional intervention studies have been conducted in the field of occupational health that specifically focuses on exposure reduction to hazardous substances and conducted under real working conditions.[1,2] The randomized controlled trial (RCT) is the preferred methodological approach in the paradigm for intervention research.[3-7] A randomized controlled trial is a strong and transparent prospective research design as in principle confounding and selection bias are optimally controlled for.[5,6] Although this type of study is mainly used in the clinical setting, it is also used in other settings like occupational hygiene. Here, large variation in workplace factors and work practices need to be monitored to enable the evaluation of intervention effects, while accounting for these potential confounding variables might be impeded by real life practices and environmental conditions beyond the control of the researchers.

Furthermore, frequent occurring constraints when undertaking intervention research using a RCT design in the occupational setting have been identified.[3-6,8] Worksites are temporary and mobile in the construction industry, which results in transfer of ideas, knowledge and expertise between workers from different companies and worksites. On the other hand, high mobility might increase the risk of loss to follow-up. The risk of loss to follow-up was reduced in our study by including construction companies with a considerable number of permanent employees. To minimize the risk of contamination among construction workers, groups of individuals rather than individuals were randomized. This resulted in a modified design, i.e. a cluster randomized controlled trial (cluster RCT)[4,7] which has some other advantages in the context of the construction industry. For example, it results in an increased feasibility of delivering the intervention to a group of people instead of at an individual level.[8]

Challenges regarding sample size, study population and co-interventions when conducting a cluster RCT in the construction industry

Conducting a cluster RCT in the construction industry involves several challenges that are inherently part of this sector. In general, a cluster RCT has some implications for the sample size and the required number of measurements.[4,7] Although a study with more clusters and fewer individuals within clusters has a higher power to detect an intervention effect, the number of clusters and individuals per clusters in our study was limited due to practical feasibility and costs. Regarding sample size, there were no similar previous studies which might have served as reference framework to perform a sample size calculation. One study, with a more pragmatic approach, served as a model to obtain an indication of the required sample size.[2] A sufficient number of subjects and measurements was obtained to enable accurate interpretation of the effectiveness of the intervention, but the number of observations was too small to control for all underlying (and intercorrelated) potential confounding factors. This was partly explained by the fact that workers in our study did not work in factories but at non-permanent construction sites, leading to heterogeneity in work conditions.

Also, the selection of the study population faced several difficulties. During the recruitment phase, companies could only provide limited insights regarding the number of permanent employees and work supply since this was highly variable in most cases at the time. It was hard to find large construction companies which employed multiple job categories. The modern construction industry is more and more characterized by a system of multiple contractors and subcontractors. Job categories which were identified with high exposure were often employed within specialized companies, most often small and midsize enterprises. Hence, several small and medium enterprises (SMEs) were included in the study, which only involved a limited number of specific tasks and specific job categories. These SMEs employed sufficient permanent employees to be included both at baseline and follow-up. Practical everyday working situations such as inaccessible worksites and unemployment at the time of the follow-up measurements, contributed to the fact that reassessment was only possible for 60% of the workers during follow up compared to the baseline survey. Thus, a more pragmatic approach had to be taken, at the expense of not always be able to include the same workers during follow-up. Workers who had left the industry 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.[9]

An additional challenge was the unpredictability of work. The work at hand changes from day to day and locations may shift. In theory the planning department of every single company was supposed to proactively keep in close contact with the principal researcher about the date and location of the tasks. In practice planning changed constantly resulting in very ad-hoc planning of field work. Consent on actual participation needed to be achieved at the workplace on the day itself. It was observed that workers were enthusiastic about the study if they were not involved themselves, but less enthusiastic when they were asked to participate. Hence, several workers that were a-priory selected to participate decided not to participate in the study.

Alongside the challenges regarding sample size and study population, also external changes regarding the timing of the intervention were encountered. A co-intervention was announced to the entire construction industry, initiated by the Dutch labour inspectorate. Inspection visits were intended to reinforce regulations regarding the reduction of quartz exposure.[10] A further complication was to distinguish the intervention effect from changes over time, so adjustments for this factor were explored in order to interpret the results more accurately.[9]

Pragmatic trials as an alternative to overcome practical features of performing a cluster RCT in the construction industry

To anticipate on changes over time alongside implementation of the intervention, the concept of a so-called pragmatic trials had to be used. Pragmatic trials have been designed to test interventions in clinical settings in order to maximize applicability and generalizability.[11] A pragmatic trial allows variations of the intervention to be incorporated at different (construction) worksites,[12] as interventions at different worksites are never exact copies of the original prescribed intervention in pragmatic trials.[13] Nevertheless, more emphasis in these pragmatic trials is put on a detailed evaluation of the intervention process at each worksite.[14-16] Systematic collection of data used for the process evaluation conducted in the current study provided useful insights in the underlying causes of success and failure of implementation and a satisfactory acceptance of the program. It resulted in feasible recommendations for future large-scale implementation of the intervention.[10] In most of the interventions performed in clinical settings, interventions can be seen as a single repeated process, in which every individual gets exactly the same intervention. Most interventions in the occupational setting consist of a number of components, technical as well as organizational and behavioural, which may act independently and interdependently.[17,18] When evaluating multidimensional interventions, which integrate technical, organizational and behavioural factors, it is often difficult to judge what the effect of individual components was and how the results might be translated to another context. Exploratory subgroup analyses can ideally be used to identify differential effectiveness in subpopulations, but restrictions in sample size most likely result in less precise outcome estimates.

Program and theory failure with respect to the effectiveness of the implemented intervention program

The process evaluation provided insights in the degree of implementation by many stakeholders across different companies and worksites. It also showed to what extent and how specific intervention components were received and used (differently) by workers and managers.[10] Furthermore, this evaluation yielded potential explanations on how implementation of the intervention might have contributed to the less positive outcomes of the study in terms of effectiveness. It is debatable whether the intervention described here is inherently ineffective because the intervention was inadequately developed, or whether it was inadequately applied. This is where program failure or theory failure needs to be taken into account. Program failure indicates that a poorly implemented intervention resulted in no improvement in the study outcomes, whereas theory failure implies that the rationale behind the intervention was not (entirely) correct.[16]

Some factors may be indicative of program failure in our study. Firstly, not all intervention sessions were delivered at each of the worksites because not all worksites were accessible.[16] This means that instruction for some workplaces was dependent only on the (written) instruction materials and that motivational elements of the instruction were not delivered as intended. As a result, the rationale behind the approach taken may not have been entirely clear to the employees receiving the information. Secondly, even though the training sessions were incorporated into an existing education system and implemented during working hours at the worksite, 89% of the workers still attended less than three intervention sessions. Thirdly, it could be hypothesized that the intervention was less effective because of the economic crisis. The companies did not purchase new equipment when the study started, as was initially expected. Moreover, workers may not have committed themselves to the program when they faced fear of losing their jobs.

Also some signs indicative of theory failure exist. It was noticed that the current prevention program did not show clear overall significant positive effects on either primary or secondary outcomes. The less than expected improvements in behavioural outcomes may be explained by the observation that the culture in the participating construction companies is relatively conservative and macho. Our methods seemed to be adjusted for the target population, as active strategies (e.g. workshops and worksite visits) and audiovisual intervention materials were used as a result of the limited skills of construction workers. Furthermore, the intervention program was mainly focused on the individual level. However, more involvement of supervisors might be needed in future initiatives to achieve behavioural changes at the work floor. Also continuous attention for the topic might be needed to achieve behavioural changes. For example, cooperation with an influential authorizing agency such as the labour inspectorate could enhance a continuous inspection and evaluation process.

Future implementation of the intervention program in the construction industry

For a successful large-scale implementation of the intervention program, some important lessons learned during the study should be considered.

- Branch organizations should stay involved in the recruitment phase as they were able to enthuse company management to participate. Cooperation with branch organizations also minimized drop-out of companies during the study, most likely because it was observed that companies experienced something like an external pressure. There might have been a likelihood of selection bias. Companies that volunteered to participate could be considered as early adopters when it comes to health and safety. Consequently, workers from these companies probably have more understanding of the importance of health and safety issues and might have more sympathy towards the program.

- The attendance rate should be increased and the content of three intervention sessions should be transformed into one single intervention session. Workers, managers and members from the research team mentioned that the current approach was too labour-intensive. It was observed that it was too difficult to travel from their worksite to the office of their company for a substantial number of workers. Hence, the intervention session should be organized within working hours and within the obligatory toolbox education system or as an elementary component within an already scheduled meeting at the central office in which multiple themes concerning the company's policy are addressed.

- The intervention should comprise health-related aspects. Construction workers indicated that they were willing to participate because the intervention focused for a large part on the potential health risks of quartz exposure and the solutions to reduce this exposure. The fact that a perceived influential authority such as an occupational physician joined during one plenary session, positively affected the satisfaction of both managers and workers. In line with this, the workers at the worksite need to be aware about the potential health risks, accompanied by the proper use of the available control measures. At the top national government and ministries, contractors, clients (e.g. housing associations, municipalities and local governments) and equipment suppliers need to take into account that working with state-of-the-art technical controls by the workers is the only option to reduce quartz exposure.

- The importance of considering the different perspectives of employers, society and employees in assessing and sharing the costs and benefits of the intervention should be applied in the construction industry. Nowadays, absenteeism has become one of the main aspects of interest in the construction industry, followed by secondary or tertiary prevention. There is very little interest whether a chronic respiratory disease, for instance silicosis, has been caused by occupational quartz exposure. Besides, the disease burden is highest after the working career, especially for diseases that take a long time to develop. In a cost-benefit analysis in the bakery sector, it was observed that the employers have few financial incentives to implement interventions as the benefits are received by others.[19] This is in line with discussions about alternative cost sharing mechanisms in which the government is involved. A government might decide to subsidize employers in order to encourage implementation of an effective intervention, but may also base the scale of subsidies. Although the companies which participated in our study were motivated to purchase state-of-the-art equipment, the current economic situation did not permit it. As a government agency the labour inspectorate almost forced the companies in order to promote a healthy and safety work environment.

General conclusion

The practical and methodological challenges have been anticipated partly by increased effort in the organization of the fieldwork. Among others, being early at workplaces and considering workers as experts in their field when actually using technical control measures, seemed to have a positive effect on the willingness to participate. This contributed to a relatively successful intervention.

Future implementation of elements of this intervention program is required in the construction industry. The construction industry still suffers from the highest occupational health risks. Also in the current study it was observed that the occupational exposure limits for quartz was still exceeded in almost 40% of the measurements during follow-up in the intervention group. More attention is needed for dust and silica exposure, in particular by organizations with knowledge and experience in this sector. A culture change is required as a first step towards effective reduction of quartz exposure.

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Summary

Background

A large study conducted in the construction industry more than a decade ago demonstrated that silica exposed construction workers are at risk for developing chronic respiratory diseases, in particular silicosis. Following this study, several other studies have been conducted in order to develop approaches to reduce or prevent occupational quartz exposure. Most of these studies focused only on the instalment or implementation of technical control measures, like local exhaust ventilation and water suppression techniques. Other factors known to have a large impact on the efficacy of (technical) control measures, like worker behaviour and organizational factors, were in most studies not explicitly taken into account. Hence, multidimensional intervention studies, integrating technical aspects, organizational factors and behavioural components, with sufficient methodological quality are urgently needed. Such studies should make use of randomization, include a control group and have a prospective design, in order to provide convincing evidence of the effectiveness of interventions.

Aims

In order to contribute to construction workers' health, the main objectives of this thesis were to identify determinants that influence quartz exposure among construction workers and subsequently to develop, implement and evaluate a tailored multidimensional intervention among construction workers.

Methods

As starting point for this study, an intervention study following a cluster randomized controlled trial (cluster RCT) design was chosen. The study comprised a baseline assessment, development and implementation of an intervention phase and a follow-up assessment. During the baseline assessment eight construction companies were included. These companies were relatively specialized with a limited number of job titles. Construction workers who were permanently employed at these companies and whom were included in the study had one of the following job categories: bricklayer, carpenter, concrete driller, demolisher or tuck pointer. The baseline assessment consisted of full-shift exposure assessments and a detailed walk-through survey in order to gain insight in exposure determinants, work practices and use of technical control measures. Next to these exposure assessments, all workers were asked to complete a questionnaire considering behavioural elements. This questionnaire included psychosocial factors like knowledge and beliefs regarding effectiveness of controls, risk perception, social influence and motivation. Furthermore, separate questions addressed factors that may be (perceived as) a constraint of facilitator for a worker to perform dust-reducing work practices. Employers were asked to complete a questionnaire on the health and safety policy of the company towards workers' exposure to hazardous substances, in particular quartz, at the workplace. Among others, the employer questionnaire included topics such as presence and compliance of work procedures and workplace instructions, training of employees, management support of proactive health and safety (e.g. toolbox meetings) and communication and feedback with equipment contractors to improve services.

After the baseline study four companies were randomly allocated to the intervention group and four companies were allocated to the control group. The intervention which was given to the intervention group was developed according to the Intervention Mapping approach. This meant that information derived from the baseline study was combined with information from the literature and from focus groups which were held with several stakeholder groups, e.g. construction workers, managers, branch organizations and researchers. By using this approach, the intervention was tailored to the needs of the target population and to the abilities and opportunities of managers and implementers. The program objective of the multidimensional intervention was to establish an increase in the proper use of technical control measures by targeting both the workers' behaviour and organizational factors in order to reduce quartz exposure.

Follow-up measurements were aimed at reassessing individuals included in the baseline sample. However, several workers could not be included again for practical reasons. 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. During follow-up, full-shift exposure assessments were conducted again and similar questionnaires were administered to the workers and employers in order to evaluate the effectiveness of the intervention. Workers and managers in the intervention group were asked to participate in a process evaluation. This evaluation focused at the appreciation of the intervention for future implementation. Suggestions for future improvement were asked for. Next to these effect and process evaluations, success and failure factors and lessons learned during all phases of the study were evaluated in order to gain insights for effective intervention strategies to reduce occupational quartz exposure which can be used by the entire construction industry.

Results

During baseline, 116 workers from eight companies were included for the exposure assessment. Mean exposure levels among the high-exposed job categories, i.e. concrete driller, demolisher and tuck pointer, ranged from 0.12-0.20 mg/m^3 (range 0.01-1.36 mg/m^3). Quartz exposure levels for bricklayers and carpenters were much lower, i.e. 0.02 mg/m^3. Exposure levels exceeded the occupational exposure limit (OEL) for quartz (0.075 mg/m^3) in 62 % of the measurements. Detailed observations showed that technical control measures were only used among the high-exposed job categories. Nevertheless, these control measures were not used frequently among all three high-exposed job categories; concrete drillers used control measures more frequently than demolishers and tuck pointers. However, if control measures were used, they resulted in approximately 40% reduction in quartz exposure among concrete drillers and tuck pointers. Determinants related to an increased exposure identified during baseline were performing several abrasive tasks, i.e. drilling and sanding and material worked on. The outcomes from the organizational and worker questionnaire were descriptive. Although several associations seemed present between behavioural factors and the use of control measures, overall no clear patterns were observed in these relationships.

Information on associations between human factors and use of control measures were used in focus groups with employers and other stakeholders during the development of the intervention strategy. The finding that knowledge and risk perception about quartz exposure and its potential health risks were important to address were endorsed by the steering committee. Furthermore, the target population was relatively low educated and the use of audio-visual techniques was therefore recommended. Thus intervention development should contain elements that integrate technical, organizational and behavioural factors. In order to achieve the predefined program objective, the intervention consisted of two plenary sessions for all employees (managers and construction workers) at the company. These plenary meetings comprised presentations by the principal researcher, an occupational physician and a labour inspector, accompanied by a documentary about potential health risks of quartz exposure and PIMEX videos and discussions about key-solutions to overcome the main constraints when using technical control measures. Next to these plenary meetings, individual sessions for the construction workers were organized at the worksite to teach construction workers how to use technical control measures. In parallel to 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.

The process evaluation involved almost 100 workers in the intervention group and showed rather positive outcomes. The protocol was mostly implemented as intended and the workers and employers appreciated the intervention and recommended the intervention for future implementation. Furthermore, the identification of contextual factors alongside implementation that might influence correct interpretation of the results was valuable. Important other concerns when upscaling the intervention were the relatively low number of workers who received a worksite visit, the compliance with the assessment and labour-intensiveness of the intervention. Alongside the intervention study, the Dutch government initiated a survey in the construction industry which comprised of inspection visits focusing on the reduction of quartz exposure by the labour inspectorate. This survey complicated interpretation of the intervention effect. Evaluation of the effectiveness of the intervention comprised two outcome measures: exposure and use of control measures and on the other hand behavioural aspects. During follow-up, 60% of the same workers who were measured during baseline were reassessed. The quartz exposure levels in both the control and intervention group decreased probably to some extent because of the effect of the labour inspectorate surveys. Nevertheless, an additional reduction was observed in the intervention group . The decrease in exposure was also reflected in the lower number of measurements exceeding the OEL during follow-up. An increased use of technical control measures during follow-up was observed among the high-exposed job categories in the intervention group. More specifically, water suppression techniques were more frequently used among concrete drillers and tuck pointers.

The overall scores for several behavioural moderators improved in the intervention group at follow-up, compared to baseline scores. Besides this overall change, workers in the intervention group showed more often correct answers on questions that specifically considered the content of (components of) the intervention. Important constraints to use technical control measures mentioned during follow-up were time pressure and technical difficulties. On the other hand, important facilitators of using control measures at follow-up were health and social pressure. Health was mentioned most likely because the intervention was intended to focus on health and social pressure was most likely mentioned because the previous announced inspection visits in the entire construction by the labour inspectorate. Outcomes on the organizational aspects seemed to show a tendency that employers were more involved with quartz exposure during follow-up.

Discussion

This is the first study that evaluated the effectiveness of a structured, well-designed randomized, multidimensional intervention aimed at the reduction of quartz exposure in the construction industry. The large reduction in quartz exposure in the intervention group, compared to the control group, seems at least partly to be explained by the introduction of intervention measures. This result may at least partly be attributed to the effort put in conducting the exposure assessment, despite the faced difficulties and challenges inherent to these type of studies in the construction industry. The use of a cluster RCT at company level showed to be the most appropriate alternative to the classical randomized controlled trial in an occupational context. Especially in the construction industry the risk of contamination between workers from different companies who are working at different worksites was minimized. Implications for the sample size and study population inherent to the cluster RCT were obviated based on a pragmatic approach. No other previous studies were conducted and the recruitment of the study population faced several difficulties. The dynamic nature of the construction industry, e.g. unpredictable workload and subsequent uncertainty about permanent employees and workers whom were working at inaccessible worksites, contributed to the fact that not all workers were reassessed at baseline and follow-up. The evaluation of the actual effect of this intervention study was complicated because a co-intervention was undertaken by the labour inspectorate alongside this study and because several other underlying (and inter-correlated) factors which were not part of the intervention strategy changed over time. This means that the exact magnitude of the effect was difficult to assess. Outcomes of the behavioural factors were studied in a relatively descriptive way, but provide valuable insights.

A so-called pragmatic approach was followed in order to anticipate factors changing over time. As a consequence of using this pragmatic approach, emphasis was put on a systematic process evaluation. This was also the first study with a systematic conducted process evaluation alongside the implementation of the intervention. This evaluation provided important insights in contextual factors that changed over time and provided insights about the implementation on a larger scale. Based on the valuable information of people from the construction industry itself, i.e. workers and managers, this intervention should be adapted on certain points. For instance, the content of all three intervention sessions should be transferred into one single session, of which the attendance rate should be increased by organizing it as a mandatory meeting during work hours. Within this single intervention session the intervention components should be rather (audio)visual to disseminate the information among the, in general, lower educated construction workers.

Conclusion

The intervention was relatively successful in achieving an increased use of technical control measures, which at least partly attributed to the reduction in quartz exposure. Furthermore, the intervention had a positive influence on the behavioural outcomes. But the exact magnitude of the effect of the intervention is difficult to assess, due to other factors that changed over time. This in inherent to conducting an intervention study under real working conditions in the occupational setting. The results of this study can be used for future (intervention) studies in the occupational setting.

Samenvatting

Achtergrond

In Nederland zijn kwartsblootstelling en de bijhorende effecten van oudsher geassocieerd met de mijnbouw. Met de sluiting van de mijnen leek de beroepsmatige blootstelling aan kwartsstof uit Nederland verdwenen. Daarmee verdween ook de bekendheid met de effecten van kwartsblootstelling. De risico's van kwartsstof werden daarmee een vergeten probleem. Dit terwijl op een groot aantal werkplekken kwartsblootstelling prominent aanwezig bleef.

Een omvangrijke studie, die ruim 10 jaar geleden in de bouwnijverheid is uitgevoerd, toonde aan dat werknemers in de bouwnijverheid die worden blootgesteld aan kwartsstof een hogere kans hebben op het ontwikkelen van chronische luchtwegklachten, met name silicose (ook wel stoflongen genoemd). Op basis van de uitkomsten van deze studie startte vervolgonderzoeken met als doel om werkwijzen te ontwikkelen die de blootstelling aan kwartsstof op de werkplek zou verminderen. Het merendeel van deze onderzoeken richtte zich voornamelijk op het implementeren van (technische) beheersmaatregelen op de werkplek, zoals (lokale) afzuiging, ventilatie-systemen en/of watersuppressietechnieken. Overige aspecten die een grote invloed blijken te hebben op de effectiviteit van beheersmaatregelen, zoals het gedrag van de werknemer en diverse organisatorische factoren, werden in deze onderzoeken niet expliciet onderzocht. Multidisciplinaire interventiestudies zijn het beste alternatief om zowel technische, organisatorische als gedragsgerelateerde factoren samen te onderzoeken. De methodologische kwaliteit van deze interventiestudies kent wel bepaalde randvoorwaarden om aan het einde van de studie iets te kunnen zeggen over de effectiviteit van de interventie: de verdeling over groepen dient plaats te vinden op basis van randomisatie, naast een interventiegroep moet er ook een controlegroep aanwezig zijn én de gehele studie dient prospectief te worden uitgevoerd.

Doelstellingen

De belangrijkste doelstellingen van deze thesis waren het identificeren van determinanten die de blootstelling aan kwartsstof beïnvloeden, om vervolgens een specifiek multidisciplinair interventieprogramma voor werknemers in de bouw-nijverheid te ontwikkelen, te implementeren en te evalueren.

Methode

Een zogeheten cluster gerandomiseerd onderzoek (cluster RCT) diende als basis voor de interventiestudie beschreven in dit proefschrift. Deze opzet kende drie onderdelen: een voormeting, de ontwikkeling en implementatie van het interventieprogramma volgens de zogeheten Intervention Mapping benadering en een nameting. De voormeting werd uitgevoerd binnen acht bouwbedrijven. Deze bedrijven hebben een gespecialiseerd takenpakket en binnen deze bedrijven is een beperkt aantal beroepen werkzaam. Werknemers van deze bedrijven die in vaste loondienst waren én die metselaar, timmerman, betonboorder, sloper of voegenhakker waren, mochten deelnemen aan de studie. Tijdens de voormeting werden alle werknemers een hele werkdag geobserveerd door een onderzoeker en op die werkdag werd ook een blootstellingsmeting naar kwartsstof uitgevoerd. Hiermee kregen onderzoekers inzicht in de blootstellings-determinanten, de manier van werken en het wel of niet (correct) gebruiken van (technische) beheersmaatregelen. Naast de blootstellingsmetingen vulden de werknemers ook een vragenlijst in met onder andere vragen over hun kennis, perceptie en attitude ten aanzien van kwartsstof en de mogelijke gezondheidseffecten. Werkgevers kregen vervolgens nog een vragenlijst over het beleid van het bedrijf ten aanzien van veiligheid en gezondheid van de werknemers bij het werken met kwartsstof. Zo werd er bijvoorbeeld gevraagd of werknemers vanuit het bedrijf training en scholing krijgen in het veilig en correct gebruiken van (technische) beheers-maatregelen.

Na de voormeting werden vier bedrijven op basis van randomisatie toegewezen aan de interventiegroep; de overige vier bedrijven vormden de controlegroep. Alleen bij de bedrijven in de interventiegroep werd het interventieprogramma geïmplementeerd. Het interventieprogramma werd samengesteld op basis van informatie verzameld tijdens de voormeting, uit de literatuur en tijdens focusgroepen. Focusgroep-bijeenkomsten werden gehouden met diverse partijen, waaronder werknemers, werkgevers, brancheorganisaties en onderzoekers. Door de informatie geleverd door mensen van de werkvloer mee te nemen tijdens de ontwikkeling van het interventieprogramma bevatte het programma diverse elementen die specifiek van toepassing waren op de doelgroep. Daarnaast werd ook rekening gehouden met de praktische haalbaarheid om het programma te implementeren, voor zowel de werkgevers als voor de onderzoekers. Het uiteindelijke doel van het interventie-programma was het verlagen van de blootstelling aan kwartsstof, door enerzijds het juist gebruik van beschikbare (technische) beheersmaatregelen en anderzijds door de aanpak van organisatorische factoren en het gedrag van de werknemers.

Tijdens de nameting werden wederom een gehele werkdag persoonlijke blootstellingsmetingen gedaan bij alle werknemers en vulden de werknemers en werkgevers elk afzonderlijk weer eenzelfde vragenlijst in. Het was de bedoeling gegevens te verzamelen van werknemers die zowel in de voor- als nameting aanwezig waren. Vanwege praktische redenen kon echter een aantal werknemers niet meer worden bemeten tijdens de nameting. Deze werknemers werden vervangen door werknemers van hetzelfde bedrijf met eenzelfde beroep en een vergelijkbaar takenpakket. Naast de blootstellingsmetingen en de vragenlijsten werd aan werknemers en werkgevers in de interventiegroep gevraagd om een vragenlijst in te vullen ten behoeve van een procesevaluatie. Deze evaluatie had als doel om te vragen naar de ervaring met het interventieprogramma en naar eventuele aanpassingen van het programma. Tijdens de nameting werden ook de belangrijkste succes- en faalfactoren van het onderzoek geëvalueerd. Dit alles had als doel om een beter inzicht te krijgen in effectieve interventieprogramma's die blootstelling aan kwartsstof op de werkplek kunnen verminderen, om deze vervolgens beschikbaar te stellen aan de bouwnijverheid.

Resultaten

De voormeting is uitgevoerd onder 116 werknemers, werkzaam bij acht bedrijven. De gemiddelde blootstellingsniveaus aan kwartsstof van de hoog-blootgestelde beroepen, te weten betonboorder, sloper en voegenhakker, waren respectievelijk 0,20 mg/m^3, 0,12 mg/m^3 en 0,18 mg/m^3. Voor metselaars en timmerlieden waren de blootstellingsniveaus beduidend lager; 0,02 mg/m^3. De norm zoals gehanteerd door de arbeidsinspectie voor beroepsmatige blootstelling aan kwartsstof op de werkplek van 0,075 mg/m^3 bleek tijdens de voormeting in 62% van de metingen overschreden. Werkplekobservaties toonden aan dat enkel door de hoog-blootgestelde beroepen slechts af en toe gebruik werd gemaakt van (technische) beheersmaatregelen. Wanneer de beheersmaatregelen echter wel werden toegepast door betonboorders en voegenhakkers, resulteerde dit in een blootstellingsreductie van ongeveer 40%. Determinanten voor een hogere blootstelling aan kwartsstof waren het uitvoeren van verspanende werkzaamheden (o.a. boren en schuren) en het werken met materialen die kwartsstof bevatten (o.a. beton en kalkzandsteen) **(hoofdstuk 2)**.

Ondanks het feit dat er tijdens de voormeting geen eenduidig verband leek te zijn tussen gedragsgerelateerde factoren en het toepassen van (technische) beheersmaatregelen, werd deze informatie wel voorzichtig ingebracht tijdens focusgroepbijeenkomsten met werkgevers en brancheorganisaties. Tijdens deze bijeenkomsten werd onderschreven dat kennis en risicoperceptie van werknemers in de bouwnijverheid ten aanzien van kwartsstof en de potentiële gezondheidsrisico's zeker aandacht moest krijgen tijdens het interventieprogramma. Om deze boodschap duidelijk te laten overkomen bij de, over het algemeen laagopgeleide werknemers in de bouwnijverheid, werd het gebruik van audiovisuele middelen aangeraden. Het uiteindelijke multidisciplinaire interventieprogramma bestond uit vier sessies. Twee plenaire sessies, een individuele werkpleksessies voor de werknemers en een aparte bijeenkomst voor de werkgevers. Beide plenaire sessies vonden plaats op het kantoor van het bouwbedrijf en werden bijgewoond door zowel werknemers als werkgevers van het bedrijf. Deze plenaire sessies bevatten presentaties van de onderzoekers, van een longarts en van een arbeidsinspecteur. Daarnaast kregen de werknemers en werkgevers een documentaire en zogeheten PIMEX video's te zien over de potentiële gezondheidsrisico's van kwartsstofblootstelling. Tijdens de tweede plenaire sessie vond daarnaast een discussie plaats tussen werknemers, werkgevers en onderzoekers over de mogelijke oplossingen om de grootste belemmeringen weg te nemen die ervaren werden tijdens het gebruik van (technische) beheersmaatregelen. Naast deze plenaire sessies kregen werknemers tijdens aparte werkplekbezoeken advies hoe ze beschikbare (technische) beheersmaatregelen op een juiste manier konden gebruiken. Voor werkgevers werd een aparte bijeenkomst georganiseerd om hen meer inzicht te verschaffen in de beschikbaarheid van de huidige (technische) beheersmaatregelen **(hoofdstuk 3)**.

De procesevaluatie, die werd ingevuld door ongeveer 100 werknemers uit de interventiegroep, liet voornamelijk positieve resultaten zien. Het protocol werd geïmplementeerd zoals vooraf gepland en zowel de werknemers als de werkgevers waardeerden de interventie en bevolen de interventie aan voor implementatie in de toekomst. Belangrijke aandachtspunten die naar voren kwamen voor opschaling van de interventie waren de intensiviteit voor de onderzoekers, het niet deelnemen van de werknemers aan de opdracht waar ze zelf input voor moeten leveren en de relatief kleine groep werknemers die een werkplekadvies hebben gekregen voor het juist gebruik van (technische) beheersmaatregelen **(hoofdstuk 4)**.

Inherent aan interventieonderzoek op de werkplek is de invloed van factoren die niet samenhangen met de interventie en die plaatsvinden zonder dat er invloed op kan worden uitgeoefend. Tijdens de studie beschreven in dit proefschrift startte de arbeidsinspectie een inspectietraject gericht op het verminderen van kwartsstof-blootstelling. Dit traject, waarbij de angst van werkgevers en werknemers voor het krijgen van een boete duidelijk naar voren kwam, bleek een belangrijke factor. De blootstellingsniveaus aan kwartsstof in zowel de controle- als de interventiegroep waren tijdens de nameting namelijk beduidend lager en werknemers gaven ook aan dat ze meer druk van zowel de werkgever als de arbeidsinspectie ervaarden om (technische) beheersmaatregelen te gebruiken.

Tijdens de nameting werd 60% van de werknemers die hadden deelgenomen aan de voormeting wederom bemeten. Evaluatie van de effectiviteit van de interventie had betrekking op twee uitkomstmaten: enerzijds de invloed van het interventieprogramma op blootstelling en het gebruik van (technische) beheersmaatregelen en anderzijds de invloed van de interventie op verandering in gedragsgerelateerde factoren. De afname in blootstelling die voornamelijk toe te schrijven lijkt aan het interventieprogramma bedraagt ruim 25%. Deze afname in blootstelling komt ook naar voren in het kleiner aantal metingen dat tijdens de nameting boven de limiet voor beroepsmatige blootstelling uitkomt. In de drie hoog-blootgestelde beroepen kwam in de interventie- en controlegroep tijdens de voormeting respectievelijk 75% en 86% van de metingen boven de limiet. Tijdens de nameting was dit gedaald naar 40% van de metingen in de interventiegroep en 60% in de controlegroep. Een toegenomen gebruik van (technische) beheersmaatregelen tijdens de nameting werd waargenomen voor de hoog-blootgestelde beroepen in de interventiegroep: watersuppressietechnieken werden frequenter gebruikt door betonboorders en voegenhakkers **(hoofdstuk 5)**.

De scores voor verschillende gedragsgerelateerde factoren verbeterden in de interventiegroep tijdens de nameting vergeleken met de voormeting. Naast deze verbetering op groepsniveau bleek ook dat werknemers uit de interventiegroep vaker juiste antwoorden gaven op de vragen die specifieke (componenten) van de interventie bevatten. Werknemers in zowel de controle- als interventiegroep gaven tijdens de nameting aan dat tijdsdruk en (technische) moeilijkheden de belangrijkste belemmeringen waren om (technische) beheersmaatregelen te gebruiken. De meest genoemde motiverende factor tijdens de nameting om deze maatregelen te gebruiken was echter het belang voor de eigen gezondheid. Ook op basis van dit resultaat lijkt het interventieprogramma het gewenste resultaat te hebben gehad, omdat diverse onderdelen van het interventieprogramma zich inderdaad richtten op gezondheid. Uitkomsten met betrekking tot de organisatorische factoren leken een trend te laten zien dat werkgevers tijdens de nameting vanuit hun eigen organisatie meer bezig waren om kwartsstof op de werkvloer aan te pakken **(hoofdstuk 6)**.

Discussie

Dit is de eerste studie die de effectiviteit heeft geëvalueerd van een gestructureerd, gerandomiseerd, multidisciplinair interventieonderzoek dat als doel heeft om de blootstelling aan kwartsstof in de bouwnijverheid te verlagen. Het feit dat een reductie in blootstelling gerealiseerd kan worden lijkt veelbelovend, maar er moet zeker nog veel werk worden verzet om ook het resterend aantal metingen boven de norm voor beroepsmatige blootstelling aan kwartsstof op de werkplek te verlagen.

Het gebruik van een cluster RCT met randomisatie op bedrijfsniveau bleek het best passende alternatief voor de klassieke gerandomiseerde gecontroleerde studieopzet in een werkgerelateerde omgeving. Implicaties voor de omvang van de studiepopulatie inherent aan het cluster RCT werden voorkomen door een pragmatische benadering. Het rekruteren van de studiepopulatie kende verschillende uitdagingen. Het dynamisch karakter van de bouwnijverheid, bijvoorbeeld de onvoorspelbare werkvoorraad en daaruit volgende onzekerheid over het aantal werknemers in vaste loondienst en werknemers die werkzaam zijn op werkplekken die niet toegankelijk zijn tijdens de metingen, hebben bijgedragen aan het feit dat niet alle werknemers zowel tijdens de voormeting als de nameting bemeten konden worden.

De afname in kwartsstofblootstelling in de interventiegroep, vergeleken met de controlegroep, lijkt gedeeltelijk verklaard te kunnen worden door het effect van het interventieprogramma. Het inzicht in de verschillende factoren die invloed hebben gehad op de reductie in blootstelling kan grotendeels worden toegeschreven aan alle energie die is gestoken in het uitvoeren van de blootstellingsmetingen, ondanks de moeilijkheden en uitdagingen die ervaren werden en die inherent werden geacht aan dit type studies op de werkvloer en in de bouwnijverheid in het bijzonder.

De co-interventie die door de arbeidsinspectie gelijktijdig werd gehouden lijkt naast de interventie geïmplementeerd in deze studie een belangrijke factor in de reductie van de blootstelling. Daarnaast veranderden verschillende onderliggende (en met elkaar samenhangende) factoren die geen onderdeel waren van de interventiestrategie over de tijd, wat ook de bepaling van de grootte van het echte effect van dit programma bemoeilijkt. Uitkomsten met betrekking tot gedragsgerelateerde factoren werden in een relatief beschrijvende manier bestudeerd, maar het gaf wel waardevolle inzichten waar mogelijk nog winst valt te behalen voor de toekomst.

De eerder genoemde gevolgde pragmatische aanpak had als doel om te anticiperen op factoren die veranderden over de tijd. Door het volgen van een dergelijke aanpak kwam ook het belang van een systematische procesevaluatie naar voren. Dit is namelijk ook de eerste studie die een systematische procesevaluatie deed naast de implementatie van het interventieprogramma. Deze evaluatie biedt enerzijds bruikbare inzichten in factoren die veranderden over de tijd, maar geeft ook inzicht in de mogelijk- en moeilijkheden van implementatie van het programma op bredere schaal. Op basis van de waardevolle informatie die zowel de werknemers als de werkgevers gaven zou het huidige programma op diverse punten kunnen worden aangepast. Zo zou de inhoud van de drie afzonderlijke sessies samengevoegd kunnen worden in één sessie, waarbij de aanwezigheid van de werknemers verhoogd zou kunnen worden door de bijeenkomst verplicht te stellen en te houden tijdens gangbare werkuren. Tijdens deze ene bijeenkomst zouden de onderdelen van de interventie zich nog meer moeten focussen op het audiovisuele gedeelte, om hiermee een nog groter effect te bereiken onder de werknemers in de bouwnijverheid.

Conclusie

Het interventieprogramma is relatief succesvol ten aanzien van de toename van het gebruik van (technische) beheersmaatregelen, wat vervolgens gedeeltelijk heeft geleid tot een afname van de blootstelling aan kwartsstof. Bovendien lijkt het programma een positieve invloed te hebben op de gedragsgerelateerde factoren. Het exacte effect van het programma is echter moeilijk te bepalen, omdat ook diverse factoren mee veranderden over de tijd. Dit is echter inherent aan het uitvoeren van een interventiestudie in de bouwnijverheid. De uitkomsten van deze studie kunnen daarom ook zeker gebruikt worden voor vervolgstudies binnen de arbeidshygiëne.