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An application of the mental models approach

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GENERAL INTRODUCTION

General introduction

The workplace can be a dangerous place. People who are working in practical professions are often harmed not only by direct physical risks, such as tripping or falling, but also by a vast array of exposure risks. These exposures include physical, chemical or biological agents; when talking about the epidemiological concept of ‘risk’, we consider both the nature of the hazard itself as well as the probability of the effects that may occur after being exposed. Even though the past century brought forth a vast number of rules and regulations to decrease illnesses and deaths related to workplace exposure, and these regulations have been successful to some extent, exposure risks still account for an estimated number of 1.5 million deaths per year worldwide (Loomis, 2020). Exposure risks are often difficult to perceive and invisible to the naked eye, making them less salient than direct physical risks (Koehler & Volckens, 2011).

Against most of these exposure risks, mitigation methods are possible to alleviate the exposure and thereby reduce the effects of the exposure. In some cases, the environment of the workers can be structured in such a way that workers are protected automatically, but in other cases, mitigation requires a conscious effort. Therefore, the presence of mitigation methods does not automatically mean that people who are exposed are motivated to maintain these mitigation methods. This potential lack of motivation is explained by the Protection Motivation Theory, or PMT (Rogers, 1983). This theory states that, in order to feel motivated to protect themselves against a certain risk, people should have a high ‘threat appraisal’ – that is, they should view the agent as potentially threatening – as well as a high ‘coping appraisal’ – that is, they should perceive that the risk is manageable with certain precautions.

There are various factors that play a role in how people interact with each of these risks. A classic study by Slovic, Fischhoff & Lichtenstein (1982), also known as the psychometric paradigm, shows that people have the highest perception of risk when considering so-called ‘dread risks’, risks that are uncontrollable and potentially catastrophic on a global scale. Risks that play a role on a more individual level are often considered to be smaller. In the case of workplace exposure risks, they can be perceived as more controllable, reasonably well-known, and less potentially catastrophic, as larger-scale catastrophes involving these risks are unlikely. Furthermore, the effects are more likely to be noticeable on an individual level.

Workers may still fear the effects of exposure, especially if they know of any victims of exposure risks personally. However, there are other aspects of exposure risks that may be detrimental to threat appraisal. Risks that cause cumulative long-term effects – that is, risks where smaller doses over longer periods of time cause adverse effects – are often underestimated (Doyle, 2006; Linville, Fisher & Fischhoff, 1983; Slovic, 2000). These factors contribute to the potential problems with workplace exposure risks and their underestimation by workers.

In this thesis, we discuss two specific hazardous agents, electromagnetic fields (EMF) and particulate matter (PM). The first agent, EMF, is a physical agent; the focus will more specifically be on extremely low frequency EMF (ELF-EMF). The other agent, PM, can be thought of as both a physical and a chemical agent, as particle size and chemical composition both play an important role in its effects. We will first give an overview of each of these two risks individually, and then we will present the further focus of this thesis.

Electromagnetic fields (EMF)

EMF are produced by any type of electric equipment, and are therefore ubiquitous in our daily life, which is something many people are unaware of (European Commission, 2010). EMF are also known as 'non-ionizing radiation', since the frequency of the radiation lacks the ability to cause disruptions in cells on the molecular level (Kemp, Kheifets, Repacholi, Sahl, Van Deventer & Vogel, 2002). Non-ionizing radiation involves the range of the electromagnetic spectrum below 300 GHz, including static (0-1 Hz), low frequency (1 Hz – 10 MHz), and high frequency EMF (100 kHz – 300 GHz) (Health & Safety Executive, 2016).

The doses measured during everyday activities, for example the radiofrequency fields from sources for wireless communication by mobile telephones, are not expected to cause any adverse health effects (ICNIRP, 2010). However, there are some studies that report a slight increase in leukemia incidence in areas close to high voltage powerlines emitting extremely low-frequency magnetic fields (Kemp et al., 2002; Kheifets, Afifi & Shimkhada, 2006). Higher doses of EMF exposure can occur in the workplace, which could lead to harmful effects (Karpowicz & Gryz, 2007). High EMF exposures can lead to tissue heating and induction of current, and short term effects such as nausea, dizziness, disruptions in metal implants and pacemakers, and injuries due to flying metal objects (Health & Safety Executive, 2016). The evidence for long-term effects of higher doses of EMF exposure is less abundant, but there are some indications that high doses of EMF exposure may lead to Parkinson's disease or ALS (Huss, Koeman, Kromhout & Vermeulen, 2015).

On July 1, 2016, the new European Directive for electromagnetic fields in workplace situations was implemented in The Netherlands (Directive 2013/25/EU). This Directive is based on data from the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2010), and it gives exposure limit values for the electric field in the human body. The new Directive (2013/25/EU) replaces the older Directive (2004/40/EG), and retains more flexibility for workers in environments with a high EMF exposure, while still protecting them from possible detrimental health effects.

Since it is not always clear for companies to see whether their employees are exposed above the AV, a non-binding practical guide was compiled to help companies assess if they need to take extra control measures, and if so, for which employees (European Commission, 2015). This non-binding guide contains valuable information on various workplaces and their potential for excessive EMF exposure, but it alone is insufficient for solving the problem of EMF exposure risks in the workplace, as it does not concern direct risk communication for workers.

Earlier research has shown that workers in environments with high EMF exposure do not always perceive this exposure as dangerous, and therefore do not always protect themselves, as the mitigation methods are seen as inconvenient (Bolte & Pruppers, 2006). Furthermore, exposure reduction regarding EMF is seen as a governmental issue primarily (Freudenstein, Wiedemann & Varsier, 2015). This hampers coping appraisal in employees who are confronted with EMF exposure. In the general public, perceptions of EMF risk vary strongly, with a minority of people being extremely concerned about potential adverse effects of exposure to EMF in the context of base stations, even in doses that are highly unlikely to have any direct effect (Van Dongen, Smid & Timmermans, 2011; Martens et al., 2015). Interestingly, however, risk perceptions of EMF among the general public in the case of base stations are much higher than with other sources of EMF such as cell phones or other household appliances. These anomalies in threat appraisal are important to address when discussing the subject of risk communication about EMF.

In this thesis, we decided to focus on power plants for the EMF case, as research by Stam (2014) has shown that workers in power plants may still be exposed above the Action Values even under the new European Directive.

Particulate matter (PM)

PM is any type of matter, solid or liquid, that can be found in air, with a particle diameter of 10 micrometers or less. It is often further broken down in coarse (2.5-10 micrometers), fine (.1-2.5 micrometers) or ultrafine (smaller than .1 micrometers) PM; in some cases, the classifications 'thoracic' and 'respirable' are used to further elaborate how far the particles are able to penetrate beyond the larynx (thoracic) and ciliated airways (respirable) (Brown, Gordon, Price & Asgharian, 2013). PM is an important source of environmental pollution (Roels et al., 2014), and especially the fine particulate matter fraction (PM2.5) is considered to be an important health risk (Hänninen & Knol, 2011). PM consists of a number of substances, including black carbon, sulphur dioxide, ammonia, and several nitrogen-based compounds (Buijsman et al., 2005; Hänninen & Knol, 2011).

Environmental pollution from PM has several sources. Various industrial processes contribute to PM exposure, for example due to diesel emissions (Buijsman et al., 2005; Loschiavo, 2013). Sawing and drilling equipment used in construction and maintenance industries may also induce several forms of PM (Van Deurssen, 2015). Some types of PM are also found in nature, such as sea salt, but these are often not as much of a health risk (Buijsman et al., 2005).

High exposure to PM is associated with various respiratory and cardiovascular diseases (Anderson, Thundiyil & Stolbach, 2012; Hänninen & Knol, 2011). The effect size of PM exposure risk is not exactly known, but most studies seem to agree that it leads to a life expectancy reduction of several months or even years (Buijsman et al., 2005). Some estimates say that around 800,000 people worldwide die prematurely due to PM exposure each year, making it an important exposure risk to consider (Anderson et al., 2012). For the Netherlands, exact numbers are unknown, but some sources imply that 10,000 people or more die prematurely due to PM related reasons (Buijsman et al., 2005).

There have been several studies on PM risk perception and air pollution in general, many of which confirm that perceptions of PM risk are highest among those people who are indeed strongly exposed (Cori, Donzelli, Gorini, Bianchi & Curzio, 2020). Nevertheless, there are still knowledge gaps and misconceptions surrounding the subject of PM, both in the general population and in exposed workers. For example, people tend to under- or overestimate which modes of transportation yield the highest PM exposure (Chaney, Montgomery, King, Hendrickson, Sloan & Johnston, 2019). The threat appraisal of air pollution appears to be hampered by a general lack of direct physical effects on the body, as well as only mild olfactory effects (Bickerstaff, 2004). Regarding coping appraisal, Downs et al. (2010) found that people perceive to have a large amount of control over air pollution within their own home, but a much smaller amount of control over air pollution in locations elsewhere. This implies that there are several factors hindering a sufficient threat and coping appraisal for air pollution, including particulate matter.

In this thesis, we will focus our research within the PM case on workers in road construction and maintenance companies, since these workers appear to be especially high at risk from several sources of PM (Meier, Cascio, Danuser & Riediker, 2013; Sobus et al., 2009; Van Deurssen, 2015). These sources include emissions, but also usage of various types of equipment such as mowing machines or chain saws (Meier et al., 2013). Although earlier research has focused mostly on highway maintenance (Meier et al., 2013), road construction companies are similarly exposed to various forms of PM (Sobus et al., 2009).

Risk communication and mental models

As mentioned, this thesis investigates two cases of occupational exposure risks, namely PM in road construction and maintenance companies and EMF in power plants. For each of these two exposure risks, it is important that people are aware of the properties of these agents, the potential effects on the human body, and possible methods of mitigation. Awareness of this information may increase both threat appraisal and coping appraisal within the framework of the PMT (Rogers, 1983). Knowledge from the domain of risk communication will be used in this thesis to investigate the methods of influencing workers' awareness of occupational exposure risks and mitigation methods, as well as their motivation to protect themselves against these risks.

When it comes to workplace risk communication, the intuitively most obvious factor for success is the information need of the employees, as people must understand what the risk is before being able to change their behavior (Petts, McAlpine, Homan, Sadhra, Pattison & MacRae, 2002; Welbourne, Hartley, Ott & Robertson, 2008). In many situations, employees working under exposure risks feel that they should have more information, or that the information should be given in a way more suitable for their needs (Hambach et al., 2011). Giving more information has proven to be effective as a prevention tool in similar workplace-related exposure situations, involving welding fumes (Cezar-Vaz, Bonow & Cezar-Vaz, 2015), other chemical risks (Petts et al., 2002), and ionizing radiation (Sheyn, Racadio, Ying, Patel, Racadio & Johnson, 2008). However, proper risk communication involves more than just information, as individual risk perceptions should be taken into account, and there are other psychological factors that contribute to work safety.

When designing a risk communication strategy, it is important first to ask oneself the question what the goal really is (Smith & Ragan, 2005). Fischhoff et al., (2011) distinguish three possible goals for risk communication: sharing information, changing beliefs and changing behavior. In the case of occupational exposure risks, changing behavior is the ultimate goal: it is essential that workers do not just know how to work safely, but actually do work safely on a daily basis (Petts et al., 2002).

The Theory of Planned Behavior (Ajzen & Fishbein, 2005) states that behavior can be predicted from intention, which in turn is influenced by attitudes, subjective norms and perceived behavioral control. There is a strong overlap between Ajzen & Fishbein (2005)'s idea of perceived behavioral control and Rogers (1983)' idea of coping appraisal, as a high degree of perceived control over one's own behavior is fed by a tendency to trust the efficacy of certain mitigation methods. However, attitudes and subjective norms are often less concrete and tangible when compared to the idea of threat appraisal, which, according to the PMT, is mostly fed by knowledge and experience (Rogers, 1983). This is why giving information alone is often insufficient; risk communication should target more implicit ideas about the relevant risk as well. Most safety issues in the workplace tend to be behavior-related, underlining the importance of behavior change as a risk communication goal (Toppazzini & Wiener, 2017).

An effective way to investigate employees' risk perception and the possible fallacies in their train of thought is the mental models approach. Mental models are described as "cognitive tools that allow people to reason and put into order what would otherwise be an incomprehensible and disorderly world, [and they] are comprised of a system of knowledge, attitudes, beliefs, impressions and images" (Petts et al., 2002). The mental models approach itself seeks to define the mental models of experts and non-experts, contrasting these two with each other (Morgan, Fischhoff, Bostrom & Atman, 2002). By doing this, the contrasts between the mental models can be used as a starting point for developing risk communication strrategies.

In many cases, there is no single universal expert mental model (Petts et al., 2002; Slovic & Weber, 2002). Nevertheless, this mental models approach can be effective as a basis for developing an occupational risk communication system, and it has been used in this way, for example with chemical risk assessment (Petts et al., 2002). The reason for this is that the information and the way of presenting should be tethered to the specific needs of the intended audience, and a mental models approach can help to identify these information needs. When designing a risk communication strategy, it is recommended to focus on the aspects of the hazard that are in practice often ill understood by the users, in order to alleviate the discrepancies between expert and non-expert mental models of risk (Riley, 2014; Slovic & Weber, 2002). On the other hand, this method also helps to determine aspects that are important to non-experts, but are often overlooked by experts. This means that the differences between expert and non-expert mental models may be used to investigate where the focus should be, when developing educational materials on the matter.

Objective and overview

This thesis will provide insights into the mental models of employees working within each of our two selected domains; that is, road construction and maintenance for the PM case, and power plants for the EMF case. These mental models will then be used as a basis for deciding on the appropriate course when it comes to risk communication.

In chapter 2 and 3 of this thesis, we will focus on the qualitative mental models studies with workers, both for the EMF and PM cases. Chapter 2 will be about the EMF case, with a focus on power plants, whereas chapter 3 will be about the PM case, with a focus on road maintenance and construction workers. There are other differences between these two cases besides the agents that are investigated themselves; for example, workers in power plants tend to be educated on a higher vocational level, whereas workers in road maintenance and construction tend to have had a more practical education or even no higher education. In both of these studies, employees of the relevant companies are interviewed in other to investigate their mental models on PM and EMF respectively. We contrast the expert mental model with the worker mental model, and provide recommendations for work safety policies, including risk communication.

For one of the cases, we developed an educational material to be used as a risk communication tool in companies. The development process of this educational material can be used in the future as an example in other cases of occupational exposure risks. We concluded that the PM case would be a more relevant case for further development of an educational material, as EMF turned out to be more mitigated already, and knowledge and attitudes about PM turned out to have more room for improvement than those about EMF (see Chapter 2 and Chapter 3 respectively). The chapters 4, 5 and 6 focus on the development and testing procedure of this educational material. Chapter 4 is about the general development process as well as the initial usability test with a small number of participants. We thoroughly describe the process by which we made the decision to develop an educational folder to be used in work safety meetings, alongside a practical assignment involving an exposimeter displaying actual exposure to PM, and we again ask stakeholders such as experts and workers for their input.

Chapter 5 describes the larger-scale digital experiment of the finished educational material. We investigate the effects of two separate versions of our educational folder, one with and one without risk and exposure visualizations, on outcomes related to knowledge and protection motivation. We also compare these effects to that of a 'good practice' folder as well as an unrelated 'dummy' text. Chapter 6 involves an implementation study of the material in a workplace setting, where we again look at outcome measures of knowledge and protection motivation, but where we also include the practical assignment with an exposimeter. It should be noted that the exposimeter we used does not comply with standard ISO (1995) measurement criteria for inhalable and respirable PM; it is only to be used for educational purposes. We added the assignment to the intervention to make the risk more visible to the target audience. Finally, chapter 7 concludes this thesis with a general discussion.

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ELECTROMAGNETIC FIELD EXPOSURE IN POWER PLANTS: A QUALITATIVE ASSESSMENT OF WORK SAFETY PERCEPTIONS AMONG EMPLOYEES.

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Abstract

Electromagnetic fields, or EMF, are ubiquitous in our daily life. Extremely low frequency magnetic fields (ELF MF) are generated by any device using electric current. Especially in workplace situations involving MRI scanners, welding equipment, induction heaters, and power plants, they are known for potentially high field strengths. These high field strengths may lead to adverse health effects if insufficient preventive measures are in place. This study investigates employees' perceptions on work safety regarding EMF exposure. We held 15 semi-structured interviews in three different (non-nuclear) power plants in the Netherlands. We found that power plants in this study made ample use of fences and warning signs where needed, creating a safe working environment. Nevertheless, some workers perceive that there are vague regulations, organizational issues and lack of clarity on the properties of EMF. Participants also indicated that there is some room for improvement with respect to work safety meetings on EMF. Employees want to be informed about EMF and its potential health effects and mitigation methods, but their information need is limited and straightforward. A simple warning system, along with safety information on paper, may be sufficient.

Keywords: EMF, Electromagnetic fields, Power plants, Risk communication, Risk perception, Work safety

Introduction

Electromagnetic fields (EMF) are ubiquitous in our daily life. In certain working environments, the application of high electric currents leads to extremely low frequency magnetic fields or electric fields (ELF MF or EF) (European Commission, 2010), with a frequency range of 1 Hz to 100 kHz. ELF MF exposure can generate an internal electric field or current in the body, which can lead to adverse short-term effects. These effects include nausea, vertigo, dizziness, flashes of light (phosphenes), metallic taste, muscle contractions, tissue overheating, arrhythmia, disruptions in metal implants and pacemakers, and injuries due to flying metal objects. ELF EF exposure to low-frequency electric fields may cause well-defined biological responses, ranging from perception to annoyance, through surface electric-charge effects (ICNIRP, 2010; Health & Safety Executive, 2016).

Typical outdoor sources of exposure are overhead powerlines, high power transmission lines and electric means of transportation, such as trams and trains. Higher doses of ELF MF occur in the workplace (Karpowicz & Gryz, 2007), for example with MRI scanners, welding equipment, induction heaters, and in power plants. Some studies claim an increase in the relative risk in leukemia for children living near powerlines (Ahlbom et al., 2000; Kemp et al., 2002; Kheifets, Afifi & Shimkhada, 2006). Although the IARC classifies ELF MF as category 2B “possibly carcinogenic”, a causal effect has not been proven, as the mechanism that may lead from exposure to leukemia is yet unknown. There are some scientific indications that workplace ELF MF exposure may lead to long-term effects such as Parkinson’s or ALS (Huss et al., 2015), but no causal effect is known here either. Finally, some studies found indications for an association between residential exposure levels of ELF MF and non-specific physical symptoms, such as headache, painful muscles and dizziness (Baliatsas et al., 2015; Bolte et al., 2015); however, the mechanism for a causal effect is yet unknown.

European Directive 2013/35/EU set Exposure Limit Values for EMF, dose levels in the body, and derived the so-called Action Values from these, exposure limits outside the body, to protect workers against effects of EMF exposure. The so-called low Action Values prevent occurrence of sensory effects such as vertigo or phosphenes. The high Action Values are to prevent effects in the peripheral nerve system, such as involuntary muscle contraction. However, Stam (2014) shows that exceedance of both the low and high Action Values for ELF MF may occur in power plants.

The European Directive also considers two main methods of combatting the exceedance of these Action Values. Firstly, safety by design is recommended, with a focus on emission reduction, combined with limitations on access and audiovisual warnings (ICNIRP, 2010). Literature supports this idea of safety by design, which makes it impossible to work unsafely (Mols, Haslam, Jetten & Steffens, 2015). Secondly, the European Directive also assigns the task of workers' education to the employer. This can be seen in the Dutch national law as well, which mandates informing workers on relevant risks periodically. Literature agrees that education on work safety and providing risk information can be effective as a prevention tool (Cezar-Vaz, Bonow & Cezar-Vaz, 2015; Sheyn, Racadio, Ying, Patel, Racadio & Johnson, 2008). Ideally, workers should be aware of the risks involved with their work, aware of possible mitigation methods, and willing to participate in mitigation. Therefore, an efficacious education system both informs workers about risks and mitigation, thereby influencing their risk perception, and incentivizes safe behavior (Cezar-Vaz et al., 2015).

This study investigates how workers in power plants perceive work safety concerning EMF, in order to determine the appropriate course of action regarding work safety and education. We decided on power plants as a workplace case, since Stam (2014) showed that a high EMF exposure occurs within companies involved in electricity supply, potentially exceeding the Action Values. Our research question is: "How do employees in power plants perceive work safety with regards to EMF?" We will present our findings regarding employees' risk perceptions, as well as recommendations for further work safety development and education.

Method

In order to study the perceptions of risk and mitigation by various employees of power plants, we held a series of semi-structured interviews. According to McIntosh & Morse (2015), semi-structured interviews are characterized by a general systematic order, but a tendency to allow deviations from the script when appropriate. The general systematic order allows for a focused development of the conversation, with basic information about work-related risks before methods of instruction and contextual factors. Conversely, deviations from the script were sometimes necessary whenever unexpected important or interesting topics came up, such as the inclusion of a complete work safety instruction.

Sampling

We contacted three of the largest suppliers of electricity in the Netherlands, and all of these companies chose to participate in this study. Although the companies were willing to participate, they could only offer a limited number of participants for various reasons, including reorganizations; for example, one of the companies cancelled the final four interviews due to unforeseen circumstances. In the end, the process yielded 15 interviews, with a variety of workers from different layers of the organization. Although this number of 15 is small, it still exceeds the minimum benchmark of 12 recommended by Guest, Bunce & Johnson (2006).

All 15 participants were male, and ages ranged from 33 to 63 years at the time of the interview (during the summer and fall of 2017), with a (rounded) average of 51 years. This could be perceived as a bias regarding age or gender, but it should be noted that power plants still involve predominantly male-oriented professions, and many of these companies appear to struggle to find young recruits. Therefore, our sample appears to be in line, demographically, with the actual work force in power plants.

In general, the participants working in these companies were educated at a medium or high vocational education level. Of the 15 participants, seven were mostly involved with mechanical engineering, four were mostly involved with electrical engineering, and four did something else, including one occupational hygienist, one risk manager, one education manager, and one ICT specialist.

Data collection

All participants were asked beforehand whether they had any objections to the recording of the interviews. Participants were informed that they would retain full anonymity and that they could say anything they pleased without repercussions. The participants all agreed to the terms of these interviews.

The interviews began with a number of general questions involving job description, age, level of education, and work satisfaction. Subsequently, we asked participants about the risks that are present in the workplace, and we focused on the question to what extent EMF exposure was considered an important risk compared to other risks. After exploring the perceptions of

EMF and other risks, we asked about mitigation, rules and regulations towards EMF, and then about practices concerning risk communication and work safety instruction. We also asked participants which information about EMF they would find important to know, and about various contextual elements that might influence work safety. All participants were given the opportunity to make further additions at the conclusion of each interview. An overview of the interview guideline can be found in Appendix 1. This guideline was thoroughly tested in an earlier study involving PM exposure in roadwork companies (Stege et al., 2019), and it was slightly altered to fit the situation involving EMF in power plants.

Data analysis

After getting a verbatim transcription for all 15 interviews, we used Atlas.TI version 5.2 for a qualitative analysis involving coding. Coding is the process by which short phrases or keywords are attached to text fragments in order to systematically analyze and interpret these fragments, and to uncover links between these fragments in the data (Merriam, 1998). The grounded theory approach states that qualitative analysis is usually accompanied by three types of coding, namely open, axial and selective coding (Strauss & Corbin, 1990). Open coding is the first step, in which the initial interpretation is made; axial coding groups similar codes together within categories; and selective coding identifies the core categories (Strauss & Corbin, 1990).

In a process of open coding, the author who performed the interviews defined an initial coding scheme based on the first three interviews. These codes corresponded to some extent with the questions we asked during the interview, but they were categorized further by means of axial and selective coding. For example, we asked for participants' thoughts about EMF, and the actual coding provided details on whether the answer was related to the definition of EMF, sources of EMF, mitigation methods, and so on. This yielded codes such as 'EMF_cause_generator', 'EMF_effect_pacemaker' and 'EMF_mitigation_warningsigns'. We also asked about work safety instruction, which in these companies was called 'toolbox', and participants gave us information about things such as the frequency, contents and methods of instruction. Therefore, this yielded codes such as 'toolbox_frequency', 'toolbox_contents_EMF', and 'toolbox_method_elearning'.

When 12 of the 15 interviews were coded, the first and third authors discussed and refined the coding scheme and each coded the final three interviews separately. There were no significant discrepancies concerning the actual contents of the codes. The total number of codes added up to 157.

Results

The results from the interviews are categorized into three main themes: perceptions of exposure to EMF, safety by design, and education. This is in line with the important aspects of work safety mentioned in the introduction, with the first theme corresponding with our research question and the second and third themes corresponding with the two main areas of mitigation.

Perceptions of exposure to EMF

During the interview, all participants were asked which risks were involved with their work. Various risks were mentioned, including heat, high pressure, electrocution, falling and tripping, toxic substances, particulate matter, mechanical risks and noise. Although all participants were aware of the presence of EMF within their company, less than half of them mentioned EMF as a relevant risk themselves. For example, one participant mentioned several risks other than EMF, and that participant was then asked to tell something about EMF.

> *Electromagnetic fields. Yes, we have those around the transformers. [...] We usually stay away from those as much as possible. We do not get involved with them a lot.* [ptcp. 12]

The sources of EMF were often mentioned implicitly, not explicitly. To most participants, it made intuitive sense that EMF exposure is present in power plants. However, some more specific sources were mentioned, including generators, transformers, cables, and communication devices such as transceivers.

The majority of participants mentioned that people with pacemakers and other active implants are at risk of disruptions when exposed to EMF. Other short-term effects of exposure to EMF such as muscle contractions, headaches, nausea and phosphenes were also mentioned. One participant mentioned the possibility of current induction in your body, and one participant talked about sleeping disorders. Two participants pointed out that effects such as muscle contractions might also lead to indirect effects such as tripping or falling, as illustrated by the following quote:

> *If you are working in a certain situation surrounded by dangers, but you are standing on your ladder just fine, having everything under control, and then suddenly you get an involuntary muscle contraction, that could mean that you fall off your ladder.* [ptcp. 6]

Considering the long-term effects, about half of the participants simply had no idea about any long-term effects, although some were aware that these are unknown for the most part. Only one participant referred to a study that showed a link between EMF and childhood leukemia, although he was skeptical about the scientists' conclusions:

> *[I have read about] childhood leukemia. People are living in a neighborhood under transmission towers, and they just say harshly [to them], "it has been proven that more cancer occurs among these children", but they say "whether there is a causal link is not proven". Well, I think that is a big lie, because if you measure it in several areas and it is simply more under the transmission towers, then it is proven in my opinion.* [ptcp. 13]

Nevertheless, all participants who were asked agreed that EMF exposure had not led to any health effects in their company, as illustrated by this quote:

> *Well, EMF… I have never heard of anyone actually being hurt by it.* [ptcp. 8]

In two of the three companies, detailed measurements had recently taken place by third parties, and for the third company it was planned shortly after these interviews. The stakeholders took the task of measuring EMF exposure seriously:

> *Some time ago we heard from the work inspectorate, I think, that we had to pick this up. Well, we bought a meter immediately. […] We visited all units, did the*

measurements and pasted the stickers. [ptcp. 8]

One participant showed a more detailed description of the measurements during the interview. The results of these measurements indicated that EMF exposure was indeed below the action values of 1000 microtesla as stated in the European Directive:

> *This is a list of measurements. […] [In this specific situation, with a 50 Hz frequency] I measured a field strength of 86 microtesla. Which is very low, as it is allowed to go up to 1000.* [ptcp. 1]

Safety by design & Mitigation

One participant, the occupational hygienist, gave a detailed overview about the occupational hygiene strategy for EMF within the branch. He referred to the four-step overview of the strategy, filling in each step in the process:

> *It starts like this: address the source, for if you remove the source, there will never be a problem. But that is impossible [with EMF] since the power plant will just shut down. […] The next step in the strategy is: take care of technical measures. A fence is a technical measure. […] Organizational measures include a sticker, an icon, a warning. […] The final safety option is personal protection. That is not possible [with magnetic fields].* [ptcp. 6]

The two mitigation methods mentioned above, fences and warning signs, are also mentioned by most of the other participants. According to several participants, there has been such a strong reduction in EMF exposure due to fences that the risk was completely mitigated, at least for people without pacemakers or active implants. This is illustrated by the following quote:

> *Not anymore, because we have mitigated it. If you look at the working distances to the source, I would think "well, that is not the most exciting thing". I can imagine that it would be different with a different type of installation. […] But we have managed it away in the design.* [ptcp. 4]

Most participants also mentioned the warning signs, and the fact that these people take the warnings seriously is illustrated by this quote:

> *If I see such a pictogram, I will keep my distance.* [ptcp. 10]

Two participants pointed out that fences and other enclosures were sometimes already in use for other types of risk, such as electrocution or noise, thereby mitigating all EMF risk in the process:

> *Often it is also about noise reduction, that it [an enclosure] is already around [the installation].* [ptcp. 3]

Education

The three companies all maintained periodical work safety meetings. Company A sent employees an email before having a plenary session in which employees could ask questions and had to sign a presence sheet. Company B had implemented all workplace risk instruction within an e-learning format, with a small test at the end of it. Company C had assimilated the work safety meetings with the department meetings, setting apart time within these meetings for several safety issues.

Most of the risk information was either embedded within these work safety meetings or given more informally. However, all companies provided short instruction films and small quizzes both visitors (including the interviewer of this study) and new employees need to watch before entering the premises.

Company A had recently implemented a work safety meeting on EMF, but this meeting was considered too bureaucratic and unpractical:

> *We are really saying here, 'we are going to make a task risk analysis' [in places with high EMF exposure]. Then we say, 'alright, there is a risk, we are going to do [the work] anyway.' Appointing an EMF guard. That just means that you are working and I am watching from two meters distance wearing a transceiver. 'Oh, he looks a bit pale, I am going to take him back.' Should I walk into the area where you are working*

and pull you away, or should I walk away and get help? [ptcp. 15]

Company B had a standardized e-learning instruction about EMF, which had been successful but needed some updating:

> *It might be about time to look out for other ways of giving safety and health information […] because I think that it gets a little less attention than before. The novelty is gone, many people have heard it two or three or four times already. And sometimes you just need to apply some new methods to reach the knowledge or attitude or behavioral change.* [ptcp. 6]

Company C did not appear to have any work safety meetings dedicated to EMF; one participant thought that they did, but could not recall any details, and one other participant was adamant that they had not. EMF was mentioned in the instruction film everyone needs to watch before entering the premises, but only in relation to active implants such as pacemakers.

Even though participants did not consider exposure to EMF as an important risk in power plants, the majority of them, regardless of the company they were in, still thought some information is needed, as illustrated by the following quotes:

> *I think it is definitely useful to make a work safety meeting out of it. Inform the people [about EMF].* [ptcp. 13, company A]

> *We have to recognize [EMF]. We have to instruct people about it.* [ptcp. 11, company B]

> *Give information. Show people what it is about, but especially mention whether it causes damage or not. Do not just throw the words [electromagnetic fields] out there.* [ptcp. 3, company C]

The majority of participants, regardless of the company, also said that possible effects of EMF should at least be discussed, as well as possible protective measures. For the most part, this meant that people should know the appropriate minimum distance to keep from several EMF sources. This is illustrated by the following quote:

> *For us it is like this: it is a certain area. It is fenced off. And you should just not come behind it, or too close to it. So then it is done. That is really [all we need to know].* [ptcp. 9]

Participants mentioned some other information needs as well, including information on EMF detection, various sources of EMF, and a definition of EMF. About a quarter of the participants found it important to have a dedicated EMF expert present within the company. Interestingly, this is mostly (but not exclusively) seen in company C, the company without a dedicated EMF work safety meeting.

> *They need to be able to find the procedure. They need to know where their expert is, so to say, in the area [of EMF].* [ptcp. 4, company C]

> *[I find it important to know] who is responsible. So whom should you ask if there is a problem [about EMF]?* [ptcp. 9, company B]

Many participants were to some extent satisfied with the work safety meetings. One participant pointed out that, no matter what form you choose for the instruction, it will never be ideal, but retention is crucial no matter what you choose:

> *An e-learning tool is an option. A plenary session is an option. And in both cases I can say with certainty that it will never be one hundred percent perfect. […] The best option would be that which makes the receiver remember what it is about, and which extracts the most relevant things for him.* [ptcp. 11, company B]

Various factors may influence the efficacy of safety instruction, other than the mere presence of risk information. About half of the participants pointed out the need for communication within the company. For example, one participant said that work safety meetings are more effective when employees are given the opportunity to give their opinion on the contents:

I would say: "Well, did everyone read the [instruction]? What do you think about it? Does it still fit with us, or do we need to change [it]? Or do you think that there are things that are irrelevant for us, or illogical?" [ptcp. 7]

Discussion

General discussion

In this study, we investigated the perceptions of employees in power plants concerning work safety with regards to EMF. We found that the employees in power plants that participated in this study perceived EMF not as an important health risk. These power plants use fences and warning signs to mitigate the risks, and employees perceive a high degree of safety by design. Employees in this study agree that being informed about EMF is still important even if the actual risk is low, and they feel that there is room for improvement in the companies involved when it comes to instruction methods.

Safety by design & Mitigation

It appears that EMF risks are mitigated to a large degree in power plants in this study. All companies already provide fences, as well as warning signs indicating strong electromagnetic fields, to alleviate any potential for EMF exposure that exceeds legal limits. Since these legal limits have become somewhat less strict in the past few years (Alanko et al., 2014; European Commission, 2015), the chance of exceeding the legal limits has decreased further. Even though this does not automatically guarantee the safety of the legal limits, there are also no clear indications that there are adverse effects of EMF present in the companies in this study. Since several participants mentioned that there have been recent measurements as well as additional warning stickers, it is plausible that in these three power plants no sections exist where exposure at accessible places will exceed the Action Values.

EMF perceptions & Education

Participants are aware of the existence of EMF as well as the potential presence within their companies. Nevertheless, employees' perceptions regarding effects of EMF are not always accurate. Even though there is a European Directive to protect workers against short-term health effects from exposure to EMF, some employees are unaware that EMF exposure might have short-term adverse effects even in people without implants (Health & Safety

Executive, 2016). Most participants do not mention long-term effects, but at least one participant assumes that there are long-term adverse health effects such as cancer, based on the studies involving transmission towers and leukemia (e.g. Kheifets, Afifi & Shimkhada, 2006). It appears that the misconception here, the idea that a causal link between EMF and cancer would be proven, can be explained by a lack of understanding of scientific methods.

One difficulty in designing a system for EMF health risk information is the absence of clarity about long-term effects (Health & Safety Executive, 2016). One approach is to include information about potential long-term risks, including neurodegenerative diseases (Huss et al., 2015) and non-specific physical symptoms (Baliatsas et al., 2015; Bolte et al., 2015), while also mentioning that these effects remain unproven and are therefore uncertain. By including these uncertain effects, employers ensure themselves of being thorough in informing their workers of potential risks. If future research turns out to confirm these long-term effects of EMF, employers can then be credited with their expeditious approach of risk communication.

Literature suggests that employees should get sufficient practical instructions, not just theoretical insights (Niewöhner et al., 2004; Petts et al., 2002). However, participants in this study point out that, besides keeping distance and shielding yourself from the source, there is not much to be done about EMF if exposure levels are exceeded. Although the amount of practical instructions to be given in the context of EMF is limited, clear information about these basic preventive measures might already be helpful. For example, companies could give facts and figures about the potential exposure within a certain distance, and tell workers to keep the fences and warning signs in check. Since power plants appear to be well-informed about precise EMF exposure in various locations on their premises, they could even include a 'heat map' of EMF exposure in their risk information system, as recommended by Koehler & Volckens (2011).

Strengths and limitations

This study gives an overview about the EMF safety systems that are in place in the large power plants in the Netherlands. Of course, the relatively small sample size is a limitation for the generalizability for these results, and we cannot claim that our sample is representative. We cannot be certain that we have a complete overview of relevant issues regarding EMF exposure risk and mitigation. We believe we have nevertheless succeeded in getting a fair cross-section of both the participating companies and the Dutch electricity branch in general (all three major Dutch electricity companies were involved in this study), with sufficient diversity in participants. The generalizability to other countries remains an issue, though; differences in laws and safety culture might lead to an increased EMF exposure, and thereby more adverse effects. We feel this is an important starting point for future research. Finally, the qualitative set-up of this study has led to insights from employees of these power plants regarding EMF exposure, but there as we did not perform any measurements ourselves we have no way of knowing that these insights are accurate.

Conclusion

Based on this study, employees in power plants do not appear to perceive EMF as one of the most important risks within their companies, mainly because there is a high degree of mitigation. Participants in this study are aware of the most important mitigation methods, fences and warning signs, and they feel that their workplace has a high degree of safety by design because of this.

While mitigation methods are in place, participants still feel that they should be informed about basic aspects of EMF. We recommend that power plants give at least the most relevant EMF risk information to employees, such as the Action Values from the EU Directive, how to recognize potential high exposure areas (signs and fences) and the possible health effects, including nausea, vertigo, phosphenes and so on (Health & Safety Executive, 2016). Participants in our study often mentioned these subjects when asked for their information needs. It also turned out that they would like more clarity on who would be responsible within the company for EMF-related issues, so we also recommend including this in the risk information.

Education about risk helps as a prevention tool in its own right. Risk information about EMF should aim to alleviate misconceptions that are present, as well as provide more clarity on effects and mitigation methods. Even though periodical work safety meetings are in place in all companies, one of them does not explicitly discuss EMF. All companies should do that. To prevent the meeting from getting bureaucratic, a plenary question-answer session may be a fitting method. In order to reduce (perceived and actual) bureaucracy, we recommend thoroughly investigating whether safety measures are actually necessary to work safely or if they are superfluous, with the caveat that companies should of course comply with legally mandated safety measures.

Finally, it is interesting to note that employees are allowed to provide input for the work safety meetings, at least in one of the companies involved. Work safety experts ask questions about the contents of these meetings to the engineers and other employees, and they can give their opinion on which content might be outdated or irrelevant. We certainly recommend maintaining this practice, as it is a perfect example in line with the idea from Hambach et al. (2011) that employees want to feel listened to.

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Appendix 1: Interview guideline (translated from Dutch)

- Can you tell me something about [company name] and the work you are doing here?
    - How long have you worked here?
        - And how old are you?
    - What education did you follow?
    - Are you satisfied about your work?
- What risks would you say are involved with this work?
    - [if not yet mentioned] Can you tell me something about things in your workplace that might make you ill?
        - Do you struggle with health issues?
            - What is the cause of these issues?
            - To what extent does your work play a role in this?
    - Can EMF (electromagnetic fields) be a risk? [if not yet mentioned] / Can you tell me more about EMF? [if mentioned]
        - [if they have no idea at all, give them a short explanation of what EMF is]
        - To what extent is EMF a relevant health risk?
            - What are the properties of EMF?
            - What does that mean for your health?
    - How does [company name] handle issues regarding EMF exposure?
        - What rules and guidelines are in place?
        - To what extent are these guidelines prioritized?
        - What is your opinion on how these issues related to EMF are handled?
- How do you get safety instructions at work?
    - To what extent is EMF given any attention?
    - Which materials and instruction methods are used?
    - What is your opinion on the current state of affairs regarding safety instruction?
    - What would you like to know about EMF?
        - What would you consider a good method of getting this

information?
        - From whom would you like to get this information?
    - Can you think of any ways to prevent work-related risks other than methods of instruction?
- To what extent do you feel that you are in a safe and healthy work environment?
    - To what extent are you aware of methods to mitigate risks?
    - How do you handle this in practice? [If needed, assure them that this is not an inspection and they can give any answer without repercussions]
    - Would you say that [company name] has a good safety culture?
- Would you like to add something we have not discussed before?
    - Do you have any questions for me?

3

PARTICULATE MATTER EXPOSURE IN ROADWORK COMPANIES: A MENTAL MODELS STUDY ON WORK SAFETY.

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Abstract

Particulate matter (PM) exposure, amongst others caused by emissions and industrial processes, is an important source of respiratory and cardiovascular diseases. There are situations in which blue-collar workers in roadwork companies are at risk. This study investigated perceptions of risk and mitigation of employees in roadwork (construction and maintenance) companies concerning PM, as well as their views on methods to empower safety behavior, by means of a mental models approach. We held semi-structured interviews with twenty-two employees (three safety specialists, seven site managers and twelve blue-collar workers) in three different roadwork companies. We found that most workers are aware of the existence of PM and reduction methods, but that their knowledge about PM itself appears to be fragmented and incomplete. Moreover, road workers do not protect themselves consistently against PM. To improve safety instructions, we recommend focusing on health effects, reduction methods and the rationale behind them, and keeping workers' mental models into account. We also recommend a healthy dialogue about work-related risk within the company hierarchy, to alleviate both information-related and motivation-related safety issues.

Keywords: Risk communication, Particulate matter, Mental models, Work safety

Introduction

Particulate matter, or PM, is an important health risk in modern society (WHO, 2013), as well as an environmental risk (Roels et al., 2014). It originates from a number of sources, such as vehicle emissions, machinery and industrial processes, but also natural sources (Anderson, Thundiyil & Stolbach, 2012). PM exposure through air is associated with various diseases, mainly respiratory and cardiovascular diseases (Anderson et al., 2012; Hänninen & Knol, 2011), due to people breathing in the particles. These health effects lead to a reduction in life expectancy; annual premature death estimates due to PM exposure are 800,000 worldwide (Anderson et al., 2012), and 12,000 in the Netherlands alone (Health Council of the Netherlands, 2018). This study focuses on PM in the workplace, and investigates to what extent blue-collar workers are empowered to protect themselves against PM.

The two main characteristics of PM that contribute to health effects are particle size and chemical composition. When it comes to particle size, the fraction of PM with a particle size of 2.5 micrometers or less (PM2.5) is likely to have most detrimental health effects, including lung cancer, bronchitis and cardiopulmonary disease (Hänninen & Knol, 2011). The PM2.5 fraction permeates more deeply into your lungs than the PM10 fraction (Hänninen & Knol, 2011; Strak, 2012) while having higher levels of inflammatory response compared to the PM0.1 fraction (Strak, 2012). When it comes to chemical composition, various adverse health effects are caused by substances such as black carbon (Janssen et al., 2011), silicon (Van Deurssen, 2015), metals and various organic compounds (Strak, 2012).

Research indicates that blue-collar workers in construction companies (Van Deurssen, 2015) and highway maintenance companies (Meier, Cascio, Danuser & Riediker, 2013) have a high PM exposure risk. Especially usage of equipment such as mowing machines or chain saws causes PM exposure (Meier et al., 2013). There are indications that it increases workers' risk of cardiovascular disease; therefore, earlier research recommends taking actions to reduce PM exposure in highway maintenance companies (Meier, Cascio, Ghio, Wild, Danuser & Riediker, 2014). In this study, we broaden our focus to roadwork companies in general instead of only highway maintenance companies, because the aforementioned causes of PM exposure are also relevant for road construction companies (Sobus et al., 2009), or companies that maintain other roads than highways.

European and national laws require rules and regulations towards exposure risks, and companies should take precautions whenever exposure limits are exceeded. Exposure limits for the course and fine PM fractions (PM10 and PM2.5) have not been determined for the workplace, but there are exposure limits for specific substances. For example, the quartz exposure limit in occupational settings is 75 µg/m3 (Van Deurssen et al. 2015), and these exposure limits are regularly exceeded. According to Uchiyama (2013), the most important precautions against dust inhalation, other than avoiding certain locations altogether, include using respirators and sprinkling water.

In the occupational hygiene strategy for the Dutch situation, additional precautions regarding PM are mentioned, specifically regarding diesel emission (Heederik, Maas, Siegert & Wielaard, 2009). These include using other types of fuel, alternative work schedules, filtering systems and ventilation. The occupational hygiene strategy is based on a four-level hierarchy of types of precautions. If possible, companies should focus on taking away the source of exposure, before choosing collective measures, such as filtering systems, or individual measures, such as alternative work schedules. Protective equipment, such as respirators, should be used if none of the other options is sufficient.

Awareness about possible risks and precautions is essential for health protection, since accurate perceptions of risk lead to safe risk behavior (Milne, Sheeran & Orbell, 2000). In some cases, simply giving the appropriate information about PM exposure, health risks and mitigation options to workers is used as a means of risk communication. This has been effective to a certain extent in workplace situations involving other exposure risks, including welding fumes (Cezar-Vaz, Bonow & Cezar-Vaz, 2015) and ionizing radiation (Sheyn, Racadio, Ying, Patel, Racadio & Johnson, 2008). Influencing risk perceptions by means of instruction might especially be useful with mostly imperceptible exposure risks such as PM, since these types of risks could be relatively overlooked due to their imperceptibility, and workplace prevention has traditionally focused more on observable direct physical risks (Arezes & Miguel, 2008).

Fischhoff, Brewer & Downs (2011) state that ideally, risk communication takes workers' mental models into account. Mental models were originally defined as '"small-scale models" of reality that [the mind] uses to anticipate events, to reason, and to underlie explanation'

(Craik, 1943). According to Craik (1943), having such a model is essential in choosing safe alternatives in emergencies, which underlines its importance in risk communication. In a more recent publication, Jones et al. (2011) define mental models as "personal, internal representations of external reality that people use to interact with the world around them". Here, they focus on the contrast between the internal idea and the external reality, which may be a key factor to focus on in risk communication. Ideally, this would lead not just to an increase in safety knowledge, but also in safety motivation, which is also strongly related to safety performance (Christian, Bradley, Wallace & Burke, 2009).

The mental models approach in risk communication and perception studies seeks to construct the mental models of scientific experts and non-experts with respect to a specific risk, contrasting these two with each other (Morgan, Fischhoff, Bostrom & Atman, 2002). Non-experts have some intuitive idea about certain risks, which can be mapped in a systematic way (Breakwell, 2001). The differences between the mental models can then be used to identify specific information needs: gaps in knowledge relevant for decisions, misconceptions, questions and concerns, different use of terminology and typical non-expert beliefs (Slovic & Weber, 2002). Breakwell (2001) states that basic information about risk properties, effects and control measures is always necessary, and that new information should match the level of understanding of the target group. In group settings such as workplaces, this target group tends to have a shared mental model, which helps facilitate the task performance in companies (Lim & Klein, 2006). The shared mental model of a certain risk can be influenced by means of risk communication.

Although the concept of safety culture is rather ill-defined (Nielsen, 2014), safety culture is important nonetheless. Having a culture in which it is considered normal to discuss improvement of safety measures has a positive effect on work safety (Hambach et al., 2011; Petts et al., 2002; Toppazzini & Wiener, 2017). Nielsen (2014) argues that a change in culture, specifically towards higher levels of safety behavior and commitment, can be equated with a change in basic assumptions. In our situation, the mental models approach can identify which basic assumptions, both about PM itself and about work safety in general, need to be addressed in order to improve work safety related to PM.

It should be noted that designing a system of risk communication is not always the only, or even the best, solution when it comes to inducing work safety behavior (Fischhoff et al., 2011; Mankin, 2009; Smith & Ragan, 2005). Before focusing on risk communication, companies should design the workplace in such a way that working safely becomes the automatic thing to do (Evans & Stanovich, 2013; Mols, Haslam, Jetten & Steffens, 2015). Another method is to force workers to work safely by coercive means (Hasle, Limborg & Nielsen, 2014), but this might lead to defiance (Sunstein, 2016) and loss of safety culture (Lipscomb, Nolan, Patterson, Sticca & Meyers, 2013). Safety climate, which is subtly different from safety culture but sometimes used interchangeably with it (Nielsen, 2014), is more related to safety participation than to safety compliance (Christian et al., 2009) – that is, a company with a healthy safety climate leads its employees to actually feel involved with the safety procedures, not just comply with its rules.

In this study, we use a mental models approach to investigate to what extent workers are empowered to work safely in occupational circumstances involving PM exposure risk. Based on scientific knowledge about PM, mentioned earlier in this article, we construct a scientific mental model that encompasses the properties, causes, health effects, control measures, and education about PM. We then contrast this mental model with the employee mental model

The two main research questions in this paper are as follows: 'How do roadwork companies and their employees perceive PM exposure risk and mitigation', and 'How are employees in roadwork companies empowered to work safely?' We discuss how companies could empower their employees to work safely, resulting in specific ideas for a risk communication solution.

Method

This study aims to use a mental models approach to investigate PM risk perception and empowerment to work safely. The scientific mental model is based on insights from literature, as discussed in the introduction section. The content has also been cross-checked with an expert on the subject, in order to help prevent inaccuracies. To build the employee mental model, we held semi-structured interviews with various employees of roadwork companies. We chose semi-structured interviews because they aim for a general systematic order while still allowing deviations from the script (McIntosh & Morse, 2015), and because they emphasize the intended meaning of the questions over the phrasing (Denzin, 1989). This setup matches up well with the mental models approach, as this approach also aims to investigate the thought processes of certain groups of people (Morgan et al., 2002). The employees in these companies can be further divided into work safety specialists, site managers, and blue-collar workers.

Sampling

We contacted seven companies in the Netherlands that are involved with roadwork, and three of those companies participated in this study; the other four chose not to participate due to time constraints. The three companies each selected one work safety specialist, two or three site managers and four blue-collar workers to interview; the total number of interviews added up to 22. We did not get any further details on the selection procedure of participants within the companies. All participants were men, which was unintentional, but a logical consequence of the predominantly male demographic of the roadwork branch. Their ages varied between 23 and 59 years old.

The three companies are all involved with roadwork, but the specific primary processes for each company are slightly different. Company A is mainly involved with highway maintenance, including road reparations, but also activities such as lawn mowing and cleaning. Company B is more involved with road construction, both inside and outside of urban areas, but also with ground preparations involving electricity and sewerage. Company C focuses on both road construction and maintenance.

Data collection

We interviewed all participants face to face and one on one, with the exception of one interview where one manager wished to join the interview with another manager near the end. The first author performed all the interviews over the course of four months, during the spring and summer of 2017. They were held in various locations, but always related to the companies themselves, ranging from offices to work shacks. Before the interviews, we asked them whether they had any objections to recording. We also informed all participants of their guaranteed anonymity, and we guaranteed that anything within the limits of the law would remain between the researchers and the participant. No participants had any objections to these terms.

The interviews started by asking participants to give a description of their job, in order to set the stage of the conversation. Subsequently, participants were asked which risks they encounter within their work, to see whether they consider PM one of the primary risks. If they did not include PM at this point, they were asked about it directly, by using questions such as 'what do you know about PM?'. The participants were also asked about their knowledge and beliefs about PM exposure, health effects and mitigation, and about rules and regulations regarding safety behavior present within the company. In the second half of the interview, the focus was on information and instruction practices in the company and on contextual influences on work safety behavior. Participants were also asked about PM information needs for blue-collar workers. The interviews were all concluded by asking participants whether there were other noteworthy things to mention.

Data analysis

All 22 interviews were transcribed verbatim. We then performed a qualitative analysis using Atlas.TI version 7 (Muhr et al., 2016), a program that helps structure the coding process. In the coding process, keywords are systematically linked to certain fragments of text, in order to identify themes that were present in various interviews. The first author first identified and coded the relevant text fragments of the first two interviews through open coding; that is, keywords were added without following a predetermined schedule for coding. To a certain extent, these codes were in line with the questions we asked during the interviews, but we did not have a predetermined schedule, in order to remain open to unexpected findings.

After the coding of the first two interviews, the first and third authors deliberated the codes and potential overarching themes and discussed how to refine and continue the coding process. These steps were repeated several times. In this iterative process, returning to the earlier transcripts to ensure that all codes were applied consistently across transcripts, the codes and themes evolved and became more refined, resulting in 143 codes. Using the evolved coding scheme both authors coded the final three interviews (allowing for additional newly defined codes) and compared the coding. In this last step, a few more codes were added, but no profoundly new themes or subthemes were identified, implying that the data were close to reaching saturation. Although we found some differences between coders in code name usage and quote length, both researchers identified the same themes and subthemes within these interviews. After discussing the differences and revising the coding scheme accordingly, we concurred that there were no essential discrepancies between coders.

Results

As mentioned, the scientific mental model of risk was based on insights from literature. This mental model can be found in Figure 1, and it provides a schematic overview of expert knowledge on this subject. In order to increase the legibility, some of the nuances provided in the introduction section were left out; for example, the scientific mental model mentions the distinction between particle sizes, but it does not specify that PM2.5 is considered the most important fraction when it comes to health risk. The scientific mental model focuses on several aspects of the risk that were identified during the data analysis of this study. These aspects include: definitions of PM, causes, effects, precautions, and empowerment (including education).

The scientific mental model (Figure 1) shows in the 'Properties' section that PM is (mostly) solid matter suspended in air (Strak, 2012), consisting of small, usually imperceptible particles often divided into size fractions such as PM0.1, PM2.5 and PM10 (Hänninen & Knol, 2011), varied in chemical composition (Janssen et al., 2011, Van Deurssen, 2015). Its sources include, among others, traffic, machinery, and natural causes (Anderson et al., 2012), as shown in the 'Sources' section. The center of the model shows that PM causes ecological problems (Roels et al., 2014), and health effects in humans due to exposure through air via breathing (Strak, 2012). These effects, shown in the 'Health effects' section, include cardiovascular, respiratory and other diseases, resulting in around 800,000 annual premature deaths worldwide (Anderson et al., 2012). There is an occupational hygiene strategy involving a four-level prevention model (Heederik et al., 2009), which is shown in the 'Control measures' section, recommending various measures including alternative fuel, ventilation, dust filters, water sprinkling, alternative work schedules, and respirators (Heederik et al., 2009; Uchiyama, 2013). Various factors involving workplace education on PM were included in the 'Education & Empowerment' section of the model, including effects of protection motivation (Rogers, 1983), rules' effect on culture (Hasle et al., 2014), culture's effect on work safety (Lipscomb et al., 2013), safe work behavior and safety by design (Evans & Stanovich, 2013; Mols et al., 2015).

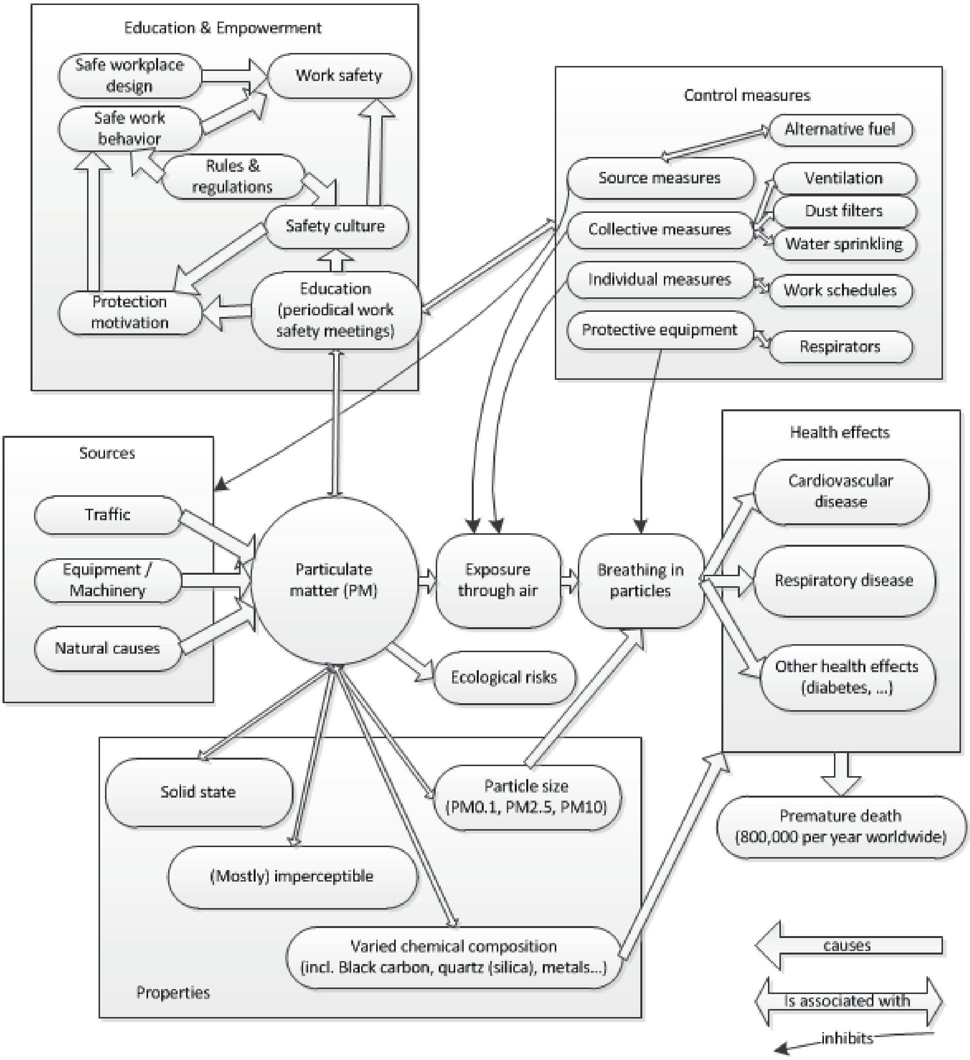

Figure 1. Scientific mental model of PM.

A schematic overview of employees' perceptions of PM risk, as well as risk information needs, can be found in the employee mental model (Figure 2). The same five aspects of the risk were used, and both of the mental models were designed to be able to overlap each other to investigate the differences between them. The differences between the scientific and employee mental models are shown in red in the employee mental model. As seen in Figure 2, the scientific mental model is more detailed and less conflicted in the effects and properties sections, but the employee mental model is more detailed in the control measures section. The scientific mental model also showcases more consistency between the sections. A more detailed description of the results from the interviews, including quotes, can be found from chapter 3.1 onward.

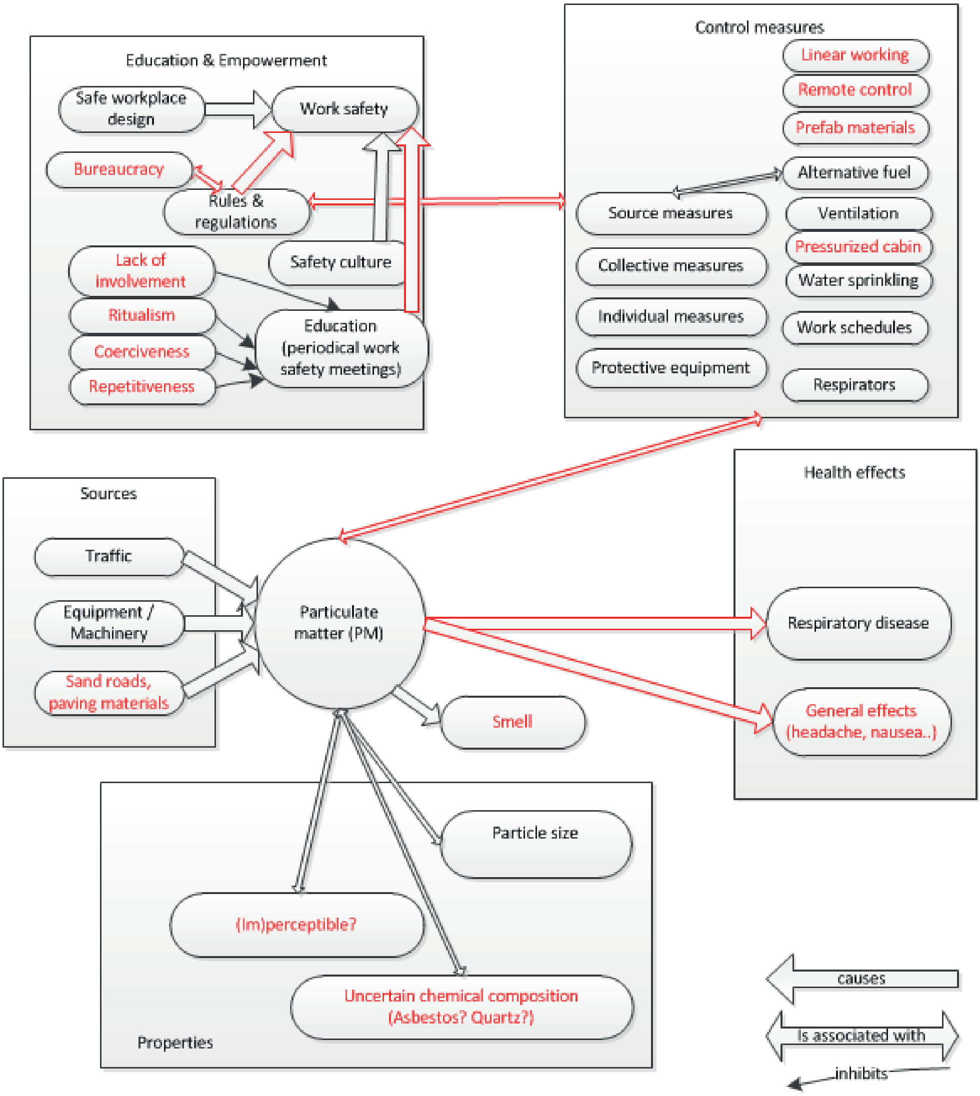

Figure 2. Employee mental model of PM.

In the analyses of the interviews five main themes were identified: perceptions of work-related risk (PM and otherwise), risk information needs, company policy towards PM, instruction methods, and contextual influences. The results will be described within the first four main themes, with the contextual influences mentioned wherever applicable. They will also be stratified, wherever possible and necessary, among the three groups of participants: work safety specialists, site managers, and blue-collar workers.

Perceptions of work-related risks

When asked about the risks that are involved with their work, the three work safety specialists unanimously agreed that traffic is the most important risk, and they all mentioned it as the first risk in the interview. Almost all other participants – workers and managers – agreed, and one participant (a worker) illustrated this with the following quote:

"The further I'm away from the highway, the safer I feel." (worker 1)

The participants then mentioned other direct physical (short-term) risks, including machinery, heavy lifting, fatigue, tripping, falling, and so on.

When asked about the long-term exposure risks, there was less unanimity. One of the work safety specialists mentioned noise as the first exposure risk that came to mind, one of them mentioned UV radiation, and the third (who is working for the company involved with ground preparations) mentioned soil pollution first. The other participants, workers and managers, also gave a wide range of answers; some of them mentioned PM as the first risk.

3.1.1.Particulate matter: sources, composition and effects

All participants except for one worker had at least heard of PM before the interview. When it came to the sources of PM, in Company A exhaust gases were most frequently mentioned, whereas company B and C focused more on dirt roads, sawing and material dust. Participants in all employee groups – specialists, managers and workers – gave similar answers.

All workers and managers struggled to give an exact definition or many properties of PM, but two out of three work safety specialists assessed that particle size is what defines PM. Site managers and blue-collar workers did not mention anything about particle size, but they expressed ideas on the composition of PM, particularly by referring to quartz and asbestos:

Well, I did not really dive into this, but there is some kind of quartz involved, I think. (manager 5)

It is possible that there are asbestos particles, and all sorts of junk, of course. (worker 10)

Conversely, not everyone agreed with the notion of quartz or asbestos being involved with PM:

Yes, that is how I view particulate matter, because quartz is not particulate matter to me. Quartz is visible. (specialist 1)

See, if I am not mistaken, it [PM] is all clean material. Yes, there is particulate matter, but asbestos and fibers? If I am not mistaken, there is no such thing inside of it. (worker 12)

The quote by the specialist above also implies that he considered PM to be invisible. However, a small number of workers thought that only visible matter qualifies as PM, as illustrated by the following quotes. The second one of these workers is fairly young and unexperienced, while the first one has about forty years of experience:

If you see it, then it is defined as PM. But there is also a lot of invisible dust that we cannot see. Diesel soot particles cannot be seen. (worker 8)

Well, it can be easily seen in the tunnels. There is some sort of fog. (worker 1)

One of the site managers pointed out that PM is present whenever visible dust is present, implying (but not specifying) that PM and visible dust are different things, but are always present at the same time:

As soon as you see smoke, there is PM present. (manager 3)

When it came to health effects of PM, only one participant, a site manager, mentioned the possibility of cardiovascular diseases. However, most participants agreed that PM is unhealthy, specifically for the lungs. The phrase 'black lung' (also called miner's lung or pneumoconiosis, a lung disease caused by inhalation of particles) was mentioned several times as a potential health effect, and lung cancer was also seen as a possibility by some. Other participants mentioned different, more direct effects, attributing headaches and nausea to PM. For some, the presence of a nasty smell was an indication of the unhealthiness of PM. Some participants, on the other hand, did not see PM as an important source of risk at all, mainly because they give priority to other types of risks.

Considering precautions against PM, the majority of employees are aware of the two most important precautions: moistening materials and using respirators. A few other precautions were mentioned once or twice, including alternative fuel sources, working night shifts, working in pressurized cabins, using prefabricated materials to avoid unnecessary sawing, and using a remote control to avoid high-exposure areas. A more detailed overview of the company policies on these precautions can be found in the next section.

Risk information needs

The most frequently mentioned information needs by work safety specialists and site managers are health effects and preventive measures. This is illustrated by the following quote:

What I find important is that they know that it is bad for them, that you will not notice the effects immediately, but only in the long term. I say to them: "It is like a retirement plan; that is also not something you are aware of at the age of twenty-five, but it becomes interesting at fifty-five." […]So that they recognize the risk, that they understand that they might notice the effects later in life. And how do you protect yourself against it? How do you implement it? Because the work has to be done either way. (specialist 2)

The chemical and physical characteristics were deemed not that important by blue-collar workers. It should be noted that two of the site managers were interested in getting more information about PM for themselves, even the 'less important' physical and chemical characteristics, although they recognize that it would be unfit for the blue-collar workers:

I would find it [physical/chemical characteristics] rather interesting, but those guys outside, well, they probably would not. (manager 4)

One work safety specialist made the point that workers should not only know what they should do, but also why they have to do it:

Actually, if you ask someone "You are wearing a helmet, why are you wearing a helmet?", and he answers, "Because I have to", then that is not the right answer. For what you actually want to hear from him is: "Well, I am walking in an environment where the risk exists that someone falls down, or that I bump my head, and that is why I am wearing a helmet." And then he understands why he does it. (specialist 3)

The blue-collar workers had somewhat differing opinions on what they would like to know. As well as the people higher in the hierarchy, they tend to consider health effects and reduction methods most important. Some of the younger, more inexperienced workers are particularly vocal about this, as illustrated by this quote:

I find it important to know what the dangers are. [...] A man who is in this business for thirty years, but still dies because of the slow killer. And your lungs are pulled closer together and you die, so to say. (worker 5)

A few workers were interested in finding out more details about PM than just basic information, for example concerning dosimetry:

Or maybe they could send someone with some kind of measuring equipment for a week. (worker 1)

See, that might be a good idea. To see how much you take in, and whether or not it is really damaging. So they could inform us in a way such as: "You are subjected to dust for a certain percentage, and that could probably not hurt you", or... (worker 11)

A small number of workers – older workers with a lot of work experience – had little interest in information about PM at all, as illustrated by this quote:

There are few things [regarding PM] of which I say 'boy, I would like to know that'. (worker 10)

Even more than specific information about PM or other risks, workers feel the need to be taken seriously, because they are in charge of the primary process. Workers sometimes perceive a lack of understanding and involvement of people higher in the hierarchy of the company, which in turn might make them question their superior's authority. This is illustrated by the following quote:

If anyone is worried about safety, it is the people outside. But the people on the inside do not get that. They really think, "oh, we need to spell it out for them, because they do not understand a thing." They are thinking every day that we are on some kind of suicide mission, but we are not. We care the most about safety out of everyone, more than the one walking outside, the safety coordinator. He is not concerned half as much about safety as we are. (worker 11)

Company policy towards PM

The companies involved in this study did not seem to have a specific policy towards PM when it came to allowed PM concentrations, but they are strict about certain reduction methods. Since material sawing is an important source of PM exposure, workers are required to moisten these materials beforehand, which the majority of participants considered important. Furthermore, at least two of the companies imposed sanctions to those who forego moistening the materials, with one company using a warning system in which getting too many warnings might get an employee fired, and one company using financial sanctions.

In situations where moistening materials is required due to high PM exposure, workers are also prompted to wear respirators, although this is not considered mandatory. The majority of the participants who mentioned respirators had negative opinions on it, describing them as obstructive and unnecessarily alarming to other people. Some examples of these sentiments include:

Well, not necessarily, but sometimes some things need to be communicated. For example, if a dangerous situation arises or we need to warn someone, or we need to talk to someone. And then, well, you have that thing [a respirator] in front of your mouth, so… (worker 1)

If we, for example, have to clear out trees in an urban neighborhood, and we are going to walk with these things [respirators], people might think: 'What is going on here?', you know, 'Is this dangerous?'. (manager 1)

Of course, company policy can be broader than simply defining rules for workers to follow. One of the specialists made the important point that designing a safe workplace is actually more important than complying with all of the rules:

We do not want to bring people into temptation, so we want to design it optimally, so that they do not need to make any choices on the building location about safety, because the choices are already completed in the initial planning phase. (specialist 3)

One worker added that they cannot always follow every rule, because it would lead to an immense loss in productivity. This is illustrated with the following quote:

I think […] everything is being done here to keep it all as safe and healthy as possible. I think so. But as I am saying, some things are just not doable. […] Well, then you cannot do anything anymore. Then you will just sit there with your arms crossed. […] I do not believe that you can eliminate everything for one hundred percent, all the risks. (worker 12)

There are situations in which a safety regulation can get in the way of people performing their job. An example given by one participant involves the sand roads; they might cause a large amount of dust in the summer, but there are no water trucks in sight. To comply with PM limits, one might have to stop working in such a situation.

Instruction methods

All three companies utilize mandatory periodical work safety meetings in which they share risk information with employees, and they all do it in roughly the same way. The site managers send a letter to the workers in advance, clarifying the contents of the upcoming meeting. Then the workers get the required information from the managers on paper and read it. Sometimes the managers explain some more details if needed, and sometimes the workers get the opportunity to ask questions. Finally, the managers sign the papers for the workers, to prove that they attended.

The majority of specialists and managers deemed the principle of keeping every employee up to date about work safety issues important. There are many possible hazards that could be the focus of such a meeting. However, the specific approach was also criticized. The main problem, mentioned by about half of the participants in all hierarchical layers of the companies, appears to be that the work safety meetings are performed more as a ritual than as an actual method of instruction. This is illustrated by the following quotes:

In the meeting itself it has occurred that we are shoved a piece of paper under our nose. "Just sign this and… […] and get out of here." (worker 1)

I am moderately satisfied in the sense that… […] Every month again you have to remind managers of the fact that… "You have not done it [the meeting] yet – go and do it." And I do feel that a number of the site managers are taking it very seriously. […] But there are also some colleagues that are doing it simply because they have to. And, yes, for them the signature is the most important thing, so they can show me that they did it. (specialist 1)

One of the site managers highlighted another problem. He tried to explain that workers are expected to know everything they ever learned, and that they will be punished unfairly if it turns out that they made a mistake:

But then you will see, the application of it is more in the sense of a criminal record, and in the end there is some employee who was supposed to know something because it was shared with him in a roundabout way a year ago. Or that he had heard something nine years ago in his VCA [safety checklist for contractors], and now he will get a large fine and a sanction instead of compassion and tolerance from a governmental institution. […] Even though in the end it is human work, and wherever humans work, mistakes are made. (manager 2)

Work safety meetings about PM specifically appear to be rare. In one of the companies, there appears not to have been any instruction about PM at all in the last years; the employees did not specify any further how they got information on PM. The other two companies have had a meeting about PM at least once, but they have no institutionalized educational materials regarding PM.

Most risk information is shared with employees in the work safety meetings, but there are other informal and formal methods of discussing and sharing work safety issues, the most notable of which is the instruction booklet. New employees in all three companies got an instruction booklet about quality, safety and environment-related subjects. They contained at least some reference to situations involving PM exposure and reduction, but none of them specifically mentioned the phrase ‘particulate matter’.

Discussion

The aim of this study was to investigate how employees in roadwork companies perceive particulate matter (PM) exposure risk and mitigation, and how they are empowered to work safely. We found that participants tend to know about the most important safety procedures related to preventing PM exposure. However, workers are often unaware why these safety procedures are so important, and they tend to have fragmented or incomplete knowledge about other aspects of PM, such as the health effects of exposure. The incompleteness of employee mental models of PM can be problematic, as the urgency of using certain mitigation methods might not be felt as much if there is insufficient clarity about the scope of the problem. The three companies we visited all held mandatory periodical work safety meetings, which appear to be the main framework in which risk information is given. However, these meetings tend to suffer from being more of a ritual than an actual means of risk communication.

Scientific and employee mental models of PM

A similarity between the expert and employee mental models is the knowledge and beliefs about mitigation methods, as well as most sources of PM. The vast majority of employees in roadwork companies, even blue-collar workers, appear to be aware of the most important safety procedures against PM, sprinkling water and respirators (Uchiyama, 2013). Employees sometimes even mention some of the less common mitigation methods, including using newer equipment, asphalting sand roads, working linearly and working night shifts (Heederik et al., 2009). Furthermore, some of them mention mitigation methods that could prove useful, but are nowhere to be found in literature – the idea to use remote controlled systems to stay out of environments with high PM exposure comes to mind. These procedures are in line with the idea from one of the specialists that it would be best to design a safe workplace in advance, so that workers do not have the opportunity to work unsafely (Evans & Stanovich, 2013; Mols et al., 2015). However, in the case of PM, these procedures do not sufficiently decrease PM exposure from the workplace (Heederik et al., 2009), indicating a further need for exposure reduction from the workers themselves, for example by means of respirators.

Although workers know about mitigation methods, they do not always know why they perform these procedures, even though both the participants and the risk communication literature (Hambach et al., 2011; Petts et al., 2002) say they should. This might be an indication that workers perform safety procedures only because they feel coerced, which is a symptom of an unhealthy safety culture (Lipscomb et al., 2013). Nevertheless, it should be noted that few workers complain about their companies' safety culture.

An important difference between the scientific and employee mental models of PM can be found in knowledge and beliefs about health effects. The findings indicate that employees of roadwork companies have little knowledge about the health effects of exposure to PM, beyond the fact that PM is bad for your lungs. While this is certainly true (Anderson et al., 2012; Hänninen & Knol, 2011), the evidence for cardiovascular diseases because of PM exposure in roadwork companies is stronger (Meier, 2014), and employees tend to be unaware of those cardiovascular diseases. Furthermore, the way in which roadwork employees speak about health effects – often claiming that PM is bad for you without giving many more details – indicates that their ideas may be based more on hunches than on facts, and that they need more detailed information about long-term effects of PM exposure. Another thing that leads to confusion is the invisibility of PM; some workers are under the misconception that PM is in fact visible, which might lead to workers not protecting themselves in situations where they should, because they are not seeing any PM.

The most important aspects of PM for workers to know, according to the participants in this study, would be health effects and reduction methods. Dosimetry and physical or chemical characteristics of PM were mentioned, but considered less important. Although literature does not give details on which aspects to focus on when it comes to PM risk communication, research does suggest that blue-collar workers value practical and direct instructions over more theoretical and thorough explanations (Niewöhner, Cox, Gerrard & Pidgeon, 2004; Petts et al., 2002). It should be noted, however, that employee mental models of PM characteristics tend to be lacking and in conflict with each other, for example concerning the visibility of PM and the presence or absence of quartz and asbestos. The mental models approach recommends focusing on subjects such as these in risk communication, so that misconceptions are alleviated and omissions are filled (Morgan et al., 2002).

Empowerment to work safely

The mandatory periodical work safety meetings remain the most salient source of risk information throughout the roadwork branch. Research supports periodical repetition of the most important risk information (Hasle et al., 2014), as well as periodical meetings about health and safety (Nielsen, 2014), and therefore the idea of these meetings is well supported. Currently, many instructions are read out aloud or even just given on paper, and the meetings simply require a signature to complete them. For these meetings to fulfill their aim, they should be taken more seriously, both at the top and at the bottom of the company hierarchy. If the system sheds this problem, it could provide a framework for development of better risk communication, provided companies consider workers' mental models as well as their individual needs.

Even though the meetings themselves are mandatory, there is ample freedom when it comes to their form. Petts et al. (2002) describe a wide variety of instruction methods, including "notices, posters, in-house bulletins, information sheets, circulars, safety committee minutes, incident and near-miss reports, meetings and team briefings" (p. 3). Literature recommends using a two-way system of sending and receiving (Visschers et al., 2011). This is in line with findings from this study, suggesting that communication within the hierarchy can be improved.

Some frictions were found in the roadwork branch when it comes to authority, which was also found in earlier research (Lipscomb et al., 2013; Sunstein, 2016). Besides their more advanced technical knowledge about risk, safety specialists should also value the pragmatic insights from blue-collar workers (Slovic & Weber, 2002). Communication within the hierarchy could easily take place in work safety meetings, as referred to by several participants in this study; this could help with the need for employees to be heard (Hambach et al., 2011). By using the work safety meetings as platforms for discussing possible improvements in the work safety area, while also allowing more input from the workers themselves, these meetings could shed the problem of being too ritualistic, and they could provide a way for employees in all layers of the company to share their ideas on PM mitigation. This idea of getting employees more involved in the safety process is associated with a positive safety culture (Christian et al., 2009).

Strengths and Limitations

This study provides insight into perceptions of PM risk and mitigation, as well as promising leads for development of better risk communication in roadwork companies regarding PM, but there are also some limitations. We focused on the situation in the Netherlands, but this does not consider different approaches in surrounding countries. Furthermore, additional risk communication systems beyond the periodical meetings, such as incidental participation evenings or instruction booklets, might not be getting enough attention. Finally, since this qualitative study only focused on a limited number of participants, the findings cannot be generalized to the entire roadwork branch. It is also possible that there was some selection bias involved, since we did not get any details from companies how employees were recruited for this study. Nevertheless, this study can be used as a starting point for further research into risk communication regarding PM, and it will help to improve its status in roadwork companies.

Conclusions & Recommendations

Our findings suggest that blue-collar workers in roadwork companies tend to have sufficient knowledge about protective measures against PM, but they do not always know why and when they should use them. Their knowledge and beliefs about the properties (i.e. the composition and perceptibility) and health effects of PM are incomplete, which may contribute to a lack of risk awareness. Other than discrepancies in the mental models of PM, we also found various factors that are perceived to be detrimental to the effectiveness of periodical work safety meetings, of which ritualism seems to be the most salient.

We recommend a further development of work safety meetings regarding PM to empower workers, provided they are performed as an actual method of risk communication and not just as a ritual. The mental models approach in this article provides a good starting point for investigating the most necessary bits of information. For example, the invisibility of PM and the visibility of 'normal' dust that is present at the same time have proven to lead to confusion, so this subject should certainly be included. Beyond that, a focus on health effects and reduction methods, with the rationale behind them, seems plausible; participants in all layers of the hierarchy agree that these subjects are important. Including the characteristics and possible sources of PM can make workers more aware of risk situations and help to decide when to use which reduction methods.

Blue-collar workers need information on these subjects, but mostly they need a dialogue on various mitigation methods, in which all layers of the hierarchy can be involved. This should lead to an improvement not just in workers' safety knowledge, but also their safety motivation. As it turned out, various types of employees mentioned mitigation methods not even mentioned in literature, sometimes very creative and potentially useful in practice. For this reason, and in order to help with workers' need to feel heard, an improved system of interactive work safety meetings could help improve safety culture and empower blue-collar workers in work environments with PM exposure risk.

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4

DEVELOPMENT AND USABILITY OF EDUCATIONAL MATERIAL ABOUT WORKPLACE PARTICULATE MATTER EXPOSURE

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Abstract

Background. Particulate matter (PM) exposure is an important health risk, both in daily life and in the workplace. It causes respiratory and cardiovascular diseases and results in 800,000 premature deaths per year worldwide. In earlier research, we assessed workers' information needs regarding workplace PM exposure, the properties and effects of PM, and the rationale behind various means of protection. We also concluded that workers do not always receive appropriate risk communication tools with regards to PM, and that their PM knowledge appears to be fragmented and incomplete.

Methods. We considered several concepts for use as an educational material based on evaluation criteria: ease of use, costs, appropriateness for target audiences and goals, interactivity, implementation issues, novelty, and speed. We decided to develop an educational folder, which can be used to inform employees about the properties, effects and prevention methods concerning PM. Furthermore, we decided on a test setup of a more interactive way of visualisation of exposure to PM by means of exposimeters. For the development of the folder, we based the information needs on our earlier mental models-based research. We adjusted the folder based on the results of ten semi-structured interviews evaluating its usability.

Results. The semi-structured interviews yielded commentaries and suggestions for further improvement, which resulted in a number of alterations to the folder. However, in most cases the folder was deemed satisfactory.

Conclusion. Based on this study, the folder we developed is suitable for a larger-scale experiment and a practical test. Further research is needed to investigate the efficacy of the folder and the application of the exposimeter in a PM risk communication system.

Keywords: Particulate matter; risk communication; occupational exposure; educational folder

Background

Particulate matter (PM) is an important exposure risk in society (WHO, 2013), as well as in various workplaces, for example in roadwork companies (Meier, Cascio, Danuser & Riediker, 2013; Van Deurssen, 2015). People in these companies regularly inhale the small particles of PM, especially ones with a diameter smaller than 2.5 µm ($PM_{2.5}$), resulting in potential detrimental health effects (Hänninen and Knol, 2011; Strak, 2012). These effects may include cardiovascular and respiratory diseases, such as lung cancer and bronchitis (Hänninen and Knol, 2011). The effects of PM exposure are estimated to cause around 800,000 annual deaths worldwide (Anderson et al., 2012). Protection against PM involves such measures as sprinkling water, respirators, filtering systems and ventilation (Heederik et al., 2009; Uchiyama, 2013). Research shows that personal protection against PM, mainly in the form of various types of respirators, has a profound effect on PM reduction; however, not all workers that are exposed to PM use them appropriately (Liu, Noth, Eisen, Cullen & Hammond, 2018).

The protection motivation theory, or PMT (Rogers, 1983), distinguishes two processes that influence the motivation to protect against risk. These processes are threat appraisal, which is the perceived expected risk subtracted by the benefits of risky behavior, and coping appraisal, which is the perceived efficacy of protective behavior subtracted by its cost. In general, a higher threat appraisal and a higher coping appraisal lead to a higher tendency to protect oneself against a certain risk. However, in some cases, higher threat appraisal might be counterproductive, and cause people to ignore the message (Goldenbeld, Twisk & Houwing, 2008; Ruiter, Kessels, Peters & Kok, 2014). This may be explained by fear eliciting a maladaptive response as people avoid the risk communication message rather than the risk itself (Rogers, 1983). However, not all researchers agree that these counterproductive effects exist, and some say there is simply a cap on the benefits of threat appraisal (Tannenbaum et al., 2015). Either way, these factors should be taken into account when designing a risk communication material.

In earlier research (Stege et al., 2019), we assessed specific information needs of employees in roadwork companies concerning PM exposure. We did this by means of a mental models approach. Mental models can be defined as *"personal, internal representations of external reality that people use to interact with the world around them"* (Jones et al., 2011). In risk communication and risk perception research, the mental models approach is a systematic way to map these representations of a risk (that is about sources, properties, exposure, effects and mitigation options), and to contrast the representations of various groups of people, such as experts and non-experts (Breakwell, 2001; Morgan, Fischhoff, Bostrom & Atman, 2002). The concepts of threat appraisal and coping appraisal from the PMT model mentioned earlier resemble the various aspects of mental models of risk. That is, beliefs about sources, hazardous properties, exposure and effects of a certain risk are closely linked to threat appraisal, and beliefs about mitigation methods can be linked to coping appraisal.

After mapping the mental models of various groups, the differences between them are used to identify information needs in risk communication. This way, risk communication can alleviate common misconceptions and answer common questions about the subject matter (Slovic & Weber, 2002). The mental models approach has been used in a wide array of risk-related subjects resulting in suitable risk communication tools, ranging from flood prevention to cigarette smoking (Riley, 2014).

The mental models approach in our previous study (Stege et al., 2019) yielded a scientific and an employee mental model for particulate matter. The scientific mental model was extracted from literature on PM, and corroborated by interacting with experts in the field. The employee mental model was erected after conducting 22 semi-structured interviews with employees in the roadwork sector. An overview of the main differences between both of these mental models can be found in Table 1.

Subject	Scientific mental model	Employee mental model
Properties	PM is usually invisible	It is unclear whether PM is visible or not
	It is not possible to smell PM	It may be possible to smell PM
	Black carbon, metals, silicium and rubber are important constituents of PM	-
	Particle size is most often defined in terms of PM_{10}, $PM_{2.5}$ and $PM_{0.1}$	-
	PM mostly consists of solid particles, but may also include liquid particles or semi-volatile compounds.	-
Sources	-	Sand and dirt roads cause PM
	There are natural sources of PM, such as sea salt, which don't cause adverse health effects.	-
Effects	-	PM exposure may cause headaches and nausea
	PM exposure is associated with cardiovascular disease, even more so than with respiratory disease	(Almost) no mention of cardiovascular disease; only attention for respiratory diseases
	PM causes about 800,000 annual premature deaths worldwide.	-
	PM is also an environmental risk (for example due to acid rain or nutrient depletion).	-
Prevention	There is an occupational hygiene strategy that involves a four-level hierarchical model, which should be followed to reduce PM exposure.	There are a large number of prevention methods (sprinkling water, respirators, …) that could be used to reduce PM exposure.
Education and empowerment	A viable education system improves safety culture and willingness to protect against (exposure) risks.	The current education system could be improved; it is often too ritualistic and repetitive, and not everyone is involved with the process.

Table 1. Overview of discrepancies between scientific and employee mental models (Stege et al., 2019).

One question that comes to mind is how to convey quantitative risk information about health effects and exposure. Research recommends using a so-called 'X in 100' format to convey the potential health effects in a population (Trevena et al., 2013; Visschers, Meertens, Passchier & De Vries, 2009), as percentages alone may confuse the reader and lead to false interpretations. These 'X in 100' formats are generally preferred by respondents to similar formats such as '1 in X' (Visschers et al., 2009). In general, visually enhancing risk information with graphs tends to be more effective than simply providing verbal or numeral information (Fischhoff, Brewer & Downs, 2011; Lipkus, 2007). Our own experience in an earlier study was that employees in the roadwork branch tend to find graphs about workplace exposure interesting and insightful (Bolte et al., 2018).

Nevertheless, graphs can also be inadvertently misleading; an example of this involves participants judging a cardiovascular risk from a bar chart as relatively low compared to 100%, even though experts would say that the risk is quite high (Damman et al., 2015). Therefore, it is imperative to choose an appropriate format. Specifically, when considering the number of individuals affected in a population, a ten-by-ten matrix of human icons may be used to convey a percentage (Lipkus, 2007). Visualizations such as these help reduce several biases, including framing effects and denominator neglect (Trevena et al., 2013), although their effectiveness is not explained by an improvement of exact knowledge about the risk; only 'gist knowledge' appears to be increased (Etnel et al., 2020).

In our situation, we would like to give a rough but accurate estimate of the health risk of PM, in order to induce an accurate representation of the risk. Exact numbers for the amount of work-related deaths due to PM are unknown, as the earlier mentioned 800,000 deaths per year worldwide applies to all people in general, without any indication how many of these deaths are work-related (Anderson et al., 2012). There are studies that estimate the burden of disease for workplace exposure, although these studies generally only take forms of cancer into account, not other adverse health effects; one estimate states that 10% of all lung cancer in males and 5% in females can be attributed to work, which amounts to a worldwide DALY loss of 969.000 (Driscoll et al., 2005). Another estimate can be generated from a factsheet about hazardous substances at work (Arboportaal, 2018), which mentions that one million people in the Netherlands are exposed to one or more hazardous substances at work, and 3,000 of those people die each year. Although these may be various types of substances and not just PM, the most important substances mentioned are all a form of PM, such as diesel emission (Heederik et al., 2009) or quartz (Van Deurssen, 2015).

In our earlier research (Stege et al., 2019), we found that interventions in the workplace about exposure risks tend to focus on a specific substance. Work safety meetings about, for example, minuscule quartz or wood particles appear to be more commonplace than work safety meetings about PM in general. We decided to broaden the scope to PM in general for this study for several reasons. Many of these types of PM are caused by similar acts, such as sawing and drilling. Although the substances that are a part of PM differ in their toxicity, the effects on the human body are still explained for a significant part by their particle size as well, as the small particles enter into the lungs and blood stream (Hänninen & Knol, 2011). For these reasons, we decided to develop an educational material with a focus on PM in general, mentioning various types and sources of PM in the material itself. It should be noted that, because of this decision, our educational material should be used with the goal of general health promotion in mind, in smaller-scale work safety meetings. For more in-depth education on a specific subject or a specific content of particulate matter, additional educational material on potential adverse health effects may be needed.

In this study, we considered the aforementioned recommendations about contents as a basis for developing and testing new educational material about workplace PM exposure. Next, we will present the method by which we developed this new educational material. Furthermore, we consulted experts on risk communication, particulate matter, or both, as well as workers that may be exposed to PM, in order to inquire about the usability of our educational material. The question we would like to answer is, 'How do stakeholders perceive the usability of a mental model-based educational material about workplace PM exposure?'

Methods

Materials

We considered six potential concepts for use as an educational material: a folder, a presentation, an instruction movie, an e-learning tool, a serious game, and a practical assignment. We chose these six concepts to accommodate for a large range of options in complexity and scale. We evaluated each of these six options based on the eight criteria mentioned of the SECTIONS model, a framework for selecting an appropriate medium for education developed by Bates & Poole (2003). A detailed evaluation of these six options by Bates & Poole's (2003) criteria, including a table, can be found in Appendix A.

Based on the SECTIONS model, we decided to develop an educational folder, provide companies with an opportunity to incorporate the folder into a presentation, and amplify the intervention by adding a practical assignment. This way, we cover all of the eight criteria mentioned by Bates & Poole (2003) in our intervention. At present, a suitable assignment already exists to be used in practice with minimal adjustments (Bolte et al., 2018); however, a suitable educational folder still needs to be developed. For that reason, the remainder of this article focuses on the development of the folder.

When designing an educational folder, the contents should first be decided. Based on our previous study (Stege et al., 2019), we assessed the information needs of workers in road work companies about the properties, sources and effects of PM, as well as mitigation methods and, wherever possible, the rationale behind them. A schematic overview of the folder we developed can be found in Figure 1.

Since workers tend to value practical instructions over technical details (Niewöhner et al., 2004; Petts et al., 2002), we minimalized the technical details. Limiting these technical details also helps prevent information overload (Chen, Pedersen & Murphy, 2012). For example, we omitted the distinctions between PM_{10}, $PM_{2.5}$ and $PM_{0.1}$, which is often used in more academic settings to signify particle size (where PM_{10} refers to particles with a standardized diameter smaller than 10 µm, and so on). In occupational settings, the terms 'inhalable', 'thoracic' and 'respirable' are often used instead of defining particle size by the micrometer, which is more practical, but still has the downside of including technical terminology which may not be necessary. Nevertheless, the distinction between PM that can permeate deep into your lungs and blood stream and coarser fractions of PM that cannot is important. Therefore, we explain in the folder (with an image) on page 2 and 3 that the smaller the particles get, the deeper they can permeate your body.

Page 4 describes sources and activities that may cause PM, and page 5 and 6 visualize the exposure and the risk, respectively. On page 6 and 7 we specifically addressed various mitigation methods using a practical hierarchical model that showcases which mitigation methods should be prioritized (the four-step STOP model; Substitution, Technical measures, Organizational measures and Personal protection) (Heederik et al., 2009). In order to accommodate for the tensions that may arise between different levels of the company hierarchy (see Stege et al., 2019), the possible mitigation methods were split in two columns, 'What can the company do' and 'What can I do'.

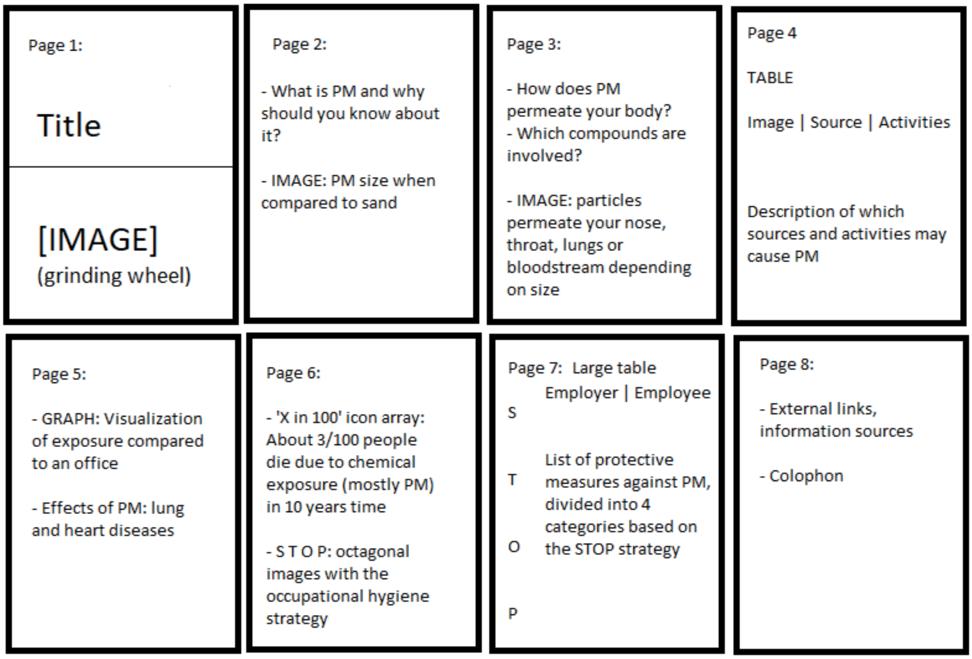

Figure 1. *Schematic overview of the folder.*

We used the differences between the mental models (see Table 1) to determine which bits of information should be included. For example, we mentioned that PM is usually invisible, due to the fact that it consists of very small particles, and cannot be smelled. We did not include the distinctions between PM fractions such as PM_{10}, as mentioned before, but we did mention that black carbon and rubber are important constituents of PM that may cause adverse health effects. We left out any references to ecological effects, since this study is concerned with individual health risks.

Regarding the effects, we mentioned that PM can not only cause lung diseases, but also cardiovascular diseases. We lead with the more well-known lung diseases in the folder, giving examples such as bronchitis and lung cancer, and then we mention that PM may have other effects as well, such as heart diseases. We gave a general indication of the number of deaths per year in the Netherlands, as we felt that this would resonate more with our target group than the number of deaths worldwide. Finally, we included an 'X in 100' graph based on the data from a factsheet on chemical exposure in the Arboportaal, the website for Occupational Health and Safety of the Dutch Ministry of Social Affairs and Employment, giving an indication of the chance of premature death for workers exposed to PM (see Figure 2).

Figure 2. *'X in 100' graph, as recommended by literature (Timmermans & Oudhoff, 2011; Trevena et al., 2013; Visschers et al., 2009).*[1]

Procedure

In order to investigate the usability of the newly designed educational folder, we contacted four experts and recruited six workers regularly exposed to PM in the workplace for a usability test (more details can be found in Table 3). We conducted a semi-structured interview with each of these participants, face to face and one on one, for ten interviews in total. We developed the interview guideline ourselves, but many of the questions we asked were based on the Suitability Assessment of Materials (SAM) tool (Doak et al., 1996), which is a tool used primarily to assess the quality of instructions about health related issues for people with low health literacy. The criteria from the SAM involve content, literacy demand, graphics, layout, learning stimulation, and cultural appropriateness (Doak et al., 1996).

The interviews for the experts started with a few questions where they could specify their daily work and their expertise on PM and risk communication. Subsequently, we asked

1 The text reads (in Dutch): 'Number of people similar to you that die prematurely in the next 10 years due to chemical exposure.' The folder goes on to explain that these chemical exposures are mostly PM-related. It should also be noted that this is image does not comply with the normal 10x10 standard of the icon array, a choice that was made due to layout issues but was ultimately deemed invalid; it was fixed in a later version (see Figure 3 in Appendix B)

about the material, starting with a question about the participants' general impression. We followed with questions about the contents; especially important to us was whether there were any scientific inaccuracies in the folder. We also asked questions about the amount of information, the build-up, the layout, and whether there was enough focus on practical advice, as this is recommended by literature (Niewöhner et al., 2004; Petts et al., 2002). We also asked how we should cope with potential downsides of our folder, such as the lack of interactivity (Bates & Poole, 2003) and the absence of an explicit introduction or conclusion section in our folder (Doak et al., 1996).

Similar to the expert interviews, the worker interviews started with questions about their daily activities at work, including a question whether they work more inside or outside. This was to get an indication how these workers may be exposed to PM on their job. Beyond that, we asked the workers similar questions about the folder as well, related to the contents, amount of information, build-up and lay-out. We also asked about the workers' perceptions of PM after reading this folder, including a question whether they were now more inclined to protect themselves, to get an initial indication about the practical applicability of the folder. As always, both interviews concluded with the question whether there was anything else to add. The full interview guidelines, both for the expert and worker, can be found in Appendix C.

Participants

The four experts were all professionals working for health and safety related institutes, and they were recruited from the professional network of the researchers. Two of the four experts worked for the National Institute of Public Health and the Environment (in Dutch: RIVM), one worked for an institute involving agricultural safety, and one worked for the organisation for occupational health and safety in the Netherlands (Arbo Unie). They all had ample knowledge both about PM itself and about risk communication, and they all had at least ten years of work experience with PM or similar exposure risks as well as a higher education on toxicology, epidemiology or an equivalent study. They were asked for informed consent before the interview, none of them objected to the recording of the interview.

The six workers that may be exposed to PM were recruited from the Flycatcher panel, which is an internet research company from the Netherlands that hosts an ISO certified online panel, for use in studies that require representative samples of participants. To select participants, two questions were asked : 'Do you work outside or near the side of the road', and 'Do you work with machinery or carry out activities such as sawing, drilling or lawn-mowing during your work?', with the answering options of 'often', 'regularly', 'sometimes', 'rarely', or 'never'. Participants who answered 'often' or 'regularly' to one or both of the questions and indicated to be interested in participating in an interview were eligible to participate in the interview. This process yielded 39 potential participants with interest in participating. Out of these 39, six participants were selected non-randomly, in order to incorporate various branches, age groups, levels of education, and regions of the country in our sample. These details can be found in Table 2. The participants were asked for informed consent as well as permission for recording the interview.

#	*Area of work*	*Level of education*	*Region*	*Age group*	*Gender*
1	Logistics	High	North Holland	60-64	Male
2	Logistics	Low	Gelderland	65+	Male
3	Construction	Medium	Utrecht	30-34	Male
4	Construction	Medium	Gelderland	60-64	Male
5	Agriculture	Low	Overijssel	55-59	Female
6	Construction	Medium	South Holland	35-39	Male

Table 2. Area of work, level of education, region, age and gender of the six participating workers.

Analyses and follow-up

After conducting the expert interviews, the first author summarized transcripts and analyzed the interviews in a question-and-answer format. For the expert interviews, we collected all potential improvements to our material suggested by one or more experts into a table (see Table 3). Most of the potential improvements from the expert interviews were straightforward, so we decided to make some adjustments to the folder before starting the worker interviews. Some suggestions, however, proved to be more controversial. One expert thought we should remove the '3 in 100' icon array, because it was based on a calculation that they deemed questionable and confusing. However, two other experts were in favor of maintaining it, praising the insightfulness and the visual appeal of the illustration.

The worker interviews were analyzed in the same way as the expert interviews. Since there were not nearly as many suggested improvements by the workers, we decided not to assemble these in a table, but instead opted to show some of the most relevant quotes from these interviews, as is good practice in qualitative research.

Suggested change:	[2]Multiple experts suggest?	Disagreement among experts?	Led to change in folder?
CONTENT			
Clarify that not all types of PM may cause cancer	N	N	Y
Smoking is a source of PM, but should not be in the folder, since it is not work-related	Y	N	Y
Exhaust gases are a source of PM, but should not be in the folder, since it is not work-related	N	N	N
Legal exposure limits should be included	N	Y	N
Mention that not only peak exposure, but also overall exposure is important	N	N	Y
Maintain the calculation that shows '3000 people dying as a result of PM', but make sure it does not cause confusion	Y	N	Y
LITERACY DEMAND			
Use simple language and remove complicated idioms	Y	N	Y
Use nuanced and objective language	Y	N	Y
GRAPHICS			
Remove the 'X in 100' array	N	Y	N
LAYOUT			
The order of the folder should start with the measures against PM	N	N	N
Have an introduction section and a conclusion	N	N	N
LEARNING STIMULATION			
Clarify that there are various types of respirators, not all of which are effective against PM	N	N	Y
'Process automatization' should be mentioned as a measure against PM	N	N	N
'Vacuum cleaning instead of sweeping or using compressed air' should be included as a measure against PM	N	N	Y
Sweeping the floor should be mentioned as a cause of PM	N	N	N
Provide a reference to a common VEM system (Video Exposure Monitoring) at the back of the folder[3]	N	N	Y
Remake the folder into a collection of separate elements which can be combined by a professional, to be more tethered to a specific target group	N	N	N
CULTURE			
Show types of jobs with high PM exposure, instead of just tasks	N	N	N

Table 3. Experts' suggestions about a workplace PM exposure folder

2 Legend: The column 'Multiple experts suggest' signifies whether or not a particular recommendation was done by more than one of the four participating experts in this study. The column 'Disagreement among experts' signifies whether or not a particular recommendation by one expert was explicitly disapproved of by another expert. The column 'Led to change in folder' signifies whether or not we made any changes to the folder based on a particular recommendation. (Y = Yes, N = No)

3 VEM or Video Exposure Monitoring is a movie-based method of instruction, in which people are shown doing work in ways that cause high and low levels of exposure to a certain agent (Beurskens-Comuth, Verbist & Brouwer, 2011).

Results

Recommendations from expert interviews

The four experts gave a large number of recommendations for the folder, most of which were relatively minor. The results of these interviews will be presented in the form of a table (see Table 3), and classified within the six main categories of the SAM tool (Doak et al., 1996): content, literacy demand, graphics, layout, learning stimulation, and cultural appropriateness. Minor adjustments, such as changes of a single word or phrase, are not shown in this table. Some suggestions were done by several experts, and these always led to a change in the folder; other suggestions by one expert were explicitly disagreed with by another expert, and these suggestions never led to a change in the folder. However, all suggestions, including these, were evaluated on a case-by-case basis. This can also be seen in more detail in Table 3.

Recommendations from worker interviews

Contrary to the four experts, the workers had few comments about the folder. When asked what their general impression was, most workers responded that they were satisfied with how the folder looked, although some of them still made a few suggestions for improvement. Some more detailed descriptions of participants' views will be outlined below, and they will again be classified within the six categories of the SAM tool (Doak et al., 1996).

Content

One participant stated that wood particles should be mentioned as a source of PM somewhere. One participant thought that a recommendation to work night shifts should not be in the folder, since it would lead to other adverse health effects. Another recommendation would be to add a clarification how long respirators can be used:

> *For how long can you use a respirator? It is never stated on the thing itself. I always wait until it looks dirty, [...] but then I am too late already. [worker 3]*

Based on these comments, we removed the recommendation to work night shifts, and we added wood particles as one of the forms of PM near the '3 in 100' icon array, as wood particles are also mentioned in the source material. As there is no clear-cut answer to the question how long respirators should be used, we would have needed to expand the folder quite a bit to address this issue thoroughly enough; we decided against this to maintain its brevity.

Literacy demand

The participants had no clear problems regarding the understandability of the text. One interesting problem was found in the four-step occupational hygiene strategy, regarding the word 'Substitution', of which at least one participant did not know the meaning. However, since this word is essential in maintaining the four-letter STOP strategy for occupational hygiene, we kept it in. Otherwise, no problems with the difficulty of the text were identified. Several participants correctly identified that PM is invisible, and that its health effects may include not only lung diseases, but also cardiovascular diseases.

Some of the phrases in the folder inadvertently led to misconceptions. For example, one participant thought that three in hundred workers who are exposed to PM acquire adverse health effects, which indicates that they took the '3 in 100' icon array to mean something different than intended. One other participant correctly identified that the '3 in 100' refers to deaths, but thought that only 3 in 100 died of PM exposure in their lifetime, even though it is meant to refer to the next ten years. We discuss the issues with the icon array further in the discussion section, as well as in Appendix B.

Graphics

Regarding the layout, participants thought that the folder looked professional and that the illustrations helped to maintain the interest of the reader. Therefore, no changes to the graphical layout were made. Worker 4, who contrasted our folder with an existing folder about PM and pneumoconiosis, stated that ours avoids the mistake of overwhelming the reader, for example with a picture of a dying man with a severe lung disease:

> *One of my colleagues died in 2014, lung cancer due to asbestos.[…] If you look at the hospital bed, you are reminded of that thing [company name] gave us [because it shows a dying man due to pneumoconiosis]. […] I do not like what they are doing; they should not do that. […] You should not see someone die like that. I find this much more appealing and a better explanation. [worker 4]*

Layout

Two separate workers, both of whom were above 60 years of age, thought that the font was too small. Therefore, we increased the font size of the folder (see also Appendix B). Otherwise, no further comments regarding the layout were found.

Learning stimulation

One participant was not quite sure whether the amount of information in the folder was adequate, and that it may be either too little or too much depending on the situation in which it would be used. On the other hand, one participant specifically praised the amount of information, and contrasted it with an existing, much more elaborate folder about PM and pneumoconiosis:

> *It is just fine. No more is needed. […] You can give a lot more information, if you are sawing than you need to do this, but [everything you need] is in here. [Company name] gives way too much information, that is their down side. [worker 4]*

Culture

Several participants asked whether the folder was going to be translated in other languages, specifically languages of common minority groups in the Dutch workforce. This is illustrated by the following quotes:

> *Will it also be in other languages? Because there are always a lot of Polish guys working there. [worker 1]*

> *Foreigners, they do not know anything about this. So you should translate this into ten different languages. [worker 2]*

At present, no foreign language versions of the folder exist, but this may change in the future.

Discussion

In this article, we discussed the development of an educational material to provide workplace risk communication on PM exposure risk, and we asked the question to what extent experts and workers would value the usability of this educational material in the workplace. We investigated various methods of instruction, assessed a combination of a folder embedded in a company training with a practical assignment to be the best fit, and subsequently developed the folder based on our earlier findings from our mental models study (Stege et al., 2019). The resulting folder was presented to ten stakeholders – four experts and six workers that may be exposed to PM – which led to a considerable amount of commentaries and suggestions. More details on the adjustments based on these suggestions can be found in Appendix B.

Strengths and limitations

Reflecting on the process by which we developed the folder, it is noteworthy that we used a combination of various models and methods. A strength of combining these models and methods is the way in which they supplement each other. We used the mental models approach to identify stakeholder information needs, in order to provide appropriate information in the folder from the user's perspective (Morgan et al., 2002; Riley, 2014; Slovic & Weber, 2002). For example, the fact that PM is mostly invisible and the fact that it may cause cardiovascular diseases are often unknown to workers (Stege et al., 2019), so we included these bits of information in the folder to alleviate common misconceptions. The protection motivation theory, or PMT (Rogers, 1983), then plays a role in ordering and structuring the information. We present facts about PM such as its invisibility and its tendency to cause (cardiovascular) diseases first, in order to increase threat appraisal; then, near the end of the folder, we thoroughly discuss prevention methods in order to increase coping appraisal. This focus on coping appraisal is especially important within the framework of the PMT, because only focusing on threat appraisal may be counterproductive for improving safety behavior (Goldenbeld et al., 2008; Ruiter et al., 2014).

The mental models approach and the PMT gave us insights in which information should be presented, but the SECTIONS model (Bates & Poole, 2003) answered the question how it should be presented. From six potential concepts of an educational material, we eventually chose two that may be combined, namely the folder and the practical assignment. We chose for these two options, as the positive and negative aspects of these concepts appear to balance each other out, and the two concepts appear to be most suitable for our situation; furthermore, the practical assignment makes the health threat we discuss in the folder more tangible by means of active learning (Boswell & Eison, 1991). The folder was filled in with the information as determined by the mental models approach and the PMT.

Finally, we kept the principles for designing educational material for low health literacy people in mind as mentioned by the Suitability Assessment of Materials (SAM) tool (Doak et al., 1996), and we also used this SAM tool for a formative evaluation within the context of the usability test in this study. After combining these methods and theories to design and develop our folder, we tested and adjusted the layout and contents of the folder based on comments by both professional occupational hygienists and workers in professions involving particulate matter. The method we used to develop this folder resulted in a product that was generally viewed as favorable by the participants in this study. This can be seen by the nature of their suggestions, as they mostly suggested minor alterations and clarifications, while the main contents, layout and structure were often praised.

Nevertheless, the method we used has its limitations. There is no theoretical basis to assume that the different models can be integrated. The SECTIONS model itself is not based on evidence from learning and behavior theories, but experience-based and highly subjective; this is acknowledged by the authors, who argue that "*decision making in this area cannot be driven by hard and fast formulae or rules*" (Bates & Poole, 2003). Indeed, a more scientific approach to this end does not appear to exist. However, we found that making use of these models supplements the mental models approach, as the mental models approach mostly answers questions related to the content of the material, whereas the shape and the usability of the material are equally important.

A limitation of the usability test itself, of course, is the small sample size. We only included a small number of participants in this study so that we could focus on the design and the development of the folder before testing it in a larger-scale experiment. In most cases, we were able to find a consensus on the preferred design of the folder. However, this was not the case for the risk visualization, as experts strongly disagreed among each other whether the

‘3 in 100’ icon array should be used in our folder. The visualization itself was commended by two of the four experts; however, the calculation on which the image was based was seen as vague and even potentially misleading. Indeed, direct data on worker deaths due to PM was unavailable, and we used data from all chemical exposure (including but not limited to PM) instead, but we clarified this in the folder. Interestingly, another issue with the icon arrays was found in literature, as studies disagree whether this type of visualization is sufficiently effective (Etnel et al., 2020; Lipkus, 2007; Trevena et al., 2013). Overall, the question whether the icon array should be included in our folder remains unresolved, and more research on this subject is needed.

Finally, one limitation of this study is the focus on the folder. In the Method section of this article we described a design involving both a folder and a practical assignment. We are aware that the usage of the folder alone may not result in the outcomes of awareness and attitude that we would like to achieve. Nevertheless, as mentioned, an assignment from an earlier study (Den Broeder & Bolte, 2018) can likely be reused with minimal changes, and we will study the combination of such an assignment and our folder in future research.

One downside that cannot be alleviated is costs. A work safety meeting that involves our proposed design consists of four steps: filling out a pretest questionnaire, reading a folder, fulfilling a measurement assignment at the workplace and filling out a posttest questionnaire. The time constraint easily adds up to half an hour on the folder and half an hour for the measurement assignment, and on top of that half an hour for discussing and explaining the measurements. Furthermore, the measuring equipment invokes considerable financial costs. Nevertheless, we found in our earlier study (Stege et al., 2019) that work safety meetings that consist of only reading material are heavily criticized and appear not to be very effective. Therefore, we will test the combined method of folder and measurement assignment and will add a reflection of the total costs and benefits.

Conclusion

As a result of this study, we deemed the updated version of the folder fit for a larger scale experiment. In this experiment, we will test the learning effects of our folder. We will also investigate whether our newly developed folder has any added effect compared to existing material, when evaluated on PMT-related outcomes of threat appraisal, coping appraisal and safety behavior. Since the '3 in 100' icon array has proven to be controversial, there will be two versions of this folder, one with and one without the icon array. We will test both of these versions against each other and against an existing folder in a digital experiment, and we will include a control condition with an unrelated text. After further studying the quality of the folder, we proceed by testing the folder alongside the assignment at the workplace. This practical test will investigate the added effects of the assignment as opposed to only using the folder, and it has the additional benefit of testing the folder in a practical setting.

Abbreviations

ISO: International Organization for Standardization

PM: Particulate Matter

PMT: Protection Motivation Theory

RIVM: Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)

SAM: Suitability Assessment of Materials

SECTIONS: Students, Ease of use, Costs, Teaching, Interactivity, Organizational issues, Novelty & Speed

SPR: Strategic Programme RIVM

UMC: University Medical Center

VEM: Video Exposure Monitoring

WHO: World Health Organization

WMO: Wet Medisch wetenschappelijk onderzoek met mensen (Medical Research Involving Human Subjects Act)

Declarations

Ethics approval and consent to participate: The authors declare that all participants consented verbally to participation in this study; this consent was documented by recording the participants' explicit approval prior to the recording of the interview itself. No ethics approval is needed according to Dutch law, considering the fact that we only made use of interviews in this study: *In the Netherlands, the Medical Research Involving Human Subjects Act (Wet Medisch wetenschappelijk onderzoek met mensen, WMO) came into force since 1998. All medical scientific research in which humans are subjected to (medical) procedures or are required to follow rules of behavior, falls under the scope of this Act. All other research with humans (e.g. research with medical data or interviews) is not subject to the WMO.* (Amsterdam UMC, n.d.)

Consent for publication: No detailed individual information was presented in this article.

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Authors' contributions: The first author (TS), a PhD candidate, is the main writer of this article as well as the interviewer. The second author (JB), an occupational epidemiologist, is the project leader and the grant writer for the project in the SPR framework mentioned above. The third author (LC), a communication scientist, is a thesis advisor. The final author (DT) is the promotor, mainly responsible for scientific content and quality. The second, third and fourth authors all provided critical comments and substantial alterations to this article, as well as valuable input for the study design. All authors have read and approved the manuscript, and agree to be personally accountable for the result.

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Appendix A: Evaluation of six potential materials by means of the SECTIONS model (Bates & Poole, 2003).

The eight criteria in the SECTIONS model include: Ease of use, costs, appropriateness for the students, appropriateness for the learning goals, interactivity, organizational issues towards implementation, novelty, and speed (both speed of development and of revision). We will evaluate the six approaches we considered – a presentation, a folder, a movie, an E-learning system, a serious game, and a practical assignment – based on these eight criteria. The results can be found in Table 4. We will then elaborate on the choices we made in our evaluation, and discuss some other considerations before we made the final decision as seen in the main text of this article.

Criteria	Folder	Presentation	Movie	E-learning	Game	Assignment
Appropriateness for target audience ('Students')	+	-	+	-	-	+
Ease of use	+	+	+	-	-	-
Costs	+	+	-	-	-	-
Appropriateness for the learning goals ('Teaching')	-	-	+	+	-	+
Interactivity	-	+	-	-	+	+
Organizational issues for implementation	+	+	+	-	-	-
Novelty	-	-	-	+	+	+
Speed of development & revision	+	+	-	+	-	+

Table 4. Evaluation of the six potential educational materials by means of the SECTIONS model.

Students: An important issue in our situation is involving several types of workers in our intervention. There are large differences in literacy and level of education among workers. A presentation tends to have the downside of mostly answering the questions of those who already had some basic knowledge; e-learning systems and serious games may not be suitable for less educated employees. The remaining three options appear to have the highest chance of involving everyone.

Ease of use: The more complicated options – a serious game, an assignment and an e-learning system – all need a briefing or some practical instruction for the teacher in order to succeed. The other three options are more straightforward to use.

Costs: Developing a movie, e-learning system or serious game is very time-consuming and therefore expensive. A practical assignment is quicker, but measuring equipment can still drive up the costs.

Teaching/learning: A game tends to have many superfluous bits of information to the learning goal. Presentations and folders often make it difficult to maintain the learner's attention. The other three options are generally clear and interesting to the learner.

Interactivity: Interacting with a folder, movie or e-learning tool is not as easy as with a teacher giving a presentation, explaining the rules of a serious game, or giving an assignment.

Organization: A folder, a presentation and a movie can be implemented in an existing workplace situation more easily than the other three options.

Novelty: E-learning tools, games and assignments are not often used as a means of risk communication in workplaces yet, and therefore they are interesting for the novelty factor.

Speed: Adapting a movie or a game is extremely time-consuming; the other options are clearly more suitable for a 'rapid prototyping' idea.

Other considerations. The first option, a folder, is fairly easy to create based on our mental models research, and also easy to implement, since we had found that many companies already use similar materials for other safety-related subjects. On the negative side, however, a folder lacks interactivity, might not be sufficiently stimulating and thus not fulfill its learning goals, and it is not very original. Compared to a folder, a presentation is similar; it is more interactive than a folder, but it might not be as appropriate for the learners as they do not always have a solid reason to pay attention. A movie may be a lot more stimulating, but it is not very cost-effective. E-learning and serious games are useful educational tools, but we deemed them unfit for our current situation as they have too few upsides for a small-scope intervention such as this.

Finally, a practical assignment in the workplace, for example using a PM meter, is also viable option. For example, participants could use a PM meter with display, looking for the occupational activity or microenvironment generating the lowest and highest exposure. A real life measurement assignment such as this can be seen as a form of active learning (Bonwell & Eison, 1991), and thereby stimulates thinking. Moreover, it forces the participants to go over all activities and think about the exposure. Additionally, it may introduce a gaming element in which the group of participants is battling for the lowest and highest measurement results. In earlier research, we used wearable sensors to determine workers' exposure to PM and other agents, and gave them feedback by means of a presentation (Bolte et al., 2018). This sparked discussion about safety behavior, both work-related (mowing downwind) and not work-related (smoking). An assignment involving PM meters and magnetic field exposimeters has also been used before (Den Broeder & Bolte, 2018). In this earlier study on environmental exposures in an occupational setting with 40 higher educated professionals, it was shown that finding the highest and lowest exposure situations and discussing it in the group made them assess their environment seriously. These promising results may be extrapolated to our current situation.

Appendix B: Most important changes to the folder based on the interviews

We will discuss the most important findings and changes to our folder from the interviews, in accordance with the six categories of the SAM tool: content, literacy demand, graphics, layout, learning stimulation, and cultural appropriateness (Doak et al., 1996). However, no changes related to culture were made in our folder, so five of these categories remain.

Content

Some of the wordings were changed after the expert interviews, in order to accommodate for the fact that PM does not always cause cancer and that overall exposure is just as important to mention as peak exposure. We also made a number of changes based on the worker interviews, for example because working night shifts might not be ideal as a mitigation method, since it introduces new safety risks. For that reason, we removed any literal reference to night shifts, instead saying more generally that employers may adjust work schedules to combat PM exposure. We also added some information about the type of respirator that should be used.

Literacy demand

The folder was rechecked for language issues after some of the experts mentioned issues with difficulty and neutrality. Accordingly, we removed difficult wordings such as ‘prematurely deceased’, and we changed contentious phrases such as the description of PM as an ‘assassin’ to a more nuanced statement such as ‘PM is mostly known for its long-term effects’.

Graphics

The most noticeable change in graphics can be seen in the section with the ‘3 in 100’ icon array and the corresponding calculation. This may have been the most controversial part of the folder, with two experts claiming that the calculation was confusing and one expert insisting that the icon array should be removed altogether. Furthermore, various workers found the section to be confusing as well. We decided not to remove it, in order to stay in line with the theoretical background (Trevena et al., 2013), but we did overhaul the section to make both the image and the calculation clearer. The result can be seen in Figure 3.

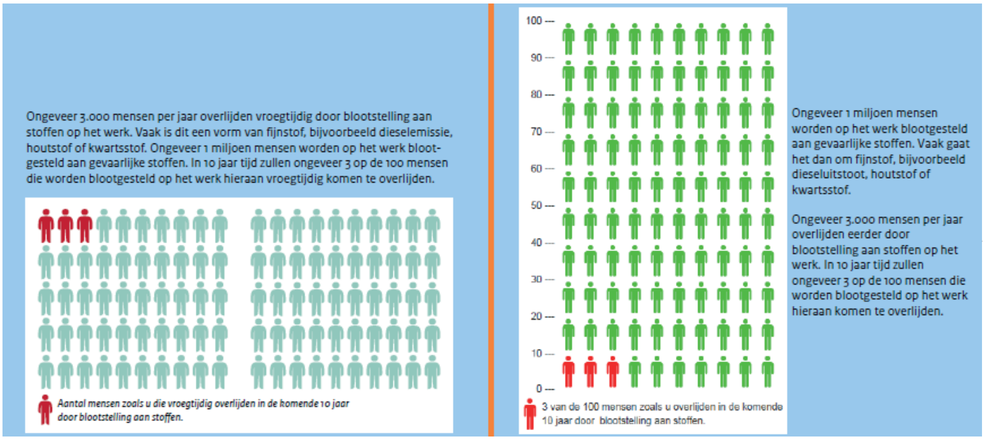

Figure 3. '3 in 100' icon array with calculation, in the pre-usability test (left) and post-usability test (right) versions of the folder.

Learning stimulation

The workers' comments about the amount of information, that may either be too high or too low depending on your specific purposes, did not lead to any further changes. The main reason for this is that our folder occupies a niche that is not yet occupied by any other material, and any more in-depth ideas can always be shared in a work safety meeting alongside the folder.

Appendix C: Interview guideline for expert and worker interviews

Expert interview

- [Welcome; Informed consent]
- Before we start talking about the folder, could you tell me something about your work / your expertise?
    - How many years of experience do you have?
    - What was your prior education?
- What was your general impression about the educational material?
    - [We show our material step by step and discuss the following aspects:]
        - [Design choice]
        - [Content selection: background, PM sources, health effects, measures]
        - [Mental model subjects such as: visibility, cardiovascular disease…]
        - [Illustrations, especially the visualizations of risk]
- What is your opinion about the material's contents?
    - Have you identified any factual errors? If so, could you elaborate?
    - What is your opinion about the amount of information?
        - Do you have any suggestions about which information to add or to remove?
    - How do you feel about the structure of the folder?
- Our main end users of the folder would be practically educated employees working in the roadwork and construction branches. To what extent do you feel that this material fits the end users?
    - Could you elaborate on language use?
    - Could you elaborate on the appropriateness and content of the illustrations?
    - Can you tell something about cultural factors?
- We wished to put a focus on practical instructions. To what extent do you feel that we have succeeded in doing so, and how could we do any better?
    - How would you describe the balance between what the company could do and what the employees could do?

  - To what extent are our recommendations viable?
  - How could we include any further means to help employees protecting themselves?
- What is your opinion on the layout of the folder? (For example, note the positions of illustrations and text, whitespace, color use, contrast, line length…)
- Our folder is not very interactive. How could we accommodate the need for interactivity in work safety meetings, if needed and possible?
- We chose not to include a lengthy introduction or conclusion, in order to improve the folder's concision. How do you feel about this choice?
- Which information in the folder would you classify as essential core information?
- Which information may be less essential or even superfluous?
- Are there any campaigns or other events going on right now that are relevant for us to keep into account?
- Are there any other things you would like to discuss?

Worker interview

- [Welcome; Informed consent]
- Before we start talking about the folder, could you tell me something about your work?
  - Could you describe an average working day?
  - Do you mainly work indoors or outdoors?
  - How many years of experience do you have?
- What is your opinion on this folder?
  - What is your opinion about the amount of information?
  - How do you feel about the structure of the folder?
  - What is your opinion on the layout of the folder? (For example, note the positions of illustrations and text, whitespace, color use, contrast, line length…)
- Can you describe in your own words what this folder is about?
  - Can you explain what PM is?
  - Can you tell me something about the sources of PM?
  - Can you tell me something about the effects of PM exposure?
  - Can you explain what to do against PM?

        - Which measures against PM did you already take?
        - Which measures against PM would you be less likely to take?
        - Would you become more or less likely to take certain measures against PM after reading this folder?
- How do you see your own PM risk right now?
- To what extent do you feel that this folder is suitable for workers in your situation?
    - To what extent does this folder fit your situation?
- To what extent is a folder a suitable material for explaining PM risk?
    - Do you have any suggestions for other materials?
- Which measures against PM are being carried out in your workplace?
    - How did your employer educate you on PM?
- Are there any other things you would like to discuss?

5

RISK COMMUNICATION ABOUT PARTICULATE MATTER IN THE WORKPLACE: A DIGITAL EXPERIMENT.

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Abstract

Workers do not always showcase adequate knowledge on potential long-term health effects and other properties of particulate matter (PM), which may lead to a decreased tendency to work safely in a high-PM environment. To empower workers to work more safely in environments with high PM exposure, we developed an educational folder tethered to their information needs. In the present study, we test two versions of our folder in a digital panel experiment with 227 participants who regularly worked in environments where they are potentially highly exposed to PM. We tested one version with and one without visualizations of the exposure and health effects, as it is currently unclear whether such visualizations can improve risk understanding. We compared them with an existing folder about PM and with a control condition involving a text unrelated to the subject. The outcome variables included people's opinions about the quality of the material; learning effects by means of knowledge questions; and perception- and behavior-related effects about PM and mitigation methods. The results revealed a significant and relevant difference on improvement of knowledge scores between our folder with extra visualizations and the control condition. No significant difference between the conditions with regards to perception and behavior effects were found.

Keywords: particulate matter, work safety, risk communication, risk visualization, educational folder

Introduction

In recent years, there has been a strong focus on the chronic aspects of work safety. One risk that is currently in the spotlight of occupational hygienists, is particulate matter (PM). PM consists of small particles in the air, mostly invisible to the human eye (Hänninen & Knol, 2011). It is defined by its particle size; any solid particle smaller than 10 micrometers is considered to be PM_{10}, and further fractions that are often distinguished include $PM_{2.5}$ and $PM_{0.1}$ (ultrafine particulate matter) (Strak, 2012). It consists of various chemical compounds, including black carbon, heavy metals, organic compounds and salt (Janssen et al., 2011; Strak, 2012, Van Deurssen, 2015). The presence of high doses of PM in air leads to 800,000 premature deaths per year worldwide (Anderson, Thundiyil & Stolbach, 2012), many of which can be attributed to occupational exposure (Van Deurssen, 2015).

Industrial workplaces, mines, and workplaces that involve dense traffic or heavy machinery are among the most PM-heavy environments (Buijsman et al., 2005; Loschiavo, 2013; Van Deurssen, 2015). Construction and maintenance industries, for example with roads or buildings, often involve high PM exposure due to activities such as sawing and drilling (Cheriyan & Choi, 2020; Giunta, 2020; Meier, Cascio, Danuser & Riediker, 2013; Van Deurssen, 2015). The presence of this PM exposure within construction and maintenance industries causes a number of premature deaths among workers. Although exact numbers are unknown (Cheriyan & Choi, 2020), an estimate of the number of premature deaths due to occupational substance exposure exists for the Dutch situation (Arboportaal, 2018), which amounts to around 3000 deaths per year. Not all of these deaths involve PM exposure, but several of the most important substances mentioned can be classified as PM, including quartz, wood particles, or diesel emissions (Arboportaal, 2018). Since PM is caused by a large array of individual actions, governmental policies alone cannot sufficiently diminish exposure, prompting the need for a more individual response (Kim, Kim & Hwang, 2021).

Even though a number of mitigation methods are often in place when PM exposure is high, these methods tend to not diminish PM exposure sufficiently (Li, Zhao & Xu, 2019). This may at least partially be explained by a lack of awareness by workers and managers alike, as PM is mostly invisible and therefore difficult to perceive (Zuo et al., 2017). In a previous study (Stege et al., 2019), we concluded that many workers in construction and maintenance industries have specific information needs concerning PM. For example, they do not always know when they are exposed to PM and what effects this exposure has on the human body (Stege et al., 2019).

In this study, we evaluated the effects of an educational folder about PM, presented to people who regularly come into contact with PM during their work, in a digital experiment with an online questionnaire. This folder intends to influence both knowledge and attitudes of workers regarding PM. We compared the effects of three separate folders on perceived quality of the folder, knowledge about PM, and protection motivation (consisting of threat appraisal, coping appraisal, and self-proclaimed work safety behavior). Other than the two versions of our folder, one with and one without icon arrays and exposure visualization, we also included one of the existing folders about PM (Volandis, 2016), which is a 'best practice' folder recommended by the trade union. We also included a control condition in which an unrelated text was shown.

The outcome measures are based on Kirkpatrick's four-level evaluation model (Kirkpatrick, 1959). In this model, used in educational science, reaction level concerns the opinions of users about the quality of the material; learning level concerns the increase in knowledge on the users' part; behavior level concerns the users' behavior after the intervention with the material; and result level concerns the desired outcomes, which in our case involves improved health. In this situation, assessing whether an addition to the existing risk communication proceedings would have such effects would be very difficult, since many other factors may influence this over a long period of time. For this reason, other more proximal outcome measures have been identified, involving the other three levels of evaluation from Kirkpatrick (1959) – reaction, knowledge and behavior. The behavior level will be further operationalized using the PMT (Rogers, 1983), with the concepts of threat appraisal and coping appraisal, as mentioned earlier. For the knowledge level, potential confounding and effect modifying factors will be included; safety warnings may be interpreted differently among different groups of people, and demographics such as age and gender are therefore important variables to consider when designing a risk communication tool (Fischhoff et al., 2011).

In this way we tested if our folder based on a mental models approach is an improvement over the trade union folder (Volandis, 2016)[4]; if the visualization of exposure and potential health effects is worthwhile; and if any folder is an improvement over simply probing employees by a questionnaire on exposure and risk of PM, i.e. if a folder itself is necessary. We ask ourselves the following questions:

- How does the perceived quality of our newly developed mental models-based educational folder, with or without risk visualizations, compare to that of a current 'best practice' folder?
- How does our folder, with or without risk visualizations, compare to a current 'best practice' folder (or a control condition), with regards to PM knowledge outcomes? And how do personal characteristics affect the outcome of PM knowledge?
- How does our folder, with or without risk visualizations, compare to a current 'best practice' folder (or a control condition), with regards to threat appraisal, coping appraisal or self-proclaimed safety behavior?

Theoretical framework

The development process of an educational material tethered to the needs of employees starts with an understanding of the main goals of risk communication in the workplace. Visschers & Meertens (2010) state: *"Risk communication should lead to an informed decision related to the risk".* In other words, proper risk communication in the workplace should elicit a response in workers in the way they act. This was also known by Rogers (1983), who identified two main routes of causation by which engagement in safe working behavior is accomplished, namely threat appraisal and coping appraisal. Firstly, there is threat appraisal – if workers perceive something as a large threat, they are more likely to protect themselves against it. Secondly, there is coping appraisal – workers need to feel that protecting themselves against the threat is feasible and efficacious in order to actually do so. An increased threat appraisal and coping appraisal should, according to the PMT (Protection Motivation Theory), lead to an increase in safety behavior, which should in most cases be the end goal of workplace risk communication (Fischhoff, Brewer & Downs, 2011; Petts et al., 2002).

4 Volandis is a non-profit 'joint effort' organization by various trade unions for the building and infrastructure branches.

Generally speaking, training on the job tends to be somewhat lacking in giving critical information about workplace risk, amplifying unsafe behavior (Okun, Guerin & Schulte, 2016). To empower workers to work more safely in an environment with high PM exposure, we developed an educational folder tethered to their information needs (Stege et al., 2021). We did this by employing a mental models approach, meaning that we compared knowledge and beliefs of these workers to the insights from scientific literature and experts on PM in the workplace (Morgan, Fischhoff, Bostrom & Atman, 2002), thereby getting crucial insights in workers' understanding of PM risk. We used the information needs as stated by various stakeholders alongside this to determine the desired contents of this folder, so that workers are empowered to work safely by gaining critical information.

Although other means of risk communication about PM did already exist (e.g. Cumela, 2009; Volandis, 2016), the mental models approach used in our study provided a more thorough method to select the scope and contents of the educational material. Although the earlier materials gave valuable and factually correct information about PM, they may have downsides related to implementation, neutrality, or appropriateness for the target audience. For example, in our earlier studies we found that existing materials are sometimes criticized for lengthiness and use of fear-inducing imagery, which was deemed inappropriate by some participants (Stege et al., 2021). Furthermore, other educational material developed for use in work safety meetings is often focused on more specific substances, such as quartz (Volandis, 2016), or specific disease prevention, such as pneumoconiosis (Cumela, 2009). Our material has a broader focus on PM exposure in the workplace in general; furthermore, it specifically uses the input from the mental models approach to investigate which PM-related subjects are most important to discuss. The mental models approach keeps the end users' needs into account while still providing the key information for workers to improve their safety.

In a systematic review of mental models-related studies for risk communication, Boase et al. (2017) state that while studies like these are common, only a small minority of these studies actually end up developing and testing educational material. According to Boase et al. (2017), the studies that do test educational material tend to omit control conditions and subsequent field studies, and PM does not appear to be the direct subject of an earlier mental models-based intervention. This further cements the necessity for this particular study on the efficacy of our mental models-based risk communication tool.

When designing the educational material, we considered other options besides an information folder. Evoking playfulness in learners, even adult learners, does not only increase likability of the material, but also potentially increases learning outcomes (Deterding, Dixon, Khaled & Nacke, 2011; Petts et al., 2002). Therefore, we considered gamification-based interventions as well. Furthermore, practical assignments and simulations were considered, since Thalheimer (2010) recommends to align the learning and the performance contexts. We considered these and other options, comparing them to each other within the frameworks of the so-called SECTIONS model, a tool to investigate the proper use of media in a learning context (Bates & Poole, 2003). After analyzing these potential materials, we settled on the combination of a folder and a practical assignment in the workplace involving an exposimeter. However, since a similar practical assignment was already available for use, we focused our attention on the development of the folder.

After developing an educational folder to provide PM risk communication to workers, we performed an initial usability test with a small number of participants (Stege et al., 2021). A specific aspect that emerged from this usability test was whether or not to include certain risk visualizations, such as an icon array, as explained in Lipkus (2007). As Daradkeh (2017) states: *"An effective visualisation tool to support decision-making must enable decision makers to not only access decision-relevant information, but also explore and analyse the risk involved in their decisions".* These risks are in our case, as in many cases, described using statistical information. Statistical information is notoriously difficult to understand for many people, but risk visualizations may help alleviate some of these difficulties (Binder, Krauss & Bruckmaier, 2015).

Including risk visualizations may change employees' threat appraisal, but it is currently unclear whether our icon arrays increase or decrease threat appraisal. Icon arrays are generally considered efficacious (Trevena et al., 2013; Trevena et al., 2021), but both the quality of the visualizations itself and literacy-related issues on the user's end may decrease this efficacy (Garcia-Retamero, Okan & Cokely, 2012; Okan, Garcia-Retamero, Cokely & Maldonado, 2015). This, along with some disagreements in research about the effectiveness of icon arrays and similar risk visualizations (e.g. Etnel et al., 2020; Zipkin et al., 2014), is why we decided to test two separate versions of the folder, one with and one without risk visualizations.

Method

Participants

We approached participants through an online panel specialized in recruiting participants for online questionnaires.[5] We used a selection item for the recruitment: *"How often do you perform work that may yield high PM exposure, such as sawing, drilling, or industrial lawnmowing, or work in a place with high emission of exhaust gases?"* If people answered 'sometimes', 'regularly' or 'often' to this question, they were regarded as potential participants (those who answered 'rarely' or 'never' were not selected). We did this in order to only include participants whose daily work is at least to some extent relevant for an intervention about PM exposure.

Materials: folders

We used three different folders as materials for the intervention in this study. We also used a 'dummy text' for the control condition, unrelated to PM, in order to investigate whether any effects on outcome measures may be explained by probing; participants may look up information about PM between questionnaires even when they are shown a text unrelated to PM.

The first two folders are two versions of the same folder that we developed. We developed this folder after performing a study in which we assessed expert and employee mental models of PM risk; we investigated the differences between these two mental models and used these differences to identify the main information needs. Both versions of the folder start by explaining what PM is by showing an image of its particle size and an explanation how various particle fractions can penetrate the human body. Then, various work-related sources are shown, and afterwards the potential effects (respiratory and cardiovascular) are explained. The 'effects' portion of the folder is where the two versions differ, as one version shows an icon array where 3 out of 100 icons are colored in red and a graph comparing exposure

5 The panel we used is the Flycatcher panel. Flycatcher is situated in Maastricht, The Netherlands, and affiliated with the University of Maastricht. It was certified ISO 20252 and ISO 26362 for research quality, as well as ISO 27001 for information safety.

levels in various working situations, and the other version omits there two visualizations and instead explains the effects of PM in plain text. Both folders end by mentioning a wide range of mitigation methods against PM exposure, categorized into the four levels of the occupational hygiene strategy: substitution, technical measures, organizational measures, and personal protective equipment.

The third folder, the trade union folder, was not created by us, but used with permission from the trade union. Its focus is on quartz rather than PM in general, but the contents are otherwise comparable to our folder, with a similar goal of empowering employees to work safely when exposed. The trade union folder does not have an emphasis on risk visualization, but it does contain a quiz for the reader about their own exposure at work. The 'dummy text' was acquired from the website of the RIVM (Dutch National Institute for Public Health and the Environment), and is about work safety in general without specifically mentioning PM.

Materials: outcome measures

As mentioned in the introduction, the framework for the outcome measures is provided by the four-level evaluation model by Kirkpatrick (1959) as well as the Protection Motivation Theory or PMT (Rogers, 1983). For perceived quality (equated to Kirkpatrick's 'reaction level'), we utilized the Suitability Assessment of Materials tool (SAM) in order to identify the most important aspects of material quality (Doak, Doak & Root, 1996). For knowledge level, we compiled a pre- and post-test based on the content. Finally, for behavior level, we assessed the determinants of Protection Motivation according to Rogers (1983), regarding threat appraisal and coping appraisal. These three concepts are operationalized in this study in order to investigate the efficacy of our folder on the third ('behavior') level of evaluation (Kirkpatrick, 1959).

By basing our questionnaire on existing, widely utilized psychological and educational models for evaluation, such as the four-level evaluation model by Kirkpatrick (1959), the PMT (Rogers, 1983) and the SAM tool (Doak et al., 1996), we have tried to maintain the validity and reliability of the outcome measures of reaction and behavior level. For knowledge level outcomes, we consulted experts in the field in order to ensure that the contents of the questionnaire were factually correct. The full questionnaire (translated from Dutch), based on the three measurable levels of the four-level evaluation model, can be found in Appendix A.

Perceived quality. The quality-related items were divided into 'layout' and 'content' items, and they were answered by means of a five-point Likert scale. Examples of these items included: 'I think the folder looks nice' (layout, 5 items in total) and 'I think the information in the folder is clear' (content, 8 items in total). We assessed all 13 items together in an exploratory factor analysis with Varimax rotation and subsequent reliability analysis.

Knowledge. Regarding the knowledge-related items, we constructed ten multiple-choice questions with four answers. These multiple-choice questions covered the full range of topics discussed in the various versions of the PM folder, including properties, causes and effects of PM and mitigation methods. They were made with the expert and worker mental models in mind, and they were fact-checked by an expert in the field. One example of such an item is: 'What is the most effective method of preventing PM exposure when sawing or drilling', with the options being 'To work in a closed-off space', 'To work with outstretched arms', 'To make the materials wet first', and 'To work as quickly as possible' (C is the correct answer here). We compiled knowledge sum scores for both the pretest and the posttest by counting the amount of correct answers, as well as difference scores by subtracting the pretest score from the posttest score.

Protection motivation. These items were further categorized in 'threat appraisal', 'coping appraisal' and 'safety behavior' items, as defined in the PMT (Rogers, 1983). All items were answered by means of a five-point Likert scale, with options ranging from 'completely disagree' to 'completely agree'. The threat appraisal block contained such items as: 'I am worried about PM exposure at work' (6 items in total). The coping appraisal block contained such items as: 'I think that it is useful to protect myself against PM' (5 items in total). The safety behavior block contained such items as: 'In work situations with PM exposure I wear personal protective equipment, such as a respirator' (6 items in total). We performed an exploratory factor analysis with Varimax rotation and a reliability analysis on the pretest data related to the threat appraisal, coping appraisal and safety behavior scales, to investigate whether the items asked were indeed related to the constructs we intended to measure. We compiled sum scores for each of these scales, and we also calculated difference scores by subtracting the pretest from the posttest.

Procedure

After completing an initial version of the questionnaire, we performed a pilot test. The online experiment was pilot tested among 19 potential participants (who did not participate in the final experiment), after which minor adjustments were made with regards to wording. The outcome measures were deemed usable for large-scale deployment.

The experiment consisted of a pretest and posttest questionnaire, so that we were able to make a comparison with their answers to the same questions after the intervention. First, participants were asked questions related to their knowledge about PM, perceptions towards PM, protective behavior, general demographical questions and whether or not they had had any previous instructions about PM at work. We made two versions of the list of ten knowledge-related items that differed only in the order that the items appeared in, to prevent any bias due to the order of the items as much as possible.

After filling out the questionnaire, the participants were randomly assigned to one of four conditions. Participants were asked to carefully read the folder or the text before continuing to the end of the questionnaire; there were no further questions after reading the folder, but we wanted participants to read the folder as thoroughly as possible for the posttest. After about one week, all participants received the same questions about knowledge, perceptions and safety behavior again, with the option to take a look at the material while answering the questions; it was logged whether or not they did check the material during the posttest questionnaire. Afterwards, they were also asked questions related to the quality of the material.

Data analysis

The data analysis was performed using SPSS version 16. After calculating perceived quality scores for all 227 participants and pretest, posttest and difference scores on knowledge, threat appraisal, coping appraisal and safety behavior, we performed several analyses. In order to investigate the differences between the conditions on the folder quality scales, we performed a series of one-way ANOVA's with post-hoc tests with Least Significant Difference (LSD) correction. In order to investigate the differences between pretest and posttest scores on knowledge scores, we performed paired-sample T-tests. In addition, we used a regression analysis on difference scores to investigate the difference between conditions and to accommodate for possible confounding or effect modification of personal characteristics. Other than confounding and effect modification, we also performed a follow-up analysis investigating whether any effects on knowledge scores were more pronounced among people who performed better or worse in the pretest questionnaire, by splitting the participants in quartile groups. Finally, we performed regression analyses on the differences between conditions regarding the threat appraisal, coping appraisal and safety behavior scales.

Results

After participants in the online panel answered the selection questions, 783 potential participants were identified. We randomly selected 400 from these 783 participants to take part in our study. The 400 participants were asked to complete the pretest questionnaire, and 286 (71,5%) of them did this. Of these 286, 229 participants (57,3% of the original 400) finished the posttest questionnaire (1 week later) as well. Of these 229 participants, two more were excluded due to extreme outliers in their answer pattern. The other 227 (56,8%) participants were included in the analyses.

Out of the 227 participants, 162 were male (71,4%) and 65 were female (28,6%). Ages ranged from 19 to 79, with an average of 49. Regarding education, most people had a medium vocational education level or equivalent, at about 43%; around 20% only had high school or lower, around 30% had a higher vocational education level, and the remainder of around 7% had studied at a university.

Folder quality

For this analysis, we excluded the control condition (in this condition participants were asked to read an irrelevant text), leaving 170 cases for the analysis. We performed an exploratory factor analysis with Varimax rotation on all 13 items related to perceived quality, revealing a three-factor solution. The first factor consisted of 6 items (items 6, 9, 10, 11, 12, 13), mostly related to the clarity of the folder; therefore, we named this factor 'clarity'. The second factor consisted of 4 items (items 1, 2, 4, 8*), mostly related to layout and visual aspects; we named this factor 'layout'. The other 3 items (3, 5, 7) all loaded sufficiently on the third factor, and these three items were all negative items related to the folder being incomplete or not the correct format; we named this factor 'insufficiency'.

We performed a reliability analysis on the three factors mentioned above. For clarity, we found a Cronbach's α of 0.91. For layout, we found a Cronbach's α of 0.77; however, this could be increased to 0.82 by removing item 8 *("I think there is unnecessary information in the folder",* rescaled). For insufficiency, we found a Cronbach's α of 0.62. We used these three factors for further analysis, considering item 8 as a separate item named 'Redundancy'. In Table 1, an overview of the means of each of these perceived quality scales can be found for each of the three conditions.

Table 1

Perceived quality scores in each of the conditions (excluding the control condition)

	Clarity	Layout	Insufficiency	Redundancy
'Risk Visualization' condition[6]	25.46 (range 16-30)	11.94 (range 5-15)	6.81 (range 3-13)	2.02 (range 1-4)
'No Risk Visualization' condition	25.20 (range 18-30)	11.65 (range 7-15)	7.39 (range 3-12)	2.22 (range 1-5)
'Trade Union' condition	25.24 (range 15-30)	12.01 (range 7-15)	6.78 (range 3-13)	2.29 (range 1-4)

Between the 3 folder conditions (Risk visualization, No risk visualization, Trade Union), no significant differences were found on clarity, layout, insufficiency or redundancy. The differences between each of the conditions on each of these perceived quality scales turned out to be not significant (all $p > 0.05$).

Knowledge scores

Knowledge scores ranged from 0 to 10 points on both the pretest and posttest. A paired-sample T-test revealed that there was an increase from an average knowledge score (among all conditions) of 5.19 to 5.77, an increase of 0.58 point, which is significant at the $p < 0.001$ level. Table 2 shows the results from the analyses per condition, revealing significant increases in all conditions except for the control condition. Table 2 also shows the results of the regression analysis on the difference score, when comparing all conditions to the control condition (the dummy variable). The knowledge scores between conditions are also shown visually in Figure 1. The regression analysis revealed a significant difference between the Risk Visualization condition and the control condition, but no significant differences between the No Risk Visualization or the Trade Union and the control conditions.

6 In the 'Risk Visualization' condition, participants were shown the full version of our folder; in the 'No Risk Visualization' condition, two risk visualizations including the icon array were omitted, but otherwise the folder was identical; in the 'Trade Union' condition, an entirely different folder was shown, designed by the trade union organization Volandis (2016).

Table 2

Paired-sample T test and regression analysis on the knowledge scores

	Paired-sample T test				Regression[7]	
	Pretest	Posttest	Diff.	*p*	t	*p*
Control condition	5.07 (SD = 1.51)	5.28 (SD = 1.65)	0.21	0.406		
'Risk Visualization' condition	5.12 (SD = 1.54)	6.04 (SD = 1.40)	0.92	0.001	2.022	0.044
'No Risk Visualization' condition	5.47 (SD = 1.42)	6.06 (SD = 2.09)	0.59	0.046	1.070	0.286
'Trade Union' condition	5.13 (SD = 1.52)	5.76 (SD = 1.49)	0.63	0.002	1.284	0.201

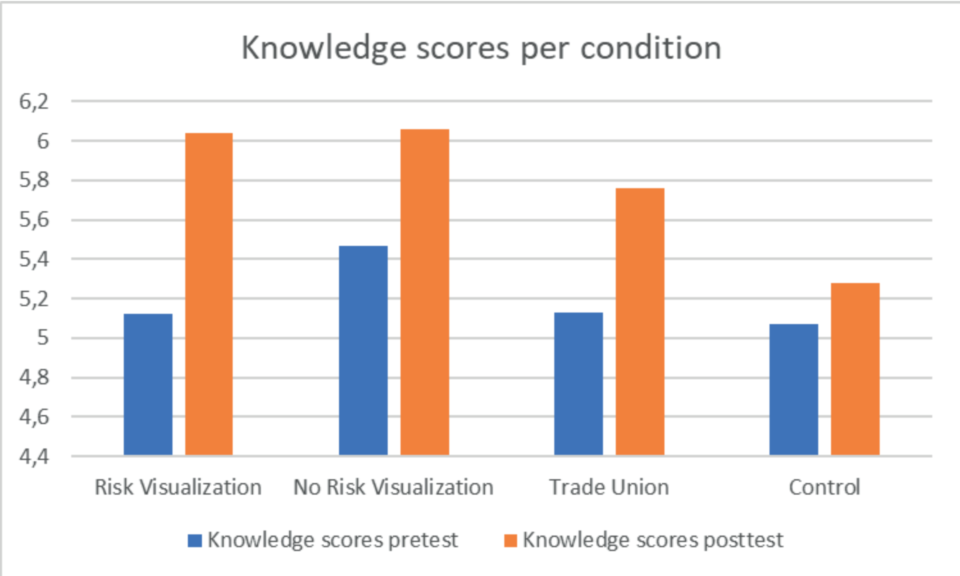

Figure 1. Knowledge scores per condition on the pretest and posttest.

7 Potential confounders and effect modifiers were added in this regression analysis in the next section. Coefficients B of this regression analysis were compared with and without the extra variables added.

Effects of personal characteristics

The variables age, gender, whether or not participants worked in a branch with an increased PM risk, whether or not participants had prior experience with education about PM exposure, and whether or not participants had checked the folder were all included in the regression analysis to check for confounding. Two of these five variables yielded a change in coefficient levels of more than 10%, namely age and checking the folder, indicating that these variables may be confounders or effect modifiers. These two variables were further analyzed to check for effect modification by including their interaction effects in two separate regression analyses.

When performing a regression analysis of only age on knowledge difference score, no significant effect was found (B = 0.006, SD = 0.01, $p = 0.59$). Furthermore, a regression analysis including an interaction effect for age revealed no significant effect with any of the conditions (all $p > 0.05$). Therefore, age can be seen as a confounder, not as an effect modifier. When corrected for age, the coefficient B of the 'No Risk Visualization' condition increased from 0.385 to 0.431, but the effect of this folder was still not significant ($p = 0.239$). The other conditions did not reveal a change of more than 10%.

Only a relatively small number of participants checked the folder when answering the questions: 11 out of 52 in the Risk Visualization condition, 12 out of 49 in the 'No Risk Visualization' condition, and 18 out of 68 in the Trade Union condition. No participants checked the folder in the control condition, which is logical, since only a 'dummy text' was shown instead of a real folder. A regression analysis including an interaction effect for checking the folder revealed a significant interaction effect of checking the folder with the 'Risk Visualization' condition (t = 2.191, $p = 0.029$). Therefore, checking the folder can be seen as an effect modifier. In Figure 2, a visual overview can be seen, revealing, among others, that knowledge scores increase with around 2 points among people in the Risk Visualization condition who checked the folder and barely at all among people in the Trade Union condition who checked the folder.

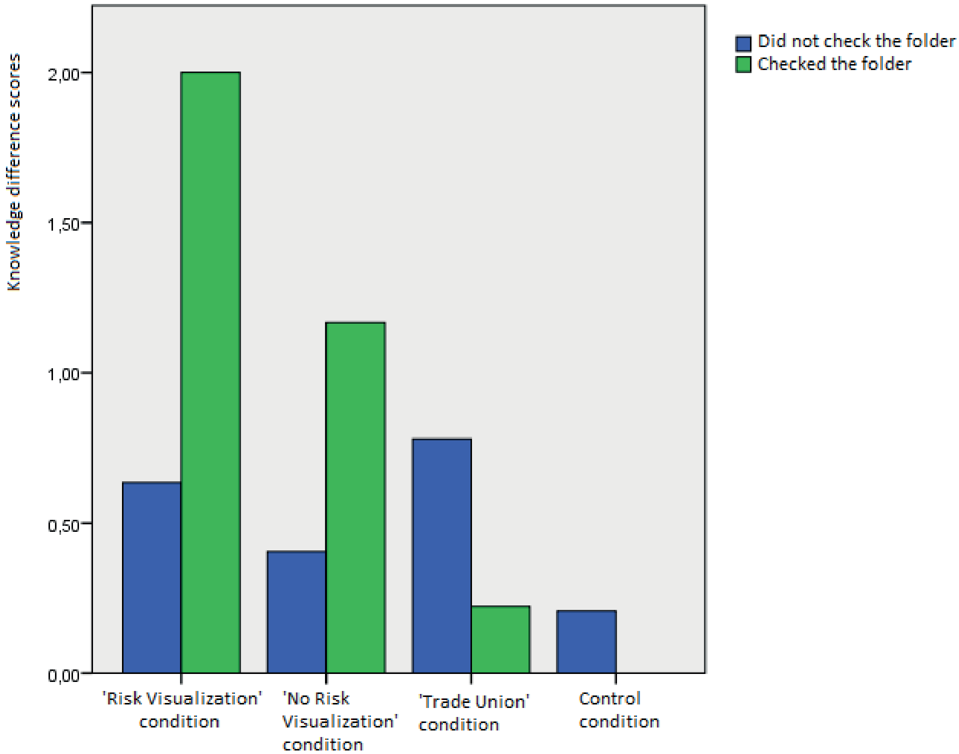

Figure 2. Interaction effect of checking the folder on knowledge scores.

Despite the small sample size, a one-way ANOVA with LSD (Least Significant Difference) correction still revealed a significant difference between the Risk Visualization and Trade Union condition among people who checked the folder, with a mean difference of 1.78 points (p = 0.018). The difference between the No Risk Visualization condition and the other two conditions was, in both cases, not significant ($p > 0.05$).

Explorative analysis: quartile analysis

The different folders had only relatively small effect sizes and borderline significant effects on knowledge scores. A possible explanation is that people who are already quite knowledgeable about PM have little left to learn from our folder, while people who have no prior knowledge about PM may not have enough basic understanding of the subject to learn something new about PM. For this reason, we performed a follow-up analysis with quartile groups. We divided the participants in four roughly equal-sized groups, based on their pretest scores. Participants with a score of 4 or lower on the pretest were put in quartile group 1; participants with a score of 5 in group 2; participants with a score of 6 in group 3; and participants with a score of 7 or higher in group 4. We performed new regression analyses for each of these groups to investigate any further effects. Due to issues with small sample sizes, we did not combine the quartile analysis with confounding or effect modification analyses.

The regression analyses with the quartile groups revealed no significant effects of any condition on knowledge scores for quartile group 1, 3, or 4 (all $p > 0.05$). However, significant effects were found in quartile group 2. When comparing the difference scores of the control condition with each of the other 3 conditions, differences in difference scores were 1.44 (Risk Visualization), 1.18 (No Risk Visualization), and 1.44 (Trade Union) respectively. The outcomes from the regression analysis can be found in Table 3. When performing an additional one-way ANOVA, no significant differences between the quartile groups were found with regards to age; we suspected that this may have been the case because of the earlier found confounding, but no such results were found.

Table 3

Regression analysis on the knowledge scores for quartile group 2

	Mean diff. score	SD	t	*p*
Control condition	-0.44	1.82		
'Risk Visualization' condition	1.00	1.10	2.28	0.027
'No Risk Visualization' condition	0.73	2.05	2.03	0.047
'Trade Union' condition	1.00	1.37	2.61	0.011

Threat appraisal, coping appraisal and safety behavior

Based on the exploratory factor analysis and reliability analysis, we excluded one item related to threat appraisal *('Exposure to PM could make me severely ill*') and one related to coping appraisal (*'I think it is inconvenient to protect myself against PM'*). These items did not load sufficiently on the primary factor in the corresponding factor analysis while the other items did; furthermore, the reliability analyses revealed that Cronbach's α could be improved for both scales by removing these items (threat appraisal from 0.79 to 0.84, and coping appraisal from 0.62 to 0.68).

The remaining items were used to compile pretest and posttest scores on each of these three scales, as well as difference scores. The average threat appraisal difference score among all conditions was 0.15, meaning that people increased 0.15 points on this outcome when comparing the pretest to the posttest (SD = 3.17). For coping appraisal, this average difference was 0.87 (SD = 2.40); for safety behavior, 0.24 (SD = 0.67). The results of the regression analysis regarding threat appraisal can be seen in Table 4; coping appraisal can be seen in Table 5; and safety behavior can be seen in Table 6. None of these analyses revealed significant differences between conditions on any of the outcome variables, with all $p > 0.05$. Since an earlier analysis on effect modification revealed that 'checking the folder' can be seen as an effect modifier, we analyzed the subgroup of participants who checked the folder separately. However, within this group, still no significant effects were found.

Table 4

Regression analysis on the threat appraisal scale

	Mean diff. score	SD	t	*P*
Constant (control condition)	0.57	3.07	1.365	0.174
'Risk Visualization' condition	0.12	3.38	-0.748	0.455
'No Risk Visualization' condition	0.47	3.64	-0.162	0.872
'Trade Union' condition	-0.40	2.71	-1.702	0.090

Table 5

Regression analysis on the coping appraisal scale

	Mean diff. score	SD	t	*P*
Constant (control condition)	0.47	2.12	1.476	0.141
'Risk Visualization' condition	1.00	2.62	1.165	0.245
'No Risk Visualization' condition	1.00	2.32	1.147	0.253
'Trade Union' condition	1.03	2.51	1.314	0.190

Table 6

Regression analysis on the safety behavior scale

	Mean diff. score	SD	t	*P*
Constant (control condition)	0.14	0.63	1.529	0.128
'Risk Visualization' condition	0.25	0.58	0.797	0.426
'No Risk Visualization' condition	0.39	0.79	1.814	0.071
'Trade Union' condition	0.21	0.65	0.539	0.591

Discussion

In this study, we investigated various effects of a folder about workplace PM exposure in a digital experiment. We compared a version of our folder with risk visualizations to a version of our folder without risk visualizations. We also compared both versions to an existing, non-mental models based folder about quartz that is currently in use, and to a dummy text, for outcomes on reaction, knowledge and protection motivation. We did this in order to better investigate the efficacy of the mental models approach for risk communication than is presently common, and to specifically assess the quality of our own developed risk communication tool.

We found no significant differences between folders regarding perceived quality or protection motivation outcomes. We did find that the folder with risk visualizations has a significant positive effect on learning outcomes compared to a dummy text. Further subgroup analyses revealed that effects are clearest among participants who checked the folder when answering the questions; in this subgroup, the icon array folder also fares better than the trade union folder. Also, the effects are clearest in the group of participants who had some prior knowledge about PM, but not the greatest amount of prior knowledge.

Perceived quality

The quality of the three folders (excluding the control condition) was appraised equally. Since the two folders of our own making differed only in the risk visualization, and not in any further content, the differences between them may have been too minor to have a significant effect on the perceived quality. Nevertheless, despite small disagreements in literature (Etnel et al., 2020; Zipkin et al., 2014), icon arrays and other risk visualizations are generally viewed in a positive light (Trevena et al., 2013; Trevena et al., 2021), depending on the quality of the visualizations and the end user's graph literacy (Garcia-Retamero, Okan & Cokely, 2012). The absence of any positive effect of the risk visualizations on perceived quality of the folder may be partially explained by either of these factors.

When comparing our own folder with the existing folder (Trade Union), no clear differences were found on perceived quality either. One element that the other company folder used and ours did not, involved a small quiz at the end, titled 'How dusty are you?'. This quiz puts the practical instructions into a more playful setting, which can be found as a possible recommendation in literature to increase the likability of an educational material (Petts et al., 2002). We did not include any such quiz, because we were more focused on the optimization of the visualization, and instead put the practical instructions in a visually appealing and insightful table near the end; these visual aspects are considered to be important as well (Petts et al., 2002). Participants in this study gave comparable evaluations to each of these approaches.

Knowledge scores

Participants who were shown our folder including icon arrays and exposure visualizations demonstrated more increases in knowledge about PM compared to people in the control condition, involving no folder at all. This is an indication that our folder has been effective, at least to a certain extent, in giving people information about PM. These effects cannot be seen as clearly in the condition without the risk visualizations. As icon arrays and exposure visualizations are recommended by literature (Garcia-Retamero, Okan & Cokely, 2012; Trevena et al., 2021), it makes sense that the learning effects are most pronounced when the visualizations are included.

Notably, people in the control condition also demonstrated small (albeit non-significant) increases in knowledge. If anything else than statistic noise, it may be the case that people felt the need to look up information about PM themselves after participating in the pretest part of our study, especially if they received a dummy text unrelated to PM.

There was a substantial increase in knowledge scores within the small subgroup of participants who checked the folder. Furthermore, in this subgroup, the folder with the risk visualizations resulted in larger increases in knowledge scores compared to the existing folder from the trade union. This may indicate that information found from the mental model approach (Stege et al., 2019) leads to a folder design better tuned to the needs of the workers.

The much higher effect size among people who checked the folder may also be an argument to provide employees in the workplace with 'just in time' information, that is, to give workers the folder just before performing certain tasks that involve high PM exposure. Providing 'just in time' information is often recommended when people need to perform practical tasks in order to reduce cognitive load (Kester, Kirschner, Van Merrienboer & Baumer, 2001). In this case, work related safety information shown before entering a room or handling a machine increases knowledge and may lead to less errors on the job. The small number of people who checked the folder may also be an indication that getting the target audience to read the folder is a bigger challenge than containing the relevant information within the folder, although this problem may be mitigated when the folder is used in the context of the workplace rather than an online experiment.

The quartile analysis revealed that people with a comparatively high or a comparatively low prior understanding of PM did not show any significant increase in knowledge level. This means that all educational materials may be most suitable for those people who have some understanding about PM, but not a full understanding. In practice, it may not be necessary to keep the higher-scoring workers in mind when designing the folder, beyond giving them any sources for further in-depth information, since they may already have the information necessary to protect themselves against PM. This is different for lower-scoring workers. When using this or any other educational material in a workplace setting, a work safety specialist should certainly keep an eye out for those workers who fail to understand the basics after reading the folder. Personal attention and further elaboration may be required in these circumstances.

Protection motivation outcomes

There may be various factors that help explain the lack of effects on threat appraisal, coping appraisal or safety behavior outcomes. One important thing to consider is that information alone may teach a person something, but it tends not to be an effective risk communication tool without contextual aids, such as practical instructions in the workplace (Fischhoff et al., 2011). Of course, such contextual aids are not easy to emulate in a digital experiment such as this, so that the folder we developed is stripped from its intended context in a workplace setting. Indeed, in the development phase of the folder, we concluded that it should be augmented with a practical assignment in order to fully achieve the intended effects. One other factor is that the participants in this study may only partially overlap with the audience the folder is actually intended for. We designed the folder with specific job groups in mind who work with PM on a daily basis, but many of our participants include people who only have limited experience with PM.

Conclusion and follow-up research

Overall, we conclude that this study shows some evidence that people learn something about PM in the workplace after reading a mental models based instruction folder. The effects are most pronounced in the subgroups of people who checked the folder during the experiment, and people who are in the second-to-lowest quartile regarding pretest scores. The study did not demonstrate clear effects on perceived quality (reaction level) or on protection motivation towards PM (threat appraisal, coping appraisal or safety behavior itself).

There are some factors that limit the generalizability of our results. The participants of this study were recruited using an online panel, and they do not have a perfect overlap with the target audience of our intervention. Although we did select participants who have at least some PM exposure at work, the PM exposure might be of a different nature, or simply much lower, than the roadwork employees our folder was intended for. If we had only selected participants with a high degree of similarity to our target audience, however, we would not have had a sufficient number of participants for thorough statistical analyses.

Another limitation is that we did not test our entire proposed intervention in this online experiment. In earlier research, we propose to increase the effects of a folder by means of an exposimeter to visualize the exposure (Stege et al., 2021). We chose to test our folder first with as many participants as possible given the budget limitations, and subsequently test for additional effects of a practical assignment in a real life workplace environment in a follow-up. Therefore, in future research we will amplify the information material with a more practical instruction visualizing the exposure level. We will then, as mentioned above, research the effects of the combined intervention in the workplace.

In this study, the participants simply read an online version of the folders without any further support or additional assignment; thus, only a small effect could be expected. In such a context, the readers typically retain a relatively small amount of information. The often quoted 10% and 20% marks for information retained while reading appear to be incorrect and based on misinformation (Subramony et al., 2014); nevertheless, people forget learnt information quickly, depending on the situation as well as individual differences (Thalheimer, 2010). Thalheimer (2010) recommends, for this reason, to align the learning and the performance contexts – which is what we will do in further research, when implementing the material in a work safety meeting and amplifying it with an assignment.

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Appendix A: Questionnaires used in the online experiment (in Dutch)

In this appendix, the full questionnaires used in the online experiment can be found. Please note that all texts are translated from Dutch, since the experiment was deployed under employees in the Netherlands.

Pretest questionnaire (translated from Dutch)

This questionnaire is part of a study by the Dutch National Institute of Public Health and the Environment (RIVM) about risk communication on particulate matter (PM) at work. We hope to get some insights on your opinion about PM. A number of questions are related to your knowledge about PM. Please try to answer these questions as accurately as possible. If you do not know an answer, please fill in the answer you think might be correct. The questionnaire will take about 20 minutes. Of course, we will consider all your data as confidential. All information will be anonymized.

Thank you for your participation!

General questions

- Age
- Gender
- Occupation / branch
- Years of work experience in current occupation
- Level of education

Selection question:

- How often do you perform tasks at work that involve a lot of PM exposure, including sawing, drilling, lawn mowing, or working in locations with a lot of emissions? (1 = never, 2 = rarely, 3 = sometimes, 4 = regularly, 5 = often)

Knowledge questions

We will now ask you ten knowledge questions about particulate matter (PM). Please try to answer them as accurately as possible. Please circle the answer you think might be correct, even if you are unsure.

(These questions are randomized to prevent bias)[8]

1. Which statement about PM is true?
    a. PM is always visible.
    b. PM is usually visible, except in very low concentrations.
    c. PM is usually invisible, except in very high concentrations.
    d. PM is never visible.
2. Which statement about PM and visible dust is true?
    a. If you cannot see any dust in the workplace, then there will not be any PM.
    b. If you can see any dust in the workplace, then that is PM.
    c. If you can see any dust in the workplace, then PM is often present.
    d. There is no connection between visible dust and PM whatsoever.
3. Which of the following diseases **cannot** be caused by PM (as far as is known)?
    a. Stroke
    b. Colon cancer
    c. Heart failure
    d. Lung cancer
4. How many workers do you think die prematurely in 10 years due to substance exposure at work (including PM)?
    a. Less than 1 in 1000.
    b. About 3 in 1000.
    c. About 3 in 100.
    d. About 3 in 10.
5. Which kind of weather increases PM risk?
    a. Drought.

8 The correct answer is italicized in this article. Of course, this was not the case in the original questionnaire.

b. Rainy weather.
c. Storm.
d. Extreme cold.

6. Where or when if PM exposure highest?
    a. During lawn mowing.
    b. When sawing or drilling.
    c. Near highways or other main roads.
    d. In the office.
7. What is the best way to mitigate PM exposure when sawing or drilling?
    a. Treating the material in a closed-off space.
    b. Treating the material with outstretched arms.
    c. Wetting the material before use.
    d. Treating the material as quickly as possible.
8. When do you wear a dust mask when working outdoors?
    a. Only with certain types of work, such as lawn mowing.
    b. Whenever other measures against exposure are not sufficient.
    c. During very hot or very cold weather.
    d. Always.
9. Which of the following statements is **not** true?
    a. When performing task indoors that cause PM exposure, it is sensible to open a window.
    b. Most tasks should be performed indoors to prevent PM exposure.
    c. When driving on the highway, it is sensible to close the window against PM exposure.
    d. There is usually more PM exposure during rush hour.
10. Which is the following statements is true?
    a. Ventilation systems often do not work against PM.
    b. Diesel causes more PM exposure than gasoline.
    c. To prevent PM exposure, people should only work at night.
    d. Employees are fully responsible for their own protection against PM.

Opinions on particulate matter

These questions will ask you about your personal views on particulate matter (PM). For each of the following statements, please answer to what extent you agree with it, on a scale from 1 (completely disagree) to 5 (completely agree).

The following questions are about PM at work.

- I think that the health risk of PM in my workplace is large.
- I think the exposure to PM in my workplace is not that great.
- There is only a small chance that I would become sick due to PM.
- Exposure to PM could make me severely ill.
- I am worried about PM exposure at work.
- I feel safe in my workplace concerning PM.

The following questions are about protection against PM.

- I do not know how to protect myself against PM.
- I think it is inconvenient to protect myself against PM.
- I think it makes sense to protect myself against PM.
- At work, I get the necessary equipment to protect myself against PM.
- I think it is important to protect myself against PM.

The following questions are about how you protect yourself against PM in practice. Please answer them on a scale from 1 (never) to 5 (always).

- When performing work that gives PM exposure, I disregard protection against PM.
- When performing work that gives PM exposure, I use personal protective equipment, such as a dust mask.
- When performing tasks such as sawing or drilling I make the materials wet first.
- When performing work indoors that gives PM exposure, I enable the ventilation system.
- When performing work outdoors that gives PM exposure, I made sure that no dust

is blown into my face.

- I use protection against PM in other ways than mentioned above.

Open question: Do you have any additions or other remarks to elaborate the answers given before?

(Participants are randomly put into one of the conditions now, and they are shown one of the folders.)

Next week, we will send you a new questionnaire in which we will ask some more questions about this subject. Thank you for your cooperation so far, and we will see you next week!

Posttest questionnaire (translated from Dutch)

This questionnaire is part of a study by the Dutch National Institute of Public Health and the Environment (RIVM) about risk communication on particulate matter (PM) at work. Last week, you have answered a previous questionnaire about PM. Afterwards, you were shown a folder. We would like to ask you to thoroughly read the folder before continuing.

You will again be shown a number of questions to answer. These questions are partially the same questions as last week. Near the end, we will also include some questions in which we ask your opinion about the folder. You can always check the folder when answering the questions.

Answering the questions will take about 15 minutes. Of course, we will consider all your data as confidential. All information will be anonymized.

(The sections 'Knowledge questions' and 'Opinions on particulate matter' are now given as in the pretest)

Opinion about the folder

For each of the following statements, please answer to what extent you agree with it, on a scale from 1 (completely disagree) to 5 (completely agree).

The following questions are about your general impression about the folder.

- I think this folder looks nice.
- I think the balance between text and illustrations is good.
- I think the use of language is quite childlike.
- I think this folder is easy to read.
- I would prefer to get the information in a different way than in a folder.
- Open question: You can elaborate on the answers given above.

The following questions are about the contents of the folder.

- I think the folder contains useful information.
- I think there is information missing in the folder.
- I think there is unnecessary information in the folder.
- The folder is understandable.
- I think it is clear what is mentioned in the folder.
- The folder clearly explains what PM is.
- The folder clearly explains the health effects of PM.
- The folder clearly explains how to protect yourself against PM.
- Open question: You can elaborate on the answers given above.

End of the questionnaire

We would like to thank you for your participation in our study.

If you wish to be updated and eventually receive a summary of our results, please enter your email address here.

6

PARTICULATE MATTER IN THE WORKPLACE:

Effects of a mental models-based folder combined with a practical assignment

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Abstract

Background: With increasing knowledge on the adverse health effects of certain constituents of PM (particulate matter), such as silica, metals, insoluble ions, and black carbon, PM has been under the attention of work safety experts. Previously, we investigated the perceptions of blue-collar workers in highly exposed areas of work. Subsequently, we developed an instruction folder highlighting the most important aspects of PM risk and mitigation, and tested this folder in a digital experiment. The digital experiment yielded positive results with regards to acquired knowledge about PM, but did not on risk perception or safety behavior. **Methods:** In this study, we investigate the effects of the folder when combined with a practical assignment involving a PM exposimeter, showing the amount of particulate matter in microgram per cubic meter in real time on its display for various activities. We tested this at six workplaces of four companies in the roadwork and construction branch. **Results:** The results indicate that the folder itself yields an increased knowledge base in employees about PM, but the effects of the practical assignment are more contentious. Nevertheless, there is an indication that using the assignment may lead to a higher threat appraisal among employees for high exposure activities. **Conclusion:** We recommend implementing our folder in companies with high PM exposure and focusing further research on appropriate methods of implementation.

Keywords: particulate matter, work safety, risk communication, educational folder, exposimeter

Background

With increasing knowledge on the adverse health effects of certain kinds of PM (particulate matter), such as silica, iron and black carbon, PM has been under the attention of work safety experts. For the general public (WHO, 2013), but especially for people who work in environments with high PM exposure, such as the roadwork and construction branches (Loschiavo, 2013; Meier, Cascio, Danuser & Riediker, 2013; Van Deurssen, 2015), PM can be an important health risk. Adverse health effects include a wide array of respiratory and cardiovascular diseases (Hänninen & Knol, 2011), which are caused by a variety of different substances that make up the contents of PM, such as black carbon and metals (Janssen et al., 2011; Strak, 2012).

Although various means of protection against workplace PM exposure exist, not all employees that work in an environment with high PM exposure make sufficient use of these means of protection (Liu, Noth, Eisen, Cullen & Hammond, 2018). This discrepancy was the basis of a study on the situation in the roadwork and construction branches in the Netherlands, in which employees' perceptions of risk and mitigation were identified (Stege, Bolte, Claassen & Timmermans, 2019), with the intention of empowering workers in these branches to work more safely in an environment with high PM exposure. We did this based on a mental models approach, in which discrepancies between blue-collar workers' views on PM and experts' views on PM are the basis of which information to include in the communication of risks and mitigation (Breakwell, 2001; Morgan, Fischhoff, Bostrom & Atman, 2002; Slovic & Weber, 2002).

In our earlier studies (Stege et al., 2021a; Stege et al., 2021b, in preparation), we developed and tested a folder about workplace PM exposure and its mitigation. The folder turned out to improve participants' knowledge about PM in a digital experiment (Stege et al., 2021b, in preparation). However, effects on risk perception variables and safety behavior, as seen in the Protection Motivation Theory (PMT) (Rogers, 1983), could not be demonstrated. Although the effects on PM knowledge in the digital experiment were promising, the extrapolation to potential effects in the workplace is nontrivial. This is partly because the population composition of the digital experiment may be slightly different from that of an actual company, but also because the instructions in work safety meetings may be given in a different way than in an online experiment.

The absence of the opportunity for active learning in the digital experiment may explain the lack of effect on risk perception and safety behavior. Based on the SECTIONS model (Bates & Poole, 2003), we investigated the optimal means of instruction. A practical assignment that visualizes the exposure in the working environment with and without mitigation methods in place may induce active learning (Bonwell & Eison, 1991). An exposure visualization assignment like this has been used in a similar setting with promising results (Bolte et al., 2018). We did not test such an assignment in the digital experiment, as a personalized workplace setting could not feasibly be simulated.

The present field study on PM risk communication in the workplace is aimed at answering two main research questions. Firstly: 'To what extent does an intervention involving our educational material lead to more knowledge and a better risk perception about PM when used in a workplace setting?' Secondly: 'Is the intervention involving our material more effective if it is augmented with a practical assignment?' Based on our earlier experiences, we expect our educational folder to at least improve employees' knowledge about PM, In addition, based on the potential positive effect on active learning we expect that the practical assignment will affect threat and coping appraisal.

Methods

Participants

We contacted various companies in the roadwork and construction branches, i.e. branches whose employees tend to have high PM exposure, from our professional network in the Netherlands. Four of those companies agreed to participate in our study. The four companies found 74 participants able and willing to participate in total; however, of these 74, 17 dropped out during the study or failed to adequately fill in the study questionnaires. The four companies respectively had 24, 8, 16 and 9 employees completing the experiment successfully, yielding 57 participants in total. Of these 57 participants, 55 were male, which appears to be representative of the roadwork and construction branches as a whole, as we found similar male-dominated demographics in earlier studies (Stege et al., 2019). Participants' ages ranged between 17 and 65, with an average age of 42.9.

Design

This study can be seen as a mixed methods study, albeit with a larger focus on the quantitative part. For the quantitative part, all participants were subjected to a pretest and a posttest. These were two identical questionnaires, meant to investigate the differences in PM knowledge and risk perception before and after the intervention. The intervention itself consisted of two parts. The first part was a work safety meeting, in which participants were each given the educational folder about PM that we developed and tested in earlier studies (see appendix A) (Stege et al., 2021a). An instructor (either the work safety specialist or the first author of this article) summarized the key points of this folder, provided some additional information, and answered questions. The second part was a practical exposure visualization assignment.

We use a step-wedge design, in which some participants are given the practical assignment before the final questionnaire, and some after. The latter is not strictly necessary to investigate the effectiveness of this practical assignment, but it could prove useful for the companies themselves even beyond the scope of this study. Furthermore, we felt that all participants should at least get the opportunity to work with the PM dosimeters. In this way, we managed to make a clear distinction between conditions with and without the practical assignment on the posttest, without withholding a potentially valuable learning experience from half of the participants.

For the smaller qualitative part of this study, we compiled a logbook of each of the instances of data collection. For these four companies, there were six instances of data collection in total, as two companies had two locations each. Any noteworthy questions, complications and important moments from each of these six instances were written down in the logbook. Furthermore, work safety experts of all four companies involved in this study, who were all present during the intervention, were asked to answer a few questions by email after participating in our study.

Materials

The questionnaires involved five multiple choice questions related to PM knowledge (related to properties of PM, its causes, its effects, and the mitigation methods), the answer to which could be found in our folder. It also involved seven questions related to risk perception;

three of these seven questions are related to the PMT variable of ‘threat appraisal’, three to ‘coping appraisal’, and the final question is about safety behavior, i.e. to what extent people work safely in practice with regards to PM. These seven questions are answered with five-point Likert scales. The full questionnaire can be found in Appendix B. All questions, both the knowledge and the perception questions, were used earlier in the larger online questionnaire from our previous study (Stege et al., 2021a); we made a smaller selection of the most relevant questions in order to decrease workload for participants, as they should not be held from their job longer than strictly necessary.

The longer questionnaire from our previous study (Stege et al., 2022) was validated in the following way. For the PMT-related questions, we used questions that were very similar to those in existing PMT research, and we performed reliability analyses afterwards to confirm the internal consistency of the measures constructs. For the knowledge questions, we discussed the answers with experts in the field of PM and risk communication. We did not perform any additional checks for this smaller questionnaire, but it is unlikely that any new problems should arise related to validity or reliability.

The small follow-up email questionnaire for the involved safety experts contained eight open questions such as ‘To what extent do you think employees learned something from the practical assignment?’ These questions were answered by email. The full questionnaire can be found in Appendix C. Finally, for the practical assignment, portable PM exposimeters are given to participants, and they are prompted to answer questions about PM exposure in their company. The full assignment can be seen in Appendix D. A photograph of the exposimeters used in this study can be found in Figure 1.

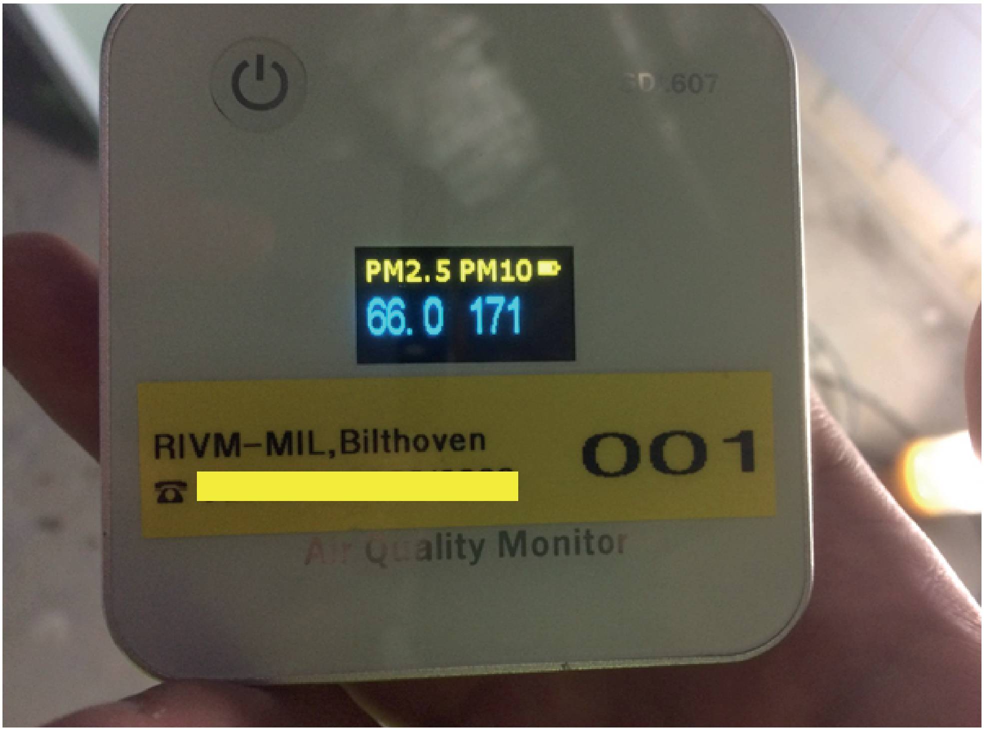

Figure 1. A low cost, portable PM exposimeter with real time display of the amount of microgram per cubic meter, Nova Fitness SDL607. (Phone number censored)

Procedure

The data was collected during the year 2020, in which some companies had to postpone participation due to COVID-19 restrictions. The remaining companies were visited in the summer, and all participants, work safety specialists and researchers made sure to comply with COVID-19 related regulations. All four participating companies were visited on weekdays, during a timeframe in which they were already planning to organize a periodical work safety meeting. These meetings are required by law in the Netherlands for roadwork and construction companies.

Participants were gathered in a room (sufficiently large enough to maintain COVID-19 regulations if applicable), and as the meeting started, they were asked to fill in the pretest questionnaire. These questionnaires were clearly marked to avoid confusion with posttest questionnaires (as they are otherwise identical). After filling in the pretest questionnaire, the participants received a physical copy of the folder, and they were prompted to read it. The work safety specialist was then asked to tell something about PM based on the contents of the folder. Then, upon compliance of the work safety specialist, the group was split in half, as randomly as possible. One half of the group (the 'safety meeting only' group)[9] received the posttest questionnaire immediately, and the other half (the 'added assignment' group) was given the practical assignment as well as a PM meter. After both groups were finished, they switched. We made sure that as many participants as possible filled in both the pretest and posttest questionnaires, and we answered questions during the assignment if needed. We wrote down the most important observations during this assignment in our logbook. After finishing the work safety meeting, we emailed the work safety specialist the short qualitative questionnaire.

Analyses

For the quantitative analysis, we compiled a dataset based on the pretest and posttest questionnaires in SPSS version 16. First, we checked whether there were any differences in demographic variables between conditions and companies, such as gender, level of education (both by chi-square tests), age and work experience (both by ANOVAs). We recoded the answers to the different knowledge-related questions into 'correct' (1) or 'incorrect' (0), and subsequently compiled a knowledge sum score.

We analyzed the reliability of the scales of threat appraisal and coping appraisal in order to check whether the questions could indeed be viewed as part of a larger scale and calculated average scores (for threat appraisal and coping appraisal). The reliability analysis revealed that the threat appraisal scale has a Cronbach's α of 0.83, which is sufficient for use as a coherent scale. We therefore computed threat appraisal scores on the pretest and posttest by calculating an average of the scores on each of the three items. A coherent scale could not be constructed for coping appraisal. The Cronbach's α with all four items included was 0.31; inter-item correlations ranged from smaller than 0.01 to 0.41; and removing any item from the scale could not increase Cronbach's α any further than 0.46. Therefore, we decided to view the coping appraisal items not as a scale, but as independent items.

9 It should be noted that, when naming the two conditions in this study, we define the 'safety meeting' as the combined intervention of the folder with the oral instructions, but without the assignment. Therefore, the 'safety meeting only' condition did receive the folder before the posttest questionnaire, but not the assignment.

For each of the test scales, we analyzed the differences between the pretest and posttest scores by means of a paired-sample t-test, in order to investigate any significant general effects of the intervention. In addition, we performed univariate ANOVA's of condition ('safety meeting only' versus 'added assignment') and company on the three posttest scores, corrected for the respective pretest scores and potential differences in demographic characteristics between conditions and companies.

We also performed a general analysis on the findings from the logbook and the qualitative questionnaire for the work safety experts. The amount of information from these sources was not sufficient to perform any detailed qualitative analyses. We selected the information specifically relevant for the interpretation of the quantitative information.

Results

Demographics

We performed a series of checks in order to investigate any bias between various groups when it comes to demographics. For the two conditions – the 'safety meeting only' and the 'added assignment' condition – we performed chi-square tests with gender and level of education. The results of the chi-square tests revealed no significant differences between the two conditions regarding gender ($\chi^2 = 0.03$, df = 1, $p = 0.86$), nor regarding level of education ($\chi^2 = 3.69$, df = 3, $p = 0.30$). Then, the four companies involved were checked for the same biases, with two additional chi-square tests with gender and level of education. The results of the chi-square tests revealed no significant difference among the four companies regarding gender ($\chi^2 = 3.47$, df = 3, $p = 0.33$). However, a significant difference was found among the four companies regarding level of education ($\chi^2 = 25.26$, df = 9, $p < 0.01$), meaning that not all companies provided similarly educated participants. In company 3, there were significantly more higher educated participants than in company 1 or 4 (25% or 4 out of 16). Company 2 also had 25% of their participants higher educated, but also 50% of their participants with a lower or no additional education (beyond grade school).

In order to also check any biases between companies and conditions regarding work experience or age, a series of one-way ANOVAs was conducted. These ANOVAs revealed no significant differences between companies regarding age (F = 0.56, df = 3, $p = 0.65$) or experience (F = 0.77, df = 3, p = 0.51), nor were there any significant differences between the two conditions found regarding age (F = 0.18, df = 1, p = 0.67) or experience (F = 0.38, df = 1, p = 0.54).

Knowledge scores

To acquire a general idea of the difficulty of the questions, as well as the effects of the work safety meeting, we first calculated the percentages of correct answers for each of these knowledge questions. The results can be found in Table 1. As can be seen from the table, the number of correct answers appeared to increase with each question, except for the question about weather effects on PM; almost all participants already knew the answer to that question before the meeting.

Table 1. *Percentages of correct answers on the knowledge questions.*

Question #	Topic	Percentage correct (pretest)	Percentage correct (posttest)
1	Visibility of PM	61%	72%
2	Diseases caused by PM	16%	35%
3	Weather effects on PM	98%	95%
4	Mitigation of PM	88%	90%
5	Diesel as a source of PM	33%	44%

The average knowledge score (on a scale from 0- 5) increased from 2.96 prior to the meeting to 3.35 after the meeting (t = -2.88, df = 56, p < 0.01). It is noteworthy that, even though many participants show an increase in score (23 in total), there are a few participants (6 in total) who show a decrease in score, one of whom even has a decrease of 3 points; all of these 6 participants with a decrease in score are found in Company A (two in one workplace of Company A and four in the other), and 5 of these 6 participants are found in the 'added assignment' condition within Company A. This is further shown in a boxplot in Figure 1. The other 28 participants had no score change at all. A more detailed overview of average scores in each of the companies, split by condition, can be found in Figure 2.

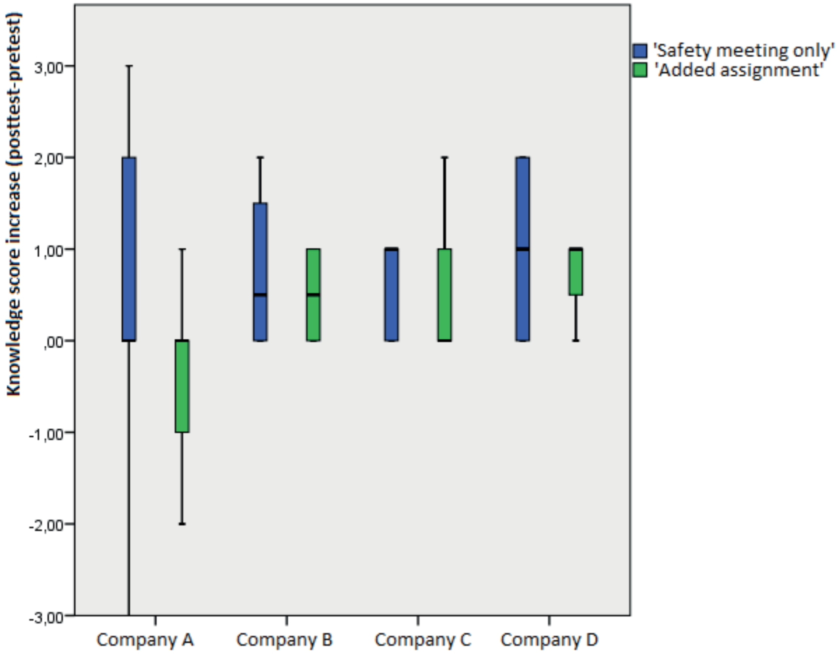

Figure 1. Knowledge score increases for all employees in each of the companies, split by condition

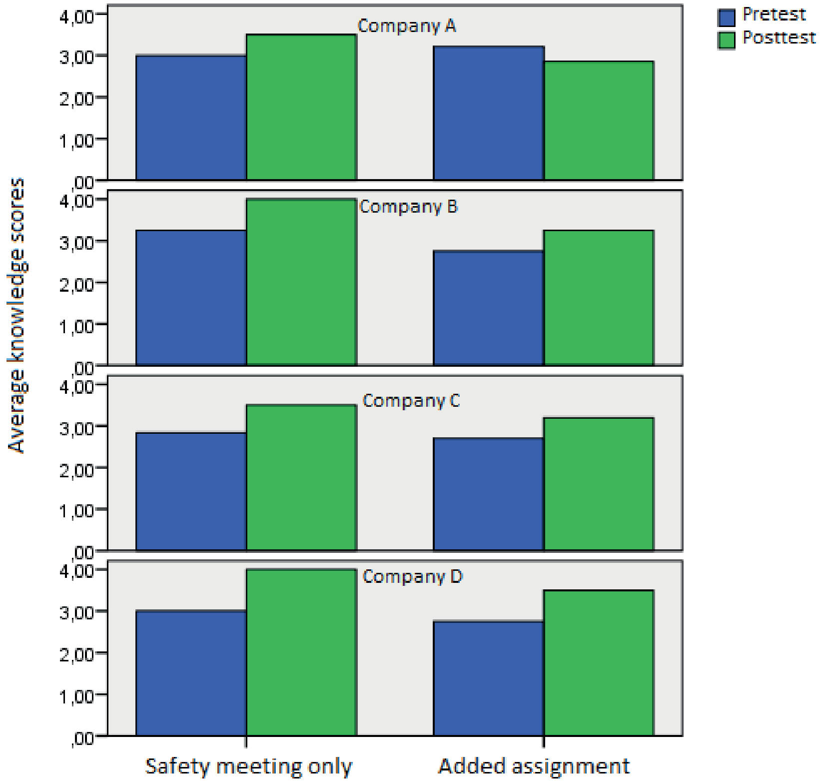

Figure 2. Average knowledge scores on the pretest and posttest, split by company and condition

We found that the posttest scores, corrected for pretest scores and level of education, were significantly influenced by condition (F = 10.89, df = 1, $p < 0.01$); people in the 'safety meeting only' condition performed significantly better than people in the 'added assignment' condition. The effect of the company was not significant (F = 2.02, df = 3, $p = 0.13$). No significant interaction effects of company and condition were found either. However, since all of the 6 participants with a decrease in score are found in Company A, and the process of the work safety meeting had some variations in Company A when compared to the other companies (we will discuss this in more detail in the process evaluation portion of this article), we performed a follow-up analysis without Company A. Nevertheless, people in the 'safety meeting only' condition still performed significantly better than people in the 'added assignment' condition, when considering only companies B, C, and D (F = 8.33, df = 1, p = 0.01). The effect of the company now becomes significant as well (F = 3.76, df = 2, $p = 0.048$), with participants in Company C performing significantly worse than the other companies. There are still no significant interaction effects.

Threat appraisal

We compared the threat appraisal scores of the pretest and posttest. Overall, an increase of threat appraisal was found, with threat appraisal scores on average increasing from 2.55 to 2.74. A paired-samples t-test revealed that this increase was significant (t =-2.11, df = 53, p = 0.04). An overview of all scores among different companies and conditions can be found in Figure 3. We performed another univariate ANOVA, investigating the effects of company and condition on posttest threat appraisal scores, corrected for pretest threat appraisal scores and level of education. We found no significant effects of condition (F = 0.61, df = 1, p = 0.44) or company (F = 1.28, df = 3, p = 0.30). We also found no significant interaction effects. A follow-up analysis without Company A did not give any significant effects either.

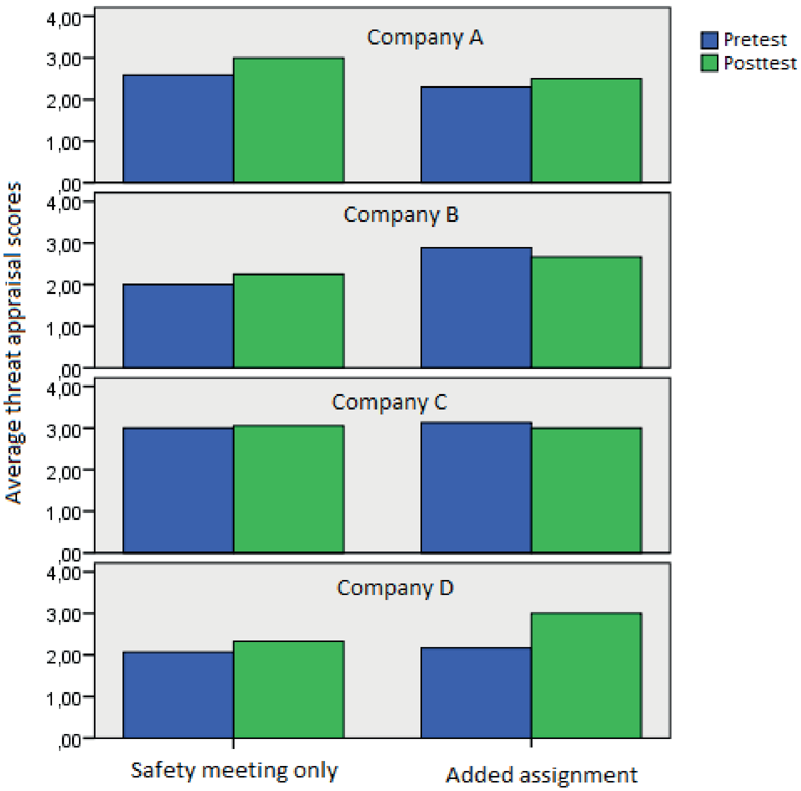

Figure 3. Threat appraisal scores on the pretest and posttest, split by company and condition

Coping appraisal

The paired-sample t-tests on each of the four coping appraisal items showed that only one of these four items, which involved the statement *'I know how to protect myself against particulate matter'*, revealed a significant increase: average scores on this item increased from 2.56 on the pretest to 2.91 on the posttest (t =-2.47, df = 53, p = 0.02). No significant effects were found for the other three items.

The univariate ANOVA on the posttest score of just this item of the coping appraisal scale, correcting for the pretest score of the same item and level of education, showed no significant direct effects of condition (F = 1.75, df = 1, p = 0.20) or company (F = 0.35, df = 3, p = 0.79). However, we did find a significant interaction effect of company and condition (F = 5.10, df = 3, p < 0.01). Figure 3 showcases all average scores on this item among various companies and conditions.

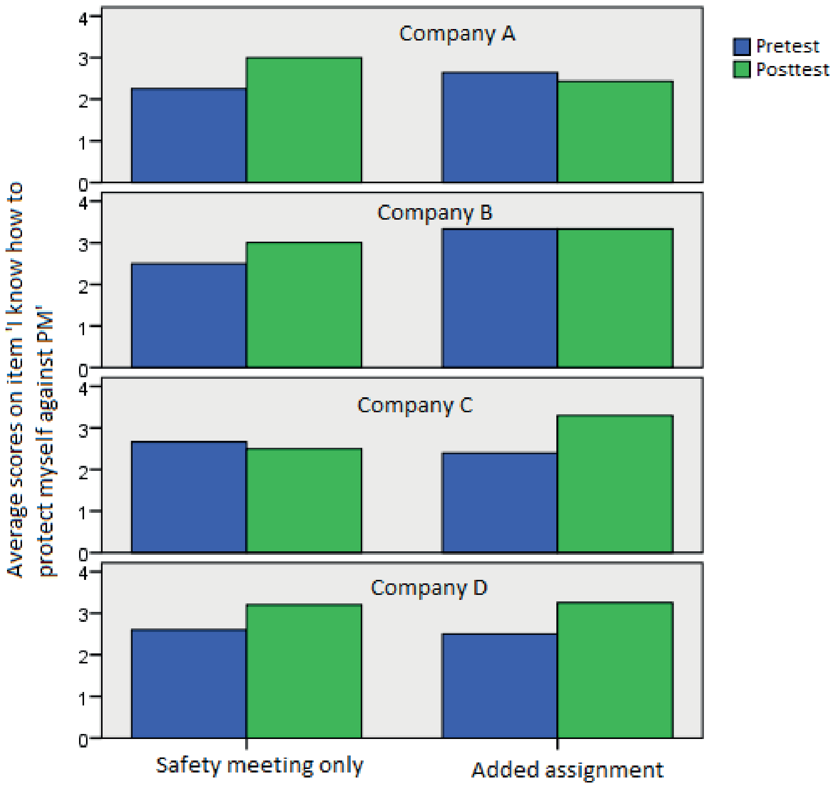

Figure 3. Scores on the item 'I know how to protect myself against PM' on the pretest and posttest, split by company and condition.

We again performed a follow-up analysis without Company A. In this case, the interaction effect of company and condition disappeared ($F = 2.51$, $df = 2$, $p = 0.12$). No other significant effects were found either.

Process evaluation: Logbook

The first practical issue was related to making sure that the same participants filled in both the pretest and posttest questionnaires. Originally, we planned to pre-emptively send the pretest questionnaire to the work safety experts who coordinated the meetings within the companies, so the participants could fill them in prior to the meeting. This would reduce the amount of time lost on questionnaires during the work safety meetings, as well as reduce potential annoyance by participants of filling in the same questionnaire twice over a short period of time. However, upon visiting company A, we found that this plan had the added downside of causing a relatively large dropout rate in company A (8 out of 32 potential participants). Also, not all participants filled out the forms prior to attending the safety meeting, leading to irritation and a slow start of the safety meeting as some participants had to wait while others were filling out their forms. For this reason, we decided to give the pretest questionnaires in the other three companies during the work safety meetings.

Another practical issue that should be noted was related to the person presenting the work safety meeting. In order to fully test the usability of the folder by these companies, we had planned the work safety meetings to be carried out by the experts who are employed by these companies. In company A, this is indeed what happened; the work safety expert presented the information in the folder as the participants listened and had the opportunity to read the folder in the meantime. In company B, however, the work safety expert did not feel confident enough about presenting the information in the folder, and instead felt that this task would be more suitable for the first author of this article. As this had the additional benefit of more thoroughly focusing on the most relevant subjects, we decided to maintain this practice for the final two companies.

When it comes to the practical assignment with the PM meters, there are large differences not just between companies, but also between locations within a single company. Some participants managed to find very high PM exposures of more than 999 microgram/m^3, the maximum value the PM meter could show, which is several orders of magnitude higher than recommended. This value of 999 microgram/m^3 was found during a wide array of activities, ranging from using heavy machinery and drilling equipment to cleaning the floor with a broom or with compressed air. However, in other companies or locations, PM exposures were relatively low, especially when working outside. One of the companies (B) was visited on a cold and rainy day with a below-average amount of traffic, resulting in low PM exposures for the workers outside, consistently below 20 microgram/m^3.

Process evaluation: Work safety expert opinions

Overall, the four work safety experts that were connected to the four companies involved with this study were all satisfied with the procedure, and gave positive feedback on the folder as well as the practical assignment. Work safety experts' opinion about the folder is illustrated by the following quote:

"The folder is compact and assembled in understandable language for my colleagues. They are usually not so keen on scientific language." (Expert Company A)

The work safety experts also agree on the added value of the practical assignment with the PM meter:

"A work safety meeting should preferably be interactive." (Expert Company A)

"Performing the measurements was great, people are still talking about it today. [...] They were skeptical at first, but after performing the measurements, this was over." (Expert Company B)

"Due to the measurements, people have become more aware about what PM is." (Expert Company D)

Some experts gave a couple of suggestions for improving the work safety meeting as a whole:

"A fitting short movie as an introduction would make it more complete. [...] In the end, talking through the results of the measurements." (Expert Company B)

One expert did point out that a briefing for the work safety experts would be useful (although three of the four experts did not find this necessary):

“A short explanation by means of an instruction movie. This should at least involve […] information about the subject, […] the goal of the work safety meeting, [… and] how to give the work safety meeting.” (Expert Company C)

Discussion

In this study, we investigated the effects of a mental-model based instruction folder about PM for use in the workplace. We assessed whether using the folder led to an increase in knowledge and risk perception about PM, and whether augmenting the intervention with a practical exposure visualization assignment led to any improvements in effectiveness. We will argue that, while not all of the expected effects that we measured were significant, the results of this study are still promising when it comes to the effectiveness of our intervention.

Knowledge scores

Based on the increase in knowledge scores, the folder can be shown to succeed in giving the participants basic information about PM, regarding its causes, effects, properties and methods of mitigation. This finding corroborates our earlier findings in a digital experiment (Stege et al., 2021b, in preparation), that also showed an increase in PM knowledge. As the present study focuses more on the actual end user of the folder, these results are potentially even more relevant.

People who were given the added assignment before the posttest scored significantly *lower* on the knowledge scores than people who were given the posttest directly after the safety meeting. This was contrary to expectations, but it may be explained by the effect of time; the participants who were busy performing the assignment had more time to forget the exact information needed to answer the questions correctly. Furthermore, they may also have been less conscientious when filling in the questionnaire because they had been busy with the assignment for quite a long time, which may have caused them to lose concentration.

If PM knowledge deteriorates quickly, this may become a problem when giving information is one of the main goals. This problem, however, may be related to the nature of the questions; perhaps we should not expect workers in a practical setting to have exact long-term knowledge on the subject, but we should focus on awareness instead. Judging by the comments of the experts on the practical exposure visualization assignment, these experts at least perceive an increase in long-term awareness about PM, which they perceive to be predominantly caused by the addition of the practical assignment.

Company A is the only company in which some participants show a *decrease* in PM knowledge after the work safety meeting. The explanation may be found in two of the anomalies we described in our logbook. Company A was the only company in which participants were given the pretest questionnaire a few days before the work safety meeting, and also the only company in which not the researcher, but the institutionalized work safety expert gave the PM-related information during the meeting. It is possible that the participants had forgotten which answers they gave during the pretest, since it was a few days before the meeting, and subsequently became confused about the information given by the work safety expert, since there may be small anomalies between the framing of the information by the expert and the information in the folder. This potential problem exemplifies the recommendation given by one of the experts in another company, to include a briefing for the person giving the work safety meeting. It should be noted that we followed the protocol as closely as possible in each of the companies beyond these two differences, so the situations between companies should still be sufficiently comparable.

Threat and coping appraisal

Contrary to our previous study in an online setting (Stege et al., 2021b, in preparation), we did find a small, but significant increase in both threat and coping appraisals after this work safety meeting. Regarding threat appraisal, it did not appear to matter much whether or not the assignment was added, nor in which company they were active; on average, participants felt slightly more aware of the potential risks of PM after receiving the toolbox. The absence of differences between companies and conditions means that differences between measured exposure – which were noteworthy, as mentioned in the process evaluation – do not appear to translate to differences in threat appraisal.

With coping appraisal, however, it appears that performing practical exposure visualization assignment increased the workers confidence in how to protect themselves against particulate matter, except for the workers in company A, where it lead to a decrease in confidence l. The exact cause of this discrepancy is unclear, but as mentioned before, company A did have a somewhat different procedure of carrying out the work safety meeting and the questionnaires than the other companies. It is possible that a more consistent procedure would have led to more consistent results.

Strengths and weaknesses

Overall, it appears that the main strength of this study is its strong alignment with what a work safety meeting might look like in practice. The findings from an earlier digital quantitative experiment were corroborated and, to some extent, even expanded on by involving the actual end user of the intervention. The researchers made every effort possible to ensure that the work safety meetings would follow the guidelines of the various companies that participated, thereby increasing the generalizability of the results of the study.

Nevertheless, the study also has some weaknesses. As mentioned before, the inconsistency of the procedure may have harmed the consistency of the results, especially since the deviant company was also the one with the most participants. Adding more companies would not have been a feasible solution if we wanted to maintain consistency in the type of companies involved; adding companies from another branch than simply roadwork and construction could have been useful for increasing the number of participants, but may also have decreased the reliability of the results. For this reason, we decided to maintain the current selection of companies despite the issues with the procedure.

Within the companies, there may have been some selection bias when it comes to the participants in this study. For example, participants who are highly disinterested in PM may fail to submit a posttest questionnaire, thereby skewing the results in favor of those participants who are interested in learning more about PM as an occupational exposure risk. Nevertheless, in general, the participants who submitted pre- and posttest questionnaires appeared to form a representative sample of the company they were a part of.

Conclusion

The mental models-based instruction folder has shown to have a positive effect on workers' knowledge about PM. This was shown both in an earlier digital experiment and in this current practical study. There is a noticeable increase in participants' knowledge about PM after taking part in a work safety meeting based on the contents of our instruction folder.

The effects of the added assignment appear to be more contentious at present. The expected positive effects on threat and coping appraisal are still somewhat dubious, and the assignment may even have a negative effect on direct retention of knowledge. Nevertheless, the fact that three of the four companies do show an increase in coping appraisal for the participants who did the assignment before the final questionnaire does make the added assignment promising as a means of increasing the work safety.

All in all, the mental models-based folder has proven to be a useful tool for use in occupational work safety meetings. We recommend looking into the option of including a briefing for the work safety experts, in order to decrease potential procedural difficulties. This may be a topic for future research. Mainly because of the enthusiasm within the companies, a practical assignment similar to ours may still be a useful addition as well; however, the set-up of the measurement assignment (duration, potency for exposure contrasts at the workplace) could be redesigned. Finally, one of the experts recommended adding a small instruction movie, which is also something that could be investigated.

Abbreviations

ANOVA: Analysis of variance

COVID-19: Coronavirus Disease 2019

PM: Particulate Matter

PMT: Protection Motivation Theory

RIVM: Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)

SECTIONS: Students, Ease of use, Costs, Teaching, Interactivity, Organizational issues, Novelty & Speed

SPR: Strategic Programme RIVM

UMC: University Medical Center

WHO: World Health Organization

WMO: Wet Medisch wetenschappelijk onderzoek met mensen (Medical Research Involving Human Subjects Act)

Declarations

Ethics approval and consent to participate: The authors declare that all participants consented to participation in this study; this consent was documented when participants signed an informed consent form prior to the pretest and posttest questionnaires. No ethics approval is needed according to Dutch law, considering the fact that we only made use of questionnaires in this study: *In the Netherlands, the Medical Research Involving Human Subjects Act (Wet Medisch wetenschappelijk onderzoek met mensen, WMO) came into force since 1998. All medical scientific research in which humans are subjected to (medical) procedures or are required to follow rules of behavior, falls under the scope of this Act. All other research with humans (e.g. research with medical data or interviews) is not subject to the WMO.* (Amsterdam UMC, n.d.)

Consent for publication: No detailed individual information was presented in this article.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: The first author (TS), a PhD candidate, is the main writer of this article as well as the data collector. The second author (JB), an occupational epidemiologist, is the project leader and the grant writer for the project in the SPR framework mentioned above. The third author (LC), a communication scientist, is a thesis advisor. The final author (DT) is the promotor, mainly responsible for scientific content and quality. The second, third and fourth authors all provided critical comments and substantial alterations to this article, as well as valuable input for the study design. All authors have read and approved the manuscript, and agree to be personally accountable for the result.

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Availability of data and materials: The data are not found online, but can be obtained from the lead author upon request.

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Appendix A. Mental models-based educational folder about PM in the workplace.

(Found in separate file)

Appendix B. Questionnaire for the workers (translated from Dutch)

Note: this part was detached from the rest of the questionnaire in order to facilitate anonymization

This questionnaire is part of a study by the RIVM and Amsterdam UMC about particulate matter in the workplace. We would like to get an impression of your ideas about particulate matter (PM). We will also ask you some questions about your knowledge of PM. Please try to answer these questions as accurately as possible. If you are unsure about an answer, please fill in what you think might be correct. Filling in this questionnaire will take about 10 minutes.

Your personal answers or data will not be given to third parties and will be treated confidentially. You will have the opportunity to view your own data. You are always free to participate or to stop participating whenever you want. If you choose to stop participating, already given answers will be deleted.

Do you understand this text and do you agree with these terms? YES / NO

Name: ____

Respondent #: ____

Thank you for participating!

General question

- Did you get any information about PM in the workplace in the last 2 years?
  YES / NO

Knowledge questions

We will now ask you ten knowledge questions about particulate matter (PM). Please try to answer them as accurately as possible. Please circle the answer you think might be correct, even if you are unsure.

1. Which statement about PM is true?
    a. PM is always visible.
    b. PM is usually visible, except in very low concentrations.
    c. PM is usually invisible, except in very high concentrations.
    d. PM is never visible.
2. Which of the following diseases **cannot** be caused by PM (as far as is known)?
    a. Stroke
    b. Colon cancer
    c. Heart failure
    d. Lung cancer
3. Which kind of weather increases PM risk?
    a. Drought.
    b. Rainy weather.
    c. Storm.
    d. Extreme cold.
4. What is the best way to mitigate PM exposure when sawing or drilling?
    a. Treating the material in a closed-off space.
    b. Treating the material with outstretched arms.
    c. Wetting the material before use.
    d. Treating the material as quickly as possible.
5. Which is the following statements is true?
    a. Ventilation systems often do not work against PM.
    b. Diesel causes more PM exposure than gasoline.
    c. To prevent PM exposure, people should only work at night.
    d. Employees are fully responsible for their own protection against PM.

Opinions on particulate matter

These questions will ask you about your personal views on particulate matter (PM). For each of the following statements, please answer to what extent you agree with it, on a scale from 1 (completely disagree) to 5 (completely agree).

- I think that the health risk of PM in my workplace is large.
  - Completely disagree / Disagree / Moderately agree / Agree / Completely agree
- Exposure to PM could make me severely ill.
  - Completely disagree / Disagree / Moderately agree / Agree / Completely agree
- I am worried about PM exposure at work.
  - Completely disagree / Disagree / Moderately agree / Agree / Completely agree
- I know how to protect myself against PM.
  - Completely disagree / Disagree / Moderately agree / Agree / Completely agree
- I think it is inconvenient to protect myself against PM.
  - Completely disagree / Disagree / Moderately agree / Agree / Completely agree
- I think it makes sense to protect myself against PM.
  - Completely disagree / Disagree / Moderately agree / Agree / Completely agree
- When performing work that gives PM exposure, I use protection against PM.
  - Completely disagree / Disagree / Moderately agree / Agree / Completely agree

Personalia

- Respondent #: ____
- Age: ______________________

- Gender: male / female / other
- Occupation: ____
- Years of work experience (current profession): _______________________
- Highest complete education: _______________________________________

(C) / (E)

Appendix C. Open email questionnaire for the work safety experts

- How did you experience giving this work safety meeting with our folder?
- To what extent do you feel the work safety meeting improves knowledge and attitudes towards PM?
- To what extent did the practical assignment with the PM exposimeter form a worthwhile addition?
- What do you consider the best method of giving the work safety meeting?
- How involved do you think workers feel when you give a work safety meeting such as this, and how would you try to increase involvement?
- Is a work safety meeting like this compatible with your company culture, and why?
- To what extent are the mitigation methods against PM that are mentioned in the folder relevant and attainable?
- How would you like to get any instructions, if any, for giving a work safety meeting about PM?

Appendix D. Practical assignment with the PM exposimeter.

You will be given a PM exposimeter for this assignment. The screen shows two numbers, you should look at the number on the right side of the screen (the higher number), denoting the total exposure to PM. Please answer the following questions about the PM exposure:

How high was the exposure at the office?	________________________ microgram/m^3
How high was the exposure in the workshop / practical workplace?	________________________ microgram/m^3
Which work situation gave the highest PM exposure you could find? How high was this exposure?	________________________ microgram/m^3 Situation: _______________________________________
Which work situation gave the lowest PM exposure you could find? How high was this exposure?	________________________ microgram/m^3 Situation: _______________________________________
How often do you think you are exposed to the highest exposure level you could find?	___________________________
How high would you think your average exposure at work would be?	________________________ microgram/m^3

7

GENERAL DISCUSSION

General discussion

This thesis investigates the proper means of risk communication for employees who are working under conditions with imperceptible exposure risks. These conditions involve physical, chemical or biological agents that may have a profound negative impact on human health when exposure becomes too high. We chose to focus on imperceptible risks because research suggests that when agents are invisible to the naked eye, their risks may be underestimated (Koehler & Volckens, 2011). Nevertheless, there are also plenty of exceptions to this rule, such as when risks involving rubber granulate on sports fields were strongly overestimated by the general public (De Vries et al., 2019), or when public outrage occurred because of relatively harmless doses of fipronil in consumer eggs (Ruzza et al., 2020). These exceptions may be explained by other factors that influence risk perception: unknown risks and so-called 'dread' risks (risks that invoke strong emotions) tend to be overestimated (Slovic, Fischhoff & Lichtenstein, 1982), while risks are often underestimated when the effects are long-term instead of short-term, or when the effects are cumulative (Doyle, 2006; Linville, Fisher & Fischhoff, 1983; Slovic, 2000). These effects should all be considered when investigating which exposure risks may be most suitable for this research project.

The main goal of this research project was to develop a risk communication tool to educate employees on the subject of imperceptible exposure risks. We set out firstly to improve knowledge about exposure risks, secondly to change attitudes about them, and most importantly empower various industry workers who are exposed to actually work safely in practice. This is in line with the three main risk communication goals as defined by Fischhoff et al. (2011).

The usefulness of our final result is twofold. Firstly, the combined intervention that we developed may be used in workplace settings, both inside and outside of periodical work safety meetings, to improve workers' knowledge and attitudes about the specific exposure risk it was focused on – namely, particulate matter (PM). Secondly, the method we used to develop this folder can be used in a wide range of subjects with regards to work safety education. In the subsection 'Conclusion and practical recommendations' we will mention a six-step plan (or potentially a seven-step plan) other researchers may emulate or adapt for their own risk communication needs. In these two ways, the results of our risk communication study may help empower workers who are confronted with imperceptible occupational exposure risks.

In this chapter, the main findings of our studies will be summarized and discussed, and the practical implications of our findings will be elaborated. We will first explain how we decided which exposure risks to investigate, and in which way we investigated them. We will also explain why we chose to focus on electromagnetic fields (EMF) and particulate matter (PM); we will also explain why we prioritized developing an educational material about PM instead of EMF. We will then describe the development and testing processes of the new educational material about PM. Afterwards, we will provide some methodological considerations concerning this study, as well as recommendations for practice and future research.

Summary and discussion of main findings

Case selection

Imperceptible exposure risks are, as mentioned before, potentially underestimated by employees. Although many branches have shown improvements over the past decades when it comes to work safety, workplace risks continue to pose a problem, especially in construction industries (Karakhan, Xu, Nnaji, & Alsaffar, 2019). This problem can sometimes be explained by a lack of knowledge or experience, but even employees who have worked in a certain workplace for a longer time can run into problems, as compliance with safety regulations tends to decrease over time (Haas, Eiter, Hoebbel & Ryan, 2019). The lack of compliance with safety regulations was also found by one of the researchers in our team as an important finding of earlier research on EMF exposure in plastic welding companies, where people failed to use a protection hood even if they personally noticed burning sensations in their body on the afflicted areas (Bolte & Pruppers, 2006). For that reason, we chose EMF as one of the cases for this thesis.

The choice to also include PM came from the current state of workplace risks in general. When considering chemical exposure risks at work, several of the most important substances that cause workplace illness and death can be considered to be a form of PM, such as quartz, diesel emissions, and wood particles (Arboportaal, 2018). Furthermore, many of the workplaces where PM plays an important role are part of the construction industry, which appears to be lagging behind when it comes to work safety (Karakhan et al., 2019). Both EMF and PM involve risks that may be underestimated, as they are individual, moderately well-known, cumulative long-term risks (Anderson, Thundiyil & Stolbach, 2012; Hänninen & Knol, 2011; Huss, Koeman, Kromhout & Vermeulen, 2015), and the agents themselves are difficult to perceive. The underestimation of the risks may lead to a reduction in protection against these risks, according to the Protection Motivation Theory (Rogers, 1983), and thereby lead to more adverse health effects.

For each of the two agents, EMF and PM, we used a mental models approach to investigate knowledge and attitudes of employees who are regularly exposed to the agent. Petts et al. (2002) define mental models as "*cognitive tools that allow people to reason and put into order what would otherwise be an incomprehensible and disorderly world, [and they] are comprised of a system of knowledge, attitudes, beliefs, impressions and images*". In the mental models approach, qualitative research methods and literature searches are used to compare mental models of various groups of stakeholders, in this case workers and experts (Morgan, Fischhoff, Bostrom & Atman, 2002). The differences between these mental models can be used as input for risk communication. For PM, we interviewed road construction and maintenance companies, and for EMF, we interviewed employees of power plants.

The mental models study on PM (reported in chapter 3 of this dissertation) revealed that roadwork employees tend to be aware of the most important safety measures against PM, such as ventilation, sprinkling water, and respirators. However, they tend to have little insight in the hierarchical mitigation model that is often used in occupational hygiene. An often-used hierarchical model involves four levels, namely source measures, technical measures, organizational measures and personal protective equipment (although different terms are often used), with the first level consisting of the most effective and the last level consisting of the least effective methods (Creative Safety Publishing, 2014). In some cases, a five-level model is used, splitting up source measures into elimination and substitution (NIOSH, 2018). We used a four-level model ourselves, in accordance with insights from Heederik et al. (2009) into PM in the Netherlands. Employees in roadwork companies within our study tended not to know about any of these hierarchical distinctions, but only (some of) the safety measures themselves.

Employees tend to have a general grasp on mitigation, but relatively few specific insights on which mitigation method to use in which situation. Furthermore, their knowledge about PM itself appeared to be fragmented and incomplete. PM is often conflated with visible dust, and most employees do not know which substances may be considered PM. The respiratory effects are, in a general sense, somewhat known to employees, but there is little or no knowledge of its cardiovascular effects. These limited insights of the properties of PM show that, while employees often know what to do against PM, they do not always know why it is important that they do it.

In the EMF study (reported in chapter 2), we found mental models among employees that appeared to be more thorough and complete compared to the PM mental models. The most important properties of EMF and mitigation methods were mentioned by participants, and most of the companies that were visited have some sort of instruction method about EMF in place. We did find some misconceptions, but they were often more related to an overestimation of risk than an underestimation, such as the case of leukemia and transmission towers – as mentioned in Kheifets, Afifi & Shimkhada (2006). In general, we also found a higher level of education about employees in the EMF study than in the PM study. Due to the nature of the work in power plants, it requires a more thorough understanding of technical concepts than is necessary in road construction or maintenance work (as in the PM case). This difference in level of education may help explain the lower degree of mismatch between mental models of experts versus employees in the EMF case.

Furthermore, power plants have a high degree of mitigation when it comes to EMF exposure, more so than we found in the PM case. Exposed areas are fenced off, warning signs are in place, and employees are aware of the existence of these mitigation methods. Contrary to our findings in the PM study, employees do not appear to be exposed highly when working in these power plants, due to the high degree of mitigation. When interviewing these employees, they did point out that they would like some more information during work safety meetings about EMF, including its potential adverse health effects.

In the remainder of this study, we focused on developing an educational material for the PM case. Based on the two mental models studies, it appeared to us that the need for such an intervention is more pressing for PM than for EMF, as PM risk communication is less standardized and appears to be less effective. Of course, that does not mean that no relevant improvements could be made to the practices involving EMF risk communication. This may be a relevant topic for future research (as we will discuss further on).

Development of educational material

Based on the mental models studies (chapter 2 and 3), we decided to develop an educational material to improve knowledge and perceptions of PM risk in roadwork companies (the development process is described in more detail in chapter 4). In the development of the folder, we used the broader categories from the mental models study to define the ‘chapters’ of the educational material. That is, we decided that the information in the folder should be divided into four subsections, namely properties of PM, sources of PM, effects of PM, and mitigation methods.

In our initial PM mental model study, we found several discrepancies between the expert and worker mental models. As recommended by literature (Slovic & Weber, 2002; Riley, 2014) we used the discrepancies between the mental models to help further fill in the contents of these chapters. For example, a lack of knowledge about the cardiovascular effects of PM among employees meant that we should at least mention these effects in the material. Of course, we also made use of other theoretical recommendations related to our target audience. For example, the recommendation to minimize technical details (Chen, Pedersen & Murphy, 2012) led us to the decision not to include distinctions between PM_{10} and smaller fractions of PM, and the recommendation to emphasize practical instructions (Niewöhner et al., 2004) led us to put a more thorough focus on the mitigation’ chapter of the material, including the four-level hierarchical model from e.g. Heederik et al. (2009).

Finally, we made use of an icon array in the ‘effects of PM’ section, an image involving 10x10 icons of humans, three of which were colored red and the other 97 green; this image was included to showcase the ten-year risk of death due to exposure at work. This is viewed as a good practice by several researchers in risk communication (Lipkus, 2007; Trevena et al., 2013; Trevena et al., 2021), but it also has some limitations and pitfalls, as it requires, for example, sufficient graph literacy on the end user’s part (Etnel et al., 2020; Garcia-Retamero, Okan & Cokely, 2012; Zipkin et al., 2014).

In the development phase of the educational material, we considered a wide variety of media. We investigated the merits and shortcomings of six potential options: a folder, a presentation, an instruction movie, an e-learning tool, a serious game, and a practical assignment. We evaluated all of these options by means of the SECTIONS model (Bates & Poole, 2003), which critically appraises media in terms of appropriateness for the students, ease of use, costs, teaching opportunities, interactivity, organizational issues, novelty, and speed. In the end, we concluded that a combination of a folder and a practical assignment would be most appropriate for our situation. We focused further attention on the development of the folder, since a useful practical assignment involving an exposimeter had already been developed for a similar situation, which could be implemented with minimal alterations.

We performed a usability test with a prototype of our folder, involving four experts in the field of PM and/or risk communication and six participants from an online panel[10] who had jobs involving exposure to PM, varying from low to high exposure. The usability test revealed that some minor adjustments to the folder were recommended, but in general the experts and workers had favorable views of the folder. The most controversial subject involved the icon array mentioned earlier. Experts and workers in our usability test disagreed among each other whether the icon array in our folder should be used for this target audience. For this reason, we progressed with a larger-scale test involving two versions of the folder, one with and one without the icon array and one other risk visualization image (both versions of the folder can be found in the attachments of chapter 5).

It should be noted that existing risk communication in the workplace is generally not focused on the broad subject of PM. Existing 'good practice' folders that we found focused more on one specific substance (Volandis, 2016) or on one specific health outcome (Cumela, 2009). Our choice to focus on PM in general has been considered, by participants in the usability test, both a strength and a weakness, as it provides a broader overview (and thereby a broader degree of applicability to various workplaces), but relatively little in-depth information. Nevertheless, the absence of a current folder about the subject of PM in general, combined with the generally favorable overview of the folder as it was, provided plenty of opportunity

10 The panel we used is the Flycatcher panel. Flycatcher is situated in Maastricht, The Netherlands, and affiliated with the University of Maastricht. It was certified ISO 20252 and ISO 26362 for research quality, as well as ISO 27001 for information safety.

to progress to a more thorough test of the effectiveness of the folder.

Effectiveness of materials

The folder was tested, first in an online experiment involving the same online panel (but different respondents) as in the usability test, and later in an actual workplace setting alongside the practical assignment with the exposimeter. The online experiment is described in chapter 5 of this dissertation, and the field study in chapter 6. For the online experiment, we compared the two versions of our folder with each other, as well as with one 'good practice' folder by the trade union and one unrelated 'dummy text' about work safety. We chose for this study design in order to investigate the effects of the icon array, the added effects of the mental models approach compared to a folder which was developed using a different approach, and simple priming effects – if showing an unrelated text gives just as much outcome as showing a folder about PM, then the outcomes can likely be explained by priming. We compared these folders in terms of outcome measures of perceived folder quality, PM knowledge, threat appraisal (the degree to which people view PM as a threat), coping appraisal (the degree to which people feel that they can protect themselves against PM), and self-proclaimed safety behavior at work.

The quantitative analyses from the digital experiment revealed that the only notable differences were seen in outcomes of PM knowledge; all effects on outcome measures related to threat and coping appraisal were non-significant. Specifically, the folder with risk visualizations performed better on PM knowledge outcomes than the control condition. During the posttest questionnaire, we enabled participants to view the folder to help them answer the knowledge questions, and we found that effects on PM knowledge outcomes were even more pronounced in participants who viewed the folder. We considered this evidence to be sufficient for a field test using only the folder with risk visualizations (including the icon array), alongside the practical assignment.

In the field test, four roadwork companies were recruited for work safety meetings involving the combined intervention with the folder and the practical assignment. This practical assignment involved giving participants a PM exposimeter and asking them, for example, to search for high and low exposure levels within their normal working environment. We chose to add this assignment in order to induce active learning (Bonwell & Eison, 1991), as well as alleviate some of the downsides of working with a folder-based instruction regarding aspects such as interactivity and teaching opportunities (Bates & Poole, 2003).

We used a similar, but shortened version of the questionnaire that we used in the digital experiment, with the same quantitative outcome measures. We also added a small qualitative portion in which work safety experts were asked to reflect on the intervention in their workplace. We found significant effects of the intervention both on knowledge scores and on threat appraisal, although the added assignment did not appear to make much of a difference in the quantitative outcomes. However, upon analyzing the qualitative results of this final study, we found that work safety experts generally claimed that their workers experienced a change in attitude upon receiving the assignment with the exposimeter. Therefore, it appears that the combined intervention has been successful to some extent in influencing workers' knowledge and perceptions about PM, as we set out to do. The quantitative effects may not have shown clear effects of a combined intervention compared to only a folder, but the qualitative results imply that there may be sufficient reason to include the practical assignment as part of the intervention. However, further research may still be necessary to provide further quantitative proof.

The direct effects of the intervention, both in the digital and in the field experiment, can be seen as somewhat modest, especially when considering only the quantitative results. Outcomes related to the Protection Motivation Theory (PMT), threat appraisal and coping appraisal (Rogers, 1983), were non-significant in the online experiment. Although we did find significant effects on threat appraisal in the field experiment, any further effects of the practical assignment remain quantitatively invisible.

The direct effects of the educational material on PMT variables may not be as visible because implicit attitudes and ideas related to threat and coping appraisal develop over time. Due to practical considerations, we performed the pretest and posttest often on the same day when conducting the field experiment. Even if participants had just completed the assignment, finding higher or lower exposure levels to PM, it is unlikely that this assignment leads to an immediate change in attitude.

Another explanation for the modest results can be seen from the effects of company culture and hierarchy. The company culture is a deciding factor in maintaining work safety. Having a culture in which it is considered normal to discuss improvement of safety measures has a positive effect on work safety (Petts et al., 2002; Toppazzini & Wiener, 2017). This is especially true because workers are often more influenced by informal sources of education, such as discussing about their activities in the workplace, than by formal instruction (Hambach et al., 2011). A more conservative and working-class culture, as is common in practical professions such as road construction and maintenance, tends to be linked to a lower focus on work safety (Van Deurssen, 2015).

Workers often feel that company staff should set the right example, and they tend not to pay as much attention to work safety whenever they feel the management doesn't care enough about it either (Hambach et al., 2011; Lipscomb et al., 2013). For many people, it seems, the hierarchy still sets the example. This idea is confirmed by Smith & Ragan (2005), who state that attitude changes can be attained under three conditions: demonstration by a role model, practice, and reinforcement. As these things cannot be attained with a single work safety meeting, nor with a single pretest and posttest questionnaire, it makes sense that the measurable effects of a single intervention are relatively modest.

Methodological considerations

Strengths

Looking at the methodology of this study, there are several strengths and weaknesses to uncover. The main strength involves the application of the mental models approach, as the end user is thoroughly involved in the development process (Morgan, Fischhoff, Bostrom & Atman, 2002). The invididual's perception is used as a starting point instead of the expert opinion. This is in line with a general move within social sciences towards more human-centered approaches. The mental models approach as used in this study and similar studies (e.g. Petts et al., 2002) can be considered a form of human-centered design, as the construction of various mental models often involves thorough contact with various stakeholders. In our case, we investigated the perceptions of PM and EMF of a large number of employees, and used them as a basis for developing the folder.

When evaluating the methodology of the mental models approach, Boase et al. (2017) state that only a minority of mental models studies on risk communication involve actually developing educational material, and even fewer involve a practical test of the educational material against a control group. In their own words, *“perhaps the most striking finding of our scoping review was just how few of the studies that claimed to be using the MMARC actually went on to develop and evaluate a risk communication”* (Boase et al., 2017). Out of the studies that do, however, similar results to ours are often found; the most pronounced effects of the interventions tend to be knowledge effects, with less emphasis on attitudes and behavior effects. These findings can be seen as a strength of our specific study, as we have studied PMT-related outcomes, where some effects (albeit modest) were found in the field test.

Another methodological strength involves the appropriate usage of mixed methods. It is common in social sciences to first investigate the general ideas about a certain subject by means of qualitative research methods before quantifying any effects. The advantage is that the results of the qualitative methods show the researcher exactly where to look for those effects. In our case, we knew a number of common misconceptions about PM from the mental models study, we based a folder partially on addressing those misconceptions, and we were able to ask specific questions in the quantitative study to investigate whether those misconceptions had been alleviated. In the field test of the combined intervention, another layer of mixed methods was introduced. In this case, the qualitative results from the questions asked to the work safety experts showed what could not be shown by the quantitative results only, namely that the combined intervention had been received in the workplace with enthusiasm.

Weaknesses

The knowledge scores are based on quite a small number of questions; ten questions in the online experiment, and only five in the field experiment. We made these decisions in order not to overwhelm the participants with lengthy texts, especially in the workplace when they were also prompted to do measurements in the practical assignment. Of course, this small number of questions does provide limitations on the construct’s validity and reliability, especially since some of the questions had a rather high percentage of participants who gave the correct answer even on the pretest (~90%). In spite of these limitations, we still found some significant effects on knowledge scores both in the digital and in the field experiment.

One could argue that, if behavior change is the main goal of workplace risk communication (Fischhoff et al., 2011), knowledge scores as an outcome are not as important as PMT-related variables. Nevertheless, in accordance with Kirkpatrick's four-level evaluation model for educational interventions (Kirkpatrick, 1959), investigating knowledge improvements has its place even if increasing knowledge is not a goal in itself.

The usage of online panels to find participants is sometimes critiqued by the scientific community at large (e.g. Pecakova, 2016). The main point of critique appears to be that there is a high degree of selection bias, since no online panel successfully recruits a uniform sample from the general population. Although we did not set out to emulate demographic proportions from the general public, focusing instead on workers exposed to PM, we agree that there may still have been selection bias in our sample. Many PM-exposed workers may fall in a demographic category that is generally underrepresented in online panels, thereby undermining, for example, the cultural neutrality of the sample and the ensuing results of our study. Although it is a methodological consideration that cannot be ignored, this does not necessarily invalidate the results.

There were a few metholodogical limitations when selecting companies for this study. For example, the selected companies for the field test had some differences among them, as some of the companies were more focused on construction activities and some more on maintenance, with a varying balance of indoor versus outdoor work. It is likely that the participants who saw extremely high PM exposure on their exposimeters during the assignment, when drilling or sawing in an indoor workshop, are more likely to change attitudes towards PM than participants who were busy with road maintenance on a cold, windy winter day. Since activities differ between companies, it is unsurprising that levels of education vary as well. Furthermore, the way in which the field test was carried out differed between companies, as not all work safety experts were similarly comfortable leading a work safety meeting on PM. Due to the relatively small number of participants in each company, it was unfeasible to perform a thorough quantitative analysis of these company differences. Therefore, some carefulness is needed in the generalization of our results to all companies where PM exposure plays an important role.

Recommendations for future research

There are some potential leads for future research that need to be discussed. The most obvious example stems from the fact that we chose to develop a folder about PM, not a folder about EMF, based for the most part on the results of the mental models studies. Nevertheless, we also concluded that small improvements and adjustments to current risk communication practices could still be made in the EMF case, for example to decrease bureaucracy and provide information that is more in line with employees' mental models. This may be a topic for future research. Furthermore, risk perception on EMF could be investigated in other branches than power plants to ensure that the high degree of mitigation is present among different branches.

When it comes to the effects of the combined intervention for the PM case, future research may focus on more long-term effects in the improvement of work safety and PMT-related variables (e.g. threat appraisal and coping appraisal). Since our study involved a posttest questionnaire shortly after the intervention, only short-term effects could be measured. A longitudinal study may prove useful for those situations in which incremental changes in company culture or general attitude are not visible in the short term, but may improve exposure mitigation in the long term. Similarly, a larger-scale study where workers are asked to keep track of their exposure for a longer time, for example by using wearable sensors, may prove helpful to confirm PMT-related outcomes and alleviate the downsides of between- and within-company differences mentioned earlier. A small-scale experiment with wearable sensors has already been done, providing some promising insights (Bolte et al., 2018).

One finding from the field test was that some work safety experts may need some kind of briefing in order to maximize the outcomes, as well as their own comfortability in carrying out the work safety meetings with our combined intervention. Although not all experts agreed that this was necessary, the development of a briefing system alongside the intervention may still be a useful focus for future research.

We are convinced that the mental models approach is a solid basis for investigating risk communication needs within companies, but different approaches are certainly possible. Future research could certainly incorporate different approaches for the development of risk communication tools, and compare this approach to ours in a similar comparative study as we did in the online experiment. Furthermore, since the SECTIONS model requires a qualitative rather than a quantitative assessment of the alternatives, it is feasible that other considerations on the designer's part may lead to different formats of risk communication. If another researcher develops, for example, an instruction movie about PM, it may also be compared to our solution to this problem by means of a comparative study. Some more high-tech solutions, such as a virtual reality experience, may also provide workers with insights that lead to more pronounced effects on threat appraisal or coping appraisal than we found in our study.

In the 'weaknesses' subsection in this discussion, we briefly mentioned the idea of cultural neutrality. As the workers in many professions related to roadwork are often of multicultural descent, it makes sense to perform a follow-up study to investigate whether there are any cultural differences in the understanding of our folder and the capacity to follow up on safety behavior. This is also in line with a finding from the usability test, where some participants mentioned that they thought translations of the folder into minority languages in the Netherlands (e.g. Turkish, Polish) may be useful. Follow-up studies may investigate whether or not some information, as well as some inductions of attitude changes, may be lost in translation.

Conclusions and practical recommendations

The mental models approach followed by the development of the combined intervention has led to some promising effects on the practice of work safety meetings related to PM. Based on these results, we recommend that the combined intervention of a work safety meeting involving our newly developed educational folder and a practical assignment be implemented in workplaces involving a high degree of PM exposure. The folder contains the necessary information for workers to fill in knowledge gaps and alleviate misconceptions, and the assignment with the exposimeter may help workers to visualize the actual exposure, so that they can infer potential health effects if this exposure builds up over time. In this way, awareness and compliance should increase regarding PM and its mitigation methods.

With regards to this process, there is a high degree of generalizability, since the individual steps can be performed in many types of workplaces with many different (exposure) risks. With that in mind, we recommend the following process for developing educational materials:

1. Investigate the mental models of risk by means of a qualitative study, both for the end user (employee) and for the expert.
2. Based on these mental models and other qualitative outcomes, decide whether a risk communication tool is necessary. Educational materials may be performed when there are many misconceptions or information gaps regarding the subject matter, when there is a low degree of mitigation, and/or a low degree of compliance with safety regulations.
3. If a risk communication tool is necessary, investigate which contents are needed in the educational material based on the mental models. Also, investigate the potential media to be used. This can be done by means of the SECTIONS model.
4. Develop an initial prototype of the material, and perform a small-scale usability test with experts and potential end users.
5. Refine the prototype afterwards, and perform a larger-scale test with a higher number of end users, defining the necessary outcome measures.
6. When a complete version of the material is decided on, test it in a practical setting.

After completing this development process, a case can be made for a seventh step, which we did not carry out in our own study, but which was recommended by some stakeholders:

7. Develop a briefing for work safety professionals to ensure smooth implementation in the workplace.

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SUMMARY

Summary

Work can be dangerous. Employees in industrial and maintenance-related occupations are often confronted with a broad array of workplace risks. These can be direct risks; employees could be at risk of falling, losing limbs due to machinery or explosions, or they could be exposed to toxic gases or noise. However, in some cases they are also exposed to not directly perceptible exposure risks, that may primarily cause long-term effects. This dissertation focuses on the latter category of risks. The reason is that these risks are often neglected compared to direct risks and perceptible exposures, which are often significantly more salient. Specifically, two not directly perceptible exposure risks are selected, which are particulate matter (PM) and electromagnetic fields (EMF).

In many branches, work safety is already notably under the attention. For example, the Netherlands mandates periodical work safety meetings in several branches, where employees are regularly instructed about safety-related subjects. The question remains, however, if the current methods of risk communication are sufficiently effective. Long term effects due to exposure in the workplace are still commonplace, and safety regulations aimed to combat this do not always lead to compliance. Risk communication should aim, therefore, not only to improve knowledge and attitudes concerning a certain subject, but also to improve safety by changing behavior in the workplace.

In this dissertation, we investigated to what extent this behavioral change is needed concerning both of the selected exposure risks. For this goal, we used the mental models approach, where employees' perceptions are systematically compared to expert views concerning the aforementioned risks. We also gave attention to the current methods of risk mitigation, and the way risk communication is currently handled, both inside and outside the mandated periodical work safety meetings. The main goal of this research is to map employees' needs for risk communication of not directly perceptible exposure risks in the workplace, and to anticipate on these needs by developing and implementing an appropriate method of risk communication.

Chapter 1 explains in more detail why not directly perceptible exposure risks are so important to consider in the workplace. To this end, several theoretical considerations are presented.

The mental models approach is explained in more detail, and for both of the exposure risks, PM and EMF, a general overview is given about the current knowledge within the scientific realm.

The two chapters afterwards explain the mental models studies themselves in more detail. These chapters answer research questions related to employees' perceptions on both of the risks, EMF and PM. In chapter 2, the EMF study is presented. For this study, various employees of power plants were asked about their perceptions on EMF. During the company visits and the interviews, we noticed that these companies had a high degree of mitigation regarding EMF, for example by placing fences and warning signs. The (minor) misconceptions by employees regarding EMF appeared to be more overestimating than underestimating the risks of EMF exposure. For this reason, the study did lead to some recommendations, but we did not develop any further risk communication tool for EMF exposure at work.

Chapter 3 presents the findings of the PM study, which were noticeably different. For this study, employees in the roadwork and maintenance branch were asked for their perceptions. We found a relatively high degree of variation concerning the knowledge and attitudes about PM. Although many participants were aware of the most important mitigation methods, such as wetting materials and wearing dust masks, they were not always aware why these mitigation methods are in place, which may negatively impact compliance. Employees' knowledge about PM appeared to be fragmented and incomplete in certain aspects. Some companies did have some degree of risk communication in place regarding PM, but a thoroughly substantiated risk communication tool was not yet present during this study. For this reason, we spent the remainder of this research project developing such a risk communication tool.

The development of a workplace risk communication tool for PM is the subject of chapter 4. First, we determined the necessary contents of such a tool by comparing the mental models of employees with those of experts, and considering the discrepancies between these mental models. This is in line with the aforementioned mental models approach. After determining the contents, we decided with the aid of models from educational science which medium would be most appropriate for our risk communication tool. We decided to combine a folder with a practical assignment with a PM dosimeter. Finally, we considered various design-related issues related to the folder, giving extra attention to risk visualizations. We decided to carry on with the testing process with two separate versions of the folder, one with and one without these risk visualizations.

After developing the folder, we tested this with an online panel in an experiment. This study can be found in chapter 5. We tested both versions of our folder with an existing 'best practice' folder, and also with a control condition, a text unrelated to PM. We investigated outcomes of respondents' opinions about the folder, PM-related knowledge, and perceptions of PM. We found that people who were shown the folder with the risk visualizations showed an increase in PM knowledge, more so than in the other conditions. For the other outcomes, in this stage, we did not find any significant effects.

In the final stage, we performed a field study, described in chapter 6. Our proposed risk communication tool did not consist of the folder only, but a combined intervention of this folder with a practical assignment, to be carried out during a work safety meeting. This practical assignment could not feasibly be tested in an online panel, but the combined intervention was tested by visiting several companies where high degrees of PM exposure are often present. In the field study, there was a noticeable degree of enthusiasm for the practical assignment with the dosimeter, but this does not yet translate to a higher degree of effectiveness than we reached with only the folder. Nevertheless, modest effects were found of the combined intervention on outcomes of workers' threat appraisal.

Chapter 7 provides a general overview and an interpretation of the most important results. We conclude here that the effects of the combined intervention may be modest when considered quantitatively, but that they do lead to a better understanding of employees' social environment, giving practical leads for risk communication. This design fills an important gap, considering the absence of a mental models-based intervention about workplace PM exposure. There was also a noticeable degree of enthusiasm showcased by the companies themselves. In this way, we have shown that the mental models approach can be applied to investigate which needs there may be within a certain branch concerning risk communication. Afterwards, it can be used to give concrete form to this risk communication. We recommend, therefore, a roadmap to further use this mental models approach with similar subjects related to occupational exposure risks.

SAMENVATTING

Samenvatting

Werken kan gevaarlijk zijn. Werknemers in industriële en bouwkundige bedrijfstakken krijgen op hun werk vaak te maken met een breed scala aan risico's. Dit kunnen directe risico's zijn; werknemers kunnen bijvoorbeeld vallen, ledematen kwijtraken door machines of ontploffingen, of blootgesteld worden aan giftige gassen of geluid. Het kunnen echter ook blootstellingsrisico's zijn die niet direct waarneembaar zijn en waar men vooral op de lange termijn gezondheidseffecten van zou kunnen merken. Dit proefschrift focust op deze laatste categorie risico's. De reden daarvoor is dat deze risico's vaak onderbelicht blijven in verhouding tot directe risico's en waarneembare blootstellingen, die doorgaans veel meer in het oog springen. Specifiek worden twee niet direct waarneembare blootstellingsrisico's uitgelicht, namelijk fijnstof en elektromagnetische velden (EMV).

Er wordt in veel branches al behoorlijk aandacht besteed aan veiligheid op het werk. Zo zijn er in Nederland verplichte periodieke 'toolboxmeetings' in veel branches, waar werknemers regelmatig worden bijgepraat over de actuele kennis omtrent een aan veiligheid gerelateerd onderwerp. De vraag is echter of de bestaande wijze van risicocommunicatie voldoende effectief is. Immers, langetermijneffecten door blootstelling op het werk zijn nog altijd wijdverspreid, en veiligheidsvoorschriften die dit proberen terug te dringen worden niet altijd zorgvuldig opgevolgd. Goede risicocommunicatie heeft dan ook als doel om niet alleen kennis en attitudes bij te stellen betreffende een bepaald onderwerp, maar ook om de veiligheid te bevorderen door middel van gedragsverandering.

In dit proefschrift is van beide uitgelichte blootstellingsrisico's geïnventariseerd in hoeverre er een noodzaak is tot gedragsverandering door middel van risicocommunicatie. Dit is gedaan door de mentale modellen-benadering, waarbij de percepties van werknemers en experts aangaande de risico's in kwestie op systematische wijze in kaart zijn gebracht. Er is daarbij ook aandacht besteed aan de methoden waarmee men op dit moment de risico's probeert te beperken, en de manier waarop risicocommunicatie, binnen en buiten de eerder genoemde toolboxmeetings, op dit moment wordt geregeld. Het doel van dit onderzoek is dan ook om in kaart te brengen waar precies de behoeftes zijn als het gaat om risicocommunicatie van niet direct waarneembare blootstellingsrisico's op het werk, en om hierop vervolgens te anticiperen door de ontwikkeling en implementatie van een passende methode van risicocommunicatie.

In **hoofdstuk 1** wordt in meer detail uitgelegd waarom niet direct waarneembare blootstellingsrisico's zo belangrijk zijn om rekening mee te houden op het werk. Hiertoe worden diverse theoretische achtergronden gepresenteerd. Verder wordt de mentale modellen-benadering in meer detail toegelicht, en wordt van beide risico's die we bestuderen, fijnstof en EMV, een beknopt overzicht gegeven wat erover bekend is in de wetenschappelijke wereld.

De twee hoofdstukken daarna zijn vervolgens gewijd aan de mentale modellen-studies zelf. Hierin worden onderzoeksvragen beantwoord omtrent de percepties van werknemers over de beide risico's, EMV en fijnstof. In **hoofdstuk 2** wordt eerst de studie over EMV gepresenteerd. Hiertoe zijn werknemers met uiteenlopende functies in elektriciteitscentrales gevraagd naar hun percepties over elektromagnetische velden. Wat er tijdens de bedrijfsbezoeken en de interviews opviel is de hoge mate van risicobeperking die al plaatsvindt op dit gebied, bijvoorbeeld door het plaatsen van hekken, andere afschermingen en waarschuwingsborden. Verder leken de (beperkte hoeveelheden) misconcepties van werknemers eerder te leiden tot een overschatting dan tot een onderschatting van de risico's van EMV-blootstelling. Om deze reden hebben we wel enkele aanbevelingen gedaan, maar verder geen risicocommunicatie-tool ontwikkeld aangaande EMV op het werk.

In de fijnstofcasus, toegelicht in **hoofdstuk 3**, kwamen we andere resultaten tegen. Hiervoor zijn werknemers uit de wegenbouw- en onderhoudssector gevraagd naar hun percepties. We kwamen hier een relatief grote mate van variatie tegen qua kennis en attitudes over fijnstof. Hoewel veel mensen wel op de hoogte waren van enkele belangrijke beschermingsmethoden tegen fijnstof, zoals het natmaken van materialen en het dragen van stofmaskers, waren ze zich niet altijd ervan bewust waarom ze deze dingen doen, wat ook de naleving vaak lastig maakt. De kennis over fijnstof leek op enkele punten gefragmenteerd en onvolledig te zijn. Sommige bedrijven besteden wel aandacht aan het onderwerp fijnstof, maar een uitvoerig onderbouwde manier van risicocommunicatie was nog niet voorhanden tijdens dit onderzoek. Om deze reden hebben we in het vervolg van dit onderzoek aandacht besteed aan de ontwikkeling hiervan.

De ontwikkeling van een risicocommunicatie-tool over fijnstof op het werk is het onderwerp van **hoofdstuk 4**. We hebben hierbij de mogelijke inhoud eerst geïnventariseerd door de mentale modellen van werknemers te vergelijken met experts, en in te spelen op de discrepanties hiertussen. Dit is in overeenstemming met de eerdergenoemde mentale modellen-benadering. Na het inventariseren van de inhoud hebben we met behulp van onderwijskundige modellen vastgesteld welk medium het meest geschikt zou zijn om de risicocommunicatie vorm te geven. We zijn uiteindelijk uitgekomen op een combinatie van een folder en een praktische opdracht met een fijnstofmeter. Tot slot hebben we gekeken naar de vormgeving van de folder. We hebben hierbij extra aandacht besteed aan de mogelijke illustraties. Uiteindelijk hebben we twee versies van onze folder meegenomen naar de volgende stap in het proces, een versie met en een versie zonder deze afbeeldingen.

Na het ontwerp van de folder hebben we deze getest met behulp van een online panel, bij wie we een digitaal experiment hebben afgenomen. Dit is beschreven in **hoofdstuk 5**. Concreet hebben we de beide versies van onze folder vergeleken met een bestaande folder van een branche-organisatie, en ook met een tekst die niet inhoudelijk over fijnstof ging (als controleconditie). Als uitkomstmaten hebben we gekeken naar de mening van de respondenten over de folder, de opgedane kennis over fijnstof, en de percepties over fijnstof. We hebben hierbij aangetoond dat bij de mensen die folder met de risicovisualisaties te zien kregen zich een stijging voordeed wat betreft hun kennis over fijnstof, meer dan bij de andere condities. Op de andere uitkomstmaten konden we in dit stadium nog geen effecten aantonen.

Tot slot is er een veldtest gedaan, die beschreven is in **hoofdstuk 6**. Onze voorgestelde risicocommunicatie betrof immers niet alleen de folder, maar een combinatie van deze folder met een praktische opdracht die uitgevoerd kan worden tijdens een toolboxmeeting. Deze praktische opdracht was niet redelijkerwijs te testen bij een online panel, maar de gecombineerde interventie is wel getest door enkele bedrijven te bezoeken waar regelmatig een hoge mate van blootstelling aan fijnstof te vinden is. In deze veldtest hebben we veel enthousiasme bemerkt voor de opdracht met de fijnstofmeter, maar dit vertaalt zich nog niet in een hogere effectiviteit dan dat we bereiken met alleen de folder. Desondanks lijkt na de gecombineerde interventie wel een bescheiden effect zichtbaar te zijn op de risico-inschatting van de medewerkers.

Hoofdstuk 7 geeft tot slot een totaaloverzicht en een duiding van de belangrijkste resultaten. We concluderen hier dat de effecten van de gecombineerde interventie weliswaar bescheiden zijn wanneer ze kwantitatief worden benaderd, maar dat ze wel leiden tot een beter begrip van de leefwereld van de werknemers en handvatten om de voorlichting daar beter bij aan te sluiten. Dit ontwerp vult immers een belangrijke lacune, getuige de afwezigheid van een mentale modellen-gebaseerde interventie over fijnstof op het werk. Ook werd er met enthousiasme op gereageerd in de praktijk. We hebben hiermee laten zien dat de mentale modellen-benadering op praktische wijze ingezet kan worden om te inventariseren welke behoefte er binnen een branche is wat betreft risicocommunicatie, en vervolgens deze risicocommunicatie vorm te geven. We bevelen dan ook een stappenplan aan om deze mentale modellen-benadering breder in te zetten, ook bij andere onderwerpen die gerelateerd zijn aan blootstellingsrisico's op het werk.

DANKWOORD

Dankwoord

De afgelopen 6 jaar ben ik intensief bezig geweest met dit proefschrift – eerst 4 jaar fulltime, daarna nog 2 jaar parttime. Ik zou de waarheid geweld aandoen als ik zou zeggen dat ik dat altijd met plezier heb gedaan, maar niettemin denk ik dat er een resultaat ligt waar ik trots op kan zijn. Ik heb buitengewoon veel geleerd over het doen van een echt onderzoek in de praktijk, waar ik ook in mijn huidige functie als docent in het hoger onderwijs nog veel voordeel uit haal. Daarnaast heb ik ook veel geleerd van het simpelweg actief zijn binnen een groot wetenschappelijk instituut als het RIVM (Rijksinstituut voor Volksgezondheid en Milieu), waar ik 4 jaar lang in dienst ben geweest. Ondanks alle worstelingen tijdens het uitvoeren van het promotieonderzoek heb ik het RIVM altijd ervaren als een prettige werkgever. Ditzelfde geldt ook voor het VUmc, waar ik al die tijd een nulurencontract heb gehad om in aanmerking te kunnen komen voor een promotieplek.

Uiteraard wil ik mijn co-auteurs als eerste persoonlijk bedanken, te beginnen met mijn promotor, Danielle Timmermans. Ze heeft zich gedurende het proces laten zien als iemand met buitengewoon veel expertise over het doen van sociaalwetenschappelijk onderzoek en over het op passende wijze verwoorden van de uitkomsten hiervan. Soms was het confronterend en vermoeiend als een stuk voor de zevende keer werd teruggestuurd met alweer nieuw commentaar, maar vaak moest ik dan toegeven dat het wel zinvol commentaar was.

Mijn copromotor John Bolte heeft vooral laten zien dat hij buitengewoon veel enthousiasme heeft voor het doen van onderzoek in het algemeen, en onderzoek op het snijvlak van exacte en sociale wetenschap in het bijzonder. Als echte wetenschappelijke duizendpoot heeft hij overal iets over te zeggen en kan hij ook overal contacten leggen, wat ook heel praktisch is als er ergens een congres of een symposium te volgen viel. Ik kan wel zeggen dan John de spreekwoordelijke peper heeft toegevoegd aan het hele promotieproces.

Dan is er nog mijn andere copromotor, Liesbeth Claassen, die vooral veel geholpen heeft bij het uitvoeren van de verschillende studies. Of het nu ging om het aandragen van literatuur of het bieden van frisse inzichten over methodologie, altijd als de boel even vastliep kon Liesbeth het weer op gang krijgen. Waar ze ook in uitblinkt is het bewaren van de balans tussen persoonlijk en zakelijk contact; als er iets persoonlijks te bespreken viel kon dat altijd, maar het einddoel werd nooit uit het oog verloren.

Hoewel Ronald van der Graaf formeel gezien geen co-auteur is, wil ik hem toch even apart benoemen. Hij was binnen het RIVM mijn directe leidinggevende en heeft die rol met verve vervuld. Net als Liesbeth heeft ook hij meer dan voldoende aandacht besteed aan de persoonlijke kwesties die het uitvoeren van het onderzoek soms bemoeilijkten. Inmiddels is ook hij werkzaam bij een andere organisatie, maar ik zal hem me altijd herinneren als het aanspreekpunt binnen het RIVM.

Hiernaast zijn er natuurlijk buitengewoon veel mensen die een ondersteunende rol hebben gehad bij het uitvoeren van het onderzoek. Allereerst wil ik hiertoe mijn contactpersonen bedanken die me hebben geholpen met het verkrijgen van respondenten bij de diverse bedrijven waar ik ben geweest. Daarnaast hebben ze me vaak ook persoonlijk nog te woord gestaan of op een andere manier geholpen. Dit zijn voor de mentale modellen-studies geweest: Erik van Doorn, Roel Korf, Klaas Schouten, Rob Kijzers, Ad Wirken en Rick van Soest. Voor de implementatiestudies zijn dit geweest: Klaas Schouten (opnieuw), Chiel Spruijt, Rob Sanders en Arjan Wigmans. Zonder hun bijdragen had dit proefschrift niet tot een goed einde kunnen worden gebracht. Dit geldt natuurlijk ook voor de vele respondenten die ze bijeen hebben gebracht voor de studie.

Naast de studies die zijn uitgevoerd bij de bedrijven is er natuurlijk ook een online panel geraadpleegd voor de hoofdstukken 4 en 5 van dit proefschrift. Het gaat hierbij om het Flycatcher-panel. Ik wil graag iedereen die werkzaam is bij Flycatcher bedanken, en natuurlijk ook hier al onze respondenten.

Ook op andere momenten gedurende het proces hebben we veel hulp gehad van binnen en buiten het RIVM. Allereerst bedank ik Nicole Janssen en Jan-Paul Zock, die van binnen het RIVM input hebben gegeven over de feitelijke accuratesse van de folder. Ook bedank ik de afdeling vormgeving van het RIVM, waarvan we veel hulp hebben gehad met de visuele aspecten van de folder. Buiten het RIVM heb ik veel hulp gehad van Tanja de Jong, werkzaam bij Stigas, met wie ik meerdere keren heb mogen sparren over risicocommunicatie op het werk. Ook vanuit de Arbo-Unie hebben we diverse bijdragen gehad, in de eerste fase van het project vooral van Nick van der Hurk, die onder andere heeft bijgedragen aan de casusselectie, en later vooral van André Winkes. Verder heeft Viola van Guldener op diverse momenten belangrijke input geleverd. Tot slot wil ik Johan Timmerman bedanken, die toestemming heeft gegeven om de 'best practice'-folder van Volandis te gebruiken in het online panel, en die ook heeft geholpen met de werving voor de veldtest.

Nadat mijn proefschrift bijeen was gebracht, moest het natuurlijk nog beoordeeld worden door de leescommissie. Ik wil dan ook Margôt Kuttschreuter, Nicole Palmen, Henk van der Molen, Frederieke Schaafsma, Han Anema en Marijn Poortvliet bedanken voor hun essentiële rol hierin. Ook wil ik hen danken voor hun aanwezigheid bij mijn verdediging en de (ongetwijfeld) vele kritische en interessante vragen die hierbij naar voren komen.

Naast het harde werken heb ik gelukkig ook veel gezelligheid mogen beleven met diverse collega's. Qua collega's vanuit het RIVM heb ik veel contact gehad altijd met Jochem, wiens wielerkennis de mijne helaas ver overtrof; Sander, met wie ik altijd leuke verhalen kon delen over onze gezamenlijke achtergrond bij Alembic; en Martina, die altijd in was voor een goede discussie over nationale en internationale maatschappelijke kwesties. De beste vriend die ik echter heb overgehouden aan het RIVM is Ruud, die enige tijd stage liep binnen ons centrum en met wie ik een goede band heb opgebouwd na ons gezamenlijke congresbezoek in Zweden. Daarnaast bedank ik natuurlijk ook overige RIVM'ers als Julia, Nina, Ilse, Inge, Ingrid, Elias, Peter, Anne, Dingyu, Kim en Joram en vele anderen voor de gezelligheid bij diverse borrels en andere aangelegenheden.

Ook vanuit het VUmc heb ik diverse fijne collega's gehad. Ik bedank Tom dat hij, bedoeld of onbedoeld, enigszins heeft mogen fungeren als een voorbeeld dat je succesvol kan zijn ook als je onderzoek niet altijd op rolletjes loopt. Ik bedank Astrid voor leuke partijen schaak, en naast hen beiden ook Amber, Linda, Dalisa, Marion, Valerie, Olga, Lorraine, Hanna, Hannah, Gizem, en anderen die ik wellicht nog vergeet voor alle gezelligheid.

Op privégebied heb ik daarnaast natuurlijk nog steun gehad van een heleboel andere mensen. Hieronder vallen onder meer mijn geliefde Emma, mijn moeder Diana en haar partner Henk, mijn tante Petra en oom Theo bij wie ik vaak na mijn bezoekjes aan Amsterdam heb kunnen eten, en een breed scala aan vrienden, waaronder Andreas, Roel, William, Martijn en vele

anderen die me altijd hebben gesteund bij deze belangrijke stap in mijn leven. Ook zonder jullie was dit resultaat niet mogelijk geweest. Hartelijk dank allemaal!

Gloria in excelsis Deo.

Thomas

Rijksinstituut voor Volksgezondheid
en Milieu
Ministerie van Volksgezondheid,
Welzijn en Sport

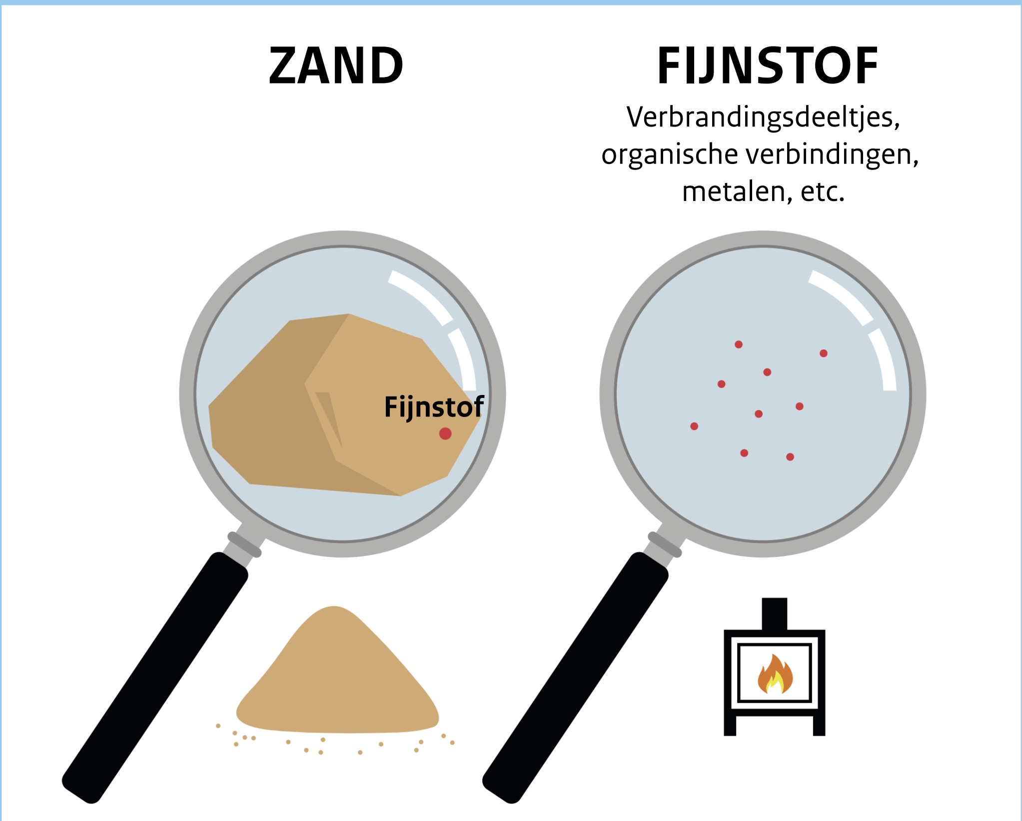
Fijnstof
op het werk

Veilig omgaan met gevaarlijke
blootstelling aan stof

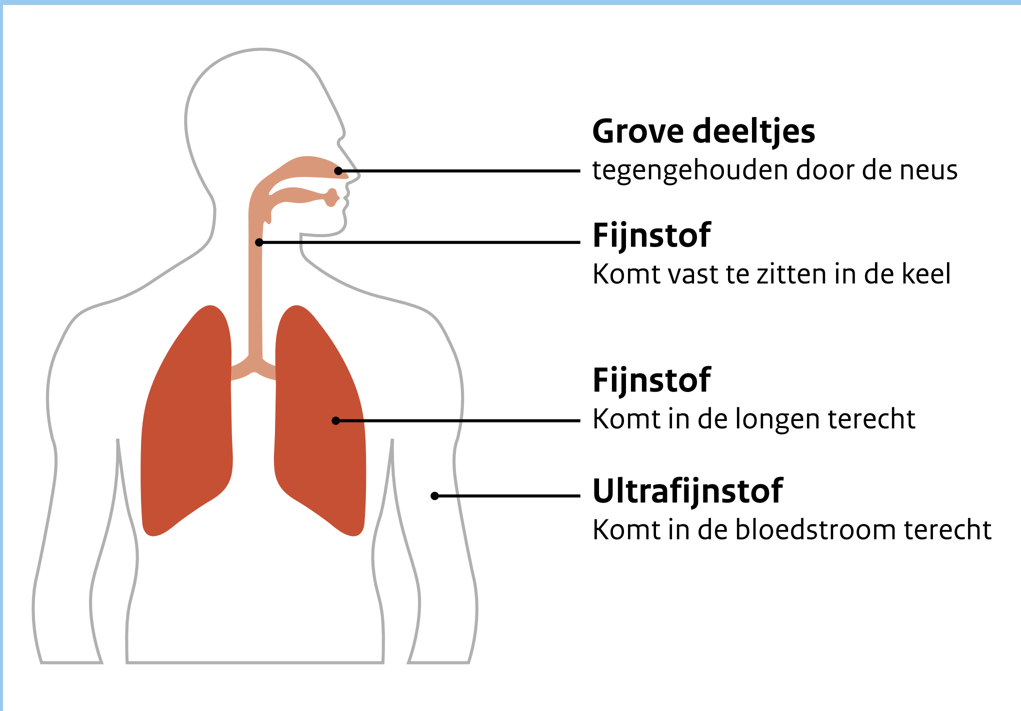
Wat is fijnstof?

Fijnstof bestaat uit kleine stofdeeltjes in de lucht, die erg schadelijk kunnen zijn voor de gezondheid. Naar schatting overlijden elk jaar in Nederland ongeveer 9.200 mensen aan blootstelling aan fijnstof. Veel van deze gevallen worden (deels) veroorzaakt door blootstelling op het werk, en deze blootstelling kan op verschillende manieren worden beperkt.

Deeltjes fijnstof zijn ongeveer tussen de 20 en 1000 keer zo klein als een zandkorrel. Deze deeltjes zijn niet te zien met het blote oog, behalve bij zeer hoge concentraties (bijvoorbeeld in de vorm van smog). Het is ook niet te ruiken. Normaal zichtbaar stof is géén fijnstof, maar: als je veel stof kan zien is er daarnaast vaak ook veel fijnstof.

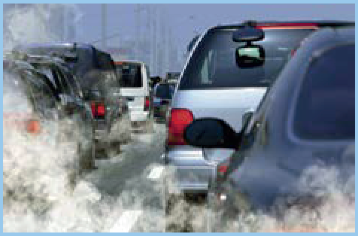


Zichtbaar stof wordt gefilterd door de neus; ’s avonds terug te zien in de zakdoek. Fijnstof wordt niet gefilterd in de neus. Hoe kleiner de deeltjes, hoe dieper ze in je longen en eventueel bloedbaan komen.



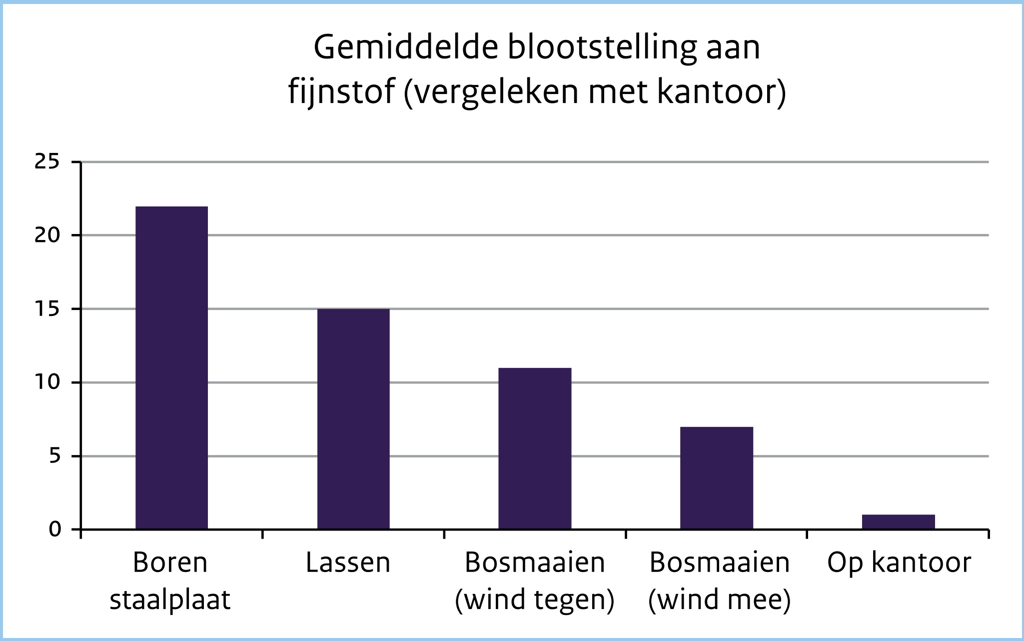
Fijnstof is niet één soort stof, maar bestaat uit verschillende soorten stoffen. Niet al die stoffen zijn even schadelijk. In ieder geval slecht voor de gezondheid zijn kwarts, roet, metalen en rubber. Al deze stoffen komen voor langs de openbare weg.

Bronnen van fijnstof

	Bron	Activiteiten
	*Roet en PAK's door dieselemissie van voertuigen en machines. Verder ook rubber uit autobanden.*	*Autorijden en machines besturen, maar ook lopen of stilstaan langs drukke wegen (bijv. snelwegen).*
	*Kwartsstof uit cement en diverse soorten stenen.*	*Boren, slijpen, zagen en frezen.*
	*Stuifmeel en andere organische stoffen.*	*Bos- en grasmaaien en andere vormen van groenonderhoud, maar ook landbouw.*
	*Sigarettenrook.*	*Roken en passief roken (meeroken).*

Hierboven zijn enkele van de belangrijkste soorten fijnstof genoemd.
Er is daarnaast ook fijnstof uit natuurlijke bron, bijvoorbeeld uit zeezout.
Dit is echter niet of nauwelijks schadelijk.

Tijdens het werk is vaak goed te zien, als je een fijnstofmeter draagt, wanneer je een activiteit uitvoert die veel fijnstof veroorzaakt. De blootstelling is vaak vele malen hoger dan op kantoor. Bij het boren van een staalplaat werd bijvoorbeeld een 22 keer zo hoge dosis fijnstof gemeten als gemiddeld op kantoor!



Mogelijke gevolgen

Fijnstof is een sluipmoordenaar. Soms merk je, na het werken tussen de stofwolken, dat je benauwd bent of gaat hoesten, maar dit gaat vrij snel weer weg. Toch bouwt de schade in je longen zich ook op in de loop van de jaren. Dit is meestal niet direct te merken!

Fijnstof kan diverse longproblemen veroorzaken, zoals longontstekingen, ernstige longziekten als COPD en longemfyseem, en op de zeer lange termijn longkanker. Verder kan fijnstof naast longproblemen ook hartziekten en beroertes veroorzaken.

Ongeveer 3.000 mensen per jaar overlijden vroegtijdig door blootstelling aan stoffen op het werk. Vaak is dit een vorm van fijnstof, bijvoorbeeld dieselemissie, houtstof of kwartsstof. Ongeveer 1 miljoen mensen worden op het werk blootgesteld aan gevaarlijke stoffen. In 10 jaar tijd zullen ongeveer 3 op de 100 mensen die worden blootgesteld op het werk hieraan vroegtijdig komen te overlijden.

Aantal mensen zoals u die vroegtijdig overlijden in de komende 10 jaar door blootstelling aan stoffen.

Wat te doen tegen fijnstof?

Bedrijven hebben de **wettelijke verplichting** om werknemers te beschermen tegen blootstelling aan fijnstof op het werk. Daarnaast kun je ook als werknemer je blootstelling aan fijnstof beperken.

Manieren om blootstelling te beperken worden verdeeld in de volgende vier categorieën:

- **S**ubstitutie
- **T**echnische Maatregelen
- **O**rganisatorische Maatregelen
- **P**BM's

	Wat kan het bedrijf doen?	Wat kan ik zelf doen?
Substitutie	*Vervuilende brandstoffen zoals diesel vervangen voor **schonere brandstoffen**.*	
Technische Maatregelen	***Voorgesneden materialen** bestellen, in plaats van werknemers dit laten doen. Zo wordt werk waar veel fijnstof vrij komt voorkomen.* *Indien mogelijk ook **apparatuur vervangen**, bijvoorbeeld eerder genoemde slijpmachines die nat slijpen gemakkelijk maken.*	*Bij zagen, boren en slijpen: houd het **materiaal nat**. Sommige slijp- en boormachines doen dit automatisch.* *Zorg zoveel mogelijk voor **afzuiging**. Bij werkzaamheden binnen: zorg voor **ventilatie**.* *In een auto of ander voertuig: **sluit de ramen wanneer mogelijk**, tegen de dieseluitstoot.* *Bij gebruik van de **overdrukcabine met stoffilter**: vervang het stoffilter regelmatig en houd de ramen gesloten.*
Organisatorische Maatregelen	*Rekening houden met **dienstroosters**. Bij zeer droog weer bijvoorbeeld werk uitstellen of verplaatsen. In uiterste gevallen kan ’s nachts gewerkt worden, al kan dit ook weer op andere manieren nadelig zijn voor de gezondheid (bv. slaapritme).*	*Ga **uit de wind staan** als je buiten werkt, zodat stof niet naar je toe blaast.* ***Nathouden** van puinbanen en zandwegen.* *Werkzaamheden waarbij veel fijnstof vrij komt doe je overigens **zoveel mogelijk buiten**.*
PBM’s	*Werknemers **voorlichten** over fijnstof, en werknemers laten meedenken over mogelijke oplossingen!* *Beschikbaar stellen van PBM’s (persoonlijke beschermings-middelen), zoals **stofmaskers**.*	*Als andere manieren om fijnstof te beperken niet voldoende zijn, dan is het noodzakelijk een **stofmasker** te dragen. Dit is niet altijd aangenaam, maar wel effectief.*

Wilt u meer weten over fijnstof?

- Algemeen over fijnstof, onder meer over effecten, metingen, wetgeving, beleid: *https://www.rivm.nl/fijn-stof*
- Achtergrondinformatie blootstelling aan diverse stoffen: *https://www.arboportaal.nl/campagnes/veilig-werken-met-gevaarlijke-stoffen*
- Diverse inzichten over bronnen en aanpak fijnstof: *https://www.infomil.nl/onderwerpen/lucht-water/lucht/overheden-overheden/fijn-stof/*

Dit is een uitgave van:

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De zorg voor morgen begint vandaag

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