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Risk communication about particulate matter in the workplace: A digital experiment

T.A.M. Stege [a], J.F.B. Bolte [a,b,*], L. Claassen [a], D.R.M. Timmermans [c]

[a] National Institute for Public Health and the Environment (RIVM), PO Box 1, 3720 BA Bilthoven, The Netherlands
[b] Smart Sensor Systems group, Faculty of Technology, Innovation, and Society, The Hague University of Applied Sciences, Rotterdamseweg 137, 2628 AL Delft, The Netherlands
[c] Amsterdam Public Health research institute, Department of Public and Occupational Health, Amsterdam University Medical Center, Amsterdam, The Netherlands

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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.

1. 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 μm 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

* Corresponding author at: National Institute for Public Health and the Environment (RIVM), PO Box 1, 3720 BA Bilthoven, The Netherlands.
E-mail address: j.f.b.bolte@hhs.nl (J.F.B. Bolte).

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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)[1]; 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?

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

1.1. 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).

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, 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.

2. Method

2.1. Participants

We approached participants through an online panel specialized in recruiting participants for online questionnaires.[2] 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.

2.2. 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 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.

2.3. 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

[2] 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 20,252 and ISO 26,362 for research quality, as well as ISO 27,001 for information safety.

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.

2.4. 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.

2.5. 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.

3. 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.

3.1. 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

Table 1
Perceived quality scores in each of the conditions (excluding the control condition).

	Clarity	Layout	Insufficiency	Redundancy
'Risk Visualization' condition[5]	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)

[5] 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).

conditions.

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 $p > 0.05$).

3.2. 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 less than 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 Fig. 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.

3.3. 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>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>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 Fig. 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.

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 ($p > 0.05$).

Table 2
Paired-sample T test and regression analysis on the knowledge scores.

	Paired-sample T test				Regression[6]	
	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

[6] 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.

3.4. 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.

3.5. 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

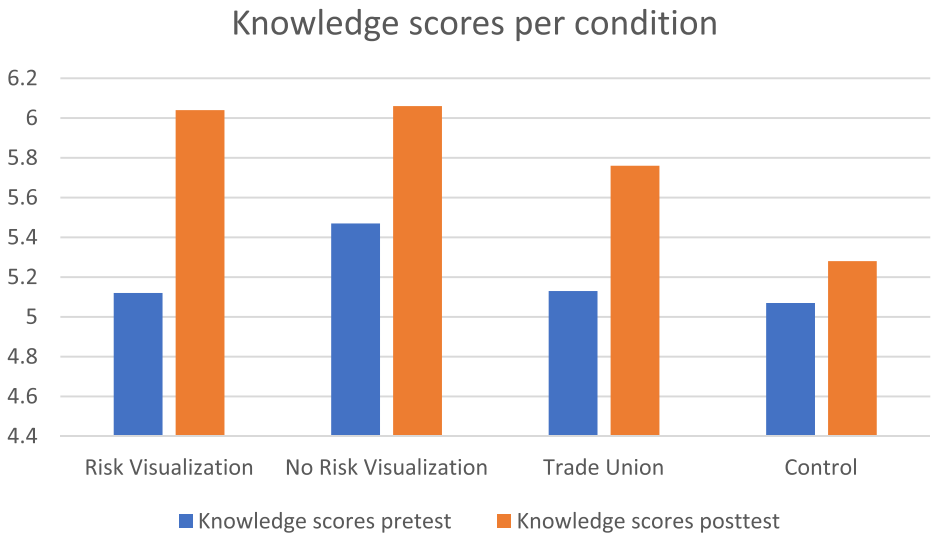

Fig. 1. Knowledge scores per condition on the pretest and posttest.

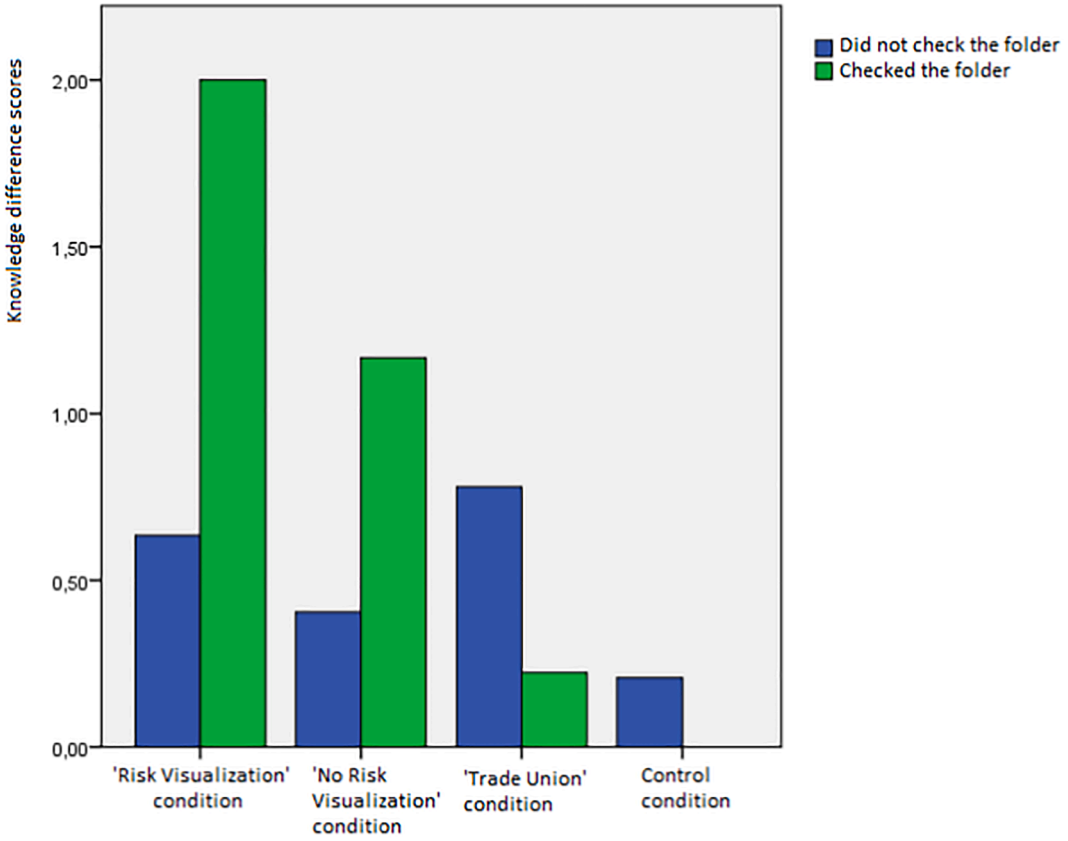

Fig. 2. Interaction effect of checking the folder on knowledge scores.

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

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

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.

4. 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.

3.1. 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.

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

3.2. 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.

3.3. 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.

4. 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 survey, 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.

CRediT authorship contribution statement

T.A.M. Stege: Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Visualization. **J.F.B. Bolte:** Funding acquisition, Conceptualization, Writing – review & editing, Supervision, Resources, Project administration, Software. **L. Claassen:** Writing – review & editing, Methodology, Supervision. **D.R.M. Timmermans:** Conceptualization, Investigation, Validation, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Questionnaires used in the online survey (in Dutch)

In this appendix, the full questionnaires used in the online survey can be found. Please note that all texts are translated from Dutch, since the survey 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 min. 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)[3]

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.

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

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.*
   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 min. 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.
- 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.

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