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Comparing immersive virtual reality and powerpoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making

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ABSTRACT

In two experimental studies, we compared safety training given via immersive virtual reality with safety training given via PowerPoint in their effects on risk perception, learning, and risky choices. In Study 1, we compared the two methods in a sample of apprentices ($N = 53$) and also investigated whether participants' conscientiousness and locus of control moderated the effects of safety training. In Study 1, we found an effect of training method on the change in risk perception in terms of probability judgments and on risky decisions but not on learning. In Study 2 ($N = 68$), we sought to replicate Study 1 and also tested whether domain-specific risk attitudes affected risk perception and choice. Furthermore, long-term effects of safety training on information recall and risk perception after a 6-month interval were assessed. The effects found in Study 1 could not be replicated in Study 2. Neither study found an interaction between presentation medium and personality. We conclude that the costly procedure of immersive virtual reality (VR) does not seem justified for safety training because the less costly PowerPoint procedure with vivid film scenes did not fare significantly worse with respect to changes in risk perception, learning outcomes, or decision making.

1. Introduction

An analysis of injuries across work domains in the 10-year period from 1998 to 2008 in Ontario, Canada showed that absence rates due to injury were three times higher in novices than in workers who had at least 1 year of job experience in their present job (Morassaei et al., 2013). Thus, preventive measures that focus on novices might prove to be especially efficient for reducing the absolute number of workplace injuries. Safety training is one standard means of prevention, and recently, immersive virtual reality (VR) has been suggested as an innovative way to present such a training (e.g., Sacks et al., 2013; Zaalberg and Midden, 2013). But are such innovative methods in fact more effective than more traditional approaches in raising awareness and promoting safe conduct? In the present paper, we tested whether VR-based safety training led to more learning, increased risk perception, and changes in decision making in comparison with a PowerPoint presentation conveying the same information.

Out of an array of constructs from the empirical literature, a meta-analysis by Christian et al. (2009) identified three predictors as repeatedly standing out as particularly relevant for ensuring safe performance: *safety knowledge* and *safety motivation* as proximal person-related factors and *general risk-taking propensity* as a distal person-related factor. Safety knowledge reflects an individual's knowledge of how to perform safely. Safety motivation reflects "an individual's willingness to exert effort to enact safety behaviors and the valence associated with those behaviors" (Neal and Griffin, 2006, p. 947; cf. Christian et al., 2009). Safety knowledge and safety motivation are important predictors of safety performance, which directly influences the likelihood of accidents and the overall number of workplace injuries (Christian et al., 2009). Furthermore, according to protection motivation theory (Maddux and Rogers, 1983) and the health belief model (Janz and Becker, 1984), risk perception in a given situation is an important prerequisite for safety motivation and results in health-protective behavior. Thus, risk perception, knowledge about hazards, and knowledge about safety measures are believed to predict protective behavior in general.

Weinstein (1993) explained that risk perception as a precondition for safety motivation is commonly regarded as consisting of two components: the perceived likelihood that an accident will occur (probability judgments) and the perceived severity of the consequences of

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such an accident (severity judgments). By contrast, knowledge about safety measures impacts beliefs about the efficacy of protective behavior (response efficacy) as well as the belief that one can use these measures (self-efficacy). The relevance of these factors was shown in a meta-analysis involving 65 studies ($N \approx 30,000$) and 20 domains (Floyd et al., 2000): The findings showed moderate positive effects of severity judgments, probability judgments, response efficacy, and self-efficacy on adaptive intentions and behaviors.

When considering the problem of reducing the risk of accidents among novices at work, theory and empirical research have suggested that safety interventions addressing *risk perception* on the one hand and *improvements in safety-related knowledge* on the other (for an overview, see Laughery & Wogalter, 2006) should be effective.

1.1. Methods in safety training: The importance of learner engagement

The methods used to communicate safety information in safety training can be distinguished according to the extent to which they require the learner to engage with the presented material and the mental effort that learners must exert to learn the material. Safety training conveying information through written descriptions can be considered to offer only low levels of engagement, whereas simulations should provide a high degree of engagement because learning in a simulation is based on interactive elements, which allow for active participation and the opportunity to experience the consequences of one's actions (Felicia, 2011). Simulations allow the learner to observe cause and effect, and learning is therefore experience-based (Bandura, 2001). Past research has emphasized the importance of experience: For example, warnings in the form of written instructions, even when they are clearly understood, are not sufficient for ensuring safe conduct (Zeitlin, 1994). A lack of experience with negative outcomes from risky behavior often leads to unrealistic optimism (Weinstein, 1984), and the experience of a negative outcome is positively correlated with the accuracy of risk perceptions and the likelihood of showing preventative behavior (Weinstein, 1989). Experience can be first hand, but it also has positive effects when it is vicarious (i.e., seeing someone else experiencing a certain outcome; Rosenstock et al., 1988).

Another factor affecting learner engagement is the degree of immersion provided by the instruction (Warburton, 2009). Immersion refers to "a computer-generated display that allows or compels the user (or users) to have a sense of being present in an environment other than the one they are actually in, and to interact with that environment" (Schroeder, 1996, p. 25). The sense of presence in a given virtual situation reflects the perceived realness, and the sense of actually being in the place that is displayed or described depends on the degree of immersion (Steuer, 1992). The degree of immersion can thus vary. For example, there is no immersion when text-based instruction is employed, low immersion when media involving video and sound is used, and high immersion when the learner actually experiences the situation in question (Moreno and Mayer, 2002).

In line with these assumptions, after reviewing 95 studies involving over 20,000 participants, Burke et al. (2006) concluded that safety training, which is engaging and provides direct experiences, is more effective than passive safety training. Thus, in order to be effective, interventions should be immersive and should depict hazards and the potential negative outcomes of certain behaviors as well as safety behavior in a realistic fashion.

Immersive VR results in a high sense of presence (Bystrom et al., 1999; Schroeder, 2008) and provides a presentation medium in which people can gain experience in situations that are rare and dangerous and thus cannot be staged. In fields such as behavioral therapy, immersive VR has successfully been used to reduce the fear of flying (Mühlberger et al., 2006) and the fear of spiders (Peperkorn et al., 2015).

Past research on the use of immersive VR in the context of safety-related research has investigated behavior during fire emergencies (Gamberini et al., 2003), aviation safety (Buttussi and Chittaro, 2017; Chittaro and Buttussi, 2015), safety behavior related to construction sites (Sacks et al., 2013), flooding (Zaalberg and Midden, 2013), and individual behavior in tunnel accidents (Kinateder et al., 2015, 2013; Mühlberger et al., 2015). Regarding the question of whether immersive VR can be more effective than traditional safety training, previous research has provided clear evidence for an increased sense of presence in immersive VR, but the advantage of this sense of presence for learning, risk perceptions, and decisions is unclear for the following reasons. First, previous studies have typically used *situations that are generally considered dangerous* by the public, such as tunnel emergencies (Kinateder et al., 2015, 2013; Mühlberger et al., 2015), flooding (Zaalberg and Midden, 2013), and airplane crashes (Buttussi and Chittaro, 2017; Chittaro and Buttussi, 2015). In these studies, there was an advantage of immersive VR with respect to knowledge retention but not with respect to changes in risk perception. It is possible that there was no change in risk perception because such situations (e.g., tunnel emergencies) are obviously dangerous, and thus, risk perception was already high. Therefore, the effects of immersive VR should be studied in situations in which the level of risk may be underestimated. Other studies did not find that a general training program delivered through immersive VR offered an advantage over a control condition when both conditions involved interaction and the material was vivid (Gavish et al., 2015; Moreno and Mayer, 2002). In fact, interactive and non-interactive methods, when they were both vivid, had similar positive outcomes for learning and changes in risk-severity perception (Chittaro and Sioni, 2015), thus suggesting that vividness might play a particularly important role. Consistent with this finding, another study showed that procedural training led to more knowledge retention after 2 weeks than a non-interactive method, and there was no difference between immersive VR and an interactive desktop presentation (Buttussi and Chittaro, 2017). Thus, the findings from the studies that have suggested the greater effectiveness of immersive VR could also be explained by the greater vividness of the material used in the immersive VR condition.

Second, studies have yet to address the effects of safety training on actual decisions and how safety training is related to risk perceptions and safety knowledge. So far, studies have addressed intentions (Zaalberg and Midden, 2013) and perceptions (Chittaro and Buttussi, 2015; Sacks et al., 2013) but not *decisions*.

Third, only two studies have addressed the *long-term effects* (1 or 2 weeks) of presentation medium (Chittaro and Buttussi, 2015; Sacks et al., 2013). However, one of these studies had a dropout rate of 70% (Sacks et al., 2013). The other (Chittaro and Buttussi, 2015) used a serious game (i.e., a game that is designed specifically to teach something and as such has more than only entertainment value) in the immersive VR condition and compared it with the traditional pictorial method, which was non-interactive and non-immersive. Thus, the results were confounded by the degree of interaction. It is not yet clear whether the effects can actually be attributed to immersive VR or whether they can be explained by the interactive nature of the presentation.

Fourth, so far, *interindividual differences* in risk-taking have not been considered in research on the effects of safety training even though such dispositions (e.g., locus of control, conscientiousness, and individuals' risk attitude) are important predictors of protective behavior (Christian et al., 2009).

Finally, the studies that provided a direct test between immersive VR and traditional methods of presentation often used only a few participants in each cell (Moreno and Mayer, 2002; Sacks et al., 2013; Zaalberg and Midden, 2013) or showed only marginally significant results when covariates were included in the analysis (Zaalberg and Midden, 2013). These methodological limitations resulted in deflated *p*-values when covariates were included (Simonsohn et al., 2014) or in overestimated effect sizes (Button et al., 2013; Nieuwenstein et al., 2015). Also, due to the small samples that were used and the