Transportation Research Part F 17 (2013) 20–32

Contents lists available at SciVerse ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Human behaviour in severe tunnel accidents: Effects of information and behavioural training

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ARTICLE INFO

Article history:
Received 10 February 2012
Received in revised form 25 July 2012
Accepted 22 September 2012

Keywords:
Tunnel accidents
Virtual reality
Information
Behavioural training
User behaviour
Safety

ABSTRACT

Immediate user self-evacuation is crucial in case of fire in road tunnels. This study investigated the effects of information with or without additional virtual reality (VR) behavioural training on self-evacuation during a simulated emergency situation in a road tunnel. Forty-three participants were randomly assigned to three groups with accumulating preventive training: The control group only filled in questionnaires, the informed group additionally read an information brochure on tunnel safety, and the VR training group received an additional behavioural training in a VR tunnel scenario. One week later, during the test session, all participants conducted a drive through a real road tunnel in which they were confronted with a collision of two vehicles and intense smoke. The informed and the behaviourally trained participants evacuated themselves more reliably from the tunnel than participants of the control group. Trained participants showed better and faster behavioural responses than informed only participants. Interestingly, the few participants in the control group who reacted adequately to the scenario were all female. A 1 year follow-up online questionnaire showed a decrease of safety knowledge, but still the trained group had somewhat more safety relevant knowledge than the two other groups. Information and especially VR behavioural training both seem promising to foster adequate self-evacuation during crisis situations in tunnels, although long term beneficial behavioural effects have to be demonstrated. Measures aiming to improve users' behaviour should take individual difference such as gender into account.

1. Introduction

Accidents and fires in road tunnels often have severe consequences for tunnel users and infrastructure. The major tunnel accidents in European transalpine tunnels (e.g., in Mont-Blanc tunnel, 1999; in Gotthard tunnel, 2001) stimulated various studies on tunnel safety. These developments led to new safety standards in European tunnels (e.g., Directive 2004/54/EC of the European Parliament and of the Council) defining minimum safety requirements for tunnels in the trans-European road network and consequently to decreased accident rates (e.g. compare Amundsen (1994) with Amundsen and Ranes (2000)).

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http://dx.doi.org/10.1016/j.trf.2012.09.001

Despite these efforts and all technological progress, another severe accident occurred in the Fréjus Tunnel in 2005, and the need for research on human factors became even more evident. Human misconduct was found to be responsible for about 95% of all accidents in road tunnels (Astra Tunnel TaskForce, 2000). Analysis of disasters in major transalpine tunnels showed that self-rescuing is crucial especially for accidents in road tunnels with fires, e.g., 27 of the 39 victims of the Mont-Blanc catastrophe in 1999 stayed in their vehicles and did not try to evacuate (Duffé & Marec, 1999; Fridolf, Nilsson, & Frantzich, 2011). Analysis of tunnel fires reveal problems in tunnel users' self-evacuation (e.g. Brocquet, 2002; for an extensive overview of tunnel fires see Martens (2008)), and that especially identifying risks and choosing adequate risk management strategies may be critical: A questionnaire study revealed that many users are aware of safety devices in tunnels, but the intention to use those seems not to be internalised (Gandit, Kouabenan, & Caroly, 2009). Therefore, maladaptive user behaviour during tunnel accidents has become the focus of research on tunnel safety (e.g., Martens, 2006; Nilsson, Johansson, & Frantzich, 2009). Previous field studies demonstrated that in a tunnel filled with smoke, the inside of a car is often falsely considered as safe. Consequently, spontaneous evacuation of tunnel users was hardly evident and participants only started to evacuate after they received instructions via loudspeakers to do so (Boer, 2002; Boer, 2003; Van Wijngaarden, Bronkhorst, & Boer, 2005).

Our recent virtual reality (VR) simulation study suggests that knowledge of adequate behavioural responses may already improve subsequent behaviour during tunnel accidents (Kinateder, Müller, Mühlberger, & Pauli, 2012). Specifically, two groups of participants were confronted with a car accident in a VR driving simulation. Prior to the simulation, one group read a brochure of the German Federal Highway Research Institute (Bundesanstalt für Straßenwesen & Bau und Stadtentwicklung, 2009) containing information about correct behaviour during various dangerous situations in a tunnel (e.g., fire and smoke). The second group received unrelated behavioural information on how to save energy. The previously informed group exhibited significantly improved safety behaviour during the simulated tunnel accident. Namely, informed compared to naïve participants were more likely to switch on the hazard flasher as well as the radio and to leave the vehicle. These results confirmed the findings of a VR study by Martens (2006), which showed that information and verbal instructions improved safety behaviour in a simulated road tunnel accident. Thus we conclude that relatively cost-effective measures such as reading a brochure may be promising in improving user behaviour and tunnel safety in general. However, it remains to be examined whether these beneficial effects can be transferred from a virtual environment to a real world setting.

Although giving information seems to be promising, this intervention has possible limitations: During stressful events declarative knowledge (facts) must be remembered and then transferred into action. A variety of variables may moderate training transfer (Burke & Hutchins, 2007). In highly stressful situations such as tunnel accidents declarative memory may not be activated as easily as procedural knowledge (de Quervain, Roozendaal, & McGaugh, 1998; Kuhlmann, Piel, & Wolf, 2005), and therefore procedural knowledge may be beneficial in such situations. Procedural knowledge is defined as knowing how to perform a certain task and can be acquired through behavioural training (Anderson, 1982; Tulving, 1983). Recent meta-analysis demonstrated that safety behaviour can be more effectively trained through highly engaging measures such as behavioural trainings (Burke et al., 2011; Sitzmann, 2011). Active training approaches are known to have a variety of positive outcomes on learning and transfer of knowledge (e.g., Bell & Kozlowski, 2008). For example certain driver's skills can be trained more effectively with an active behavioural training compared to a solely perceptive classroom lecture. Specifically, active training improved drivers' threat detection strategies stronger than a passive lecture (Romoser & Fisher, 2009). In tunnel emergencies, especially when quick evacuation is mandatory, early threat detection might give users important additional time. In addition, a driving training program with feedback was found to lead to a more internalised locus of control (Huang & Ford, 2012). Applied to tunnel emergencies, a more internalised locus of control could lead to better decision making and faster self-evacuation. In tunnel fires, smoke might move faster than most tunnel users expect. Risk avoidant decisions, such as evacuating instead of fighting a fire that is already out of control, could be improved through simulator training. For example, a simulator-based training of elderly drivers was reported to lead to fewer risky driving manoeuvres (Roenker, Cissell, Ball, Wadley, & Edwards, 2003). Finally, active learning methods were superior to passive lectures in improving elderly drivers' knowledge and driving performance (Marottoli et al., 2007). We conclude that a VR behavioural training may have stronger positive effects than mere information and therefore designed a training measure for tunnel emergencies which includes not only theoretical content, but also elements of active "hands on" training as well as feedback about training success.

The simulated situations described above are both dangerous and difficult to train in the real world. Training in virtual environments may help to overcome this barrier. In the field of medical training, VR technology has been applied and researched to some extent, and transfer of knowledge has been demonstrated for a variety of complex procedures (see Johnson, Guediri, Kilkenny, and Clough (2011) for an overview). Several studies showed that training in VR can improve behaviour in the real world: Waller, Hunt, and Knapp (1998) for example found that training in a virtual maze improves orientation in a real world building compared to only studying a map, and also surpassed a real world training. Wallet et al. (2011) reported that the transfer of spatial knowledge from VR to reality was superior when participants navigated actively through a virtual scenario compared to participants who were passively navigated through the scenario. More specifically, in the field of disaster training, Andreatta et al. (2010) showed that VR training may provide a useful tool for disaster preparedness. Studies on VR disaster training range from evacuation training in aircrafts and even spacecrafts to stress management training for potentially traumatizing events in the military field, demonstrating a large spectrum of applications for VR training (Aoki, Oman, & Natapoff, 2007; Dunne & McDonald, 2010; Sharma, Otunba, & Jingxin, 2011).