Social Influence in Emergency Situations –

Studies in Virtual Reality

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Abstract

In 1999, a tragic catastrophe occurred in the Mont Blanc Tunnel, one of the most important transalpine road tunnels. Twenty-seven of the victims never left their vehicles as a result of which they were trapped in smoke and suffocated (Beard & Carvel, 2005). Immediate evacuation is crucial in tunnel fires, but still many tunnel users stay passive. During emergency situations people strongly influence each other's behavior (e.g. Nilsson & Johansson, 2009a). So far, only few empirical experimental studies investigated the interaction of individuals during emergencies. Recent developments of advanced immersive virtual worlds, allow simulating emergency situations which makes analogue studies possible. In the present dissertation project, theoretical aspects of human behavior and SI in emergencies are addressed (Chapter 1). The question of Social Influence in emergency situations is investigated in five simulation studies during different relevant stages of the evacuation process from a simulated road tunnel fire (Chapter 2). In the last part, the results are discussed and criticized (Chapter 3).

Using a virtual reality (VR) road tunnel scenario, study 1 (pilot study) and 2 investigated the effect of information about adequate behavior in tunnel emergencies as well as Social Influence (SI) on drivers' behavior. Based on a classic study of Darley and Latané (1968) on bystander inhibition, the effect of passive bystanders on self-evacuation was analyzed. Sixty participants were confronted with an accident and smoke in a road tunnel. The presence of bystanders and information status was manipulated and consequently, participants were randomly assigned into four different groups. Informed participants read a brochure containing relevant information about safety behavior in emergency situations prior to the tunnel drives. In the bystander conditions, passive bystanders were situated in a car in front of the emergency situation. Participants who had received relevant information left the car more frequently than the other participants. Neither significant effect of bystanders nor interaction with information status on the participants' behavior was observed.

Study 3 (pilot study) examined a possible alternative explanation for weak SI in VR. Based on the *Threshold Theory of Social Influence* (Blascovich, 2002b) and the work of Guadagno et al. (2007), the perception of virtual humans as an *avatar* (a virtual representation of a real human being) or as an *agent* (a computer-controlled animated character) was manipulated. Subsequently, 32 participants experienced an accident similar to the one in study 1. However, they were co-drivers and a virtual agent (VA) was the driver. Participants reacted differently in avatar and agent condition. Consequently, the manipulation of the avatar condition was implemented in study 4.

In study 4, SI within the vehicle was investigated, as drivers are mostly not alone in their car. In a tunnel scenario similar to the first study, 34 participants were confronted with an emergency situation either as drivers or co-drivers. In the driver group, participants drove themselves and a VA was sitting on the passenger seat. Correspondently, participants in the co-driver group were seated on the passenger seat and the VA drove the vehicle on a pre-recorded path. Like in study 1, the tunnel was blocked by an accident and smoke was coming from the accident in one drive. The VA initially stayed inactive after stopping the vehicle but started to evacuate after ca. 30 seconds. About one third of the sample left the vehicle during the situation. There were no significant differences between drivers and co-drivers regarding the frequency of leaving the vehicle. Co-drivers waited significantly longer than drivers before leaving the vehicle.

Study 5 looked at the pre-movement and movement phase of the evacuation process. Forty participants were repeatedly confronted with an emergency situation in a virtual road tunnel filled with smoke. Four different experimental conditions systematically varied the presence and behavior of a VA. In all but one conditions a VA was present. Across all conditions at least 60% of the participants went to the emergency exit. If the VA went to the emergency exit, the ratio increased to 75%. If the VA went in the opposite direction of the exit, however, only 61% went there. If participants were confronted with a passive VA, they needed significantly longer until they started moving and reached the emergency exit.

The main and most important finding across all studies is that SI is relevant for self-evacuation, but the degree of SI varies across the phases of evacuation and situation. In addition to the core findings, relevant theoretical and methodological questions regarding the general usefulness and limitations of VR as a research tool are discussed. Finally, a short summary and outlook on possible future studies is presented.

German Abstract – Zusammenfassung

In der Mont Blanc Tunnel Katastrophe im Jahr 1999 starben 39 Menschen, von denen 27 nicht versucht hatten rechtzeitig zu flüchten. In der Folge wurden diese Personen vom Rauch eingeschlossen und erstickten in ihren Fahrzeugen. Bisher gibt es nur vereinzelt empirische Studien, die sich mit Fragestellungen zu menschlichem Verhalten in Gefahrensituationen beschäftigen. Noch weniger Arbeiten beschäftigen sich mit der gegenseitigen Beeinflussung von Individuen in Gefahrensituationen. Die wohl wahrscheinlichste Erklärung ist, dass es bisher kaum möglich oder zu aufwändig war, Gefahrensituationen experimentalpsychologisch zu untersuchen. Die Entwicklung immersiver virtueller Welten erlaubt es allerdings, solche Situationen ökologisch valide zu simulieren. Erstes Ziel des Promotionsvorhabens war deshalb sozialen Einfluss in virtuell simulierten Gefahrensituationen mittels experimentalpsychologischer Studien zu untersuchen. Zweites Ziel war die Untersuchung methodischer Grundlagen zur Untersuchung von sozialem Einfluss in virtueller Realität.

Die Dissertation gliedert sich in drei Teile: Kapitel 1 führt zunächst in die Themen menschliches Verhalten in Gefahrensituationen, Evakuierung und sozialer Einfluss während Notfällen ein. In Kapitel 2 werden die eigenen empirischen Arbeiten dargestellt. Dabei wurde sozialer Einfluss in verschiedenen kritischen Phasen des Evakuierungsprozesses während eines Tunnelbrandes untersucht. Insgesamt wurden fünf unabhängige Erhebungen mit insgesamt 194 Studienteilnehmern durchgeführt.

Studie 1 (Vorstudie) und 2 untersuchte den sozialen Einfluss passiver virtueller Bystander sowie den Effekt von Informationen auf das Fluchtverhalten. Die Probanden wurden mit einem Unfall und sich ausbreitendem Rauch in einem Straßentunnel konfrontiert. In einer Probandengruppe befanden sich passive Bystander am Unfallort. Die Ergebnisse zeigten erstens, dass nur wenige uninformierte Probanden überhaupt das Fahrzeug verließen um aus sich zum Notausgang zu begeben. Zweitens, konnten Information das Verhalten während des Unfalls verbessern. Drittens fand sich nur ein schwacher Einfluss passiver virtueller Bystander auf das Verhalten der Probanden in der Notfallsituation.

Studie 3 (Vorstudie) untersuchte eine mögliche alternative Erklärung für schwachen sozialen Einfluss in virtueller Realität. Hier wurde die Wahrnehmung virtueller Menschen als *Avatar* (eine von realen Menschen gesteuerte virtuelle Repräsentation) oder als *Agent* (vom Computer gesteuerte animierte Figuren) manipuliert. Anschließend erlebten die Probanden einen ähnlichen Unfall wie in Studie 1. Allerdings waren sie nun Beifahrer und erlebten den Unfall gemeinsam mit einem animierten virtuellen Menschen der das Fahrzeug lenkte. Probanden ließen sich eher von einer animierten Menschen beeinflussen, wenn sie überzeugt waren, dass es sich um einen Avatar handelt.

Studie 4 untersuchte den Einfluss von anderen Personen im Fahrzeug auf das Verhalten in einer Notfallsituation. Dabei erlebten die Probanden die gleiche Gefahrensituation wie in Studie 1 entweder als Fahrer oder als Beifahrer. Gleichzeitig befand sich ein virtueller Agent im Fahrzeug, der sich zunächst passiv verhielt aber nach einer gewissen Zeit das Fahrzeug verließ. Es zeigte sich, dass Probanden zügiger dem Verhalten des virtuellen Agenten folgten, wenn der Agent Fahrer und die Probanden Beifahrer waren.

In Studie 5 wurde das eigentliche Evakuierungsverhalten während eines simulierten Tunnelbrandes untersucht. Dabei befanden sich die Probanden wiederholt in einem stark verrauchten Tunnel und das Verhalten eines virtuellen Agenten wurde systematisch manipuliert. Die meisten Probanden suchten den Notausgang auf, jedoch zeigte sich, dass das Verhalten des virtuellen Agenten die Probanden beeinflusste: Ging der Agent in die entgegengesetzte Richtung des Notausgangs oder blieb dieser passiv, so gingen die Probanden seltener zum Notausgang und benötigten signifikant länger um diesen zu erreichen.

Kapitel 3 enthält schließlich die Zusammenfassung und Diskussion der Studien. Dabei werden die Ergebnisse der Arbeit in den aktuellen Stand der Forschung eingeordnet, praktische Implikationen abgeleitet und der weitere Forschungsbedarf beschrieben. Insgesamt konnte gezeigt werden, dass sozialer Einfluss in Gefahrensituationen von Bedeutung ist, aber während verschiedener Phasen des Evakuierungsprozesses unterschiedlich stark ist. Abschließen werden die theoretischen und methodischen Kritikpunkte der Forschungsarbeiten genannt und erörtert.

Abbreviations

BASt	Bundestanstalt für Straßenwesen
BSQ	Body Sensation Questionnaire
MMOG	Massively Multiplayer Online Game
ORSET	Occupant Response Shelter Time Model
PADM	Protective Action Decision Model
RIM	Reflective-Impulsive Model of Behavior
SI	Social Influence
SMS	Security Motivation System
SSQ	Simulator Sickness Questionnaire
STAI	State-trait Anxiety Inventory
TAQ	Tunnel Anxiety Questionnaire
VA	Virtual Agent
VR	Virtual Reality

1. Introduction

“The humblest individual exerts some influence, either for good or evil, upon others.”

Henry Ward Beechers

In 1999, a tragic catastrophe occurred in the Mont Blanc Tunnel, one of the most important transalpine road tunnels, when 39 people perished in a fire breakout. Twenty-seven of them never left their vehicles while two sought refuge in other vehicles as a result of which they were trapped in smoke and suffocated (Beard & Carvel, 2005). The analysis of this and other major fires in transalpine road tunnels showed that immediate and swift self-evacuation is crucial in such events, but still many tunnel users stay passive. In the aftermath of these severe tunnel fires new technological safety standards in road tunnels such as the Directive 2004/54/EC of the European parliament on safety requirements for tunnels (European Parliament & European Council, 2004) were developed. However, all technological progress can still not prevent human misconduct in crisis situations and despite of all efforts another severe incident happened in the Fréjus tunnel in 2005 (Beideler, 2005). At this time, the Fréjus tunnel linking France and Italy had been newly renovated and many training drills of the emergency personnel had been carried out (Perard, 1992). More recently, in early 2010, a fire alarm was triggered in a German road tunnel near Mainz which was filled with commuters in a traffic jam at that time. Fortunately, it was a false alarm and no one was injured. During the alarm, loudspeaker announcements asked the commuters to evacuate from the tunnel. However, eyewitnesses described that very few people actually followed the instructions and left the tunnel (Lang, 2010). The analysis of these events raise questions: Why do people not evacuate, although they are in immediate danger and are sometimes directly asked to do so? There is evidence in the literature that during dangerous situations people strongly influence each other (e.g. Nilsson & Johansson, 2009). But when and how does such social influence (SI) occur exactly? Is SI in emergency situations inherently negative or are beneficial effects also possible?

So far there are only few empirical experimental studies that deal with issues relating to human behavior in fire. Even less work has focused on the interaction of individuals in dangerous situations. The most likely explanation is that it had been almost impossible or very costly to experimentally assess dangerous situations without exposing participants to an actual threat. Fortunately, the recent development of advanced immersive virtual worlds allows simulating emergency situations with high external validity.

1.1 Outline of the Thesis

The present thesis consists of three parts: Chapter 1 gives an introduction to the topic of human behavior in dangerous situations, summarizes relevant concepts on evacuation behavior (1.2) and SI (1.3) from a variety of different disciplines, such as psychology, biology, safety engineering, and computer science. Furthermore, virtual reality (VR) as a means to research human behavior in dangerous situation is introduced (1.4). Last, the research objectives are defined. Chapter 2 contains the empirical studies. SI was investigated using five different studies during a fire emergency in a road tunnel. Evacuation can be regarded as a processes comprising of several distinct stages. These can be roughly divided into pre-evacuation phase (time from the begin of an emergency to the decision to evacuate), pre-movement phase (time from the decision to evacuate to begin of actual evacuation behavior), and movement phase (time from beginning to evacuate until evacuation is complete; Kobes, Helsloot, de Vries, & Post, 2010; Kuligowski, 2012). Each study looked at different aspects within the evacuation process (See Table 1 for an overview over the studies). The first two scenarios looked at the pre-evacuation phase of a severe accident with fire inside a road tunnel. In the first two studies participants were alone in a car and drove into a tunnel. Inside the tunnel an accident blocked the road and SI of virtual agents (VA) involved in the simulated accidents was analyzed. In studies 3 and 4, a VA was situated inside the research vehicle and participants experienced the accident either as a driver or a co-driver. Study 5 looked at the movement and the pre-movement phase of the actual evacuation process. Participants were situated in a tunnel and were confronted with VAs, who either went to an emergency exit, in the opposite direction, or stayed passive. Chapter 3 summarizes and discusses the results. A connection to the research objectives defined in chapter 1 is drawn, and limitations of VR as a research tool are critically assessed. Finally, an outlook on future research and practical implications is given.

Table 1 Overview of the evacuation process and studies of the dissertation

Time course	Relevant processes of tunnel users	Study
Pre-event phase	Driving, waiting in traffic jam, etc.	1, 2, 3, 4
Event		1, 2, 3, 4
Pre-evacuation phase	Perception of threat, information gathering, decision making, preparation of evacuation, etc.	1, 2, 3, 4
Decision to evacuate		1, 2, 3, 4
Pre-movement phase	Perception of threat, information gathering, decision making, preparation of evacuation, etc.	5
Movement phase	Leaving the vehicle, movement to evacuation destination	5

1.2 Concepts and Frameworks: The Theory of Human Behavior in Emergency Situations and Evacuation

For the purpose of the present dissertation, emergency situations will be referred to as situations in which the physical integrity of one or more human beings is under immediate threat and which require swift and adequate behavioral reactions to escape. This process of reaching a place of safety is referred to as evacuation behavior (ISO/IEC, 2008). A key concept to human behavior in emergency situations is the perception of threat and risk. People need to judge whether a situation provides a threat before they decide to evacuate. Most definitions of risk in psychological science include the perceived probability and severity of a negative event (Manstead et al., 1995). In the following sections, a number of theoretical models related to human behavior in dangerous situations are portrayed. Since the topic is relevant to multiple disciplines, an effort was made to summarize findings from biological and cognitive psychology, safety engineering, and computer modeling of human behavior.

1.2.1 Bio-psychological Models

Life threatening events, such as fires, occur only very rarely. Furthermore, indicators of a potential threat are often not easily detectible or may be ambiguous. Woody and Szechtman (2004) suggest a *security motivation system* (SMS) that is designed to adapt the organism to extremely rare life threatening events (Szechtman & Woody, 2004). The SMS detects “subtle indicators of potential threat, to probe the environment for further information about these possible dangers, and to motivate engagement in precautionary behaviors, which also serves to terminate security motivation” (Woody & Szechtman, 2011, p. 1019). The authors make assumptions about the neural basis of the SMS and postulate a network model, including brainstem, striatum, pallidum, and cortex (Hinds et al., 2010). Applied to the situation of fires, cues such as the smell of smoke or other people running to an emergency exit, may activate the SMS.

1.2.2 Cognitive Models

Classic cognitive stress models, such as the transactional stress model, focus on the subjectively perceived threat of a situation (Lazarus & Folkman, 1984). Specifically, psychological stress occurs, if one does not possess the necessary resources to cope with a situation which is perceived as dangerous. The importance of appraisal processes during catastrophic events has been shown in empirical studies. For example in a questionnaire study with hurricane survivors, Riad, Norris, and Ruback (1999) found that 58% of the respondents chose not to evacuate from a severe hurricane threat. The most important reasons for not evacuating during a hurricane were that the hurricane had not been perceived as a serious threat, participants had been confident that the current place is as safe as any other, and avoiding to think about the situation (Riad, Norris, & Ruback, 1999). That is, the misinterpretation of cues indicating a possible threat may be a key problem in the process of evacuation. Evidence from a vignette study showed that different types of disaster are perceived differently, and even more importantly, have different degrees of stimulating nature (Heilbrun, Wolbransky, Shah, & Kelly, 2010). The cognitive appraisal of a given situation as dangerous may influence evacuation motivation. For example, a recent meta-analysis showed that the motivation to participate in safety trainings rises if the consequences of a potential event are perceived as threatening (Burke et al., 2011). Proulx (1993) developed a cognitive stress model of people facing fire which takes different factors like information processing, decision-making, problem-solving, and stress into account. In this model so called *stress loops* are triggered when people are confronted with a fire outbreak, in which ambiguous information and increased danger, lead to fear, worry, and confusion (Proulx, 1993).

1.2.3 Evacuation Framework Models in Safety Engineering

The science of safety engineering aims to improve safety in built environments through constructional, ergonomic, and organizational measures. Despite the apparent need for behavioral models and the possible benefits from better predicting human behavior in crisis situations, working models describing the evacuation process from the view of an individual have only been developed recently (Kuligowski, 2012). Most theoretical models in the field of safety engineering aim to describe the evacuation process by quantifying the time it takes to evacuate. These differentiate between evacuation phases, sometimes labeled pre-evacuation phase (time from the onset of a threat to the decision to evacuate), pre-movement phase (from the decision to the beginning of actual evacuation behavior), movement phase (time people actually move until they evacuate), and total evacuation time (pre-evacuation phase plus pre-movement and movement time). The ACTEURS (Improving the Ties between Tunnels / Operators / Users to Reinforce Safety) group developed a phase model describing user behavior in tunnel emergencies (Ricard, 2006). At the beginning of an emergency situation in a road tunnel, tunnel users have not yet perceived an event and mainly focus on driving (phase 0). In phase 1, warning cues such as fire alarms or flames are perceived. In phase 2 users decide to evacuate, and finally, in phase 3, the actual evacuation process starts. The model assumes that users make the best choice after deliberately weighing the risks of different behavior options (Ricard, 2006).

The *Affiliative Model* aims to understand human behavior in fire (Sime, 1985). It contradicts the assumption that humans always act rationally and choose the optimal evacuation route. Moreover, it assumes that if entrapped in a fire, people tend to move towards the familiar. That is, in the case of tunnel fires, people are more likely to move in the direction of the entering tunnel portal, and not necessarily to the closest emergency exit (Sime, 1985). In a series evacuation studies from IKEA stores in which fire drills were simulated, many participants walked directly to the main entrance of the stores, passing several emergency exits on their way out (Frantzich, 2001). These findings are in line with the *Theory of Learned Irrelevance*, which states that emergency exits are often ignored because they are so rarely used (McClintock, Shields, Reinhardt- Rutland, & Leslie, 2001). Advancing the idea of movement to the familiar during emergencies, the *Occupant Response Shelter Time Model* (ORSET) was developed (Sime, 1999, 2001). The ORSET model integrates aims to a better understanding of human behavior in building fires, integrating findings from psychology, architecture, as well as technical- and building management. The model stresses the influence of the environmental context on psychological states and behavior in fires.

Criticism of the models mentioned above states that these still oversimplify the psychological processes during evacuation (Kuligowski, 2012). The *Protective Action Decision Model* (PADM) was developed by Kuligowski (2012) to provide a holistic approach to human behavior in dangerous situations (Figure 1).

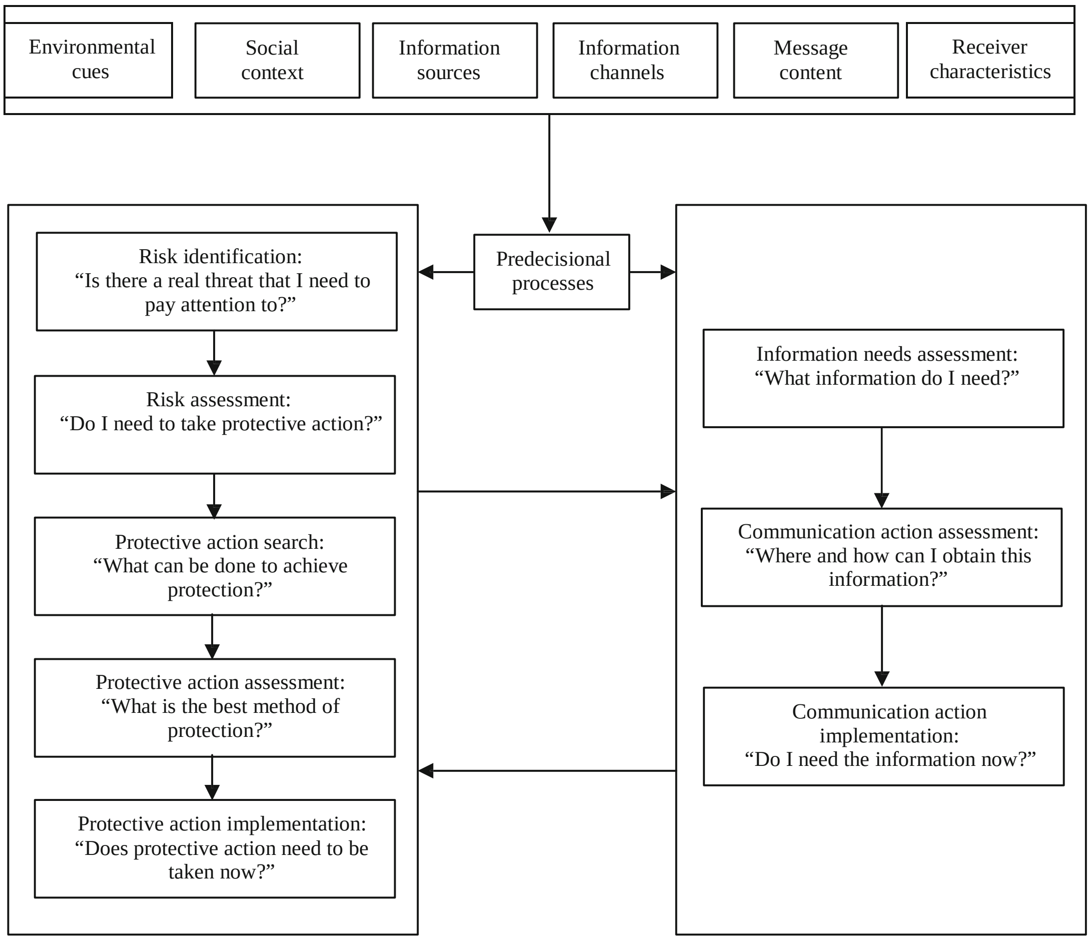

Figure 1 The Protective Action Decision Model (PADM) by Kuligowski (2012), taken from of Kuligowski (2012 p.10)

The model takes a variety of predispositions, such as environmental or social context into account. Furthermore it stresses the importance of appraisal processes, and thus links cognitive psychological approaches with classic safety engineering models. Often the theoretical measures developed in the field of safety engineering are implemented into simulation programs (Siddiqui & Gwynne, 2012).

1.2.4 Computational Evacuation Models

Computational models aim to simulate human behavior in order to predict success or failure of evacuation. This is a relatively new approach in studying human behavior in dangerous situations (Ronchi & Kinsey, 2011). The value of simulations of human behavior in dangerous situations is twofold: First, simulations allow predicting human behavior to a certain degree. Nevertheless it is important to note that even the most sophisticated simulation programs can only approximately describe human behavior in dangerous situations. Second, the development of theoretical models on human behavior in emergency situations can benefit from computational models (Mosler, Schwarz, Ammann, & Gutscher, 2001). Interestingly, one of the earliest simulation studies on evacuation used bottles filled with corks on strings (Mintz, 1951). Situations analogous to an evacuation scenario were implemented by having several participants pull corks that were tied to a string out of a bottle. Inside the bottle water was slowly rising. Only cooperative behavior allowed all participants to successfully “evacuate” their corks before getting wet. More recently, the progress in computing capacity allowed developing more complex and sophisticated models. The six most widely used models are *Simulex* (Integrated Environmental Solutions, Glasgow, UK), *FDS+Evac* (Korhonen & Hostikka, 2010), *VISSIM* (PTV AG, Karlsruhe, Germany), *STEPS* (MottMacDonald, Croydon, UK), *Pathfinder* (Thunderhead Engineering Consultants, Manhattan, KS, USA) and *EXODUS* (Galea et al., 2012; Ronchi & Kinsey, 2011). Further examples of modern far more complex computational models are the *Social Force Model for Pedestrian Movement* (Helbing & Molnár, 1995), the *Firescap* Model (Feinberg & Johnson, 1995), or the *buildingEXODUS* model (Siddiqui & Gwynne, 2012). However, only some computational models and simulation try to take SI into account (Mosler & Bucks, 2001).

1.2.5 Summary and Critique

Various disciplines have identified the need for theoretical framework on human behavior in dangerous situations. Models were developed by various disciplines, such as biological and cognitive psychology, safety engineering, and computer simulations. Recent developments in evacuation modeling take a multidisciplinary approach (e.g. Kuligowski, 2012). The models discussed in the previous sections are mainly based on analysis of actual disasters and empirical studies. Nevertheless, all models still have the character of working models, since none of them have been validated rigorously. Furthermore, SI is only scarcely taken into account and if so, no precise assumptions are made. E.g. the PADM states that in “ambiguous situations, the presence of others helps to define what behavior is appropriate in a particular situation” (Kuligowski, 2012, p.6). However, PADM does not specify in more detail how exactly SI effects human behavior in emergency situations. Since it is well documented in the literature that the presence and actions of others have an effect in dangerous or ambiguous situations, theories and frameworks on human behavior during dangerous situations could profit from precise empirical information on SI (Darley & Latané, 1968; Kuligowski, 2012; Turner, 1991).

1.3 Social Influence

1.3.1 Definition of Social Influence (SI)

Why and how is *Social influence* (SI) exerted during critical situations, such as fires or other emergencies? SI is defined as changes in attitudes, beliefs, opinions or behavior as a result of the fact that one is confronted with attitudes, beliefs, opinions, or behavior of others (Hewstone & Martin, 2008). A dual-process model of SI postulates two distinct forms of SI (Deutsch, 1980; Nilsson & Johansson, 2009). *Normative SI* is defined as the pressure social norms and expectations exert on behavior. Whereas *informational SI* describes that the behavior of others is a source of information about how to react in an ambiguous or insecure situation. In contrast to Deutsch’s dual-process model, the *Self-categorization theory* hypothesizes that SI is the result of a single process, in which perceived social identity of others and oneself to either in- or out-groups is the basis of influence (Turner, 1991). In the *Social Force Model*, SI is conceptualized as a result of social forces comparable to physical forces, such as light, sound, or gravity (Helbing & Molnár, 1995; Latane, 1981). For the purpose of the present dissertation, SI will be regarded as the effect that other people’s behavior has on an individual’s behavioral responses to a dangerous situation.

The effect of SI on other people’s behavior is well documented in the literature. The classic study of Asch (1955) showed that hearing other people’s opinion can influence one’s own decision and even lead to knowingly making errors (Asch, 1955). Perceived social pressure may even lead to extreme behavior, such as knowingly hurting others (Milgram, 1963). Conformity to other's behavior increases with the number of people observed (Milgram, Bickman, & Berkowitz, 1969). Furthermore, if the behavior of individual group members becomes less unanimous, the effect of SI on judgments decreases (Morris & Miller, 1975). In the field of military leadership training, this effect of SI on decision making was recently demonstrated: For the purpose of the study, officer cadets were standing blindfolded and half-naked on a wharf during mid-winter in Norway and had to decide to jump into the ocean or not. Over three-quarters of the cadets actually jumped. Interviews performed during and after the procedure, revealed that perceived social pressure may overcome the expectation of physical inconvenience (Firing, Karlsdottir, & Laberg, 2009). Unfortunately, this study used no experimental manipulation and reported only parts of the results.

1.3.2 Social Influence in Emergency Situations

The presence and actions of others in emergency situations influences an individual's behavior. As early as in the 1960s, Latané and Darley demonstrated the existence of SI in a series of experiments. In their classic study, participants were seated in a room that gradually filled with smoke. Participants had been assigned to one of three experimental conditions: in the first condition, the participants were alone in the room. In the second condition, three participants were together in the room. In the third condition, the participants were in the room together with two confederates who were instructed to ignore the smoke and stay seated. 75% of participants who were alone reported the smoke, but only 38% of subjects who were in groups of three, and only 10% of subjects who were with two confederates in the room did so (Latane & Darley, 1968). The work of Latané and Darley was the beginning of the research examining helping behavior in dangerous situations. In a series of studies, the *bystander effect* was demonstrated: Diffusion of responsibility causes people to be generally less helpful if other people are present (Darley & Latané, 1968). A recent extensive meta-analytical review of research on the bystander effect integrates findings from almost 50 years of research (Fischer et al., 2011). The authors conclude that helping behavior becomes more likely if situations are perceived as dangerous, perpetrators are present, and the physical costs of intervention. Fischer et al. (2006) argue that the bystander effect exists only when the perceived danger of the situation is low. The authors argue that the subjective costs of no intervention are higher than the expected cost of an intervention, if a situation is perceived as clearly dangerous (Fischer, Greitemeyer, Pollozek, & Frey, 2006). However, SI might not only hinder helping behavior. The *tend and befriend* hypothesis assumes that especially female individuals respond to acute stress, such as emergency situations, with pro-social behavior (Taylor et al., 2000). Indeed, social-evaluative stress may trigger pro-social behavior and thwart antisocial responses (von Dawans, Fischbacher, Kirschbaum, Fehr, & Heinrichs, 2012). Interestingly, cooperation during evacuation from dangerous situations may lead to slower evacuation (Heliövaara, Kuusinen, Rinne, Korhonen, & Ehtamo, 2012). Unfortunately, there are only few current empirical experimental studies that directly investigate SI during emergency situations which do not focus on helping behavior but on self-evacuation. Johansson and Nilsson (2009) examined how people influence each other in an unannounced evacuation exercise in a cinema. In a series of studies different alarm announcements were tested. The announcements included explicit information and instructions. The results of these studies showed that the amount of SI was depending on the interpersonal distance. The closer people were situated to each other in the cinema, the more likely they were to influence each other.

Based on his empirical studies, Latané (1981) developed the *Social Impact theory,* which proposes three basic rules to describe SI: First, SI is the result of social forces. The second rule states that SI is correlated with the number of sources of SI. Third, the more people are exposed to SI, the less impact each individual target perceives (Latane, 1981). In a study by Riad et al. (1999) the authors argue that an emergency situation creates new behavioral norms. The *Emergent Norm Perspective* postulates that during disasters social norms change (Fritz & Williams, 1957; Riad et al., 1999). These norms are thought to be at least partly derived from the evaluation of the behavior of others (Perry, Lindell, & Greene, 1981). *Conflict Theory* postulates that an internal conflict is aroused whenever a person believes that there are risks coming from present or new behaviors. The consequences of this conflict are perceived anxiety or psychological stress. The level of stress is determined through a person’s coping styles, which are hypothesized to be either defensive-avoidant, vigilant, or hyper vigilant (Janis & Mann, 1977a). Vigilance, conceptualized as reflective and rational decision making, is assumed to be most adaptive when a person is confronted with disaster warnings (Janis & Mann, 1977b). According to the *Reflective-Impulsive Model of Behavior (RIM),* impulsive reactions are more likely to occur in dangerous situations. Here information processing is reduced to limited salient stimuli (Strack & Deutsch, 2004). Given that most people do not have prior experiences with emergencies and, therefore no available heuristic, other people’s behavior may become an important and salient source of information.

1.3.3 Social Influence in Virtual Reality

Social psychology has examined interpersonal communication and social influence for decades. But do the same mechanisms and phenomena also occur in the virtual world? Several classic findings from SI research were successfully replicated in VR. For example, Park (2010) showed that VAs could induce a comparable social facilitation effect as real persons (Park, 2010). In another study, social compliance strategies (Foot-in-the-door and door-in-the-face technique) were successfully applied in a Massive-Multiplayer-Online Game. In the same study, skin color (black vs. white) of VAs had an influence on the success of the door-in-the-face technique (Eastwick & Gardner, 2009). Two studies showed racial biases in virtual reality (Groom, Bailenson, & Nass, 2009; McCall, Blascovich, Young, & Persky, 2009). Garau et al. (2005) showed that responsive VAs induced a stronger feeling of personal contact than static agents (Garau, Slater, Pertaub, & Razzaque, 2005). Drury et al (2009) conducted studies in which VR was used to investigate mass emergency evacuation: The authors showed that participants cooperated and competed with simulated agents, depending on different factors, such as the level of danger of a situation. Apart from their theoretical significance, these studies show that SI can be successfully investigated in VR (Drury, Cocking, Reicher, et al., 2009).

Although there is a large number of possible applications for VR as a research tool (Bohil, Alicea, & Biocca, 2011), there are theoretical and methodological limitations for studying SI in virtual environments that need to be considered. Following the *Threshold Model of Social Influence* (Blascovich, 2002b), thresholds on two dimensions have to be exceeded, in order for VAs to be perceived as humans (Figure 2). The first dimension, termed *behavioral realism*, describes how realistically an animated human behaves. The second dimension, termed *agency*, refers to whether an animated human is perceived as an agent or an avatar[1] (an animated representation of a real human in a virtual world).

[1] The term “avatar” is derived from Hindi/Sanskrit अवतार, describing a worldly manifestation of a deity.

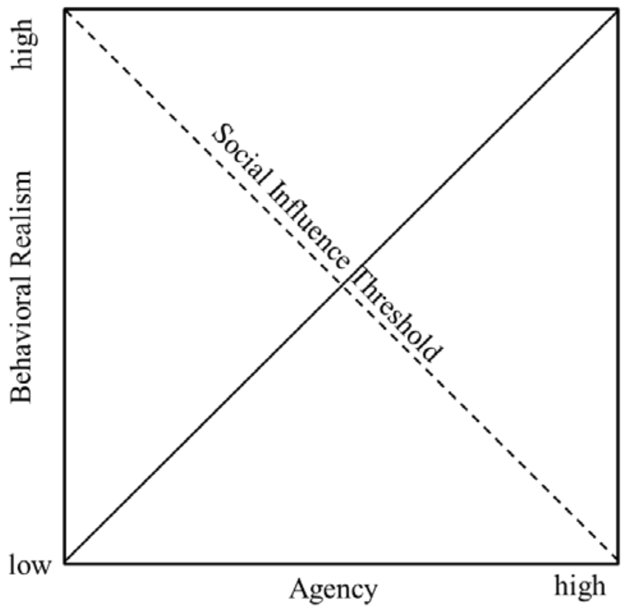

Figure 2 The *Threshold Model of Social Influence* (Blascovich, 2002, p.27)

Consequently, an important limitation for VR studies on SI may be that simulated agents could be perceived differently than “real” persons because participants might not recognize animated agents as humans. This could be the result of the *uncanny valley* effect, or the mere fact that participants infer from being alone in the laboratory that all simulated material is completely controlled by the simulation software (Cheetham, Suter, & Jancke, 2011). In fact, a study by Guadagno et al. (2007) demonstrated that the persuasion that an animated agent is actually controlled by another human being (avatar), changes the social presence and attitudes of participants towards that agent (Guadagno, Blascovich, Bailenson, & Mccall, 2007). Further studies showed that people's beliefs alone, rather than actual differences in virtual representations, can influence social perception processes (Bailenson, Blascovich, & Guadagno, 2008). However, the effect of perceived agency on actual social behavior is still under debate (von der Putten, Kramer, Gratch, & Kang, 2010). The *Ethopoeia Hypothesis* [2], for example, assumes that people perceive computer generated agents as humans and “mindlessly” transfer social norms into the virtual world (Nass & Moon, 2000; Nass, Steuer, Henriksen, & Dryer, 1994). “Ethopoeia involves a direct response to an entity as human while knowing that the entity does not warrant human treatment or attribution” (Nass & Moon, 2000, p. 94). Consequently it is necessary to test, whether the perception of virtual

[2] from the Greek ἠθοποιία: *ethos*, "character" and *poeia*, "representation".

agents as either avatar or agent is relevant for the study of SI during emergency situations in SI. Study 3 addresses this research question by adapting the manipulation of Guadagno et al. (2007) to a simulated tunnel emergency scenario.

1.3.4 Excursus: The Concept of "Panic" in the Context of Emergency Stuations

The scenarios discussed in the present dissertation are often associated with the term "panic". Media coverage of disasters often speaks of panic when numerous people try to evacuate from a site (Helbing & Mukerji, 2012). However, is this really a panic? Furthermore, in what situations does panic occur, and how do people influence each other during these situations?

> "According to a pervasive popular conception, they [people] panic, trampling each other and losing all sense of concern for their fellow human beings. After panic has subsided – so the image indicates – they turn to looting and exploitation, while the community is rent with conflict. Large numbers of people are left permanently deranged mentally. This grim picture, with its many thematic variations, is continually reinforced by novels, movies, radio and television programs, and journalistic accounts of disaster. (Fritz & Williams, 1957, p. 42)"

The expression "panic" is originally derived from the ancient Greek god Pan, whose interventions were said to cause feelings of intense fear (Pichot, 1996). More current definitions describe panic as basic fear reactions that occur in situations of danger which are associated with fight-or-flight responses (Jones & Barlow, 1990). Symptoms of panic include strong and abrupt cognitive and somatic reactions (Barlow, 2002). That is, panic can be conceptualized as irrational behavior which is damaging to oneself or to others. Note that panic is a state of individuals and not groups (Drury, Cocking, & Reicher, 2009). According to this concept, inaction during a severe fire would be regarded as a panic reaction. Moreover, running away from a dangerous fire would be regarded as highly functional behavior that might be live saving. This scientific definition opposes a lay-concept of panic often conveyed by the media, in which pictures of people running away from an emergency situation are falsely used to illustrate "panic".

When does panic occur? Panic has been reported from catastrophic events, such as earthquakes, fires, or manmade disasters during mass events or terrorist attacks (Clark, 2002; Johnson, 1987; Pfefferbaum, Stuber, Galea, & Fairbrother, 2006; Sime, 1985). Clark (2002) summarizes that over fifty years of research showed that during crisis situations people hardly lose control although they experience extreme fear. Moreover, survivors of catastrophes report that people support each other, and cooperation among strangers during evacuations is well documented (Drury, Cocking, Reicher, et al., 2009). Even in the extreme case of a so called mass panic such as the tragic events at the Loveparade in Duisburg, Germany (2011), it is reported that people try to help others who for example have fallen to the ground and are threatened to be trampled (Clark, 2002; Helbing & Mukerji, 2012).

1.4 Virtual Reality as a Method to Study Human Behavior in Emergency Situations

Virtual reality (VR) has become a well-established method in experimental psychology. It offers a number of benefits for experimental psychology research: VR allows to implement complex dangerous scenarios with full experimental control in the safe environment of a laboratory (Boyle & Lee, 2010). In comparison to field studies and observations from unannounced drills, VR studies are cost effective, easy to replicate and allow a maximum of experimental control (Wiederhold & Wiederhold, 2010). A variety of studies that cover the field of human behavior in dangerous situations have used VR: Gamberini et al. (2003) observed participants' evacuation from a simulated fire in a virtual library and showed that reflective actions were more likely than impulsive behavior or even panic (Gamberini, Cottone, Spagnolli, Varotto, & Mantovani, 2003). More recently, was VR used to explore user behavior in tunnel accidents with smoke and fire (Kinateder et al., 2013; Mühlberger et al., unpublished data). Thus, VR provides the possibility of gaining new insights in human behavior in emergency situations that otherwise would be very difficult to explore.

The usefulness of virtual worlds relies heavily on the external validity of the simulations. External validity can be assumed, if participants show similar behavioral, emotional, cognitive, and psychophysiological reactions in VR and in real world. In the last two decades, several studies examined the general usefulness of VR and the external validity of specific simulators. These studies demonstrated both the validity of driving simulators in terms of driving behavior, as well as the ability to elicit adequate emotional responses to virtual environments. Evidence for validity has been collected in a variety of studies: One study on emotional responses to virtual tunnel drives observed subjective and physiological fear responses in tunnel phobic patients (Mühlberger, Bülthoff, Wiedemann, & Pauli, 2007). Two driving simulator studies testing the behavioral validity of driving simulations demonstrated that drivers inside of virtual road tunnel drove more carefully and experienced more anxiety than on open roads (Calvi, 2010; Calvi & De Blasiis, 2011). Furthermore, results of simulator specific validation studies are promising, as behavioral similarity between driving parameters in virtual and real world drives was shown in independent studies using different simulators (Calvi, 2010; Calvi & De Blasiis, 2011; Hirata, Yai, & Tagakawa, 2007; Shechtman, Classen, Awadzi, & Mann, 2009; Törnros, 1998). The *Behavioral Assessment and Research Tool* (BART) is a *serious game* developed to simulate dangerous situations for training and research purposes. BART has been validated by comparing case studies from real evacuations with results from virtual scenarios (Kobes et al., 2010).

Although VR offers vast possibilities to study human behavior in dangerous situations some methodological and ethical limitations need to be considered. First, participants in VR studies will always know that what they perceive is a simulation. Field studies and especially unannounced drills can simulate more realistic scenarios and may let the participants believe that for example a simulated fire alarm is real. However, these methods are often highly cost-intensive and experimental control cannot as easily (if at all) be obtained as in VR laboratories. Moreover, from an ethical point of view, VR allows to investigate human behavior in scenarios that would otherwise be impossible to realize. If participants were no longer able to distinguish between virtual and real world, the same ethical conventions would have to be applied. Two important aspects need to be considered in the development of virtual emergency situations. First, the virtual environment has to be designed in a way that it is not potentially traumatizing. Second, participants' previous experiences with similar scenarios as in the study need to be assessed prior to the study. If a participant has previously been exposed to such an event, he or she should be excluded from the study. Consequently, people who had experienced severe traffic accidents or were tunnel phobic could not participate in the studies comprising the present dissertation project.

1.5 Research Objectives

The previous sections have outlined a number of critical aspects of human behavior during different stages of evacuation from potentially life threatening situations. Furthermore, methodological, and ethical difficulties of experimental psychological research in this field were addressed. The aim of the present dissertation project is to describe the experience and behavior of people in simulated hazardous situations with virtual reality experimental studies. In particular, the question of the SI of virtual agents on participants' behavior in emergency situations is investigated. Therefore, the research objectives in the present dissertation are twofold. The first objective is to systematically analyze SI during different relevant stages of an evacuation process from a simulated road tunnel fire. In order to achieve this goal, five VR studies in various settings in a road tunnel were realized. The second objective aims to investigate validity aspects of VR as a research tool.

2. Studies in Virtual Reality

"Situational variables can exert powerful influences over human behavior, more so that we recognize or acknowledge."

Philip Zimbardo

2.1 Study 1 (Pilot Study): Social Influence in a Virtual Tunnel Fire – Influence of passive bystanders

2.1.1 Introduction

As outlined in the literature review of paragraphs 1.3.2 and 1.3.3, SI may play an important role during evacuation from emergency situations and can be empirically studied using VR simulations. Mühlberger et al. (submitted) developed a VR road tunnel scenario in which participants can be confronted with an accident and smoke. For the purpose of the present dissertation project, this scenario was adapted and extended with a SI condition. Specifically, animated VAs (one driver and one co-driver) were situated in a cabriolet parking in front of the simulated accident (Figure 4 and Figure 5). The aim was to elicit the impression that the VAs had arrived at the accident just before the participants. After the participants had stopped their vehicle the driver VA turned his head into the direction of the participant, pointed at the accident and shrugged. After that, the VA stayed passive. A control group was confronted with the same emergency situation but no VA was present.

Study 1 is the first study on SI in dangerous situations within the present dissertation project and the VAs were specifically developed and animated for this purpose. Hence, a number of requirements had to be tested. A potential SI effect is only possible if the VAs were perceived and correctly recognized in the emergency situation. Thus, we had to test whether participants saw the VAs. This is not self-evident since it was possible to park the participants' vehicle at any place inside the tunnel. Consequently, it might be possible that not all participants stopped the vehicle close enough to the cabriolet to see the accident and VAs.

2.1.2 Method and Apparatus

2.1.2.1 Sample

Thirty-two participants volunteered to take part in a driving simulator experiment. During two experimental sessions the procedure had to be interrupted due to technical reasons. In total 30 participants (mean age: M = 24.20, SD = 3.37; 15 female participants) were randomly assigned into two experimental groups (Control and SI condition, each n =

15). There were no significant differences between the experimental groups regarding anxiety and sociodemographic variables. See Table 2 for descriptive statistics and questionnaire data.

2.1.2.2 Apparatus

The virtual tunnel scenarios were performed by a VR interface (CyberSession, VR-simulation software written in-house). The rendering was completed by the Cortona VRML Renderer (ParallelGraphics, Dublin, Ireland) with a personal computer (Intel Core2Duo E8600, NVidia GeForce 285GTX, 4GB RAM). The simulation was presented via a head-mounted display (HMD; nVisor SX, NVIS Inc., Reston, VA, USA; resolution: 1280*1024 pixels; monocular diagonal field of view: 60°). The participants were seated on a moving platform with six degrees of freedom (Krauss-Maffei-Wegmann GmbH & Co. KG, Munich, Germany). The head position was monitored with an electromagnetic tracking device (FASTRACK, Polhemus Corp., Colchester, VT, USA) in order to assess head orientation and to adapt the line of sight.

Table 2 Descriptive Statistics and Questionnaire data of study 1.

	Control condition		SI condition			
	M	*SD*	*M*	*SD*	t^1	*p*
STAI trait sum score	23.38	2.14	24.82	4.02	0.16	.48
STAI state sum score	38.23	10.15	34.24	4.63	1.44	.08
TAQ (driver) sum score	3.92	3.38	4.35	2.67	-0.39	.20
TAQ (co-driver) sum score	4.35	2.67	3.08	2.36	0.08	.74
IPQ Sum score	81.85	9.44	82.88	9.87	-0.29	.77
SSQ Sum score	8.54	6.09	6.23	3.91	1.26	.21

Note: each $n = 15$; SI = Social Influence; STAI = State-Trait Anxiety Inventory; TAQ = Tunnel Anxiety Questionnaire; SSQ = Simulator Sickness Questionnaire, IPQ = iGroup Presence Questionnaire; [1]Between-subjects t-test.

Navigation within the simulation was implemented using car steering elements (Logitech G25 steering wheel with gas and brake pedal). Additionally, hardware for switching on head lights, radio, hazard flasher, and ignition, as well as a handle to open the driver's door were installed and implemented in the simulation. To make the interaction as intuitive as possible the position of the mock up interaction components were at the same position as the visual representation presented in the HMD. Navigation was restricted to driving forward in the simulation to prevent participants from turning the vehicle in the tunnel. Figure 3 shows a participant fully equipped on the moving platform.

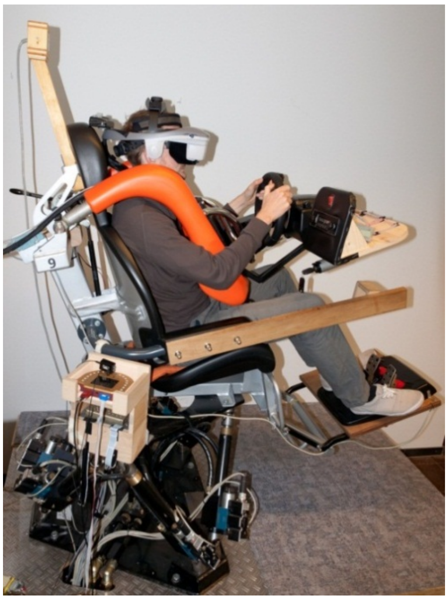

Figure 3 Participant wearing a head mounted display (HMD) and immersed into the driving simulation.

2.1.2.3 Experimental Design

The presence of passive VAs was manipulated in the experimental conditions, resulting in one *SI condition*, in which two passive VAs were situated in a cabriolet close to the accident, and one *control condition* with no VAs. The VAs represented a middle aged man as the driver, and a middle aged woman as the co-driver. The VAs' car was standing across the road so it became clearly visible for the participants when they arrived at the accident. After the participants had stopped their vehicle the driver VA turned his head into the direction of the participant, pointed at the accident and shrugged. After that he stayed passive in the driving position. The co-driver VA stayed passive throughout the whole scenario. In the control condition an empty car with no VA is standing at the accident (Figure 4).

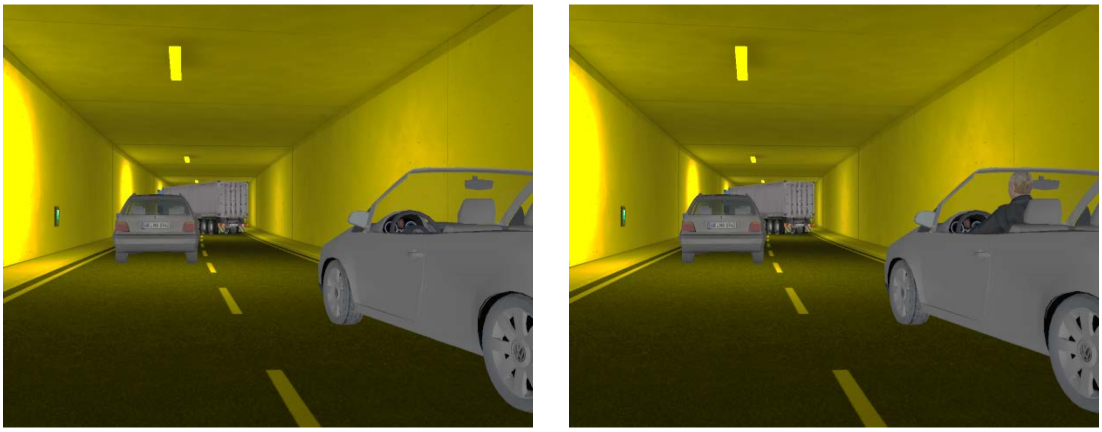

Figure 4 Screenshots of the two experimental conditions. In the control condition (left picture) no VA is present. In the SI condition (right) a VA is sitting in a cabriolet.

2.1.2.4 Dependent Variables

Behavioral data was collected from the simulation. The frequencies and latencies of relevant safety behaviors were recorded and analyzed. Relevant safety behavior defined by the German Federal Highway Research Institute (Bundestanstalt für Straßenwesen, BASt) was provided in an information brochure and included the following behavioral patterns in case of an incident in a road tunnel: Stopping the vehicle, turning off the engine, switching on the hazard flasher and the radio (to be able to receive information/instructions from the tunnel operator), as well as leaving the vehicle.

State and trait anxiety were measured using the State-Trait Anxiety Inventory (STAI; Laux, Glanzmann, Schaffner, & Spielberger, 1981; Spielberger, Gorsuch, & Lushene, 1970) and the Tunnel Anxiety Questionnaire (TAQ; Mühlberger & Pauli, 2000). Trait anxiety and tunnel anxiety scores can be found in Table 2. During the virtual tunnel drives, participants were also required to rate their state anxiety verbally on a scale ranging from 0 (no anxiety) to 100 (maximum imaginable anxiety). At certain points during the virtual drives a prerecorded question (“Please rate your anxiety now.”) was automatically played back to the participants, and the experimenter protocolled each rating (see procedure). While answering the questions the participants continued to drive. Participants were familiar with this procedure due to pre-experimental training.

Since virtual driving simulators may cause simulator sickness, symptoms of nausea were assessed with the Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, &

Lilienthal, 1993) and the Body Sensation Questionnaire (BSQ; Chambless, Caputo, Bright, & Gallagher, 1984) administered after the experiment. To define a cut-off for symptoms of nausea, item 8 from the SSQ and item 9 from the BSQ were used. The SSQ item asks the participants to rate the severity of symptoms of nausea on a 4-point Likert scale ranging from “no symptoms” to “strong symptoms.” The BSQ item asks for a rating of the frequency of these symptoms during the last 10 minutes on a 5-point Likert scale ranging from “never” to “always.” If participants reported at least either frequent (Item 9 of the BSQ > 3) or medium-strong symptoms (Item 8 of the SSQ > 2) of nausea after the drives, they were excluded from the analysis.

In order to test the experimental set-up, participants completed an additional short questionnaire about the emergency situation after the drives. The following questions were asked: (1) *How many vehicles did you see during the emergency situation?* (2) *Have other people been involved in the accident?* (3) *If other people were involved, how many people did you actually see?* (4) *If other people were involved, where were these persons in the event?*

2.1.2.5 Procedure

After giving their informed consent, participants completed the questionnaires mentioned above (Appendix B). A written instruction then explained that the participants’ task during the experiment was to conduct several drives through a virtual road tunnel on a highway and that they should drive according to traffic rules for German highways. Prior to being immersed into the VR, participants had to train using all mock-up elements until they could easily handle them even with closed eyes. After that they completed a training drive in which the handling of the virtual car was practiced. During the training drive the experimenter required the participant again to use all elements of the mock-up. The experiment itself consisted of three drives through the tunnel. Each drive started outside the tunnel, and after about 50 seconds of driving on an open road, participants entered the tunnel (See Mühlberger et al. (submitted) for a study using a similar procedure and scenario).

In the first drive, participants had to follow a car and a truck. These stopped in the middle of the tunnel and formed a traffic jam. After one minute, they continued to drive and the drive ended after leaving the tunnel. The aim of this drive was to sensitize the participants to unexpected situations. The transition between the drives was smooth so that the participants had the impression of one continuous drive. During the second drive, the participants drove through the empty road tunnel with no additional traffic. This drive was introduced to give an impression how a “normal” tunnel drive looks like. After leaving the tunnel and driving again on the open road for about 200 meters, the next drive started. In the third drive, there was no visible difference from the second drive at first. However, after two minutes of driving in the tunnel, a truck blocked both lanes (emergency situation; Figure 4 and Figure 5). One minute later, smoke started expanding from the truck. After two minutes, the participants’ vehicle was completely surrounded by smoke. The trial ended either when participants opened the door of their vehicle or automatically after two minutes.

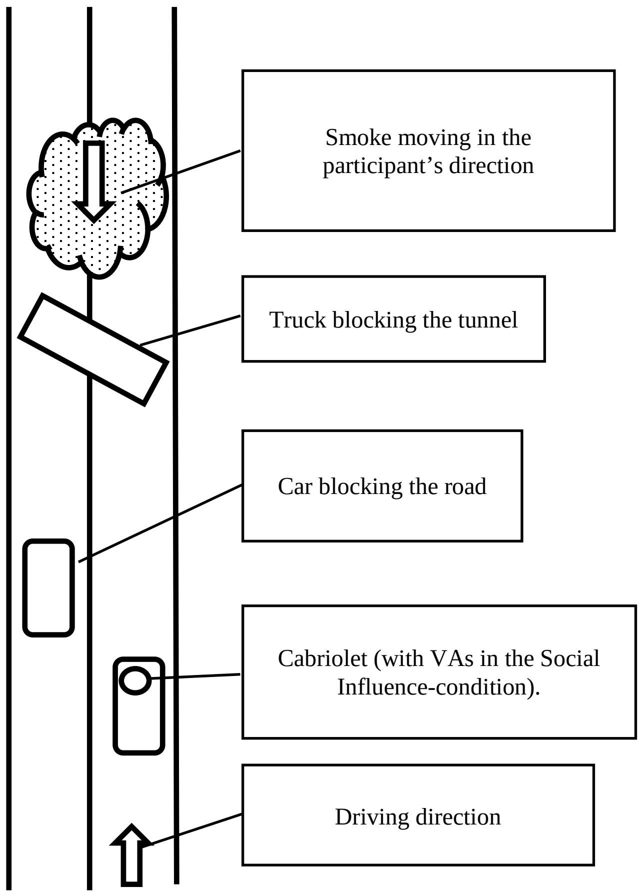

Figure 5 Overview of the emergency scenario in the tunnel.

In contrast to the other ratings the last anxiety rating was not performed within the actual simulation, but directly after the emergency situation. This meant to ensure that the rating itself could exert unintended influence on the participants’ behavioral responses during the event. The three experimental drives were administered in the same order for all participants. The emergency situation had to be in the last drive since the triggered emotional responses as reflected in the ratings would have affected following drives. There was an optional fourth drive with no event for the participants after the experiment. The purpose of this final voluntary drive was to guarantee that participants did not finish the experiment with a negative experience. After the experiment, participants completed the SSQ, the IPQ, and the additional questionnaire for manipulation check.

2.1.3 Results

2.1.3.1 Manipulation check

In total, only a minority in the SI condition could correctly describe the emergency situation: Although 92% of the participants reported to have seen at least two vehicles, 55% stated to have seen two VAs (no one stated to have seen only one VA), and only 40% answered that other people were involved in the emergency situation. Finally, 17% knew that the VAs were in the cabriolet.

Regarding the three anxiety ratings in the third drive, the scores were relatively low in the first rating (M = 3.96, SD = 8.37), a slightly elevated in the second rating (M = 21.92, SD = 22.28), and relatively high in the third rating after the accident (M = 44.23, SD = 27.95). A repeated measures ANOVA revealed a main effect of time of rating, F (2, 48) = 42.37, p < .001. Contrasts revealed that the second, F (1) = 25.75, p < .001, as well as the third rating, F (1) = 56.17, p < .001, were higher than the first rating. There were no differences between the two experimental conditions, F (1) = 0.76, p = .39.

2.1.3.2 Behavioral Data

Regarding the behavioral outcome measures, there were no significant differences between the SI condition and the control condition in the emergency situation. Both groups switched on radio and hazard flasher, and left the vehicle equally often (Table 3). In total 70% of the sample (n = 21) left the vehicle in the emergency situation. The distance between the stopping position and the accident was 119.40 meters (SD = 48.52), and the mean time from stopping the vehicle to opening the driver's door was 44.56 seconds (SD = 29.63). There were no significant differences between the groups regarding the distance between the accident and the participants' stopping position, t (28) = -0.45, p = .66, latencies from stopping to leaving the vehicle, t (18) = 1.37, p = .18. However, there was a significant negative correlation between the distance to the accident and the latency to leave the vehicle, r (30) = -.59, p < .01. The closer participants stopped to the accident, the longer they waited to leave the vehicle.

Table 3 Frequencies of safety relevant behavior in the pilot study1

	Control condition	SI condition		
	n	*n*	χ^2	*p*
Switching on the hazard flasher	12	14	1.36	.51[1]
Switching on the radio	9	13	0.20	.65[1]
Turning off the engine	8	12	1.77	.41[1]
Leaving the vehicle	10	11	0.53	.46[1]

Note: each n = 15; SI = Social Influence; [1]expected frequencies < 5 and likelihood-quotients were calculated.

2.1.4 Discussion

Only a small part in the SI condition could correctly describe the VA during the emergency situation. A possible explanation is that participants stopped the vehicle too far away from the cabriolet to perceive the VAs. Since the mean distance from the accident was almost 120 meters, the animated VA may simply have been too small to have any effect. Furthermore, due to the negative correlation between latency to leave the vehicle and distance to the accident, one may speculate that the VA had at least some effect on those of the participants who stopped relatively close to the accident and had a better view on the VAs. Nevertheless, the conclusion drawn from the manipulation check indicates that experimental manipulation in the independent variables has failed.

The following conclusions have to be implemented in the scenario for study 2: First, reducing the distance of the accident and the cabriolet might allow the participants to stop closer to the accident. Second, activating the smoke only after the participants have stopped, gives them more time to look at the accident and hence increases the probability that the VAs are perceived. Third, the control variables established in this pilot should be used to define exclusion criteria in the main study.

2.2 Study 2: Influence of Information and Passive Bystanders on the Decision to Evacuate in a Simulated Tunnel Fire[3]

2.2.1 Introduction

Inertia and delayed evacuation is one of the crucial problems in tunnel fires (Fridolf, Nilsson, & Frantzich, 2011). People who do not leave their vehicles and the tunnel risk being entrapped by smoke and consequently suffocation (Beard & Carvel, 2005). Interestingly, most studies in the field of SI focus on helping behavior and not actual self-evacuation. It seems possible, though, that psychological processes that inhibit helping behavior may also lead to inertia and delayed self-evacuation in tunnel emergencies. Specifically, SI may be a possible factor contributing to passivity either through diffusion of responsibility or perceived cost-benefit assumptions (Fischer et al., 2011). In an earlier study, the same authors argue that the inhibition of bystander intervention can also be influenced by the perception of threat. If a situation is judged as highly dangerous the bystander effect might disappear (Fischer et al., 2006). Open fire is a clear indicator of threat and should trigger protective actions. During fire breakouts in road tunnels, however, most tunnel users may be too far away from the fire to see open flames. Heat and toxic smoke are the most important threats in tunnel emergencies but may not be perceived as potentially life-threatening (Beard & Carvel, 2005). This consideration hast two important consequences. First, interventions improving users' perception of potential threats should improve evacuation. Indeed, Mühlberger et al. (submitted) showed that information about adequate reactions in case of a tunnel fire, leads to significantly higher evacuation rates. Second, similar to the findings of Fischer et al. (2006) about the bystander effect on helping behavior, passive bystanders might only inhibit evacuation in an emergency, if the situation is perceived as ambiguous and not highly dangerous. In such a situation, the benefit of information should be weakened, if other people who do not evacuate are visible. Therefore, the purpose of the present study was to study SI in a tunnel emergency and to replicate and extend the findings of Mühlberger et al. (submitted).

[3] Results of this study were presented in part at the Human Behavior in Fire Symposium 2012 in Cambridge, UK, and can be cited as follows: Kinateder, M., Müller, M., Mühlberger, A., & Pauli, P. (2012). Social Influence in a Virtual Tunnel Fire - Influence of Passive Virtual Bystanders. In *5th International Symposium on Human Behavior in Fire Symposium 2012* (pp. 506-516). London: Interscience Communications Ltd.

The research questions were addressed by having participants conduct three road tunnel drives in a virtual driving simulator with the following situations: traffic jam, no event, and tunnel blocked by trucks with smoke rising (emergency situation). In the emergency situation, participants were confronted with a simulated accident inside the tunnel. A truck and a car blocked the road and after participants had stopped their car at the accident smoke started to move towards them. Half of the participants received information about adequate safety behavior prior to the tunnel drives (*informed condition*), and the other half received irrelevant information (*no information condition*). In addition, a cabriolet was standing in front of the accident. Half of the informed and half of the uninformed participants saw two passive bystanders sitting in the cabriolet, looking at the accident and smoke, but not leaving the cabriolet (*SI condition*). In the other condition the cabriolet was empty (*no SI condition*).

2.2.2 Method and Apparatus

The results of study 1 indicated that participants need to stop vehicle close enough to the VAs. Furthermore the VAs should be surrounded by smoke only after the participants stopped at the accident. In order to do so the emergency situation needed to be at a sufficient distance from the VAs' vehicle. In addition to that, an optimized manipulation check investigated whether the participants could precisely recognize the Vas (see below).

2.2.2.1 Apparatus

See 2.1.2 Method and Apparatus of study 1 for a description of the driving simulator and the simulation software.

2.2.2.2 Sample

Sixty-two participants took part in the study. Two of them had to be excluded from the data analysis because they prematurely cancelled the experiment due to symptoms of simulator sickness. In total N = 60 participants remained in the study (age: M = 24.58 years, SD = 5.08 years; 30 female participants). Participants were randomly assigned into four different experimental groups (each n = 15; no significant differences in sociodemographic and questionnaire data between the groups). The questionnaire data of the sample is depicted in Table 4.

2.2.2.3 Experimental Design

The study realized a 2x2 between subjects design. The first independent variable was Information vs. No Information: In the *Information* condition, participants read a brochure of the German Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt, 15 pages) containing general information about German road tunnel and relevant information about safety behavior in road tunnels. Participants in the *No Information* condition, participants read a brochure containing irrelevant information. The second independent variable was *SI* vs. *No SI*: In the SI condition a cabriolet with two animated agents was standing at the emergency situation. After the participants had stopped their vehicle the driver VA turned his head into the direction of the participant, pointed at the accident and shrugged. After that he stayed passive. In the No SI condition the cabriolet was empty. Consequently, participants were randomly assigned to one of four experimental conditions.

Table 4 Descriptive statistics and questionnaire data of study 1.

	No information				Information			
	SI		No SI		SI		No SI	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
STAI trait	37.67	8.86	36.40	11.04	34.00	6.75	33.31	8.48
STAI state	37.13	6.84	36.80	7.79	34.07	6.80	32.81	4.05
TAQ (driver)	4.87	4.50	3.20	2.96	3.20	3.19	3.19	3.71
TAQ (co-driver)	5.07	7.68	2.60	1.72	3.07	4.04	2.94	1.88
IPQ	2.20	9.52	6.33	10.31	3.27	14.41	-1.50	17.11
SSQ	5.73	3.60	5.87	3.46	5.20	5.41	4.31	3.30

Note: each n = 15; SI = Social Influence; STAI = State-Trait Anxiety Inventory; TAQ = Tunnel Anxiety Questionnaire; SSQ = Simulator Sickness Questionnaire, IPQ = iGroup Presence Questionnaire; sum scores were calculated for each questionnaire.

2.2.2.4 Dependent Variables

Similar to study 1, frequencies and latencies of relevant safety behavior were assessed (See Dependent Variables of the study 1).

2.2.2.5 Procedure

The procedure was the same as in study 1 but some changes in the emergency situation were realized. Figure 6 depicts the course of the emergency situation. The two cars standing in front of the accident were placed closer to the emergency situation. Hence, these became visible later and participants might drive closer to the scene. In contrast to study 1, the smoke moved towards the participants only after they had stopped their vehicle.

In order to achieve a more precise description of the participants' perception of the event, the following question was added to the manipulation check questionnaire: *If you could see persons during the emergency situation, what kind of behavior did you observe?* In total, ten participants (five from each SI condition) did not answer this question correctly. This exclusion criterion is conservative, since it is possible that participants perceived the VAs correctly and simply did not report what they saw. The analysis of the behavioral data was carried out once with and once without the ten participants in question. All participants in the SI condition answered correctly to the other questions designed for manipulation check. In order to assess the perceived threat of the accident and the smoke two questions were added to the manipulation check questionnaire: *How dangerous did you perceive the situation to be, when you saw the truck blocking the road?* and *How dangerous did you perceive the situation to be, when you saw smoke coming towards you?* Answers to both questions were given on a five-point Likert-Scale ranging from 1 = *not dangerous at all* to 5 = *extremely dangerous*.

Event	Stopping the vehicle	Smoke becomes visible	Truck is completely covered with smoke	Vehicles with VAs are covered with smoke	Participant is surrounded by smoke
View of partici-pant					
Time	0 sec.	~20 sec.	~30 sec.	~40 sec.	~50 sec.

Figure 6 Screenshots and timing of the adapted emergency situation.

2.2.3 Results

2.2.3.1 Perceived Threat

Figure 7 depicts the perceived threat of the truck blocking the road and the oncoming smoke. There were no group differences regarding perceived threat of the truck blocking the road, as well the smoke coming towards the participants. Generally, the smoke was perceived as more dangerous than the truck blocking the view, t (58) = -8.44, p < .001.

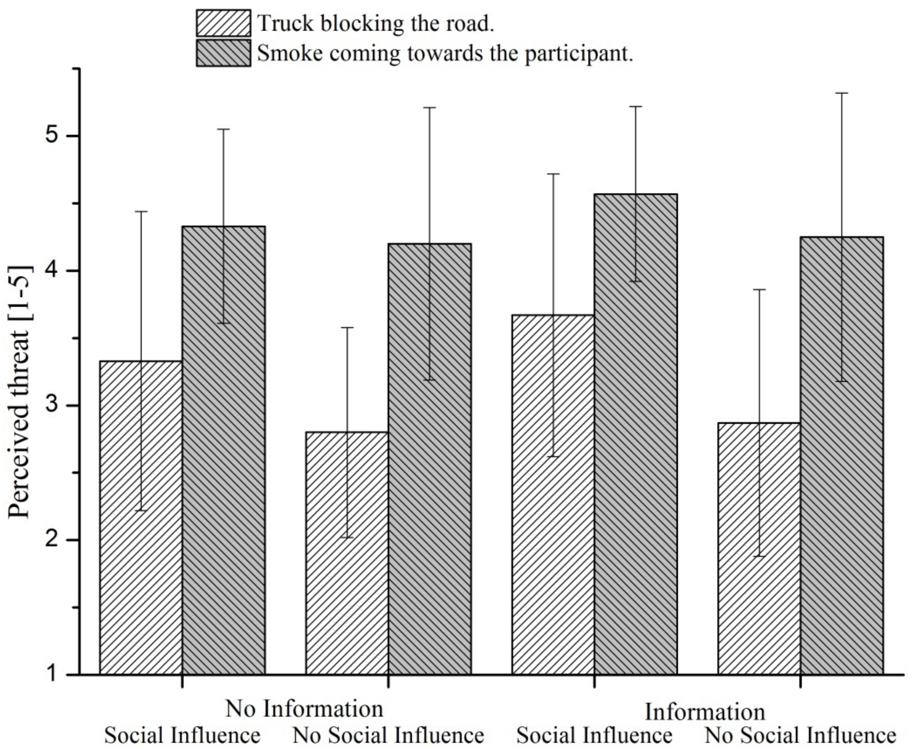

Figure 7 Perceived threat of the truck blocking the road and the smoke coming towards the participants. Answers to both questions were given on a five-point Likert-Scale ranging from 1 = not dangerous at all to 5 = extremely dangerous.

2.2.3.2 Frequencies of Safety Behavior

In total 31 participants left the vehicle during the emergency situation (Figure 8). There was a marginally significant effect of group on the number of participants leaving the vehicle, X^2 (3) = 7.35, p = .06). In order to identify specific group differences, pairwise comparisons were conducted (α level Bonferroni corrected).

Informed participants were more likely to leave the vehicle than uninformed participants in the whole sample (N = 60), X^2 (1) = 6.64, $p < .05$. In the SI condition, there was no difference between informed and uninformed participants, X^2 (1) = 1.71, p = .175 (one-tailed). In the no SI condition, informed participants left the vehicle more frequently than uniformed participants, X^2 (1) = 5.43, p = .02 (one-tailed). These results are in line with the findings of Mühlberger et al. (submitted).

There were no differences between the SI and no SI condition in the whole sample (N = 60), X^2 (1) = 0.26, p = .61. When comparing the SI with the no SI condition, no significant differences between the groups were found, neither in the informed X^2 (1) = 0.80, p = .30, nor in the uninformed condition, X^2 (1) = 0.09, p = .60. The same analysis was conducted without the ten participants who did not describe the VAs behavior correctly in the manipulation check. After that, no significant differences between the four experimental groups were found, X^2 (3) = 5.92, p = .11.

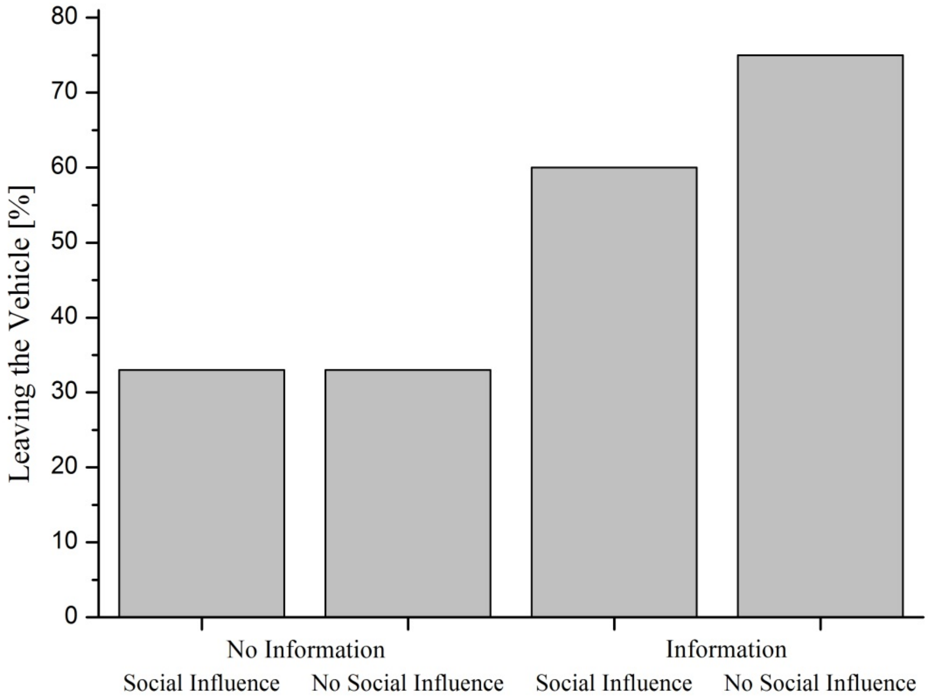

Figure 8 Percentage of participants leaving the vehicle during the emergency situation in the experimental groups

2.2.3.3 Latencies of Leaving the Vehicle

Of the 31 participants who left the vehicle during the emergency situation, most did so only after they were fully surrounded by smoke (Figure 9). There were no significant group differences regarding the latency of leaving the vehicle, F (3, 27) = 0.48, p = .70. Please note, that the statistical power of this analysis is weak, since only a small part in the sample actually left the vehicle. On a descriptive level, however, an interesting pattern could be observed: Only informed participants who were not exposed to SI left the vehicle before they were completely surrounded by smoke. All other participants did so only after their view was completely was completely blocked by smoke.

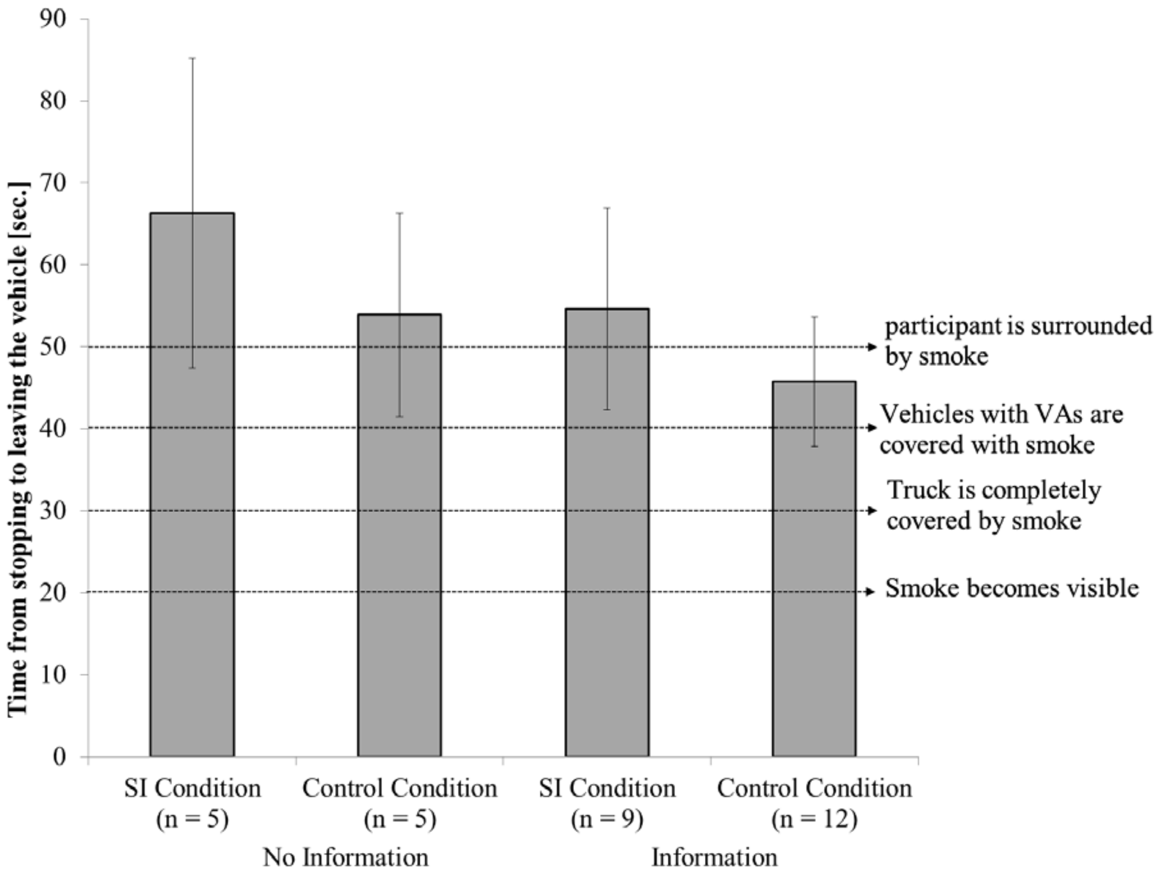

Figure 9 Time from stopping to leaving the vehicle of the participants in the four experimental groups during the emergency situation; SI = Social Influence.

2.2.4 Discussion

This study examined the effect of SI and information on participants' behavior during an accident with fire and smoke in a virtual road tunnel. Four groups (No information – SI, No information – No SI, Information – SI, Information – No SI) completed each three drives through a VR road tunnel in a driving simulator. The groups differed in information status and exposure to SI during the event. Informed participants left the vehicle more frequently and faster than uniformed participants. Only about 30 % of the uniformed participants left the vehicle. These results replicate the findings of Mühlberger et al. (submitted) and demonstrate once more the importance of investigating how to improve user behavior in tunnel fires, given both the possible dramatic consequences of passivity and the feasibility of relatively cost-effective measures, such as information campaigns.

However, there was no effect of the SI condition regarding the frequency of participants leaving the vehicle. Also, there were no significant group differences between informed and uninformed participants in the SI condition, whereas these group differences reached significance in the no SI condition. Regarding the descriptive statistics, these differences between SI and no SI condition are most likely due to the small sample size. However, it is possible that the passive bystanders inhibited evacuation in the informed group.

Earlier findings of Fischer et al. (2006) indicated that the effect of SI on evacuation behavior might be mediated by the perceived threat of a given situation. We assumed that especially uniformed participants would underestimate the danger of smoke in a tunnel, and thus, would start evacuating. In ambiguous, but not obviously dangerous situations, normative SI leads people to not want to “make a fool of themselves” in front of others (Deutsch, 1980; Nilsson & Johansson, 2009). Even though smoke is the most important threat to tunnel users, it may not be perceived as potentially life threatening in tunnel fires (Beard & Carvel, 2005). That is, it was expected that uninformed participants did not realize the immediate danger of the situation, and thus were less likely to leave the vehicle in the SI condition. Interestingly, the results show that participants in all four experimental groups judged the oncoming smoke as highly dangerous (Figure 7). Consequently, the results do not allow testing the assumption that perceived threat is an important mediator between SI and behavioral responses in emergencies. More importantly, it is clear that even uninformed participants realize the threat of oncoming smoke in a tunnel fire, but still do not begin to evacuate.

Regarding the latencies of participants leaving the vehicle there were no statistically significant differences between all four experimental groups. Considering the low statistical power (only one third of the uniformed participants actually left the vehicle), these results have to be interpreted cautiously. Descriptively, uninformed participants in the SI condition waited the longest, and only informed participants in the no SI condition left the vehicle before it was completely surrounded by smoke. Future studies should clearly investigate the effect of SI not only on quality of evacuation but also on latencies.

There are a number of possible limitations to the present study. This study only examined the possible SI of passive VAs situated in a different car. The effect of moving VAs was not inspected. One may speculate that seeing VAs actively leaving his vehicle and going to an emergency exit might trigger evacuation behavior in uninformed participants. Thus, future studies should consider active behavior of Vas (see study 5 for a study using active VAs). In addition, in the control condition the participants did not see any VAs but only an empty cabriolet standing in front of the accident. One may speculate that participants might deduce from an empty vehicle that the car's occupants had already left the vehicle. That is, we cannot exclude that some form of SI was also exerted in the control condition.

An alternative possible explanation for the non-existent effect of SI in the present study could lie within the properties of the VAs themselves. It might be that the VAs behavioral realism was too low or that participants did not perceive the VAs as "real" human beings but only as computer generated objects, and thus, the threshold of SI postulated by Blascovich (2002) was not passed. If this was the case, the possible effect of SI might have been significantly weakened. An additional study evaluating the effect of perceived agency and behavioral realism is necessary (See study 3).

Reports from tunnel fires and other incidents indicate that drivers often try to turn their vehicles and evacuate from the tunnel the same way they had entered (Frantzich, 2001; Martens, 2006). Movement to the familiar is an important aspect in evacuation behavior (Sime, 1985). The driving simulator used in the present study did not allow driving backwards and consequently turning the vehicle was not possible. This clearly limits the realism of the driving simulation with the consequence that the results cannot be interpreted in ways that this behavior does not occur.

Transfer of the information effects found in the present VR study to real world emergency situations may be limited by the fact that the relevant information was given to the participants just before the simulated tunnel drives. Kinateder et al. (in press), however, found first promising results, that information may also improve evacuation behavior in a real world tunnel emergency simulation. Future studies, therefore, need to examine possible long term effects of information on user behavior.

In summary, this study replicated the findings of Mühlberger et al (submitted), demonstrating the problem of inertia in evacuation during tunnel emergencies, and that information campaigns are promising to improve users' reactions. Furthermore, there were only weak signs of SI of passive virtual bystanders in other vehicles on the participants' behavioral responses during the simulated emergency situation. Finally, all experimental groups perceived the emergency as highly dangerous.

The scenario of Study 1 looked at SI of VAs situated in a car next to the simulated emergency situation. No other persons were present inside the participants' vehicle. Study 3 and 4 expands the scenario and looks at differential effects of SI of drivers and co-drivers during an emergency in a road tunnel.

2.3 Study 3 (Pilot Study): Perceived Agency as a Mediator of SI in VR

2.3.1 Introduction

Study 2 found only weak SI of VAs in an emergency scenario. However, it is unclear whether the VAs were even perceived as human-beings and not only as mere computer generated objects. According to the *Threshold Model of Social Influence*, SI in VR can only be exerted if VAs are perceived as avatars (Blascovich, 2002b). Guadagno et al. (2007) showed that the perception of VA as human influences the degree of *social presence* in a virtual environment. Social presence describes the subjective experience to be in a virtual environment together with others (Blascovich, 2002a). The stronger the persuasion that VAs are controlled by real human beings (meaning they are perceived as avatars), the stronger the experience of social presence. Guadagno et al. (2007) experimentally manipulated the perceived agency and measured the perceived social presence of VAs. In their study, participants were assigned either to an agent condition or an avatar condition. Both groups saw a VA giving a pre-recorded monologue. Participants in the agent condition read an instruction, telling them that the VA was controlled by the computer. Participants in the avatar condition were lead to believe that the VA was actually a live representation of another participant. In order to increase the effect of this manipulation, a live video of themselves and a pre-recorded video of a confederate representing the person controlling the VA were shown to the participants prior to the VA's monologue. After watching the video participants completed a short questionnaire on social presence. The results showed that participants in the avatar condition reported higher social presence than those in the agent condition.

The authors interpret their findings as a support for Blascovich's *Threshold Model of SI*, which assumes that social presence is a necessary condition for SI in VR (Guadagno et al., 2007). This model has been criticized, however, and opposing models such as the *Ethopoeia concept* assume that social reactions to VA are the same as to real humans unrelated of their perceived agency (Nass & Moon, 2000; von der Putten et al., 2010). Unfortunately Guadagno et al. (2007) used only self-report measures in their study, whereas a sound test of the threshold model of SI would require a behavioral test (For a more detailed description of the models, please refer to section 1.3.3). Consequently, the goal of study 3 was to test, whether an experimental manipulation of perceived agency could influence participants' behavior in a virtual environment.

In order to address this research question, two groups of participants were immersed into a virtual road tunnel. There they completed two drives as a co-driver and were confronted with a tunnel emergency. In this emergency situation the virtual road tunnel was blocked by an accident with smoke rising from the accident (See also study 1 for a detailed description of the emergency situation). The car in the virtual tunnel was driven by a VA, who stayed passive at the beginning of the emergency situation but opened his door and left the vehicle. Using the manipulation procedure recommended by Guadagno et al. (2007), one group was told that the driver was a VA and the other was lead to believe that the VA was an avatar representing another participant. According to the *Threshold model of SI*, increased agency leads to stronger effects of SI (Figure 2). Thus, participants in the avatar condition should be influenced more strongly by the VA than participants in the agent condition.

2.3.2 Method and Apparatus

2.3.2.1 Sample

Thirty-two participants (age: *M* = 21.56 years, *SD* = 3.78 years; 16 female) volunteered to take part in the study and were randomly assigned to one of two groups (avatar or agent condition; each *n* = 16). Participants were undergraduate psychology students and received course credits. There were no significant differences between the groups regarding sociodemographic and questionnaire data (Table 5).

2.3.2.2 Apparatus

See Method and Apparatus of study 1 for a description of the driving simulator and the simulation software. Some important modifications to study 2 were made: Study 3's scenario enabled participants to see a driver or co-driver in the cabin. The chair on the moving platform restricts head movements and makes it difficult to look to the driver or co-driver. In order to guarantee complete head-movement, the mock-up was fixed to a table (pedals under the table) and participants were seated on a simple wooden chair.

Table 5 Descriptive Statistics and Questionnaire data of study 3.

	Avatar condition		Agent condition			
	M	*SD*	*M*	*SD*	*t*	*p*
STAI trait	35.56	6.88	36.25	9.23	0.24	.81
STAI state	37.13	10.87	33.25	8.00	-1.15	.26
TAQ (driver)	4.47	4.14	5.06	3.60	0.43	.67
TAQ (co-driver)	4.56	5.40	4.81	3.90	0.15	.88
IPQ	1.94	8.12	3.25	10.25	0.40	.69
SSQ	5.13	3.84	4.69	5.25	-0.27	.79
Social Presence[1]	9.07	3.58	8.36	2.56	-0.61	.54
Behavioral Realism[1]	10.53	3.20	10.86	1.99	0.32	.74

Note: each n = 16; all df = 30; STAI = State-Trait Anxiety Inventory; TAQ = Tunnel Anxiety Questionnaire; SSQ = Simulator Sickness Questionnaire, IPQ = iGroup Presence Questionnaire; sum scores were calculated for each questionnaire; [1]Sumscores from the items developed by Guadagno et al. (2007).

2.3.2.3 Experimental Design

Perceived agency was manipulated in two experimental groups. The manipulation followed the procedure of Guadagno et al. (2007): Participants in the agent condition read instructions, informing them that the VA was controlled by the computer. Participants in the avatar condition were lead to believe that the VA was actually a live representation of another participant (avatar). The instructions told that the aim of the study was to “analyze differences between drivers and co-drivers in tunnels. For that reason, you and another participant will take part in the study. By drawing a lot, we will decide who of you will be the driver and who will be his co-driver”.

In order to increase the effect of the manipulation, a live video of the participant via webcam and a pre-recorded video of a confederate representing a person controlling the VA were shown to the participants prior to the experiment (Figure 10). Live- and pre-recorded video were shown both in a window on a screen in front of the experimental mock-up and also on the HMD screen during the whole experimental preparation procedure (reading instructions, explanation of the simulator)[4].

Figure 10 Screenshot of the video that was used in the avatar condition. The video shows a confederate acting as the driver.

2.3.2.4 Dependent Variables

Guadagno et al. (2007) adapted a series of items measuring perceived social presence and behavioral realism of VAs (Swinth & Blascovich, 2001). For the purpose of this study, these items were translated into German and used as control variables (Table 6). Frequency and latency of leaving the vehicle were used as behavioral measures. Frequency refers to the total number of participants leaving the vehicle in the emergency situation. Latency refers to the delay from the point when the vehicle stops in front of the accident scenario until the participant uses the door-handle to leave the car.

[4] Anecdotal note of successful manipulation: By chance one participant met the confederate (who wore the same clothes as in the video) outside of the institute and asked him what he did in the emergency situation. This is particularly interesting since all participants were debriefed after the experiment and told that the video they had seen had been pre-recorded.

Table 6 Items measuring social presence and behavioral realism in study 3.

Items measuring social presence	Items measuring behavioral realism
I felt like the other person could see me.	The virtual person acted like a real person.
I felt like the other person was watching what I did.	The virtual person moved like a real person.
I felt like the other person knew I was there.	I felt that the movement of the virtual person was controlled by a real person.
I felt like the other person was looking at me.	I felt like I was interacting with a real person.

Note: All items were rated on a five point Likert Scale ranging from *strongly disagree* to *strongly agree*.

2.3.2.5 Procedure

After giving their informed consent (Appendix C), participants completed the questionnaires mentioned above (STAI, TAQ). A written instruction then explained that the participants' task during the experiment was to drive several times together with another participant through a virtual road tunnel either as a driver or a co-driver (see Experimental Condition). After that, participants were seated in front of the car mock-up and put on the HMD. On the HMD screen they saw the video showing the confederate (see Experimental Condition). Then participants were told that they had been randomly assigned to the co-driver condition and practiced the handling of the co-driver's door. Subsequently, the tunnel drives were started. In both conditions, a VA (middle aged male, Figure 12) was seated in the driver's position. The presence of the VA was made clear during the drives through sounds (coughing, clearing his throat) and movement (moving the upper part of his body). In the first drive, a safe/neutral situation was simulated (traffic jam, see Study 1). In the second drive an emergency situation was realized. An emergency situation was implemented in the second drive. At first, there was no visible difference between the two drives. However, after two minutes of driving in the tunnel, a truck blocked both lanes (emergency situation). One minute after stopping the vehicle, smoke started expanding from the truck. After two minutes, the participant's vehicle was completely surrounded by smoke. The trial ended either when participants opened the door of their vehicle (participants were not asked to physically leave the mock-up vehicle) or if they did not open the door after four minutes had elapsed after the vehicle stopped. During the emergency situation the VA shrugged and said, while pointing at the accident: “What is happening here?” Twenty seconds later the VA unfastened his seatbelt, opened his door (this was accompanied by sounds and animations) and left the vehicle (Figure 12). The trial stopped either if the participant opened the door in the emergency situation or automatically four minutes after the vehicle had stopped.

2.3.3 Results

2.3.3.1 Manipulation Check

In order to assess perceived behavioral realism and social presence, sum-scores of the items by Guadagno et al. (2007) were calculated, resulting in two scales. Each scale ranged from 4 to 20 (four items with a 5 point on a Likert scale). There were no significant differences between the groups (Table 5). Group comparisons for each individual item also revealed no significant differences.

2.3.3.2 Behavioral Data

In total 17 participants opened the door in the emergency situation. Nine of them had been assigned to the Agent condition, and eight to the Avatar condition. There were no significant differences between the experimental groups, X^2 (1) = 0.31, p = .57. The co-driver’s door was opened on average 32.91 seconds (SD = 8.42) after the pre-recorded path had ended and the vehicle had stopped in front of the accident. Those participants in the Avatar condition who opened their door, did so about ten seconds before those in the Agent condition, t (15) = 2.42, p < .05. None of the participants left the vehicle before the VA.

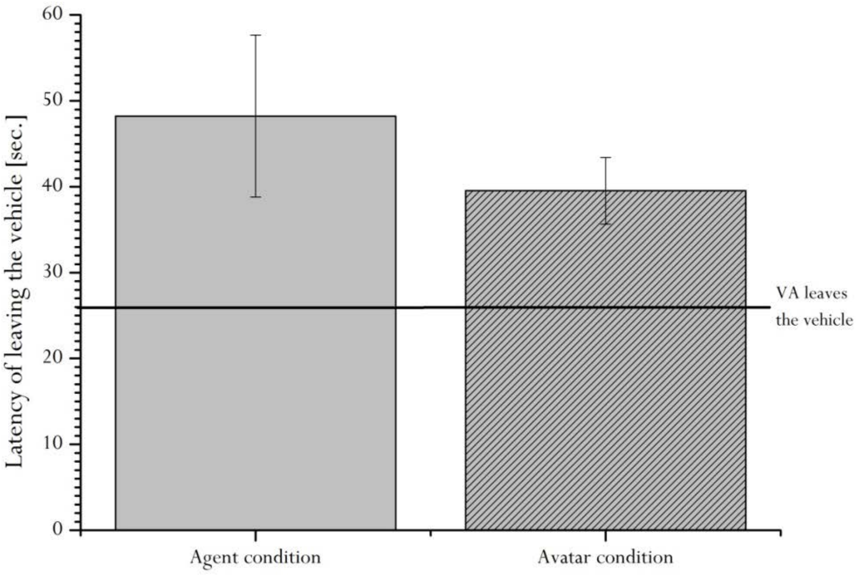

Figure 11 Latencies of leaving the vehicle in study 3. All participants leave after the VA.

2.3.4 Discussion

Study 3 sought to identify the possible effect of perceived agency in a SI paradigm. Based on Blascovich's (2002) *Threshold Model of SI* and the first experimental paradigm on perceived agency by Guadagno et al. (2007), a behavioral test of perceived agency was developed. Participants experienced an emergency situation in a road tunnel as a co-driver and were randomly assigned to one of two experimental conditions. In the Avatar condition participants were convinced that the VA driving the vehicle was actually an avatar controlled by another participant. In the Agent condition participants were told that the driver was a computer generated VA. The question was if these differences in perceived agency had an effect on a behavioral level, and it was hypothesized that the influence of the VA on participants' behavior was stronger in the avatar condition than in the agent condition.

The most important finding of study 3 is that participants in the two experimental groups reacted differently to the same scenario. Both groups opened the door of their vehicle after the VA did so. However, participants in the Avatar condition who actually left the vehicle during the emergency situation did so significantly faster compared to the ones in the VA condition. That is, perceived agency may have direct influence on behavior in the VR setting. So far, these findings are in line with the work of Guadagno et al. (2007) and support the *Threshold model of SI*.

However, unlike in Guadagno et al.'s study there were no differences between the groups regarding neither self-reported social presence nor behavioral realism of the VA. A possible explanation might be the general properties of the VAs used in the two studies. Whereas in Guadagno et al.'s paradigm participants watched the VA giving a speech and were focusing their attention on the VA throughout the whole session, the VA in the present study was not necessarily in the center of the participant's attention. Although its presence was made constantly aware (by sound and movement) it is likely that especially during the emergency situation participants focused more on the accident and smoke. This might also explain the qualitative differences in the ratings of behavioral realism: These ratings were descriptively higher (although still only mediocre) in study 3 than in Guadagno et al.'s study, where these were far below the midpoint of the scale.

Since the primary aim of the present dissertation project is to investigate mutual influence in dangerous situations using VR simulation studies, this is an important methodological aspect. Although the results of study 3 did not replicate the findings of Guadagno et al. (2007), its findings indicate that the manipulation of perceived agency had an influence on social behavior in virtual environment. This study was the first to my knowledge, documenting this effect on a behavioral level. Further studies using VAs aiming to investigate social interactions or SI should always consider to implement similar manipulation to the one used in this study. On a more general level, prior VR studies using VAs may have systematically underestimated the effect of SI. Consequently, study 4 of the present dissertation project used the identical method to manipulate perceived agency.

Some specific limitations of study 3 need to be discussed. First, it is possible that the behavioral differences found here are not necessarily results of differences in perceived agency. Future studies need to consider an improved manipulation check, for example by directly asking the participants how strongly they were convinced by the manipulation. Second, since the number of participants who actually left the vehicle was quite low, the statistical power of the latency comparisons was relatively weak. However, despite of the small sample size the effect still reached statistical significance. Further studies clearly need to use sufficiently and equally sized samples. A discussion of more general limitation (e.g.

uncanny valley effect, validity of simulated accidents) can be found in the general discussion of the thesis.

2.4 Study 4: Social Influence from the Front Seat – Influence of Passive (Co-) Drivers on Self-evacuation in Tunnel Emergencies

2.4.1 Introduction

The fourth study extends study 1 and 2 by investigating possible SI within the vehicle. Whereas the first two studies looked at the effect of passive VAs in other vehicles and found only weak indicators of SI, study 4 analyzed the mutual influence of co-drivers and drivers. This scenario is important, since drivers are often not alone in their cars and the behavior of passengers might influence the pre-evacuation behavior of the driver and vice versa. Studies on mutual influence of drivers and passengers show that passengers' behavior substantially influences driving safety and accident rates (Doherty, Andrey, & MacGregor, 1998; Ulleberg, 2004). For example, accident risk of adolescent drivers increases significantly when passengers of the same age-group are also in the car (Williams & Wells, 1995). However, in other age groups this effect diminishes (Preusser, Ferguson, & Williams, 1998). It seems likely that drivers and passengers also influence each other in dangerous situation, especially when it comes to deciding whether to leave the vehicle and evacuate or not. The close distance between driver and passengers might increase the effects of SI. For example, during an evacuation study in a cinema, some participants actively stopped others sitting in seats next to them from evacuating during a fire alarm drill (Nilsson & Johansson, 2009). However, whereas members in a cinema audience are most likely passive observers, the tasks and occupations of drivers and co-drivers vary. One may speculate that drivers behave more proactively than co-drivers in general since steering a car requires staying alert and focusing on the events outside of the car. Furthermore, it seems possible that drivers perceive higher responsibility for the safety. That is, we expect that SI of drivers on co-drivers to be stronger than vice-versa. In turn, co-drivers might pay less attention about events outside the car, as they were not relevant for them. Thus, the purpose of study 4 was to investigate how driver and co-driver influence each other's behavior during an emergency situation in a road tunnel.

Similar to the previous studies, the research question was addressed by having participants conduct two drives through a virtual road tunnel with the following situations: a safe situation (traffic jam) and an emergency situation (tunnel blocked by trucks with smoke rising from the accident). The virtual tunnel and the scenarios were the same as in study 1, however, in this study participants experienced the emergency situation either as a driver or as a co-driver. In contrast to study 1 there were no VAs present outside the vehicle. Inside the car, a driver or a co-driver VA was present (depending on the experimental condition). The VA stayed passive during the experiment most of the time until he opened his door and left the vehicle during the emergency situation.

2.4.2 Method and Apparatus

2.4.2.1 Apparatus

See study 1 for a description of the driving simulator and the simulation software. Since the results of study 3 indicated that the effect of SI is stronger if participants believe that the VA is controlled by another participants, all participants saw the video and read the same instructions describing the VA as an avatar of another participant (see 2.3.2 Method and Apparatus for a description of the video and instructions).

2.4.2.2 Sample

Thirty-four participants (age: *M* = 23.41 years, *SD* = 3.09 years; 17 female participants) took part in the study and were randomly assigned to either the driver or co-driver condition (each *n* = 17). There were no significant differences between drivers and co-drivers regarding questionnaire and sociodemographic data (Table 7).

2.4.2.3 Experimental Design

Study 4 was based on study 1, and the same basic emergency situation was implemented. Participants were driving through a virtual road tunnel and then confronted with an accident and oncoming smoke in the middle of the tunnel. One group of participants experienced the accident as drivers and a second group as co-drivers. A VA was seated either as a driver or co-driver next to the participants (Figure 12). Study 1 showed that participants varied strongly in how far away they stopped from the emergency situation. This might influence the perception of the scenario. A yoke design was used in study 4 in order to reduce the variance in this variable between the groups: Participants were grouped in pairs (matched for gender), and one participant of each pair was then randomly assigned to the driver condition and the other to the co-driver condition. The emergency drive of each driver was recorded and played back to the co-drivers. That is, the driving behavior as well as the distance in which the vehicle stopped from the accident did not vary between the two experimental groups.

Table 7 Descriptive Statistics and Questionnaire data of the study 4.

	Driver		Co-driver			
	M	*SD*	*M*	*SD*	*t*	*p*
STAI trait	37.12	8.43	36.71	9.07	0.11	.91
STAI state	34.71	6.05	34.29	5.54	0.14	.89
TAQ (driver)	5.35	4.03	4.41	3.50	0.21	.84
TAQ (co-driver)	5.19	5.05	4.12	3.53	0.73	.47
IPQ	0.24	13.17	-0.71	13.27	0.71	.48
SSQ	7.00	6.96	4.29	3.12	0.21	.84

Note: each n = 17; all df = 32; STAI = State-Trait Anxiety Inventory; TAQ = Tunnel Anxiety Questionnaire; SSQ = Simulator Sickness Questionnaire, IPQ = iGroup Presence Questionnaire; sum scores were calculated for each questionnaire.

2.4.2.4 Dependent Variables

Similar to studies 1-3, frequencies and latencies of relevant of participants leaving the vehicle were assessed and analyzed.

2.4.2.5 Control Variables

After the experiment a number self-reported questions concerning the perception of the emergency situation and the VA were assessed. For this purpose three items, each with five point Likert Scales were constructed. Participants answered the following questions about the VA: *Did you pay attention to the behavior of the driver/ co-driver? Did the behavior of the VA affect you?* (*Not at all* to *Very strongly*). Furthermore, the following questions regarding the perception of the emergency situation were asked: *How dangerous was the situation, when the truck blocked the road? How dangerous was the situation, when the smoke moved towards you?* (*Not dangerous at all* to *Very dangerous*).

2.4.2.6 Procedure

After giving their informed consent, participants completed the questionnaires mentioned above (Appendix C). A written instruction then explained that the participants' task during the experiment was to complete several drives through a virtual road tunnel on a highway and that they should drive according to traffic rules for German highways. After that, participants were seated in front of the car mock-up and put on the HMD. On the HMD screen they saw the video showing the confederate (Figure 10). Then participants in the driver condition had to train using all mock-up elements until they could easily handle them even with closed eyes. In the co-driver condition, only the handling of the co-driver's door was practiced. After that they completed a test drive in which the handling of the virtual car and the verbal anxiety ratings were practiced. During the test drive the experimenter required the participants again to test all elements of the mock-up. The experiment consisted of two drives through the tunnel. Each drive started outside the tunnel, and after about 50 seconds of driving on an open road, participants entered the tunnel.

Similar to the previous studies the first of the two drives included a traffic jam scenario (See procedure of study 1 for a detailed description of the traffic jam scenario). Here, participants were either driver or co-driver. In the second drive the same emergency situation as in the study 3 was realized in the virtual road tunnel. Participants in the driver group drove the vehicle themselves, and participants in the co-driver were seated on the passenger seat and the recorded path of their yoke partner was played back to them. In both conditions, a VA (middle aged male) was seated either in the driver (if the participant was co-driver) or the co-drivers (if the participant was driver) position. The presence of the VA was made clear during the drives through sounds (coughing, clearing his throat) and movements of the VA (moving the upper part of his body).

An emergency situation was presented in the second drive. At first, there was no visible difference from the first drive. However, after two minutes of driving in the tunnel, a truck blocked both lanes (emergency situation). One minute after stopping the vehicle, smoke started expanding from the truck. After two minutes, the participant's vehicle was completely surrounded by smoke. The trial ended either when participants opened the door of their vehicle (participants were not asked to physically leave the mock-up vehicle) or four minutes after stopping the vehicle. During the emergency situation the VA shrugged after the vehicle had stopped and said while pointing at the accident: “What is happening here?” Twenty seconds later the VA unfastened his seatbelt, opened his door (sounds and animations), and left the vehicle (Figure 12).

a)  b) 

Figure 12 Screenshots of the VA in the two experimental conditions: VA is driver (a) or co-driver shrugging in front of the emergency situation (b). The driver and the co-driver VA showed exactly the same behavior during the emergency situation.

2.4.3 Results

2.4.3.1 Control Variables

Responses to the questions concerning the perceived threat of the emergency situation and the perception of the VA are depicted . On average, drivers and co-drivers rated the emergency situation as very dangerous. There were no significant differences between the two groups concerning this judgment. Self-reported perception of the VA, however, differed between the groups. Co-drivers reported that they paid more attention to the VA and felt influenced by its behavior marginally significantly stronger than the drivers Table 8.

Table 8 Responses to control variables.

	Driver		Co-driver			
	M	*SD*	*M*	*SD*	*T*	*p*
Did you pay attention to the behavior of the driver/ co-driver?[1]	2.06	1.14	2.71	0.98	-1.77	.08
Did the behavior of the VA affect you?[1]	1.35	0.61	2.06	1.30	-2.03	.05
How dangerous was the situation, when the truck blocked the road?[2]	4.23	0.83	4.18	0.88	0.20	.84
How dangerous was the situation, when the smoke moved towards you?[2]	4.71	0.47	4.82	0.39	-0.79	.43

Note: each n = 17; all df = 32; Responses to questions were each on a five point Likert Scale [1-5]; [1] Likert Scale: *not at all* to *very strongly*; [2] Likert Scale: *not dangerous at all* to *very dangerous.*

2.4.3.2 Frequencies of Leaving the Vehicle

In total 11 participants (35.48%; seven participants in the driver and four in the co-driver condition) left the vehicle during the emergency situation (Figure 13). Although more drivers than co-drivers left the vehicle, these differences between the experimental groups were statistically not significant, X^2 (1) = 1.21, p = .27).

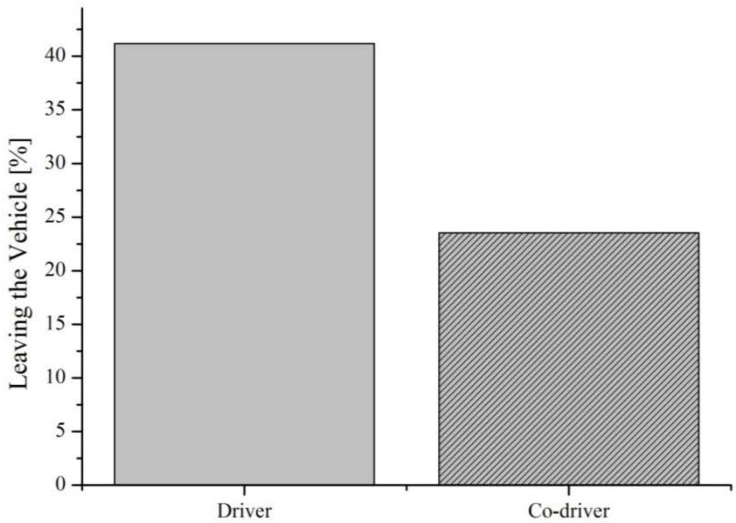

Figure 13 Percentage of participants leaving the vehicle during the emergency situation in the experimental groups.

2.4.3.3 Latencies of Leaving the Vehicle

The latencies of leaving the vehicle are depicted in Figure 14. Drivers (*M* = 29.95 seconds, *SD* = 12.48 after the vehicle had stopped) left the vehicle significantly earlier than co-drivers (*M* = 51.46 seconds, *SD* = 10.79), t (9) = -2.87, $p < .05$. Most participants left after the VA had opened his door. Four participants – all of them were drivers – left the vehicle before the VA.

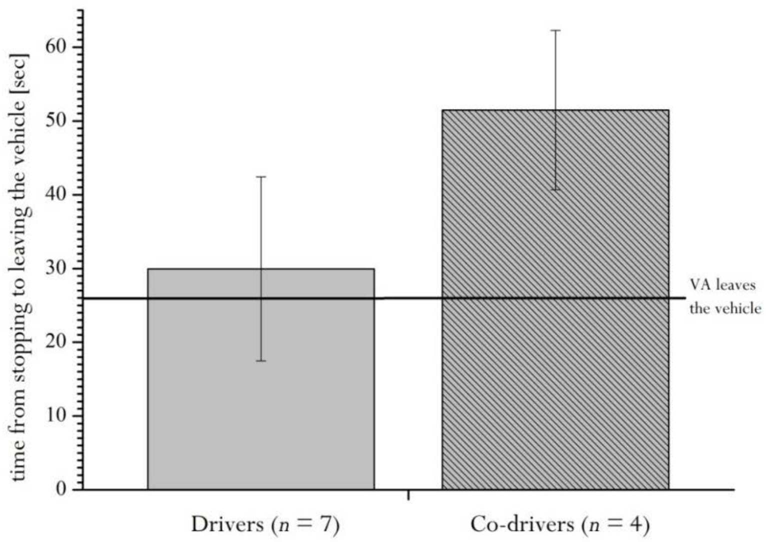

Figure 14 Latencies of leaving the vehicle of drivers and co-drivers.

2.4.4 Discussion

This study examined SI inside the vehicle. Specifically, differential effects of passive drivers and co-drivers on behavior during an accident in a virtual road tunnel were studied. Participants were confronted with a simulated emergency situation in a road tunnel together with a VA. The VA who was in the car with the participants, stayed mostly inactive during the situation but started to evacuate about half a minute after the vehicle had stopped. Similar to study 1, about one third of the sample left the vehicle during the situation. There were no differences between drivers and co-drivers regarding the frequency of leaving the vehicle. These findings underline once more one of the core problems during dangerous situations such as tunnels fires: The majority of tunnel users might not start to evacuate early enough to reach emergency exits.

Furthermore, co-drivers waited more than 20 seconds longer than drivers, who stayed in the vehicle for about half a minute after the vehicle had stopped. During fire breakouts in tunnels, immediate self-evacuation is extremely important since smoke and fire move rapidly, making orientation and evacuation more difficult and dangerous. Interestingly, most participants only started to evacuate after the VA had already left. However, it seems possible that the VA triggered the evacuation process only in drivers. This seems even more likely, since co-drivers similar to uninformed participants in study 1 left the vehicle after around 50 seconds. This would indicate that SI within the driver’s cabin is mainly exerted from the co-driver’s seat.

One may speculate that drivers behave more proactively than co-drivers in general, as they have been more active during the whole drive. Throughout the whole experimental drives, they experienced that their actions had an immediate effect (e.g. the speed of the car). In contrast, co-drivers had no possibilities to influence the course of the drive. Furthermore, safely steering a car requires staying alert, vigilant, and focusing on the events outside of the car. In turn, co-drivers might pay less attention about events outside the car, as they were not relevant for them. That is, the effect of SI might be indirect in this case: Drivers may have been more alert in general and earlier aware of the danger in the emergency situation. The VA might have served as a source of information for the drivers (informational SI), leading to quicker decisions whether to leave the vehicle or not in drivers. Another possible explanation might be that different stereotypes were activated for drivers and co-drivers. Indeed, theoretical frame-works on drivers’ behavior include safety motivation as stereotypes for drivers (e.g. Van Der Molen & Bötticher, 1988). That is, being a driver and being confronted with an emergency situation could more easily trigger safety behavior through priming active behavioral stereotypes. In contrast, co-drivers stereotypes might be less active. However, to our knowledge there are no studies that explicitly compare behavioral stereotypes as well as safety motivation in drivers and co-drivers.

Interestingly, co-drivers reported that they paid more attention and felt influenced more strongly by the VA than drivers. This could explain why none of the co-drivers left the vehicle before the VA but some of the drivers did. However, this could also offer an alternative explanation to the differences in latencies for leaving the car: Having fewer possibilities to act, co-drivers could have experience lesser subjective control during the emergency situation. This might have increased the perceived dominance of the VA during the accident and thus increased the effect of SI of the driver VA.

This study overcame some of the limitations of study 1 and 2. First, the possible effect of SI of drivers on co-drivers and vice-versa was investigated. Second, the VA showed active behavior and left the vehicle. In study 2, all VAs had stayed passive. Third, using a yoke design, the variance in the distance between the participants' stopping positions and the accident was eliminated between the two experimental groups. Fourth, the video manipulation developed in study 3 was used. However, the realism of the driving simulator was still limited. First, turning the vehicle was again not possible in this study (see also 2.2.4 for a discussion of the limitations of the simulator). Second, in a real world scenario it would be very likely that driver and co-driver know each other. In the present study the VA represented a person unknown to the participants. One may speculate that the influence of a familiar person is stronger or at least different than the one of a stranger. Third, there were no real possibilities for the participants to interact with the VA. In a real world scenario, one might expect that especially in an emergency situation driver and co-driver would start interacting. However, the possibility for the participants to interact flexibly with the VA was not realized in the present study in order to keep experimental conditions the same for all participants.

In summary, this study showed that drivers and co-drivers react differently to an emergency situation in a road tunnel. Drivers are more active and begin to evacuate faster. Furthermore, co-drivers report more frequently that they were influenced by the VA than the co-drivers. However, it remains unclear whether these group differences in safety behavior are a direct effect of SI, since overall increased physical activity and perceived control in the driver group are also possible explanations. Future studies should address these differences between drivers and co-drivers and the underlying processes in more detail.

Study 2 and 4, as well as the associated pilot studies (study 1 and 3) analyzed SI during the pre-movement phase of the evacuation from an emergency in a simulated tunnel fire. The important question was how does SI effect the decision to start evacuating? Study 5 will examine SI during actual evacuation process (pre-movement, movement phase), after the decision to start to evacuate has been made.

2.5 Study 5: Social Influence in a Virtual Tunnel Fire – Influence of Conflicting Information on Flight Behavior

2.5.1 Introduction

Quick self-evacuation during tunnel-fires is very important, since tunnel-fires can spread very rapidly (Beard & Carvel, 2005). This requires adequate decision-making under time pressure from tunnel users. Interestingly, many users are aware of safety devices in tunnels, the intention to use those seems not to be internalized (Gandit, Kouabenan, & Caroly, 2009). This might be due to the fact that fire in a road tunnel is not part of the daily routine for most people. Consequently, behavioral scripts and routines for emergency situations are not available. Hence, tunnel users have to rely on their appraisal of the environment and their own resources (e.g. general knowledge about evacuation). In a recent evacuation study many users realized the threat during tunnel accidents, but did not know how to evacuate properly (Nilsson, Johansson, & Frantzich, 2009). Furthermore, study 2 showed that although tunnel users might perceive oncoming smoke as dangerous, many of them might still stay passive. In such situations, users have to rely on few and accessible information. In these cases, there is a tendency not to use the closest emergency exit but to move back towards the tunnel entrance portal (Sime, 1985). However, returning the same way one entered a tunnel may take too long or not be possible (Proulx & Sime, 1991). This is not self-evident, since road tunnels are very simply designed environments in which emergency exits as well as signage are clearly visible and thus, finding an emergency exit is supposed to be very easy (Beard & Carvel, 2005). But why do tunnel users have such problems to evacuate adequately? Unfortunately, tunnel accidents or fires are complex situations. Information processing and choosing the right evacuation strategies may be limited by ambiguous or conflicting information, since the physical environment (e.g., flames or smoke coming from different directions, covering emergency exits or signage) may become very difficult to interpret. In such unclear situations the behavior of other tunnel users may be considered as a useful source of information. As this might be the case for most people in the situation, diffusion of responsibility may lead to delayed or inadequate evacuation. This was demonstrated in a classic experimental study which showed that passive behavior of others may thwart immediate evacuation (Latane & Darley, 1968). A recent study on social influence (SI) also demonstrated that SI becomes more important if information is limited or ambiguous (Nilsson & Johansson, 2009).

However, experimental studies on this topic are still scarce, and it is unclear how exactly SI affects flight behavior.

Studies 2 and 4 of the present dissertation focused on if and how SI delayed the pre-evacuation phase, i.e. why some tunnel users do not start evacuating during a fire, although their life is in immediate danger. But what happens after tunnel users in tunnel fire realize there might be a threat, decide to evacuate, and leave their vehicle? Will emergency exits be adequately used, and what is the effect of SI during this stage of evacuation? The purpose of the present study was to investigate flight behavior after tunnel users had already left their vehicle. Specifically, the influence of conflicting informational cues from the environment (safety installations, other tunnel users) on participants' behavior during the pre-movement and movement phase of the evacuation process was investigated. The research question was addressed in a VR study. Participants were repeatedly situated in different scenarios in a road tunnel filled with smoke. During the study the presence and behavior of an animated VA was systematically varied in order to investigate SI on participants' reactions in the scenario.

The following hypotheses were tested in the present study: (A) In general tunnel users comply with emergency signage and thus, participants move towards the emergency exit more frequently than in other directions. Furthermore, the VA exerts SI. Therefore, (B) if the VA also goes to the emergency exit, participants are more likely to do so, compared to conditions with no VA present. In turn, (C) participants are less likely to go to the emergency exit, if a VA moves in the opposite direction of the emergency exit than in conditions with no VA. SI affects not only the qualitative choice of evacuation in the scenarios, but also the certainty and speed with which these choices are made. We expect that this is reflected in the time participants need for making the decision where to move and also the actual movement itself. Specifically, we anticipate that a passive VA prolongs (D) participants' pre-movement time and also (E) the movement time.

2.5.2 Method and Apparatus

2.5.2.1 Sample

Forty participants (mean age: *M* = 21.13 years, *SD* = 2.38; mean driving experience in years: *M* = 4.13, *SD* = 3.01; 21 female participants; Table 9), were recruited at a German university and randomly assigned into two experimental groups (each *n* = 20; see section Experimental Design). Since anxiety and fear may possibly influence evacuation behavior state and trait anxiety (STAI) and tunnel anxiety (TAQ) were controlled (Laux et al., 1981; Mühlberger & Pauli, 2000; Spielberger et al., 1970). In addition presence and simulator sickness were assessed after the experiment using the IPQ and the SSQ (Kennedy et al., 1993; Schubert, 2003). There were no significant differences between the groups, neither in sociodemographic nor in questionnaire data. Participants mainly were psychology students who received credit points for their participation.

Table 9 Summary of sociodemographic and questionnaire data of the sample in study 3.

	M	SD
Age (years)	21.13	2.38
Mean Driving experience (years)	4.13	3.01
TAQ (driver) sum scores	14.28	3.48
TAQ (co-driver) sum scores	12.43	3.54
STAI state prior	34.33	9.74
STAI state after	43.10	10.10
STAI trait	37.42	9.74
SSQ sum score	10.10	6.44
IPQ sum score	3.37	11.84

Note: (N = 40, 19 male, 21 female participants). There were no significant age differences beween trial-order A (n = 20, M = 21.45, SD = 2.95) and trial-order B (n = 20, M = 20.80, SD = 1.64), t (38) = 0.86, p = .39.

2.5.2.2 Apparatus

The study was conducted in VR laboratory at the Department of Psychology I of the University of Würzburg. The laboratory was sized 36m² with a 325*200cm Powerwall (3Dims Gmbh, Frankfurt, Germany). The VR scenes were presented stereoscopically by two beamers (projectiondesign F32, resolution: WUXGA, 1920x1200; projectiondesign as, Gamle Fredrikstad, Norway). Participants wore passive circularly polarized glasses for 3D effects (Figure 15).

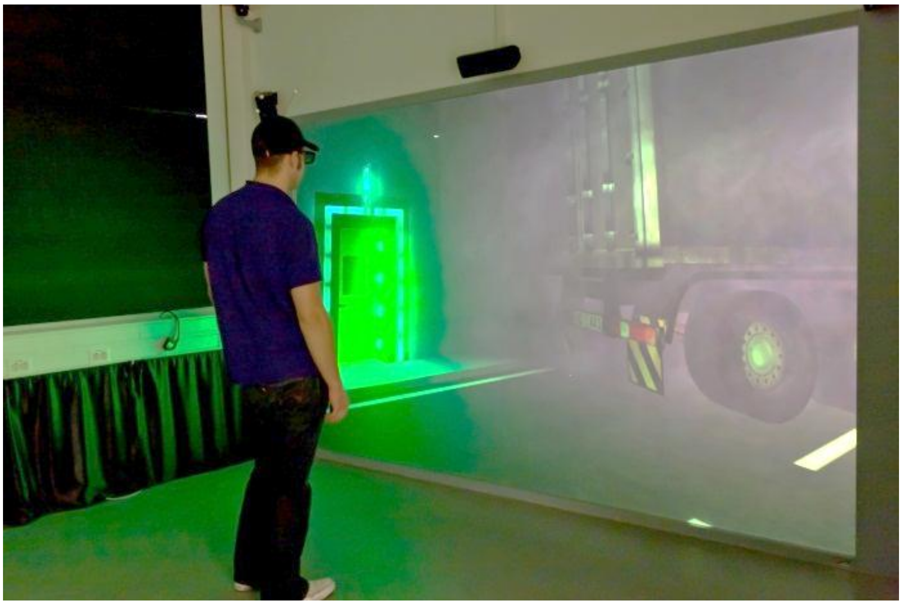

Figure 15 Participant standing in front of the Powerwall screen.

The virtual scenes are based on a modification of the first-person game Half-Life 2 and used the Source Engine (Valve, Bellevue, Washington, USA). Experimental control was established using an in-house written software (CyberSession; see www.cybersession.info for detailed information). The participants stood two meters away from the Powerwall. Navigation within the simulation was implemented using a standard gamepad: Participants could move with walking-speed and interact with the virtual environment by pressing a button on the gamepad (Logitech Rumblepad; Logitech, Morges, Switzerland).

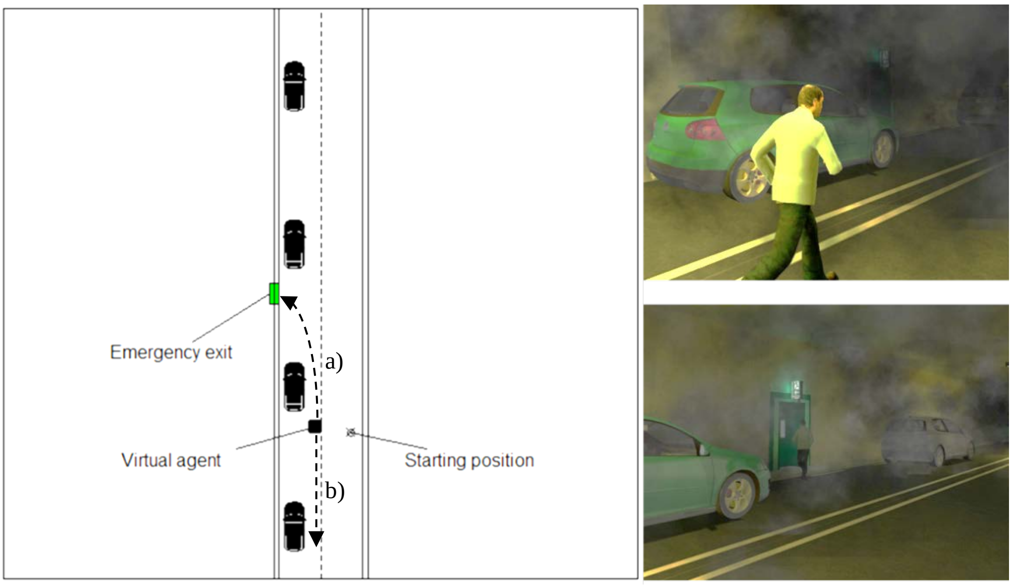

Figure 16 Experimental setup and screenshots from the simulated tunnel emergency. At the beginning of every trial participants were situated at the starting-position. In total eight tunnel scenes were realized. The emergency exit was either to the left or to the right of the starting-position. The dotted lines indicate the movement paths of the VA in the conflict (a) and the no conflict (b) condition.

2.5.2.3 Experimental Design

The experiment used a 4x2x2 mixed design. The independent variables were experimental condition (four levels within subjects), trial-order (two levels, between subjects), and the location relative to the starting-position in the virtual tunnel (two levels, within subjects). In total eight different tunnel trials were created.

In each trial participants were standing in a virtual road tunnel filled with smoke (dimensions: ca. 32*8 meters; Figure 16). The starting-position was outside of a vehicle and participants looked at the opposite wall of the tunnel. On one side of the participants' starting-position an emergency exit was visible through the smoke. The exit became visible from the starting-position if participants looked around. On the tunnel wall directly in front of the starting-position a sign indicated the direction of the emergency exit. Four cars were positioned on the lane next to the emergency exit. See Figure 16 for a schematic overview of the experimental setup.

2.5.2.4 Experimental Conditions

The four experimental conditions systematically varied the presence and behavior of an animated VA. The VA represented a middle aged man. In the first condition, no VA was present (*control condition*). In the second condition, participants received conflicting information about adequate behavior: An animated VA stood in front of the participants' starting-position and after a delay of 1.5 seconds walked approximately 2 meters towards the participants and then ran in the opposite direction of the emergency exit (*conflict condition*). In the third condition, the VA ran to the emergency exit and consequently no conflicting information about adequate flight behavior was displayed (*no-conflict condition*). In the fourth condition, the VA stayed passive and stood still during the whole trial (*passive condition*).

Trial-order and the location of the emergency exit served as control variables: In order to prevent effects of the trial-order, participants were randomly assigned to one of two trial-orders (trial-order A and B). In later analysis the two conditions were tested for differences in all dependent variables. Each condition was presented once from a starting-position left and once right of the emergency exit to balance out any effects of participants' preferences.

The main dependent variables were the participants' behavioral reactions in each trial. Frequencies of specific behavioral responses were coded into distinct categories. The time relative to the trial start for each behavior type was analyzed, specifically, the absolute *trial-duration*, the time participants needed to reach their goal in a trial (*walking-time*), and the time participants waited until they started to walk in a trial (*pre-movement time*). Furthermore, movement-paths were plotted for each participant.

2.5.2.5 Procedure

After the participants arrived at the laboratory, they read a text in which they were informed that they would take part in an experiment about tunnel safety and signed an informed consent (Appendix D). Prior to the actual experiment participants filled in questionnaires (STAI-state and trait; TAQ). Subsequently, participants were led in front of the screen of the Powerwall, put on glasses for 3D presentation and a training map was loaded. The first scene of the training map was a virtual extension of the laboratory. By walking "through" the screen with the gamepad participants were teleported into to the training map. The training map consisted of a maze and participants were instructed to find the exit. Next to the end of the maze a vehicle was situated and the participants were asked to enter it by pressing a button on the gamepad and the training ended. If the participants were sufficiently familiar with the navigation device, the experimenter loaded a camera drive through the virtual tunnel. In this camera drive the virtual tunnel was presented. The participants were told that they are in a long road tunnel filled with smoke, they had left their vehicle and smoke was moving through the tunnel. Finally the participants found themselves again in the first scene (virtual extension of the laboratory). By walking "through" the screen with the gamepad, participants started the experiment and the eight trials were presented. After each trial the screen faded to black and after an interval of seven seconds the next trial was loaded. A trial ended if the participant either went to the emergency exit, opened the door of a vehicle, walked past the vehicles in the tunnel, or automatically after two minutes. After the experiment the participants filled in questionnaires (STAI-state; SSQ; IPQ). Prior to leaving, participants were debriefed, thanked, and received credits.

2.5.3 Results

2.5.3.1 Frequencies of Going to the Emergency Exit

In order to analyze whether trial-order had an influence on the frequencies of the different behavioral responses, binary logistic regression models were computed. Each model predicts the group membership from the three possible outcome variables (moves to the right, left, emergency exit). Bonferroni correction for multiple testing was used and the alpha-level was adjusted: $\alpha_{adj} = \alpha/8 = 0.05/8 = 0.00625$. The trial-order could not be predicted by the frequencies of behavioral outcome variables in any of the eight scenarios (Appendix F). Therefore, trial-order was not considered in any further analysis.

In total, four different experimental conditions were compared. Each condition was presented once with the emergency exit to the right and once to the left of the participant in order to counterbalance preferences for a specific movement direction. In the following analysis the locations of the emergency exit were combined (Figure 17). Descriptive statistics showed that participants were less likely to go the emergency exit if the VA remained passive or moved away from it. A block-wise binomial logistic regression model was computed to analyze whether the experimental condition and the location of the emergency exit predicted the choice of walking direction, although logistic regression implies a causal connection of dependent and independent variables and requires independent errors (which is violated in a repeated measures design). Behavioral responses were dichotomized into two categories (participants who went to the emergency exit; 229 observed cases vs. those who went in another direction; 91 observed cases). Exit-location did not significantly improve the model in the first block, χ^2 (1) = 0.02, p = .90. Experimental condition significantly improved the model in the second block, χ^2 (3) = 14.09, $p < .01$, indicating that the model could distinguish between participants who went to the emergency exit and those who did not. The odds ratios for participants to go to the emergency exit were 1.89 in trials in which a VA went to the exit, 0.53 in those in which the VA went away from the exit, and 0.60 if a passive VA was present, compared to trials in which no VA was present. This indicates that participants were almost twice as likely to go to the emergency exit if a VA also went there, compared to conditions in which no VA was present. In contrast to that, they were almost half as likely to go the emergency exit, if the VA did not go the emergency exit, and .60 times less likely to do so, if a VA stayed passive. However, these results have to interpreted with caution, since the within subjects design leads accumulated dependent errors.

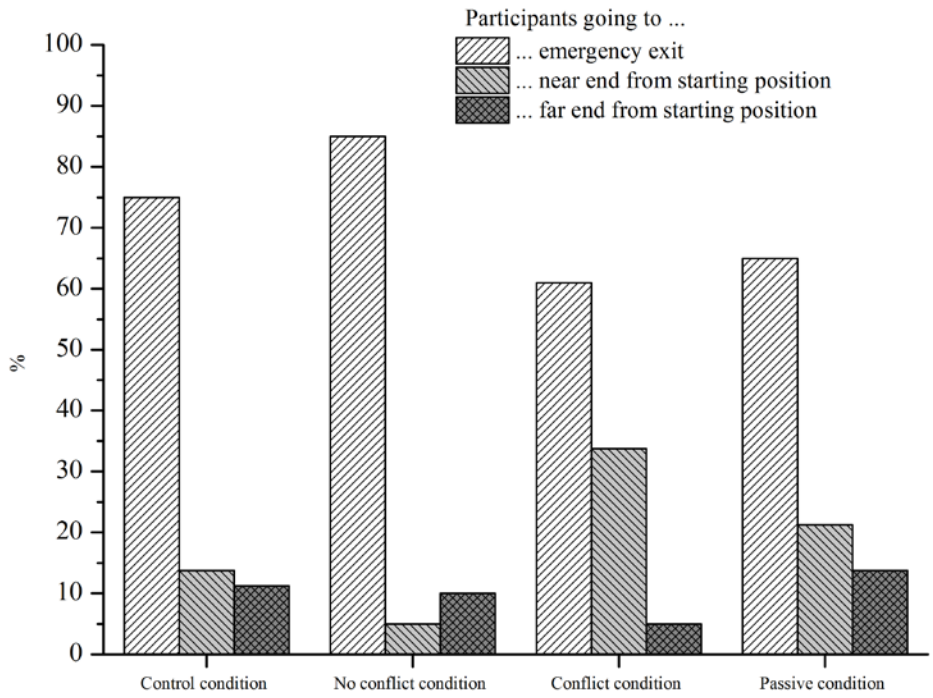

Figure 17 Observed behavioral responses in the four experimental conditions.

2.5.3.2 Pre-movement and Movement Time

In order to assess if the trial-order had an influence on trial-duration, time participants were walking in each trial until they reached their goal and the pre-movement time, were compared in Trial-orders A and B. With the exception of one condition (no conflict condition, emergency exit left from starting-position), trial-order had no influence on any of the variables. After Bonferroni correction for eight tests (α_{adj} = .006), the differences in tunnel 3 were only marginally significant (Appendix G). Therefore, it is possible to conclude that trial-order had no influence on trial-duration, the absolute time participants walked in each trial, and the latency from the beginning of each to trial until the participant actually started to walk. Thus, trial-order was not considered in the following analysis.

A 4x2 repeated measures ANOVA with the factors experimental condition (4, within subjects), location of emergency exit (2, within subjects) and the dependent variable *pre-movement time* was conducted. The dependent variable reflects the time the participants need from the beginning of a trial until they reached either the emergency exit or any other end of the tunnel. There was a significant main effect of experimental condition on trial duration, $F(3, 38) = 3.30$, $p < .05$, $\eta_p^2 = .08$, and a marginally significant main effect of the exit-location on trial duration, $F(1, 38) = 3.61$, $p = .06$, $\eta^2_p = .09$. There was a significant interaction between experimental condition and exit-location, $F(3, 38) = 3.59$, $p < .05$, $\eta_p^2 = .08$. Post-hoc repeated t-tests revealed marginally significant differences only between left and right starting-position relative to the emergency exit, if a passive VA was present, $t(39) = 2.55$, $p < .05$. Pre-movement time was longer, if a passive VA was present (Figure 18).

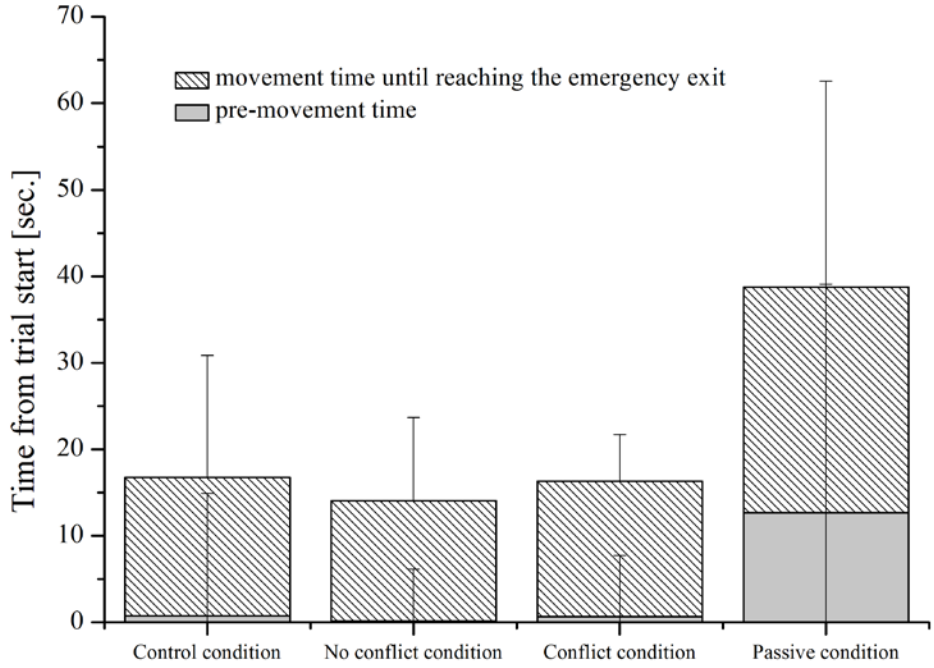

Figure 18 Pre-movement and movement time until reaching the emergency exit in the four experimental conditions; VA = virtual agent.

A 4x2 repeated measures ANOVA with the factors experimental condition (4), location of emergency exit (2) and the dependent variable *movement time* to the emergency exit was conducted. Movement time reflects the time the participants actually walk in each trial until they reached either the emergency exit or any other end of the tunnel maps. There was a significant main effect of experimental condition on trial duration, $F(3, 38) = 8.09$, $p < .01$, $\eta_p^2 = .17$, and a significant main effect of the exit-location on trial duration, $F(1, 38) = 8.15$, $p < .01$, $\eta_p^2 = .17$. If the emergency exit was on the right relative to the starting-position, participants needed longer until they reached the exit. There was no interaction effect between experimental condition and exit-location, $F(3, 38) = 2.04$, $p = .11$. Planned contrast analysis revealed significant differences between the *passive condition* and all other conditions. In this condition participants needed longer to get to their goal than in any other condition (Figure 18).

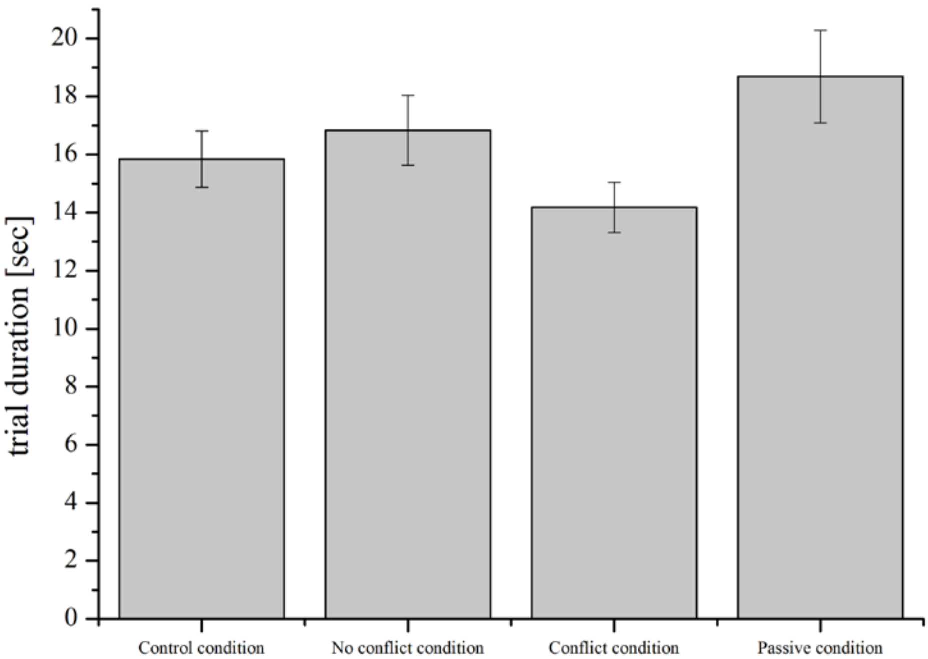

Figure 19 Mean trial duration in the four experimental conditions; VA = virtual agent.

A 4x2 repeated measures ANOVA with the factors experimental condition (4, within), location of emergency exit (2) and the dependent variable *trial duration* (seconds from start to end of a trial) was conducted. Trial duration reflects the time participants need until they reached either the emergency exit or any other end of the tunnel maps from the beginning of a trial. There was a significant main effect of experimental condition on trial duration, $F(3, 38) = 3.07$, $p = .03$, $\eta_p^2 = .07$, but no significant main effect of the exit-location on trial duration, $F(1, 38) = 1.04$, $p = .31$. There was no interaction effect between experimental condition and exit-location, $F(3, 38) = 1.03$, $p = .38$. Post-hoc tests, however, revealed significant differences between the conditions *passive condition* and *conflict condition*, $F(1, 39) = 8.89$, $p < .01$.

2.5.3.3 Movement-paths

For each participant movement-paths[5] were plotted for each of the eight tunnels (Figure 20). Visual analysis of the movement-paths confirmed that most participants went to the emergency exit. However, it became clear that participants chose different paths to get there. Most participants walked more or less directly to the exit. Only few crossed the street and then walked alongside the tunnel wall on the sidewalk. This effect is stronger in the two tunnel maps in the *control condition*. In the two maps in which the VA moved away from the exit, the movement paths become more scattered. If the VA stayed passive, most participants walked to the position of the VA before moving on.

[5] Coordinates and time were extracted from the raw data using a script written with R 2.14.

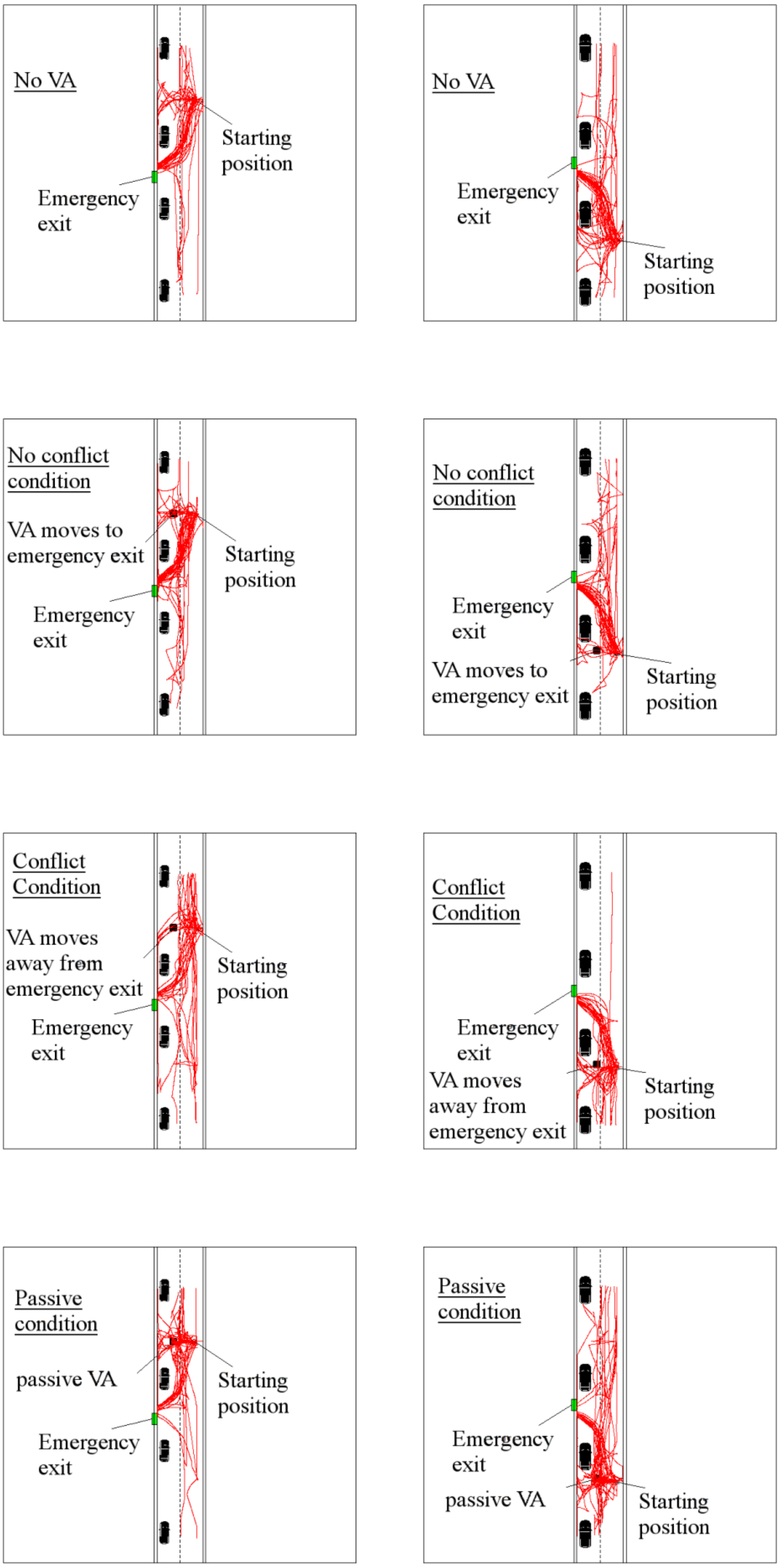

Figure 20 Movement paths in the eight tunnel maps. Each red line represents one participant.

2.5.4 Discussion

The present study systematically investigated SI on evacuation behavior in a virtual tunnel fire. Four different tunnel fire scenarios were designed. In each scenario, participants were situated in a road tunnel and dark smoke was moving towards them. Through the smoke on one side of each starting-position an emergency exit was visible. In all conditions but the *control condition* a VA was present. In one condition (*no-conflict condition*) the VA moved directly to the emergency exit. In the next condition the VA moved in the opposite direction of the emergency exit (*conflict condition*), and in the last condition, the VA simply stayed passive and stood a few meters from the participant's starting-position (*passive condition*). The aim was to create experimental conditions in which the participants had to deal with emergency situations with or without conflicting information. Across all conditions, at least 60% of the participants moved to the emergency exit. This was consistent with other studies related to evacuation behavior documenting similar evacuation rates in comparable scenarios (Kobes et al., 2010). Participants were most likely to go to an emergency exit if the VA also went there (85%). However, even in this "ideal" condition, in which all possible sources of information directed towards the emergency exit, still some participants decided to walk into the smoke. If no VA was present, 75% of the participants went to the emergency exit. If the VA went in the opposite direction of the exit, however, only 61% went there, which in turn means, that almost 40% walked into the smoke. In a real world tunnel fire, this would have been life threatening. If the VA stayed passive, about two third of the sample (65%) reached for the exit.

The difference between the control and the other conditions reflects SI: The movement of the VA leads to 10% more participants going to the exit in the *no-conflict condition*, and in turn, to less participants going to the exit in the *conflict* and the *passive condition*. These findings indicate that the behavior of other people serves as a source of information during evacuation, and that SI may have both positive and negative outcomes. Consequently, training measures improving self-evacuation are likely to have a positive effect not only on the trained persons, but also on people in their environment in case of an emergency. One may speculate that training selected groups, e.g., truck drivers or dangerous goods transporters could multiply the effect of training during emergencies through SI.

Regarding the analysis of the time participants needed to move through the tunnel, the *passive condition* had a strong effect. If participants were confronted with a passive VA, they needed longer until they started to walk (pre-movement time), and longer until they reached their goal in the trial. These findings are in line with classic studies on diffusion of responsibility, showing that passive bystanders inhibit evacuation (Latane & Darley, 1968). Nilsson and Johansson (2009) found in an cinema evacuation experiment that the pre-movement time was delayed if a fire alarm was an unspecific alarm bell compared to specific voice alarms instructing participants to evacuate. Similarly, in the present study the passive VA agent may have induced a feeling of ambiguity. Regarding the movement paths in this experimental condition it becomes also clear that many participants went to the passive VA.

Given that participants did not enter the tunnel themselves but were “teleported” directly into the scenario, we assume that the proportion of participants who did not go the emergency exit is somewhat underestimated. Observations from evacuation studies, and tunnel accidents showed that tunnel users are likely to show an evacuation behavior termed “movement towards the familiar”, and hence often move towards the portal they entered the tunnel (Frantzich & Nilsson, 2004; Mc Clintock, Shields, Reinhardt- Rutland, & Leslie, 2001). In the present study no participant entered one of the vehicles parked in the tunnel. This is particularly interesting, since this behavior was observed during the major tunnel fires in the alps (Beard & Carvel, 2005). Furthermore, during the initial training phase prior to the actual experiment, participants had trained entering vehicles. Considering Sime’s (1985) theory on movement to the familiar, one may speculate that the participants were not familiar enough with entering a virtual car in the context of the experiment.

Interestingly, not all participants took the same path, if they chose to go to the emergency exit (Figure 20). The majority opted for the shortest route leading to the emergency exit. Only a small number crossed the street to the sidewalk and then went to the exit. On the one hand, the first option may have been slightly faster. On the other hand, the sidewalk is the safer route, since there is less risk of traffic and the tunnel wall facilitates orientation in case visibility is reduced. Furthermore, in the passive condition, some participants walked to the passive VA and tried to interact with it. This could be interpreted as a *tend or befriend* reaction in response to stress (von Dawans et al., 2012).

The results of the present study have implications for measures aiming to improve evacuation behavior. For example, design of escape routes (e.g., emergency signage and exit) should be as simple and unambiguous as possible to optimize self-evacuation. Since SI might increase the ambiguity of an emergency situation, safety instructions and signage need to be as unambiguous as possible. These findings are in line with earlier studies: For example, one study showed that fewer decisions elements in the environment and less ambiguity, lead to improved self-evacuation (Heskestad, 1999). That is, emergency signage and exits should be immediately recognizable and easily understandable even for untrained users.

There are several limitations in the present study that need to be addressed: First, only one VA was present during each trial. In a real world tunnel emergency, or any other dangerous situation, it is likely that more people are present. Groups of people may exert stronger SI or give even more ambiguous and conflicting information about the adequate evacuation strategy. Second, participants had no possibility to interact with the VA. Especially in the passive condition it is likely that participants intended to interact with the VA. Third, only the SI of a male VA was tested in this study, although gender effects are well documented during evacuation. For example, in one study women were more likely to evacuate than men in a simulated tunnel accident (Kinateder et al., 2013). A cross-sectional survey study found that women were also more likely to evacuate during natural catastrophes. It is possible to explain this phenomenon with gender differences in social norms, actual and perceived exposure to risk, as well as incentives to evacuate (Bateman & Edwards, 2002). Further studies should also take into account possible differential effects of gender, social roles and individual personality traits. Fourth, it is possible that the VA used in this study fell into the so called *uncanny valley*. The uncanny valley hypothesis claims that almost perfectly humanlike VAs cause negative emotional reactions in human observers (MacDorman, Green, Ho, & Koch, 2009; Mori, 1970). If the VA of this study fell into the uncanny valley, it is possible that the effect of SI was somewhat underestimated. On a more general level, one may speculate that a humanlike VA is not necessarily perceived the same as a real human being. Fifth, the present study used an almost complete within-subjects design, and although we checked for effects of trial order (e.g. learning effects), these cannot be completely ruled out. We chose the within subject design due to its economical increase in statistical power. Further studies should consider replicating these findings in a complete between subjects design.

In conclusion this study indicates that SI effects evacuation behavior during tunnel fires, and that SI may have both positive and negative effects. An increase of ambiguity about the optimal escape route led to a higher rate in wrong decisions and longer pre-movement times. On the one hand these results show that most people might react adequately in a tunnel fire situation and move towards the next emergency exit. On the other hand, it is alarming to note that even if emergency exits are clearly visible and other people also go there, some individuals still decide to go into the smoke.

3. General Discussion

“But I always say, one's company, two's a crowd, and three's a party”

Andy Warhol

3.1 General Discussion

The aim of this dissertation project was to describe the experience and behavior of people in emergency situations simulated using virtual reality (VR). In particular, the question of mutual social influence (SI) between people facing dangerous situations was investigated in detail. The first research goal was to systematically analyze SI during different stages of the evacuation process in a simulated fire in a virtual tunnel. In order to achieve this goal VR studies in various settings were realized. The second research goal aimed at validity aspects of VR as a research tool and shed light on the question whether SI can be studied in virtual environments.

Five studies looked at different aspects during the evacuation process. The first four studies looked at the pre-evacuation phase of a severe accident with fire inside a road tunnel. In the following final chapter, the results of the studies composing the present dissertation project will be integrated and discussed under a broader perspective. First, there will be a short summary of the most important findings regarding SI in emergency situations. Second, theoretical and methodological questions regarding the general usefulness of VR as a research tool will be discussed and conclusions for further studies will be drawn. Third the general limitations of the present studies will be analyzed. Finally, a short summary and outlook will be presented. Table 10 gives an overview of the aims, methods, and main findings of the five studies of the dissertation project.

Table 10 Brief summary of the findings presented in studies 1-5.

Study	Research Goals	Evacuation phase studied	N	Design	Main findings
1	Pilot study: Test the usability of the VR scenario	Pre-evacuation	30	Between-subjects Design	Reducing the distance of the accident and the cabriolet might allow the participants to stop closer to the accident.
2	Study the effect of SI of passive bystanders and information on participants' behavior during an emergency situation.	Pre-evacuation	60	2x2 between-subjects experimental design	Giving information fostered adequate reactions during the emergency situation. Passive bystanders did not have positive or negative effects on participants' behavior.
3	Study the effect of perceived agency of Vas on SI.	Pre-evacuation	30	Between-subjects Design	Participants in the Avatar condition left the vehicle during the emergency situation faster than the ones in the VA condition
4	Study the effect of SI of passive drivers/ co-drivers on participants' behavior during an emergency situation.	Pre-evacuation	34	Between-subjects yoke design	Co-drivers left the vehicle equally often as drivers but did so significantly slower. All participants left the vehicle after the VA. Perceived agency influenced behavior.
5	Study SI on emergency exit use.	Pre-movement and movement phase	40	4x2x2 mixed design	Passive VAs and VAs moving away from the emergency exit lead to longer pre-movement and movement times. Fewer participants went to the emergency exit in these conditions.

3.1.1 Summary and Discussion

3.1.1.1 SI in Emergency Situations

The evacuation process can be roughly divided into pre-evacuation, pre-movement, and movement phase (Kuligowski, 2012). Although some authors do not differentiate between pre-evacuation and pre-movement phase (Olsson & Regan, 2001; Spearpoint, 2004) it was important to distinguish between these two processes for the present dissertation, because during both phases different processes are important. In the pre-evacuation phase the crucial question is, whether tunnel users decide to begin evacuation or not. Whereas in the pre-movement phase, tunnel users have already decided to evacuate and got out of the vehicle but haven't started to move yet. The crucial threshold that lies between these two phases is the decision of a person to evacuate. Consequently, the frame chosen for the present dissertation project covered pre-evacuation, pre-movement and movement phase.

Is it possible to embed the present studies and their results into a theoretical framework of evacuation behavior? The most current and holistic theoretical approach is the *Protective Action Decision Model* (PADM, Kuligowski, 2012). Environmental cues (e.g. smoke) indicating threat are at the beginning of all emergency situations. Here, physical and social environment are seen as sources of information. Indeed, the results of the present studies show that SI has different effects during each phase of the evacuation process. Moreover, the present studies help to understand when and how the social environment influences evacuees. According to the PADM, SI is mostly present in ambiguous situations. The social environment, such as other users in a tunnel, might inform about social appropriate (normative SI) and adequate (informational SI) behavioral responses to a certain situation (Deutsch, 1980). That is, seeing others engaging in protective actions (e.g. going to an emergency exit) may trigger self-evacuation. Conversely, inadequate behavioral responses of others to an emergency situation (e.g. staying idle, moving away from the emergency exit) might thwart self-evacuation (Darley & Latané, 1968; Latane, 1981).

Pre-evacuation phase

The pre-evacuation phase integrates all actions that happen between the onset of a threat and the beginning of the actual evacuation and is also sometimes referred to as the cue-validation and decision making phase (Kobes et al., 2010). Cue-validation refers to the process of evaluating stimuli in the environment that indicate danger. A person has to decide, for example, whether smoke in a tunnel is caused by a fire and evacuation is necessary. However, the more general concept of pre-evacuation phase seems more suitable, since other activities or psychological states (e.g. tunnel anxiety in the case of tunnel emergencies) that may not be assigned to either cue-validation or decision making might be crucial for the evacuation process, too. In the case of study 1 and 2 this comprises the time it took participants from stopping to leaving the vehicle in the simulated emergency situations. During this phase many processes, such as information gathering and processing, threat detection, as well as decision making, decide whether self-evacuation is initiated or not. According to the PADM, social context may modulate these processes (Kuligowski, 2012). For example, studies on fire alarms in a cinema showed that, participants sitting close to passive bystanders hesitated to evacuate even if an alarm bell rang (Nilsson & Johansson, 2009). According to the *emergent norm perspective* on normative SI, social norms (e.g. the norm to not stand out of the group) apply in these situations. These can lead to inertia and passivity in individuals and ultimately delay evacuation (Riad et al., 1999). Thus, it was hypothesized that passive bystanders (study 1) and passive co-passengers (study 2) lead to less frequent and delayed evacuation in a tunnel emergency situation. However, passive bystanders did not affect the frequency of participants leaving the vehicle. Interestingly, passive bystanders did also not alter the behavior of informed participants. Across all studies (including the pilot studies) only around one third of uninformed participants left the vehicle in the emergency situation. These results are in line with previous (Kinateder et al., 2013; Mühlberger et al., unpublished data) and reports from actual tunnel emergencies: During the Mont Blanc more than two third of the victims had stayed passive during the catastrophe (Duffé & Marec, 1999; Fridolf et al., 2011). That is, in a real tunnel fire passive behavior puts users at substantial risk. Consequently, the findings of the present dissertation underline among others that research on user behavior is a crucial element to further improve tunnel safety, and more behavioral experiments are necessary to reveal potential problems in tunnel safety.

Interestingly, the results of study 2 and 4 indicate that SI had effects on latencies of adequate safety behavior: Although the passive bystanders in study 2 had no statistically significant effect on latencies, it is important to note that participants stayed much longer in the vehicle than in study 4. Furthermore, all participants in study 4 left the vehicle after the virtual co-passenger. Although further studies assessing the role of passengers in a car are still necessary, these findings lead to the conclusion that SI of co-passengers is important. In addition, co-drivers waited longer and perceived the behavior of the VA as more influential than drivers. It seems plausible that the SI of co-passengers is stronger than the one of passive bystanders. Co-passengers are spatially closer and more likely to be relevant for the driver. Most likely the driver knows his or her co-passengers. Bystanders on the other side, are more likely to be strangers and probably not seen as significant for one's own safety. In addition, the driver's cabin physically separates the tunnel users from the other bystanders and the emergency situation itself.

Following the findings of Fischer et al. (2006) study 1 also investigated the role of perceived threat. It was hypothesized that perceived threat might be decisive whether normative or informative SI is exerted. We assumed that especially uniformed participants would underestimate the danger of smoke in a tunnel, and thus, would start evacuating. Even though toxic smoke is the most important threat to tunnel users, it may not be perceived as potentially life threatening in tunnel fires (Beard & Carvel, 2005). That is, we expected that uninformed participants did not realize the immediate danger of the situation, and thus were less likely to leave the vehicle in the SI condition. Interestingly, the results show that participants in all four experimental groups judged the oncoming smoke as highly dangerous (Figure 7). Consequently, the results do not allow testing the assumption that perceived threat might be an important mediator between SI and behavioral responses in emergencies. More importantly, even participants who were aware of the threat of the oncoming smoke did still not evacuate. These findings question the assumption that the degree of perceived threat directly connected to the readiness to start evacuation. However, even the highly immersive VR scenarios realized in the present dissertation project do not elicit the intensity of fear as a real world emergency would have.

Pre-movement and Movement Phase

The evacuation phase itself can be roughly divided into the pre-movement and the movement phase (Table 1). The pre-movement phase, which starts with the decision to evacuate and ends when the actual self-evacuation begins, has only recently become the focus of research (Kobes et al., 2010; Sime, 2001). The movement phase comprises the actual movement towards the intended evacuation destination. Study 5 investigated SI on decision making during the pre-movement and movement phase of evacuation from a tunnel filled with smoke. In four different scenarios participants were situated in a road tunnel and dark smoke was moving through the air. On one side of the starting-position an emergency exit was visible through the smoke. In all conditions but the *control condition* a VA was also present. The scenarios provided more or less conflicting information and ambiguity for the participants. In the *no-conflict condition* the VA moved directly to the emergency exit. In the next *conflict condition* the VA moved in the opposite direction of the emergency exit, and in the *passive condition*, the VA simply stayed passive and stood near the participant's starting-position. Across all conditions the majority of the participants decided to go to the emergency exit. However, there were differences between the control and the other conditions reflecting SI: The movement of the VA led to more participants going to the exit in the *no-conflict condition*, and in turn, to less participants going to the exit in the *conflict* and the *passive condition*. These findings indicate that the behavior of other people serves as a source of information during evacuation, and that SI may have both positive and negative outcomes. Consequently, measures improving self-evacuation are likely to have a positive effect not only on experienced persons, but also on people close by. In case of an emergency, trained tunnel users could serve as role models for others.

Regarding the analysis of the time it took the participants to move through the tunnel, the *passive condition* had a strong effect. Here, pre-movement and movement phase were significantly prolonged. These findings are in line with classic studies on diffusion of responsibility, showing that passive bystanders inhibit evacuation (Latane & Darley, 1968). Nilsson and Johansson (2009) found in a cinema evacuation experiment that the pre-movement time was delayed due to SI if an unspecific alarm bell rang, compared to specific voice alarms instructing participants to evacuate. Similarly, in the present study the passive VA agent may have induced a feeling of ambiguity. Two behavioral patterns could have led to these delays. First, as the movement paths indicate, some of the participants went in the VA's direction. It is possible that in a real emergency situation they would have tried to communicate with a passive person (e.g. for information gathering or helping). Second, since participants waited longer before they started to move, it is possible that they waited for the VA to do something. Thus passive behavior in emergency situations may thwart the evacuation process.

This effect of the VA on the participant's behavior could be classified as informative SI. Participants used the behavior of the VA as a source of information to guide their own evacuation movement. However, the *emergent norm* perspective may alternatively explain why SI of bystanders was found in study 5 but not in study 2. This theory hypothesizes that during new and unknown situations (such as severe accidents or other disasters are for most people) new social norms develop automatically (Fritz & Williams, 1957; Riad et al., 1999). In the first two studies the context (being in a car) did not change for the participants. In study 5, however, participants were in a different situation in which the social norms that apply to the context of being in a car were no longer valid. It is possible that some participants not only tried to derive valuable information from the VA about how to evacuate from the emergency situation, but also information about the emergent norms in that novel and ambiguous situation. Thus, the theoretical distinction between normative and informational SI might be deceiving and it remains unclear if these are really two distinct and independent concepts.

Conclusion

When and why does SI affect behavior in dangerous situations? The results of the five studies indicate that SI has differential effects during the process of the evacuation. In summary, the studies found mixed indicators of SI of passive bystanders in the pre-evacuation phase. Moreover, SI of co-passengers had no influence on frequencies but on latencies of leaving the vehicle. These results also indicate that effects of SI inside the vehicle are more likely to occur than SI from outside the vehicle. The practical implications of these findings are threefold: First, measures aiming to improve self-evacuation should differentiate between SI in- and outside the vehicle and such measures should also focus also on co-drivers and other passengers. Second, it is possible that the assumed negative effect of passive bystanders on self-evacuation during the pre-evacuation phase is generally overestimated. During the pre-movement and movement phase, however, the participants were clearly influenced by the VA. Consequently, SI influence should be studied in more detail during these phases (also see limitations and outlook). Third, on a more practical level, training measures aiming to improve user behavior could have secondary beneficial effects. Previous studies have shown that trained participants are more likely to move to emergency exits or emergency phones (Kinateder et al., 2013). Taken together with the findings from study 5, it seems likely that well trained tunnel users could guide others to adequate evacuation routes. Training measures could either aim at the general public (driving lessons, information campaigns, and online serious games) or at high risk groups for specific emergency situations. In the case of tunnel fires these could be truck drivers or dangerous goods transporters.

Experimental studies on SI focusing on either helping behavior or self-evacuation, often assume similar psychological processes (and consequently cite the same studies). However, although the studies of Darley and Latané (1968) are the common historical basis, it is important to clearly distinguish between these two phenomena. For example, future studies investigating the relationship of perceived threat and SI should test, whether the findings from Fischer et al. (2006) on helping behavior also apply to self-evacuation.

3.1.1.2 Is VR Suitable to Study SI during Emergency Situations?

One of the key problems of analogy studies, such as the ones presented here, is external validity and two important questions have to be answered: First, can SI be studied in VR? Second, are findings from safe virtual environments representative for real world emergency situation?

Study 3 addressed the first question and investigated the role of perceived agency. Following the *Threshold model of SI*, VAs will only serve as a source of SI if they are perceived as representations of real humans (avatars, Blascovich, 2002b). Conversely, the *Ethopoeia concept* hypothesizes that social reactions to VA are the same as to real humans regardless of their perceived agency (Nass & Moon, 2000; von der Putten et al., 2010). Extending Guadagno and colleagues' (2007) questionnaire study, which showed perception of VA as humans influences the degree of social presence in a virtual environment, we tested whether participants were influenced more strongly by an avatar or by an agent. The stronger the persuasion that VAs are controlled by real human beings (meaning they are perceived as avatars), the stronger the experience of social presence. Thus, we assumed a stronger effect of SI, if a VA was perceived as an avatar. Using a fake video stream participants were led to believe that the VA conducting the vehicle was actually the avatar of another participant. In the Agent condition participants were told that the driver was a computer controlled VA. Participants in the avatar condition left the vehicle faster during the emergency situation. That is, perceived agency may have direct influence on behavior in the VR setting. So far, these findings are in line with the work of Guadagno et al. (2007) and support the *Threshold model of SI*. Study 3 was the first to our knowledge, documenting this effect on a behavioral level. Further studies using VAs aiming to investigate social interactions or SI should always consider to implement similar manipulation to the one used in this study. On a more general level, prior studies looking VR studies using VAs may have systematically underestimated the effect of SI.

Evidence for a positive answer to the second question can be found in the literature and previous work (see 1.4). Similar to real world tunnels, driving through a virtual tunnel is accompanied by stronger feelings of anxiety than driving on an open road (Calvi, 2010; Calvi & De Blasiis, 2011). Tunnel phobic patients show increased psychophysiological fear reactions during exposure to a virtual tunnel (Mühlberger et al., 2007). In addition, driving behavior in simulators was found to be comparable to real world driving behavior in several studies (Hirata et al., 2007; Shechtman et al., 2009; Törnros, 1998). VR studies are one possibility to simulate dangerous situations and there is evidence suggesting that VR studies are externally valid to investigate human behavior in critical situations, for example as indicated by realistic flight behavior during a fire in a library (Gamberini et al., 2003). Previous studies using the same virtual environments as study 1 and study 2 compared behavior during virtual and real simulated tunnel emergencies and found comparable results indicating the general usefulness of VR studies (Kinateder et al., 2013). In study 1 and another study using the same scenario, it was found that participants experienced significant psychological stress in the simulated emergency situation (Mühlberger et al., unpublished data). However, Kobes et al. (2010) compared evacuation behavior from a virtual and a real hotel and found differences in emergency exit choices between some virtual and real world scenarios. On the other hand the same study found no significant differences in participants' reactions to simulated virtual and real world smoke. Consequently, the question of validity has to be addressed in all studies targeting human behavior in dangerous situation with VR experiments.

Various disciplines aim to better understand human behavior emergency situations and ultimately seek to improve safety. Due to the nature of the research field, it is almost impossible to access ecologically valid and at the same time experimentally controlled empirical data. The diverse methods always have to tradeoff between ecological validity and experimental control. For example, case studies and unannounced drills in real world settings provide almost perfect ecological validity. Unfortunately, experimental control is virtually impossible to achieve here, and high financial and logistic efforts as well as ethical limitations need to be considered. In contrast, questionnaire studies need to consider other ethical limitations and are easier to realize but they rely heavily on the ability of the participant's imagination and are prone to response biases. VR studies offer the possibility to realize behavioral studies with high experimental control. In conclusion, VR is a promising tool to study SI during emergency situations. However, studies using VR simulations need to consider methodological aspects such as the aforementioned perceived agency. Nevertheless, there are some important limitations, which will be discussed in the following paragraph.

3.1.2 General Limitations

There are a number of critical methodological and theoretical aspects of the studies in the present dissertation. Criticism that was specific for the individual studies are discussed in the limitations sections of each study. In the following part general limitations will be critically discussed.

Experimental studies on behavior in dangerous situations let alone on SI during these situations are scarce. The main reason for this is possibly the difficulty to develop externally valid and experimentally sound paradigms without actually putting participants' health at risk. Although studies on external validity of VR studies and tunnel safety are promising, even the most sophisticated field experiment and the most advanced simulation on human behavior in dangerous situations cannot (and should not) claim absolute external validity. Participants will always be aware that they are taking part in an experiment in a safe laboratory environment. However, if it became impossible for participants to distinguish between reality and simulated world the same ethical standards would apply. In an extreme scenario participants might even experience fear of death and the study would become ethically and morally inacceptable. Thus, analogue studies have to be considered as an important method to study human behavior in dangerous situations.

Moreover, we implicitly assume that either normative or informational SI is exerted. However, there may be situations in which both forms of SI appear at the same time and that both constructs are not necessarily independent from each other. In the tragic example of the Mont Blanc catastrophe it is possible that some people did not start to evacuate because the passivity of others might have been interpreted as an indicator of safety (e.g. “If the others do not evacuate it must be save to stay for me, too.”) and at the same time served as role models for a social norm (e.g. “Stay in the car and do not leave the vehicle in a highway tunnel”). It is difficult to disentangle these two processes during emergency situations. Consequently, the assumption that normative SI was more relevant in study 2 and 4 whereas informational SI was predominant in study 5 is plausible but difficult to falsify. Future studies should focus on the reasons why some people follow others in dangerous situations.

In study 2 a potential moderating effect of perceived threat of a situation was assumed. Indeed, the effect of SI on evacuation behavior might be mediated by the perceived threat of a given situation (Fischer et al., 2006). Thus, if uniformed participants underestimated the danger of smoke in a tunnel, they might be less likely to evacuate in presence of passive bystanders. The post hoc questionnaire revealed that participants had judged the emergency situation as highly dangerous and therefore, it was concluded that all participants experienced high levels of subjective threat. However, it is possible that this assumption is not valid and that the cognitive post-hoc judgments do not necessarily reflect the arousal and the degree of threat experienced during the actual emergency situation. This doubt is supported by the moderate presence scores in the IPQ in study 2 and 4. If participants had experienced intensive threat, it is plausible to assume that they would have felt strongly immersed into the virtual world. It seems more likely that participants were aware that the emergency situation was part of a simulation and that no real danger existed. Although the findings from study 2 and previous works show that simulated tunnel emergencies lead to increases in anxiety (Mühlberger et al., 2007; Mühlberger et al., unpublished data), it is unclear how strong these effects are.

Another critical issue lies in the use of VA. Animated artificial humans might theoretically fall into the so called *Uncanny Valley*. Uncanny valley theory postulates that artificial representations of humans, such as VAs, that are close to photorealistic may cause feelings of unease (Mori, 1970). More precisely, a non-linear function of the *dimension of* *human likeness* of an artificial human representation and the valence of such representations is postulated (Figure 21) (Cheetham et al., 2011; MacDorman et al., 2009).

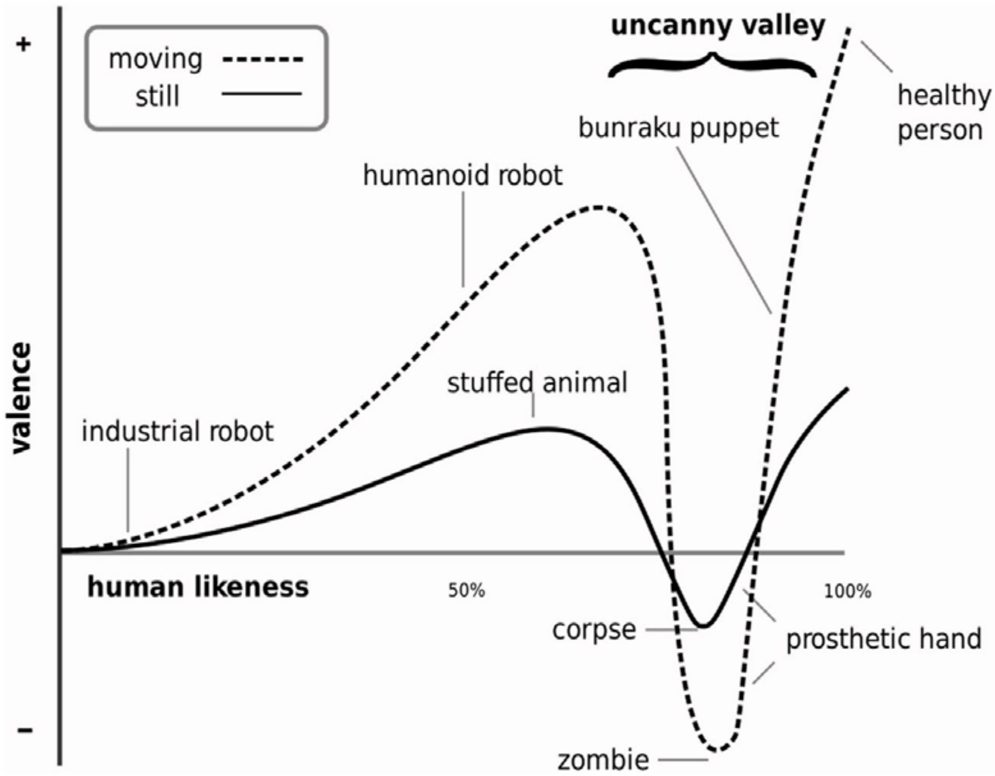

Figure 21 Postulated function of human likeness and valence illustrating the uncanny valley (Cheetham et al., 2011, p. 2).

The core assumption is that it is difficult to experience emotional engagement to human representations if they fall into the uncanny valley (Cheetham et al., 2011). Assuming that this is the case for the VAs used in the present studies, it is possible that SI effects were distorted. For example one may speculate that fewer participants followed the VAs in study 5 because they found them strange or even eerie. Further studies need to evaluate the valence of the VAs used in the present studies[6]. This could be done by comparing the VAs with other stimuli which are either on the verge of or actually in the uncanny valley. However, there is still a lack of empirical evidence of the existence of the uncanny valley (Cheetham et al., 2011).

[6] A study comparing the VAs used in the present study with stimuli developed by Cheetham et al. (2011) is currently in preparation.

In all studies the effect of a single VA was investigated. In tunnel emergencies, however, it is unlikely that only one other person is present. Studies on conformity showed that likelihood of knowingly making a wrong decision increases with the number of people observed making the same mistake (Rosenberg, 1961). A meta-analytic study on these findings confirmed this relationship, but also point out that there are different SI processes depending on the context (Bond, 2005). In addition, more bystanders could make emergency situations even more complex than the scenarios developed for the present dissertation. For example, one might think of a situation in which, a person observes several people moving in different directions during an emergency. Future studies on the pre-movement and movement phase of the evacuation process need to take this into account.

3.1.3 Outlook

The present dissertation project sought to shed light on the question of SI during emergency situations. Five studies investigated SI during different phases of the evacuation from a virtual tunnel emergency. The broadest conclusion that can be drawn from these studies is that SI is relevant and varies across different situation during emergencies. As the discussion of the results already indicates, the study of SI is more complex than previously assumed and must be approached more carefully. The following last paragraphs will cover some of the potential future research questions that can be derived from the present studies.

First, the effect of the number of bystanders or VAs has on the strength of SI in emergency situations needs to be investigated. Studies on conformity indicate that group size has an effect on SI (Bond, 2005; Rosenberg, 1961). What happens if not only one VA was present in scenario like the one used in study 5? Is there a “critical mass” of VAs? A first study could try to extend study 5 utilizing different numbers of VAs all moving in the same direction. The next step would be to differentiate between various behavioral patterns of the VAs: For example, what happens if only a part of the group began to evacuate and the other remained passive or even moved away from the emergency exit?

Another important aspect might be gender and individual differences. A previous study showed that especially men reacted inadequately in a simulated tunnel emergency (Kinateder et al., 2013). Similarly, studies found interaction effects between SI and gender on task performance. E.g., in a video game task social facilitation by an observer was only observed in men (Ferris, Fedor, Rowland, & Porac, 1985). A possible study could systematically vary the gender of VAs present during an emergency situation and look at differential effects on men and women.

As pointed out in paragraph 1.4, studying human behavior in emergency situations has several methodological and also ethical limitations. Hence, a multidisciplinary approach, combining the strength of several methods might be promising. Especially comparisons with computer modeling (for an overview of computational evacuation models see paragraph 1.2.4) could be useful. The results from VR studies could be used to implement new features into these models. In return, the results from computer modeling studies could be validated by empirical studies in VR.

A challenging approach could be to replicate the studies in a real world environment. Since external validity is a critical issue in studies on human behavior in dangerous situation, analogous field studies can help to validate the results of the present studies. Previous comparisons of VR and field studies on revealed that participants reacted relatively similar in both studies supporting the external validity of the VR scenarios (Kinateder et al., 2013; Mühlberger et al., unpublished data). The advantage of maximal experimental control in VR analogous studies has the flipside of reduced realism. Field studies allow less experimental control and experimental variations, but are often used due to their high external validity. In tunnels, however, almost every environmental parameter, from air movement to light conditions, is highly controllable. Thus, although cost-intensive and complex, field studies on SI would be highly promising.

References

Asch, S. E. (1955). Opinions and Social Pressure. *Scientific American, 193*(5), 31-35.

Bailenson, J. N., Blascovich, J., & Guadagno, R. E. (2008). Self-Representations in Immersive Virtual Environments. *Journal of Applied Social Psychology, 38*(11), 2673-2690.

Barlow, D. H. (2002). *Anxiety and its disorders: The nature and treatment of anxiety and panic* (2nd edition ed.). New York: The Guilford Press.

Bateman, J. M., & Edwards, B. (2002). Gender and Evacuation: A Closer Look at Why Women Are More Likely to Evacuate for Hurricanes. *Natural Hazards Review, 3*(3), 107-117.

Beard, A., & Carvel, R. (2005). *The handbook of tunnel fire safety*. London: Thomas Telford.

Beideler, J. (2005). L'accident du Fréjus relance le débat sur la sécurité et sur le ferroutage (déroulement de l'accident du 4 juin). *Le Moniteur des Travaux Publics et du Bâtiment, 5298*, 18.

Blascovich, J. (2002a). Social influence within immersive virtual environments. *Social Life of Aviators*, 127-145.

Blascovich, J. (2002b). *A theoretical model of social influence for increasing the utility of collaborative virtual environments*. Paper presented at the Proceedings of the 4th international conference on Collaborative virtual environments, Bonn, Germany.

Bohil, C. J., Alicea, B., & Biocca, F. A. (2011). Virtual reality in neuroscience research and therapy. *Nat Rev Neurosci, 12*(12), 752-762. doi: 10.1038/nrn3122

Bond, R. (2005). Group size and conformity. *Group Processes & Intergroup Relations, 8*(4), 331-354. doi: Doi 10.1177/1368430205056464

Boyle, L. N., & Lee, J. D. (2010). Using driving simulators to assess driving safety. *Accident Analysis and Prevention, 42*(3), 785-787. doi: DOI 10.1016/j.aap.2010.03.006

Burke, M. J., Salvador, R. O., Smith-Crowe, K., Chan-Serafin, S., Smith, A., & Sonesh, S. (2011). The dread factor: How hazards and safety training influence learning and performance. *Journal of Applied Psychology, 96*(1), 46-70. doi: 10.1037/a0021838

Calvi, A. (2010). *Analysis of Driver's Behaviour in Road Tunnels: a Driving Simulation Study*. Paper presented at the 2010 International Symposium on Safety Science and Technology, Zhejiang, China.

Calvi, A., & De Blasiis, M. R. (2011). *How Long is Really a Road Tunnel? Application of Driving Simulator for the Evaluation of the Effects of Highway Tunnel on Driving Performance.* Paper presented at the 6th International Conference Traffic and Safety in Road Tunnels, Hamburg, Germany.

Chambless, D. L., Caputo, G. C., Bright, P., & Gallagher, R. (1984). Assessment of fear of fear in agoraphobics: The Body Sensations Questionnaire and the Agoraphobic Cognitions Questionnaire. *Journal of Consulting and Clinical Psychology, 52*(6), 1090-1097. doi: 10.1037/0022-006x.52.6.1090

Cheetham, M., Suter, P., & Jancke, L. (2011). The human likeness dimension of the "uncanny valley hypothesis": behavioral and functional MRI findings. *Frontiers in Human Neuroscience, 5*. doi: 10.3389/Fnhum.2011.00126

Clark, L. (2002). Panic: myth or reality. *Contexts, 1,3*, 21-26.

Darley, J. M., & Latané, B. (1968). When Will People Help in a Crisis. *Psychology Today, 2*(7), 54-&.

Deutsch, M. (1980). Citation Classic - a Study of Normative and Informational Social Influences Upon Individual Judgment. *Current Contents/Social & Behavioral Sciences*(37), 14-14.

Doherty, S. T., Andrey, J. C., & MacGregor, C. (1998). The situational risks of young drivers: The influence of passengers, time of day and day of week on accident rates. *Accident Analysis & Prevention, 30*(1), 45-52. doi: 10.1016/s0001-4575(97)00060-2

Drury, J., Cocking, C., & Reicher, S. (2009). Everyone for themselves? A comparative study of crowd solidarity among emergency survivors. *British Journal of Social Psychology, 48*(3), 487-506. doi: 10.1348/014466608x357893

Drury, J., Cocking, C., Reicher, S., Burton, A., Schofield, D., Hardwick, A., . . . Langston, P. (2009). Cooperation versus competition in a mass emergency evacuation: A new laboratory simulation and a new theoretical model. *Behavior Research Methods, 41*(3), 957-970. doi: 10.3758/brm.41.3.957

Duffé, P., & Marec, M. (1999). Mission administrative d'enquête technique sur l'incendie survenu le 24 mars 1999 au tunnel routier du Mont Blanc [Task Force For Technical Investigation Of The 24 March 1999 Fire In The Mont-Blanc Vehicular Tunnel]. Retrieved from the Ministère de l'Intérieur & Ministère de l'Equipement,des Transports et du Logement website: http://www2.equipement.gouv.fr/archivesdusite/actu/jcg-1997-2002/dossiers/1999/rapportfr.htm.

Eastwick, P. W., & Gardner, W. L. (2009). Is it a game? Evidence for social influence in the virtual world. *Social Influence, 4*(1), 18-32. doi: 10.1080/15534510802254087

European Parliament, & European Council. (2004). Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Network. *L167/39, 2004/54/EC.*

Feinberg, W. E., & Johnson, N. R. (1995). FIRESCAP: A computer simulation model of reaction to a fire alarm. *The Journal of Mathematical Sociology, 20*(2-3), 247-269. doi: 10.1080/0022250x.1995.9990164

Ferris, G. R., Fedor, D. B., Rowland, K. M., & Porac, J. F. (1985). Social influence and sex effects on task performance and task perceptions. *Journal of Vocational Behavior, 26*(1), 66-78. doi: 10.1016/0001-8791(85)90026-0

Firing, K., Karlsdottir, R., & Laberg, J. C. (2009). Social influence in military leadership training. *Leadership & Organization Development Journal, 30*(8), 709-721. doi: 10.1108/01437730911003885

Fischer, P., Greitemeyer, T., Pollozek, F., & Frey, D. (2006). The unresponsive bystander: Are bystanders more responsive in dangerous emergencies? *European Journal of Social Psychology, 36*(2), 267-278. doi: Doi 10.1002/Ejsp.297

Fischer, P., Krueger, J. I., Greitemeyer, T., Vogrincic, C., Kastenmuller, A., Frey, D., . . . Kainbacher, M. (2011). The Bystander-Effect: A Meta-Analytic Review on Bystander Intervention in Dangerous and Non-Dangerous Emergencies. *Psychological Bulletin, 137*(4), 517-537. doi: Doi 10.1037/A0023304

Frantzich, H. (2001, 159-165). *Occupant Behaviour and Response Time – Results from Evacuation Experiments.* Paper presented at the Human Behaviour in Fire, Boston.

Frantzich, H., & Nilsson, D. (2004). *Evacuation Experiments in a Smoke Filled Tunne.* Paper presented at the Human Behaviour in Fire, Belfast, UK.

Fridolf, K., Nilsson, D., & Frantzich, H. (2011). Fire Evacuation in Underground Transportation Systems: A Review of Accidents and Empirical Research. *Fire Technology*, 1-25. doi: 10.1007/s10694-011-0217-x

Fritz, C. E., & Williams, H. B. (1957). The Human Being in Disasters: A Research Perspective. *The ANNALS of the American Academy of Political and Social Science, 309*(1), 42-51. doi: 10.1177/000271625730900107

Galea, E. R., Lawrence, P. J., Gwynne, S., Filippidis, L., Blackshields, D., & Cooney, D. (2012). buildingEXODUS V5.0 user guide and technical manual: University of Greenwich.

Gamberini, L., Cottone, P., Spagnolli, A., Varotto, D., & Mantovani, G. (2003). Responding to a fire emergency in a virtual environment: different patterns of action for different situations. *Ergonomics, 46*(8), 842-858. doi: Doi 10.1080/0014013031000111266

Gandit, M., Kouabenan, D. R., & Caroly, S. (2009). Road-tunnel fires: Risk perception and management strategies among users. *Safety Science, 47*(1), 105-114. doi: DOI 10.1016/j.ssci.2008.01.001

Garau, M., Slater, M., Pertaub, D. P., & Razzaque, S. (2005). The responses of people to virtual humans in an immersive virtual environment. *Presence-Teleoperators and Virtual Environments, 14*(1), 104-116.

Groom, V., Bailenson, J. N., & Nass, C. (2009). The influence of racial embodiment on racial bias in immersive virtual environments. *Social Influence, 4*(3), 231-248. doi: 10.1080/15534510802643750

Guadagno, R. E., Blascovich, J., Bailenson, J. N., & Mccall, C. (2007). Virtual humans and persuasion: The effects of agency and behavioral realism. *Media Psychology, 10*(1), 1-22.

Heilbrun, K., Wolbransky, M., Shah, S., & Kelly, R. (2010). Risk communication of terrorist acts, natural disasters, and criminal violence: Comparing the processes of understanding and responding. *Behavioral Sciences & the Law, 28*(6), 717-729. doi: 10.1002/bsl.940

Helbing, D., & Molnár, P. (1995). Social force model for pedestrian dynamics. *Physical Review E, 51*(5), 4282-4286.

Helbing, D., & Mukerji, P. (2012). Crowd Disasters as Systemic Failures: Analysis of the Love Parade Disaster. *EPJ Data Science, 1*(1), 1-7.

Heliövaara, S., Kuusinen, J.-M., Rinne, T., Korhonen, T., & Ehtamo, H. (2012). Pedestrian behavior and exit selection in evacuation of a corridor – An experimental study. *Safety Science, 50*(2), 221-227. doi: 10.1016/j.ssci.2011.08.020

Heskestad, A. W. (1999). Performance in smoke of wayguidance systems. *Fire and Materials, 23*(6), 375-381. doi: 10.1002/(sici)1099-1018(199911/12)23:6<375::aid-fam714>3.3.co;2-s

Hewstone, M., & Martin, R. (2008). Social Influence. In M. Hewstone, W. Ströbe & K. Jonas (Eds.), *Introduction to Social Psychology (4th edition)*. London: Blackwell Publishing.

Hinds, A. L., Woody, E. Z., Drandic, A., Schmidt, L. A., Van Ameringen, M., Coroneos, M., & Szechtman, H. (2010). The psychology of potential threat: Properties of the security motivation system. *Biological Psychology, 85*(2), 331-337. doi: DOI 10.1016/j.biopsycho.2010.08.003

Hirata, T., Yai, T., & Tagakawa, T. (2007). Development of the driving simulation system MOVIC-T4 and its validation using field driving data. *Tsinghua Science & Technology 12*, 141-150.

ISO/IEC. (2008). Fire safety — Vocabulary (Vol. ISO-13943, pp. 85): ISO.

Janis, I. L., & Mann, L. (1977a). *Decision making: A psychological analysis of conflict, choice, and commitment*. New York, NY: Free Press.

Janis, I. L., & Mann, L. (1977b). Emergency decision making: A theoretical analysis of responses to disaster warnings. *Journal of Human Stress, 3*(2), 35-48.

Johnson, N. R. (1987). Panic at 'The Who concert stampede': An empirical assessment. *Social Problems, 34*(4), 362-373. doi: 10.1525/sp.1987.34.4.03a00040

Jones, J. C., & Barlow, D. H. (1990). The etiology of posttraumatic stress disorder. *Clinical Psychology Review, 10*(3), 299-328. doi: 10.1016/0272-7358(90)90064-h

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220. doi: 10.1207/s15327108ijap0303_3

Kinateder, M., Pauli, P., Müller, M., Krieger, J., Heimbecher, F., Rönnau, I., . . . Mühlberger, A. (2013). Human Behaviour in Severe Tunnel Accidents: Effects of Information and Behavioral Training. *Transportation Research Part F: Traffic Psychology and Behaviour, 17*, 20-32.

Kobes, M., Helsloot, I., de Vries, B., & Post, J. (2010). Exit choice, (pre-)movement time and (pre-)evacuation behaviour in hotel fire evacuation — Behavioural analysis and validation of the use of serious gaming in experimental research. *Procedia Engineering, 3*(0), 37-51. doi: 10.1016/j.proeng.2010.07.006

Korhonen, T., & Hostikka, S. (2010). Fire dynamics simulator with evacuation: FDS+Evac technical reference and user's guide. FDS 5.5.3, Evac 2.3.1.

Kuligowski, E. (2012). Predicting Human Behavior During Fires. *Fire Technology*, 1-20. doi: 10.1007/s10694-011-0245-6

Lang, E. M. (2010, 30.04.2010). Schrecksekunde im Hechtsheimer Autobahntunnel - Angeblich Lebensgefahr, *Mainzer Allgemeine Zeitung*. Retrieved from http://www.allgemeine-zeitung.de/region/mainz/meldungen/8661757.htm

Latane, B. (1981). The psychology of social impact. *American Psychologist, 36*(4), 343-356. doi: 10.1037/0003-066x.36.4.343

Latane, B., & Darley, J. M. (1968). Group Inhibition of Bystander Intervention in Emergencies. *Journal of Personality and Social Psychology, 10*(3), 215-221.

Laux, L., Glanzmann, P., Schaffner, P., & Spielberger, C. D. (1981). *State-Trait-Angstinventar*.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping / Richard S. Lazarus, Susan Folkman*. New York :: Springer Pub. Co.

MacDorman, K. F., Green, R. D., Ho, C. C., & Koch, C. T. (2009). Too real for comfort? Uncanny responses to computer generated faces. *Computers in Human Behavior, 25*(3), 695-710. doi: DOI 10.1016/j.chb.2008.12.026

Manstead, A. S. R., Hewstone, M., Fiske, S. T., Hogg, M. A., Reis, H. T., & Semin, G. R. (1995). *The Blackwell encyclopedia of social psychology*. Cambridge, MA: Blackwell Reference/Blackwell Publishers.

Martens, M. H. (2006). *Human behaviour in tunnel accidents: Users, operators and rescue teams*. Paper presented at the Proceedings of the Second International Symposium Safe and Reliable Tunnels, Lausanne, Switzerland.

Mc Clintock, T., Shields, T. J., Reinhardt- Rutland, A. H., & Leslie, J. C. (2001). *A Behavioural Solution to the Learned Irrelevance of Emergency Exit Signage*. Paper presented at the Human Behaviour in Fire, Boston.

McCall, C., Blascovich, J., Young, A., & Persky, S. (2009). Proxemic behaviors as predictors of aggression towards Black (but not White) males in an immersive virtual environment. *Social Influence, 4*(2), 138-154. doi: 10.1080/15534510802517418

McClintock, T., Shields, T. J., Reinhardt- Rutland, A. H., & Leslie, J. C. (2001). *A Behavioural Solution to the Learned Irrelevance of Emergency Exit Signage*. Paper presented at the Human Behaviour in Fire, Boston.

Milgram, S. (1963). Behavioral Study of Obedience. *J Abnorm Psychol, 67*, 371-378.

Milgram, S., Bickman, L., & Berkowitz, L. (1969). Note on the drawing power of crowds of different size. *Journal of Personality and Social Psychology, 13*(2), 79-82. doi: 10.1037/h0028070

Mintz, A. (1951). NON-ADAPTIVE GROUP BEHAVIOR. *Journal of Abnormal and Social Psychology, 46*(2), 150-159. doi: 10.1037/h0063293

Mori, M. (1970). Bukomi no tani [The Uncanny Valley]. *Energy, 7*(4), 33-35.

Morris, W. N., & Miller, R. S. (1975). The effects of consensus-breaking and consensus-preempting partners on reduction of conformity. *Journal of Experimental Social Psychology, 11*(3), 215-223. doi: 10.1016/s0022-1031(75)80023-0

Mosler, H.-J., & Bucks, W. (2001). Social Influence among Agents - The Simulation of Social Psychological Theories. In N. J. Saam & B. Schmidt (Eds.), *Cooperative Agents. Applications in the Social Sciences* (pp. 125-147). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Mosler, H.-J., Schwarz, K., Ammann, F., & Gutscher, H. (2001). Computer Simulation as a Method of Further Developing a Theory: Simulating the Elaboration Likelihood Model. *Personality and Social Psychology Review, 5*(3), 201-215. doi: 10.1207/s15327957pspr0503_2

Mühlberger, A., Bülthoff, H. H., Wiedemann, G., & Pauli, P. (2007). Virtual reality for the psychophysiological assessment of phobic fear: responses during virtual tunnel driving. *Psychological Assessment, 19*(3), 340-346. doi: 10.1037/1040-3590.19.3.340

Mühlberger, A., Kinateder, M., Brütting, J., Eder, S., Müller, M., & Pauli, P. (unpublished data). *Influence Of Information And Instructions On Human Behavior In Tunnel Accidents: A Virtual Reality Study*. Manuscript submitted for publication.

Mühlberger, A., & Pauli, P. (Producer). (2000). Tunnelangstfragebogen [Tunnel Anxiety Questionnaire: short-description and questionnaire]. *electronic test-archive*. Retrieved from http://www.zpid.de/index.php?wahl=products&uwahl=frei&uuwahl=userlog.

Nass, C., & Moon, Y. (2000). Machines and mindlessness: Social responses to computers. *Journal of Social Issues, 56*(1), 81-103. doi: 10.1111/0022-4537.00153

Nass, C., Steuer, J., Henriksen, L., & Dryer, D. C. (1994). Machines, Social Attributions, and Ethopoeia - Performance Assessments of Computers Subsequent to Self-Evaluations or Other-Evaluations. *International Journal of Human-Computer Studies, 40*(3), 543-559.

Nilsson, D., & Johansson, A. (2009). Social influence during the initial phase of a fire evacuation-Analysis of evacuation experiments in a cinema theatre. *Fire Safety Journal, 44*(1), 71-79. doi: DOI 10.1016/j.firesaf.2008.03.008

Nilsson, D., Johansson, M., & Frantzich, H. (2009). Evacuation experiment in a road tunnel: A study of human behaviour and technical installations. *Fire Safety Journal, 44*(4), 458-468. doi: DOI 10.1016/j.firesaf.2008.09.009

Olsson, P. Å., & Regan, M. A. (2001). A comparison between actual and predicted evacuation times. *Safety Science, 38*(2), 139-145. doi: 10.1016/s0925-7535(00)00064-3

Park, S. J. (2010). Social responses to virtual humans: The effect of human-like characteristics. *Dissertation Abstracts International: Section B: The Sciences and Engineering, 70*(9-B), 58-98.

Perard, M. (1992, 23.-25. November). *Organization of fire trials in an operated road tunnel.* Paper presented at the 1st International Conference on Safety in Road and Train Tunnels, Basel, Switzerland.

Perry, R. W., Lindell, M. K., & Greene, M. (1981). *Evacuation planning in emergency management*. Lexington, Mass.: LexingtonBooks.

Pfefferbaum, B., Stuber, J., Galea, S., & Fairbrother, G. (2006). Panic Reactions to Terrorist Attacks and Probable Posttraumatic Stress Disorder in Adolescents. *Journal of Traumatic Stress, 19*(2), 217-228. doi: 10.1002/jts.20118

Pichot, P. (1996). Panic: Attack and Disorder. History of the word and of the concepts. [Article]. *Encephale-Revue De Psychiatrie Clinique Biologique Et Therapeutique, 22,* 3-8.

Preusser, D. F., Ferguson, S. A., & Williams, A. F. (1998). The effect of teenage passengers on the fatal crash risk of teenage drivers. *Accident Analysis & Prevention, 30*(2), 217-222. doi: 10.1016/s0001-4575(97)00081-x

Proulx, G. (1993). A stress model for people facing a fire. *Journal of Environmental Psychology, 13*(2), 137-147. doi: 10.1016/s0272-4944(05)80146-x

Proulx, G., & Sime, J. D. (1991). *To prevent 'Panic' in an underground emergency: why not tell people the truth?* Paper presented at the Fire Safety Science – Proceedings of the Third International Symposium, Edinburgh, UK.

Riad, J. K., Norris, F. H., & Ruback, R. B. (1999). Predicting Evacuation in Two Major Disasters: Risk Perception, Social Influence, and Access to Resources1. *Journal of Applied Social Psychology, 29*(5), 918-934. doi: 10.1111/j.1559-1816.1999.tb00132.x

Ricard, F. (2006). *Programme de recherche ACTEURS : Améliorer le Couplage Tunnel / Exploitants / Usagers pour Renforcer la Sécurité*. France.

Ronchi, E., & Kinsey, M. J. (2011). *Evacuation models of the future: insights from an online survey of user's experiences and needs*. Paper presented at the Evacuation and Human Behaviour in Emergency Situations, Evacuation and Human Behaviour in Emergency Situations.

Rosenberg, L. (1961). Group-Size, Prior Experience, and Conformity. *Journal of Abnormal and Social Psychology, 63*(2), 436-&.

Schubert, T. W. (2003). The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness. *Zeitschrift für Medienpsychologie, 15,* 69-71.

Shechtman, O., Classen, S., Awadzi, K., & Mann, W. (2009). Comparison of Driving Errors Between On-the-Road and Simulated Driving Assessment: A Validation Study. *Traffic Injury Prevention, 10*(4), 379-385. doi: 10.1080/15389580902894989

Siddiqui, A. A., & Gwynne, S. M. V. (2012). Employing pedestrian observations in engineering analysis. *Safety Science, 50*(3), 478-493. doi: 10.1016/j.ssci.2011.10.011

Sime, J. D. (1985). Movement toward the familiar: Person and place affiliation in a fire entrapment setting. *Environment and Behavior, 17*(6), 697-724. doi: 10.1177/0013916585176003

Sime, J. D. (1999). Crowd facilities, management and communications in disasters. *Facilities, Vol. 17*(9/10), 313 - 324.

Sime, J. D. (2001). An occupant response shelter escape time (ORSET) model. *Safety Science, 38*(2), 109-125. doi: 10.1016/s0925-7535(00)00062-x

Spearpoint, M. (2004). The Effect of Pre-evacuation on Evacuation Times in the Simulex Model. *Journal of Fire Protection Engineering, 14*(1), 33-53. doi: 10.1177/1042391504034742

Spielberger, C. D., Gorsuch, R. L., & Lushene, R. E. (1970). *Manual for the State-TraitAnxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and Social Psychology Review, 8*(3), 220-247.

Swinth, K. R., & Blascovich, J. (2001). Conformity to group norms in an immersive virtual environment. Paper presented at the annual meeting of the American: Psychological Society.

Szechtman, H., & Woody, E. (2004). Obsessive-Compulsive Disorder as a Disturbance of Security Motivation. *Psychological Review, 111*(1), 111-127. doi: 10.1037/0033-295x.111.1.111

Taylor, S. E., Klein, L. C., Lewis, B. P., Gruenewald, T. L., Gurung, R. A. R., & Updegraff, J. A. (2000). Biobehavioral responses to stress in females: Tend-and-befriend, not fight-or-flight. *Psychological Review, 107*(3), 411-429. doi: 10.1037/0033-295x.107.3.411

Törnros, J. (1998). Driving behaviour in a real and a simulated road tunnel - A validation study. *Accident Analysis and Prevention, 30*(4), 497-503.

Turner, J. C. (1991). *Social influence*. Belmont, CA: Thomson Brooks/Cole Publishing Co.

Ulleberg, P. (2004). Social influence from the back-seat: factors related to adolescent passengers' willingness to address unsafe drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 7*(1), 17-30. doi: 10.1016/j.trf.2003.09.004

Van Der Molen, H. H., & Bötticher, A. M. T. (1988). A hierarchical risk model for traffic participants. *Ergonomics, 31*(4), 537-555. doi: 10.1080/00140138808966698

von Dawans, B., Fischbacher, U., Kirschbaum, C., Fehr, E., & Heinrichs, M. (2012). The Social Dimension of Stress Reactivity. *Psychological Science*. doi: 10.1177/0956797611431576

von der Putten, A. M., Kramer, N. C., Gratch, J., & Kang, S. H. (2010). "It doesn't matter what you are!" Explaining social effects of agents and avatars. *Computers in Human Behavior, 26*(6), 1641-1650. doi: 10.1016/j.chb.2010.06.012

Wiederhold, B. K., & Wiederhold, M. D. (2010). Virtual Reality Treatment of Posttraumatic Stress Disorder Due to Motor Vehicle Accident. *Cyberpsychology Behavior and Social Networking, 13*(1), 21-27. doi: DOI 10.1089/cyber.2009.0394

Williams, A. F., & Wells, J. K. (1995). Deaths of teenagers as motor-vehicle passengers. *Journal of Safety Research, 26*(3), 161-167. doi: 10.1016/0022-4375(95)00012-f

Woody, E. Z., & Szechtman, H. (2011). Adaptation to potential threat: The evolution, neurobiology, and psychopathology of the security motivation system. [Review]. *Neuroscience and Biobehavioral Reviews, 35*(4), 1019-1033. doi: 10.1016/j.neubiorev.2010.08.003

Appendix

Table of Contents Appendix

Appendix A

Information and questionnaire for telephone screening

Screeningfragebogen

Name, Vorname: ____
Adresse: ____

Telefonnummer: **Alter (20 – 69):**

Herzkreislauferkrankungen:
(Ja: generelle Zustimmung, Herzinfarkt, Thrombose)

Ja ☐ Nein ☐

Bemerkungen:

____

Schwanger:

Ja | Nein |

Nerven-/ärztliche Behandlung:
(Ja: Depression, Abhängigkeit, Psychose)

Ja ☐ Nein ☐

Bemerkungen:

____
____

Medikamente:
(Ja: Beta-Blocker, Antidepressiva, Anxiolytika, Neuroleptika)

Ja ☐ Nein ☐

Bemerkungen:

____
____

Wie stark schätzen Sie Ihre Angst vor Tunnel ein?
(0 - 2 = nicht-ängstlich; 6 – 10 = ängstlich)

0	1	2	3	4	5	6	7	8	9	10
keine Angst					mittlere Angst					extreme Angst

Termin: ____

Appendix B

Informed Consent Study 1 and 2

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

Lehrstuhl für Psychologie I - Prof. Dr. Paul Pauli

Biologische Psychologie, Klinische Psychologie und Psychotherapie

Information und Einverständniserklärung zur Datenerhebung im Rahmen der Studie „Fahrerverhalten während Tunnelfahrten"

Würzburg, März 2011

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftliche Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären.

Sollten Sie Fragen zur Studie haben, wenden Sie sich bitte an den Versuchsleiter.

Ziel unserer Studie ist es, Fahrerverhalten während Tunnelfahrten abzubilden. Dies ist ein wichtiger Aspekt im Bereich der Sicherheitsforschung. Infrastrukturen können nur dann sicher gestaltet werden, wenn sie in ihrer Gestaltung auf das menschliche Verhalten abgestimmt werden.

In unserer Untersuchung werden Sie Tunnelfahrten in Virtueller Realität (VR) absolvieren. Sie werden mittels eines Head Mounted Displays (HMD) in die VR versetzt und dort eine Autobahnfahrt durch mehrere Tunnel absolvieren. Während der Tunnelfahrten werden wir Ihren Herzschlag (Elektrokardiogramm, EKG) und die elektrische Aktivität der Haut (elektrodermale Aktivität, EDA) mit oberflächlich auf der Haut angebrachte Klebeelektroden an Ihrem Brustkorb und an Ihren Handinnenfläche ableiten. Auch werden wir Sie während der Tunnelfahrten gelegentlich bitten, Ihre momentane Angst auf einer Skala von 0-100 einzuschätzen. Diese Skala wird Ihnen der Versuchsleiter später noch genauer erklären.

Vor und nach den Tunnelfahrten werden wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung, auf Tunnelangst und Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf ca. 90 Minuten beschränken. Sie erhalten für die Teilnahme an der Studie eine Aufwandsentschädigung von 10€.

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie aus der Untersuchung ausscheiden können. Alle erhobenen Daten werden durch einen Code anonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.

Die Ableitung der Herzrate und der Hautleitfähigkeit mit oberflächlich angebrachten Elektroden birgt kein bekanntes Gesundheitsrisiko. Durch das Gel, das in die Elektroden gefüllt wird, kann es eventuell zu leichten Hautirritationen kommen. In seltenen Fällen kann die Tunnelfahrt in VR zu Symptomen wie Schwindel oder leichter Übelkeit führen. Diese „Simulator Krankheit" ist jedoch in der Regel von kurzer Dauer. Sollten Sie jedoch

2

Schwindel oder Übelkeit empfinden, sprechen Sie bitte den Versuchsleiter an. Dieser wird die Simulation dann sofort beenden.

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Vorgehen einverstanden erklären und, dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

Durch meine Unterschrift bestätige ich:

Ich nehme freiwillig an der Untersuchung „Fahrerverhalten während Tunnelfahrten" teil und bin damit einverstanden, dass die erhobenen Daten in anonymisierter Form wissenschaftlich ausgewertet werden, im Rahmen der Veröffentlichung (Forschungsergebnisse und weiterführender Forschungsvorhaben anonymisiert also ohne Bezug auf konkrete Personen an Dritte (z. B. Gutachter für Fachzeitschriften, Bundesanstalt für Straßenbau oder Mitarbeiter des Instituts für Psychologi(weitergegeben werden können und imInstitut für Psychologie archiviert werden. Ich bin auch damit einverstanden, dass die Ergebnisse der Studie in Gruppen zusammengefasst wissenschaftlich veröffentlicht werden. Die geltenden Datenschutzbestimmungen werden beachtet. Die an der Untersuchung und den Auswertungen beteiligten Personen unterliegen der Schweigepflicht.

Ich hatte ausreichend Zeit, mir zu überlegen, ob ich an der Datenerhebung teilnehmen will, sowie die Gelegenheit, Fragen zu stellen. Mit den erhaltenen Antworten bin ich zufrieden. Ich habe darüber hinaus eine Probandeninformation und eine Kopie dieser Einverständniserklärung (datiert und unterschrieben) erhalten. Ich wurde darauf hingewiesen, dass ich jederzeit von dieser Untersuchung zurücktreten kann, ohne dass mir dadurch ein Nachteil entsteht. Die Daten werden in diesem Falle vernichtet.

Falls Sie noch weitere Frage haben, stellen Sie diese bitte jetzt.

Name des Teilnehmers: ………………………………………………… (bitte Blockbuchstaben)

…………………………………………………

Ort, Datum

………………………………………………………… ………………………………………………………

Unterschrift des Teilnehmers Unterschrift des aufklärenden Versuchsleiters

Appendix C

Informed consent study 3 and 4

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Lehrstuhl für Psychologie I - Prof. Dr. Paul Pauli
Biologische Psychologie, Klinische Psychologie und Psychotherapie

Information und Einverständniserklärung zur Datenerhebung im Rahmen der Studie „Fahrerverhalten während Tunnelfahrten“

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären.

Ziel unserer Studie ist es, Fahrerverhalten während Tunnelfahrten zu untersuchen. Dies ist ein wichtiger Aspekt im Bereich der Sicherheitsforschung. Infrastrukturen können nur dann sicher gestaltet werden, wenn sie in ihrer Gestaltung auf das menschliche Verhalten abgestimmt werden.

In unserer Untersuchung werden Sie Tunnelfahrten in Virtueller Realität (VR) absolvieren. Sie werden mittels eines Head Mounted Displays (HMD) in die VR versetzt und dort eine Autobahnfahrt durch mehrere Tunnel absolvieren. Während der Tunnelfahrten werden wir Ihren Herzschlag (Elektrokardiogramm, EKG) und die elektrische Aktivität der Haut (elektrodermale Aktivität, EDA) mit oberflächlich auf der Haut angebrachten Klebeelektroden an Ihrem Brustkorb und an Ihren Handinnenflächen ableiten. Auch werden wir Sie während der Tunnelfahrten gelegentlich bitten, Ihre momentane Angst auf einer Skala von 0-100 einzuschätzen. Diese Skala wird Ihnen der Versuchsleiter später noch genauer erklären.

Vor und nach den Tunnelfahrten werden wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung, auf Tunnelangst und auf Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf ca. 90 Minuten beschränken. Sie erhalten für die Teilnahme an der Studie eine Aufwandsentschädigung von 10€.

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie aus der Untersuchung ausscheiden können. Alle erhobenen Daten werden durch einen Code anonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.

Die Ableitung der Herzrate und der Hautleitfähigkeit mit oberflächlich angebrachten Elektroden birgt kein bekanntes Gesundheitsrisiko. Durch das Gel, das in die Elektroden gefüllt wird, kann es eventuell zu leichten Hautirritationen kommen. In seltenen Fällen kann die Tunnelfahrt in VR zu Symptomen wie Schwindel oder leichter Übelkeit führen. Diese „Simulator Krankheit“ ist jedoch in der Regel von kurzer Dauer. Sollten Sie Schwindel oder Übelkeit empfinden, sprechen Sie bitte den Versuchsleiter an. Dieser wird die Simulation dann sofort beenden.

2

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Vorgehen einverstanden erklären und dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

Durch meine Unterschrift bestätige ich:

Ich nehme freiwillig an der Untersuchung „Fahrerverhalten während Tunnelfahrten" teil und bin damit einverstanden, dass die erhobenen Daten in anonymisierter Form – also ohne Bezug auf konkrete Personenangaben - wissenschaftlich ausgewertet werden, im Rahmen der Veröffentlichung der Forschungsergebnisse und weiterführender Forschungsvorhaben anonymisiert an Dritte (z. B. Gutachter für Fachzeitschriften, Bundesanstalt für Straßenbau oder Mitarbeiter des Instituts für Psychologie) weitergegeben werden können und im Institut für Psychologie archiviert werden. Ich bin auch damit einverstanden, dass die Ergebnisse der Studie in Gruppen zusammengefasst wissenschaftlich veröffentlicht werden. Die geltenden Datenschutzbestimmungen werden beachtet. Die an der Untersuchung und den Auswertungen beteiligten Personen unterliegen der Schweigepflicht.

Ich hatte ausreichend Zeit, mir zu überlegen, ob ich an der Datenerhebung teilnehmen will, sowie die Gelegenheit, Fragen zu stellen. Mit den erhaltenen Antworten bin ich zufrieden. Ich habe darüber hinaus eine Probandeninformation erhalten. Ich wurde darauf hingewiesen, dass ich jederzeit von dieser Untersuchung zurücktreten kann, ohne dass mir dadurch ein Nachteil entsteht. Die Daten werden in diesem Falle vernichtet.

Falls Sie noch weitere Fragen haben, stellen Sie diese bitte jetzt.

Name des Teilnehmers: .... (bitte Blockbuchstaben)

....

Ort, Datum

....

Unterschrift des Teilnehmers Unterschrift des aufklärenden Versuchsleiters

Appendix D

Informed Consent Study 5

Lehrstuhl für Psychologie I - Prof. Dr. Paul Pauli

Biologische Psychologie, Klinische Psychologie und Psychotherapie

Information und Einverständniserklärung zur Datenerhebung im Rahmen der Studie „Verhalten im Tunnel“

Sehr geehrte Probandin, sehr geehrter Proband,

vielen Dank, dass Sie sich bereit erklärt haben an dieser wissenschaftlichen Untersuchung am Lehrstuhl für Psychologie I der Universität Würzburg teilzunehmen. Mit diesem Schreiben wollen wir Sie über die Art der Untersuchung, deren Ablauf und die verwendeten Methoden aufklären.

Ziel unserer Studie ist es, Verhalten in Straßentunneln zu untersuchen. Dies ist ein wichtiger Aspekt im Bereich der Sicherheitsforschung. Infrastrukturen können nur dann sicher gestaltet werden, wenn sie in ihrer Gestaltung auf das menschliche Verhalten abgestimmt werden.

Vor und nach der Untersuchung möchten wir Sie bitten, einige Fragebögen auszufüllen. Diese beziehen sich auf einige allgemeine Angaben zu Ihrer Person, auf Ihre momentane Stimmung, auf Tunnelangst und auf Ihr Verhalten in verschiedenen Situationen. Der zeitliche Aufwand wird sich für Sie auf ca. 90 Minuten beschränken.

Die Teilnahme an der Untersuchung ist völlig freiwillig. Das bedeutet auch, dass Sie jederzeit ohne einen Nachteil für Sie aus der Untersuchung ausscheiden können. Alle erhobenen Daten werden durch einen Code anonymisiert und streng vertraulich nach geltenden Datenschutzrichtlinien behandelt.

Der Versuch wird in Virtueller Realität stattfinden, d.h. sie werden durch eine 3D-Brille von Computern erzeugte, auf eine Wand projizierte Bilder sehen. Ihre Aufgabe wird es sein, mit diesen Personen auf verschiedene Art und Weise zu interagieren. In seltenen Fällen kann die Virtuelle Realität Übelkeit oder Schwindel auslösen, ähnlich wie eine Karussellfahrt. Falls dies passiert, so teilen das bitte sofort mit.

Bitte erklären Sie nun mit Ihrer Unterschrift, dass Sie die Probandeninformation sorgfältig durchgelesen und verstanden haben, dass Sie sich mit dem beschriebenen Verfahren einverstanden erklären und dass der Versuchsleiter ihre Fragen zu Ihrer Zufriedenheit beantwortet hat.

2

Einverständniserklärung

Ich erkläre hiermit, dass ich das Informationsblatt zu den Studien **„Verhalten im Tunnel"** gelesen und verstanden habe und meine Fragen zufriedenstellend beantwortet wurden.
Ich willige ein, an der Untersuchung teilzunehmen und dass die erhobenen Daten in anonymisierter Form wissenschaftlich ausgewertet werden.
Ich bin darüber informiert worden, dass ich die Untersuchung jederzeit abbrechen kann, ohne dass mir persönliche Nachteile entstehen.

Würzburg, den ………………… Unterschrift: ……………………………………………………………

Geburtsdatum: …………………

Name und Anschrift: ……………………………………………………………………………………

………

………

Unterschrift des Untersuchungsleiters: ……………………………………………………………

Appendix E

Questionnaire on tunnel safety, social presence, and perceived behavioral realism

Nachbefragung NB Proband Nr. ___________

Vielen Dank für die Teilnahme an der Studie. Bitte füllen Sie zum Abschluss noch diesen Fragebogen aus. Die Fragen beziehen sich auf die Situation im Tunnel. Es gibt keine richtigen oder falschen Antworten. Wenn Sie sich bei einer Frage nicht sicher sind, antworten Sie am besten spontan.

1. **Wie sicher waren Sie sich in der Situation, was Sie tun sollten?**

O	O	O	O	O
sehr unsicher	unsicher	weder noch	sicher	sehr sicher

2. **Wie gefährlich war die Situation im Tunnel?**

O	O	O	O	O
vollkommen ungefährlich	ungefährlich	weder noch	gefährlich	sehr gefährlich

3. **Wie sehr haben Sie daran geglaubt, dass der Tunnel so ausgestattet ist, dass Sie sich im Notfall retten können?**

O	O	O	O
gar nicht	etwas	ziemlich	sehr

4. **Wie sehr haben Sie daran geglaubt, dass Sie die Kompetenzen dazu haben, sich im Notfall aus dem Tunnel zu retten?**

O	O	O	O
gar nicht	etwas	ziemlich	sehr

5. **Haben Sie auf das Verhalten der anderen Person geachtet?**

O	O	O	O	O
gar nicht	etwas	mittel	stark	sehr stark

6. **Haben Sie sich durch das Verhalten der anderen Person beeinflusst gefühlt?**

O	O	O	O	O
gar nicht	etwas	mittel	stark	sehr stark

7. **Bitte beschreiben Sie kurz das Verhalten der anderen Person während des Ereignisses:**

____
____
____
____
____

8. **Die andere Person verhielt sich wie eine reale Person.**

O	O	O	O	O
Stimme gar nicht zu	Stimme nicht zu	Stimme etwas zu	Stimme zu	Stimme voll und ganz zu

9. **Die andere Person bewegte sich wie eine reale Person.**

O	O	O	O	O
Stimme gar nicht zu	Stimme nicht zu	Stimme etwas zu	Stimme zu	Stimme voll und ganz zu

10. **Es fühlte sich so an, als ob die andere Person mich sehen könnte.**

O	O	O	O	O
Stimme gar nicht zu	Stimme nicht zu	Stimme etwas zu	Stimme zu	Stimme voll und ganz zu

11. **Es fühlte sich so an, als ob die andere Person wusste, dass ich anwesend war.**

O	O	O	O	O
Stimme gar nicht zu	Stimme nicht zu	Stimme etwas zu	Stimme zu	Stimme voll und ganz zu

12. **Es fühlte sich so an, als ob die andere Person mich anschauen würde.**

O	O	O	O	O
Stimme gar nicht zu	Stimme nicht zu	Stimme etwas zu	Stimme zu	Stimme voll und ganz zu

13. **Wie gut sind Sie über die Sicherheitsausstattung von Tunneln informiert?**

O	O	O	O	O
gar nicht	etwas	mittel	gut	sehr gut

14. **Wie sind Sie über richtiges Verhalten im Tunnel informiert?**

O	O	O	O	O
gar nicht	etwas	mittel	gut	sehr gut

15. Wie oft fahren Sie normalerweise Auto?

O	O	O	O	O
gar nicht	Weniger als einmal im Monat	Mehr als einmal im Monat	Mehr als einmal pro Woche	täglich

16. Würden Sie sich selbst als einen sicheren Autofahrer bezeichnen?

O	O
ja	nein

17. Besitzen Sie eine Spielkonsole/ Computer mit Gamepad?

O	O
ja	nein

18. Wie oft spielen Sie Computerspiele?

O	O	O	O	O
gar nicht	Weniger als einmal im Monat	Mehr als einmal im Monat	Mehr als einmal pro Woche	täglich

19. Wie geübt sind Sie im Umgang mit Gamepads?

O	O	O	O	O
gar nicht	kaum	etwas	ziemlich	experte

20. Wie geübt sind Sie im Umgang mit Gamepads?

O	O	O	O	O
gar nicht	kaum	etwas	ziemlich	experte

21. Wie geübt sind Sie in 3D Computerspielen (Autorennen, Firstperson spiele)?

O	O	O	O	O
gar nicht	kaum	etwas	ziemlich	experte

Appendix F

Additional table for study 5: Binary logistic regression models for emergency exit location.

Results of binary logistic regression models. Trial order did not predict the frequency of the different behavioral outcome variables.

Tunnel scenario	Emergency exit relative to starting position	χ^2	p
No VA	Right	0.18	.91
No VA	Left	7.03	.03[1]
No conflict condition	Right	3.38	.06
No conflict condition	Left	3.82	.14
Conflict condition	Right	1.62	.44
Conflict condition	Left	4.49	.10
Passive condition	Right	3.95	.13
Passive condition	Left	1.16	.55

Note: all $df = 2$; [1] no significant prediction after Bonferroni correction.

Appendix G

Additional table for study 5: Comparisons of trial order A and B with regard to trial duration, pre-movement time, and movement time

Comparisons of trial order A and B with regard to trial duration, pre-movement time, and movement time

Dependent variable	Tunnel scenario	Emergency exit relative to starting position	t	p
trial duration	No VA	Right	-0.07	.94
trial duration	No VA	Left	1.42	.16
trial duration	No conflict condition	Right	3.31	.002
trial duration	No conflict condition	Left	-1.06	.29
trial duration	Conflict condition	Right	1.86	.07
trial duration	Conflict condition	Left	-0.85	.39
trial duration	Passive condition	Right	-0.63	.53
trial duration	Passive condition	Left	-0.49	.63
Pre-movement time	No VA	Right	-1.34	.18
Pre-movement time	No VA	Left	0.04	.96
Pre-movement time	No conflict condition	Right	-1.22	.22
Pre-movement time	No conflict condition	Left	0.48	.63
Pre-movement time	Conflict condition	Right	-1.16	.25
Pre-movement time	Conflict condition	Left	0.38	.70
Pre-movement time	Passive condition	Right	1.47	.15
Pre-movement time	Passive condition	Left	1.18	.24
movement time	No VA	Right	-1.33	.19
movement time	No VA	Left	1.56	.12
movement time	No conflict condition	Right	2.96	.005
movement time	No conflict condition	Left	-0.32	.75
movement time	Conflict condition	Right	0.83	.41
movement time	Conflict condition	Left	-0.16	.87
movement time	Passive condition	Right	1.27	.21
movement time	Passive condition	Left	0.78	.44

Note: all *df* = 38

Appendix H

Curriculum Vitae (German)

TAGUNGSBEITRÄGE

Kinateder, M., Müller, M., Mühlberger, A., & Pauli, P. (2012). Social Influence in a Virtual Tunnel Fire - Influence of Passive Virtual Bystanders. In *5th International Symposium on Human Behavior in Fire Symposium 2012* (pp. 506-516). London: Interscience Communications Ltd.
Kinateder, M. (2011). Gefahr bekannt, Gefahr gebannt? Der Einfluss von Informationen und Instruktionen auf das Verhalten bei einem virtuellen Tunnelbrand. Poster präsentiert auf der Tagung experimentell arbeitender Psychologen. Halle (13.-16.März).

Kinateder, M., Brütting, J., Eder, S., Mühlberger, A. & Pauli, P. (2010) Fluchtverhalten bei Notfällen in Straßentunneln. Vortrag auf dem 8.Tunnelsymposium der SIGRIST Photometer Gmbh. Hamburg (10.-11.Juni).

Kinateder, M., Brütting, J., Eder, S., Mühlberger, A. & Pauli, P. (2009) User Behavior in Tunnel accidents: A Virtual Reality Study. Poster präsentiert auf dem Annual Meeting of the Human Factors and Ergonomics Society: Europe Chapter. Linköping (Schweden).

Artikel

Mühlberger, A., **Kinateder, M.**, Brütting, J., Eder, S., Müller, M., & Pauli, P. (submitted). The Role of Information and Instructions on Human Behavior in Tunnel Accidents: A Virtual Reality Study. Manuscript submitted for publication.

Kinateder, M., Mühlberger, A., & Pauli, P. (2012). Sicher durch den Tunnel? – Menschliches Verhalten bei Bränden in Straßentunneln / Safely through the tunnel? – How People Behave in Tunnel Fires. *Tunnel*, 5/2012, 26-32.
Kinateder, M., Pauli, P., Müller, M., Krieger, J., Heimbecher, F., Rönnau, I., Bergerhausen, U., Vollmann, G., Vogt, P., & Mühlberger, A. (in press). Human Behavior in Severe Tunnel Accidents: Effects of Information and Behavioral Training. *Transportation Research Part F: Traffic Psychology and Behavior*.

Kinateder, M., Pauli, P., Müller, M., & Mühlberger, A. (in press). Stresserleben und verändertes Fahrverhalten nach einem virtuellen Autounfall. *Zeitschrift für klinische Psychologie und Psychotherapie.*

Fellgiebel, A., Keller, I., Marin, D., Müller, M.J., Schermuly, I., Yakushev, I., Albrecht, J., Bellhäuser, H., **Kinateder, M.**, Beck, M., Stoeter, P. (2009). Diagnostic utility of different MRI and MR angiography measures in Fabry disease. *Neurology*, 72, 63-8.

Appendix I

Declaration of Originality

Hiermit erkläre ich, dass ich die vorliegende Dissertation selbstständig verfasst habe und keine anderen als die angegebenen Quellen benutzt und die aus fremden Quellen direkt oder indirekt übernommenen Gedanken als solche kenntlich gemacht habe. Die Arbeit habe ich bisher an keiner anderen Universität oder sonstigen wissenschaftlichen Einrichtung vorgelegt.

(I hereby declare that this dissertation is my own work and that all the sources that I have used or quoted have been acknowledged by means of complete references. This work has not been submitted previously for a degree at any university or other academic institution.)

Max Kinateder Würzburg, 04.03.2013