A SIMULATOR-BASED TRAINING FOR EMERGENCY VEHICLE DRIVING

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ABSTRACT

Adequate hazard perception and safe driving behavior in complex traffic situations are prerequisites for efficient emergency vehicle driving. In this field of interest, simulator training can be a useful tool to prepare young drivers to cope with the demands of real traffic conditions. In a pilot project, driving simulation as part of a comprehensive driver training program was implemented by the Bavarian Police. The project aims in particular at the evaluation of a high fidelity simulator as a training device. It was carried out in cooperation with the Center for Traffic Sciences at the Wuerzburg University (IZVW).

This paper focuses primarily on the design of the simulator-based-training. It gives an overview of the training goals, the contents of the standardized curriculum and their implementation to the simulation environment. Initial results of the training evaluation are presented. The assessment of training success was based on ratings by driving instructors and independent observers. Additional measures recorded were training acceptance as well as incidence and degree of simulator sickness. Finally, the paper will outline some general demands concerning traffic scenario design in training.

INTRODUCTION

Emergency responses are associated with a heightened accident risk and therefore demand a high level of driving skills from police officers. According to current taxonomies of the driving task (e.g. Michon,1985 [1]), Hatakka et al., 1999 [2], Hoeschen et al., 2001 [3]) these skills can be described at three distinct levels: the control level which refers to vehicle handling, such as steering or speed control; the maneuvering or tactical level concerning the mastering of traffic conditions, and the strategic level which defines the general planning of a trip including an evaluation of the costs and risks involved. Emergency driving requires advanced proficiencies in all three levels. Additionally, the driving task is embedded within the wider context of policing.

Current practical driver training has so far mainly focused on advanced vehicle control skills. Up till now, the mastering of complex traffic situations – especially under emergency conditions - could only be done in real traffic with the risk of endangering others. Therefore, for safety reasons these skills were only taught in theoretical terms, rather than through practice. The development of simulation technology now offers the possibility to train emergency driving in a realistic traffic environment.

The advantages of simulator-based trainings include the following (a) controllability in terms of intentional design of situations, (b) repeatability of tasks and (c) measurability of behavior. The error-tolerant environment of simulation even allows the training of safe critical maneuvers. Whereas the advantages and in consequence the potential benefits are evident, there is some discussion about the validity of simulator training regarding behavior in the real world. In aviation, the benefits of using flight simulators - especially with the training of emergency situations – are fully accepted and it is therefore an essential part of all safety programs. These experiences can at least in part be applied to driving simulation; however these analogies are limited by the special requirements posed by simulating traffic. Whereas flight simulation is characterized mostly by the effective handling of a complex technical system, driving simulation must deal mainly with a wide variety of complex traffic situations. In addition, existing driving simulations and their respective training programs are frequently not guided by a comprehensive theory of learning, but rather result from practical considerations and limited technical capacities of the simulator in use. Consequently, convincing evaluation studies including the assessment of transfer effectiveness are rare (Mehl & Schütte,1984 [4]).

The following article describes a pilot project commissioned by the Bavarian Police Force whereby a newly developed emergency driving simulation program was integrated into a comprehensive driver education curriculum. The Center for Traffic Sciences at the University of Wuerzburg was involved with the scientific foundation of the training concept as well as with the evaluation of the program.

DESIGNING THE SIMULATOR-BASED TRAINING PROGRAM

The efficiency of simulator-based training depends substantially on a careful design. The following paragraph outlines the different steps that have been taken in the development of this simulator training program:

1. Analysis of the emergency response in terms of task requirements and demands on the driver.

2. Definition of learning targets as well as specification of training scenarios for the simulation.

3. Implementation of scenarios in the simulation environment.

4. Maneuver specific error analysis and definition of correct maneuver specific behavior.

5. Specification of the instructors' role.

6. Structure of the simulator training program.

7. Empirical evaluation.

Step I: Analysis of the emergency response

Task requirements of emergency responses and educational needs were defined by analyzing recent research literature, examining existing training curricula and by observing current police driver training courses. Furthermore, accidents involving emergency vehicles were analyzed in detail and a pilot study in actual traffic was conducted in order to compare the driving behavior of expert and novice drivers under emergency response conditions. In this study two teams of police officers (one experienced team versus one with only a little emergency response experience) were asked to drive along a predetermined route under emergency conditions (with lights and sirens) in a vehicle equipped with measuring instruments. Each officer took turns as a driver and as a co-driver. The following measures were recorded on all four drives and compared to drives without lights and sirens:

- video observation of vehicle crew behavior and behavior of other road users

- subjective measures of workload

- pulse rate

- operational inputs and vehicle reactions.

In addition, the driving situations were rated by experts for their degree of danger. From these sources of information several deficits of novice emergency driving became apparent. The most important were identified in decision making and tactical driving skills, with a substantial lack of efficient strategies for active error prevention and error avoidance. Instead of actively managing a traffic situation, novice emergency drivers showed little anticipation of situation development resulting in a pure reactive driving behavior (see also Welles & Holdsworth, 2002 [5]). In addition, young drivers often showed a poor understanding of the effects of their own driving behavior on other road users. Not only did they demonstrate a lack of anticipation for what other drivers on the road may do when confronted with an emergency vehicle, but they also allowed no margin of error for the behavior of other road users. A substantial lack of performance could also be observed in the cooperation of the crew. Whereas the experienced team showed a refined co-working both in dealing with traffic situations and mission requirements (e.g. interacting with the headquarter or asking for additional information), the novice crew was not able to manage the different requirements efficiently.

Compared to these deficiencies at the guidance level of driving and in the integration of multiple demands, the young officers showed a sufficient performance at the maneuvering level. This result can be attributed to the effectiveness of two prior driving training sessions, which are a regular part of the police education.

Step II: Definition of learning targets and specification of scenarios for the simulation

The research literature provides little information concerning the question of which scenarios should be employed in a traffic simulation of emergency vehicle driving. In order to define appropriate scenarios extensive analyses based on diverse sources were necessary, these included the following:

1. a bibliographical survey on current research of driver training and analysis of existing teaching material

2. boards of experts; police driving instructors and experienced officers were asked to participate in the designing of the scenarios and to impart their specific knowledge

3. an analysis of accident records and relevant laws and court decisions and

4. traffic observations and observations of driver behavior during emergency vehicle driving

The analyses made clear that the problems must be differentiated into two groups, those originating from the fact that police trainees are young drivers and those stemming from the particular difficulties posed by emergency driving. There is a huge body of literature concerning the problem of young drivers, e.g. risky driving, accident proneness, and safety-negative motives such as sensation and thrill seeking. Consequently, recent training programs suggest that more emphasis should be laid on teaching safe driving strategies, anticipation of potential hazards and

other higher order skills instead of merely focusing on vehicle handling. We therefore adopted the following list of tasks proposed by the EU-project TRAINER (Höschen et al., 2001 [3]):

- tasks related to traffic conditions; following, overtaking, entering and leaving traffic, lane changing, scanning the road, reacting to other road users

- tasks related to roadway characteristics; negotiating intersections, junctions and roundabouts, turning, reacting to traffic signs and signal lights, and negotiating road characteristics such as curves

- tasks related to the environment; night driving, bad weather driving

- knowledge about risk increasing factors; insufficient skills and incomplete automation, information overload, insufficient anticipation, and risky driving style.

- knowledge about self-evaluation; realistic self evaluation, awareness of personal driving style.

These general learning goals for novice drivers must be complemented by specific tasks that characterize emergency driving as derived in step I above:

- negotiating with cars that under normal circumstances would have the right of way

- proper use of irregular lanes

- clearing traffic; creating alternative paths in dense traffic or traffic jams

- teamwork; the co-driver is intended to support the driver in performing the driving task, to maintain radio communication and to pass important information at the right time to the driver

- continuous monitoring of whether the emergency vehicle is noticed by other road users

- proper use of warning devices.

The training of emergency driving should comprise both lists of learning targets and the scenarios should be chosen in such a way that all demands are met. The instructors should be sensitive to both sources of problems and give appropriate feedback (see also step V).

The list of learning goals was transformed into a list of driving scenarios, which was subsequently given to the simulator manufacturer (STN Atlas Electronic GmbH) in order to adapt the existing software to these requirements (Kirmse 2003 [7]). In contrast to the general practice, the scenarios were derived from the predefined learning goals instead of resulting from the technical capacities of the simulation software. Most scenarios specified for simulation were realized, however, a small number were not compatible with the particular set up of the simulator at the time (pursuing a car for example). These learning contents had to be imparted by other educational methods.

Step III: Implementation of training scenarios in the simulation environment

Definition of the training course and the traffic scenarios

To facilitate the design of the scenarios, a multidimensional classification scheme for intersections and roads for each of the three databases was firstly developed. The description and classification of stationary features of the road elements included traffic lights, road signs concerning the right of way, the number of lanes leading towards and away from junctions, one-way streets, speed limits, bus stops, pedestrian crossings and car-parks. Matching scenario requirements to the list of potential road environments revealed that – like in reality – each scenario could only take place in a very limited number of locations within the databases. As neither the road network nor the traffic signs in the database can be modified, the argument of limited degrees of freedom - often used in connection with training in real traffic - also applies to some degree for fixed database simulators. The flexibility in choosing driving tasks is

therefore markedly reduced and the notion of individual training by adapting the driving course to the skills of the driver is simply not applicable.

Dynamic features of the situations: parameterization of road user behavior

In actual traffic the complexity of a driving situation is defined through the existence of different kinds of road users and dynamic features of the traffic environment. Besides different motor vehicles, pedestrians and cyclists also contribute to traffic complexity. Current traffic simulation technology only allows the inclusion of different motor vehicles and of several single pedestrians. Up till now, other kinds of road users could not be represented.
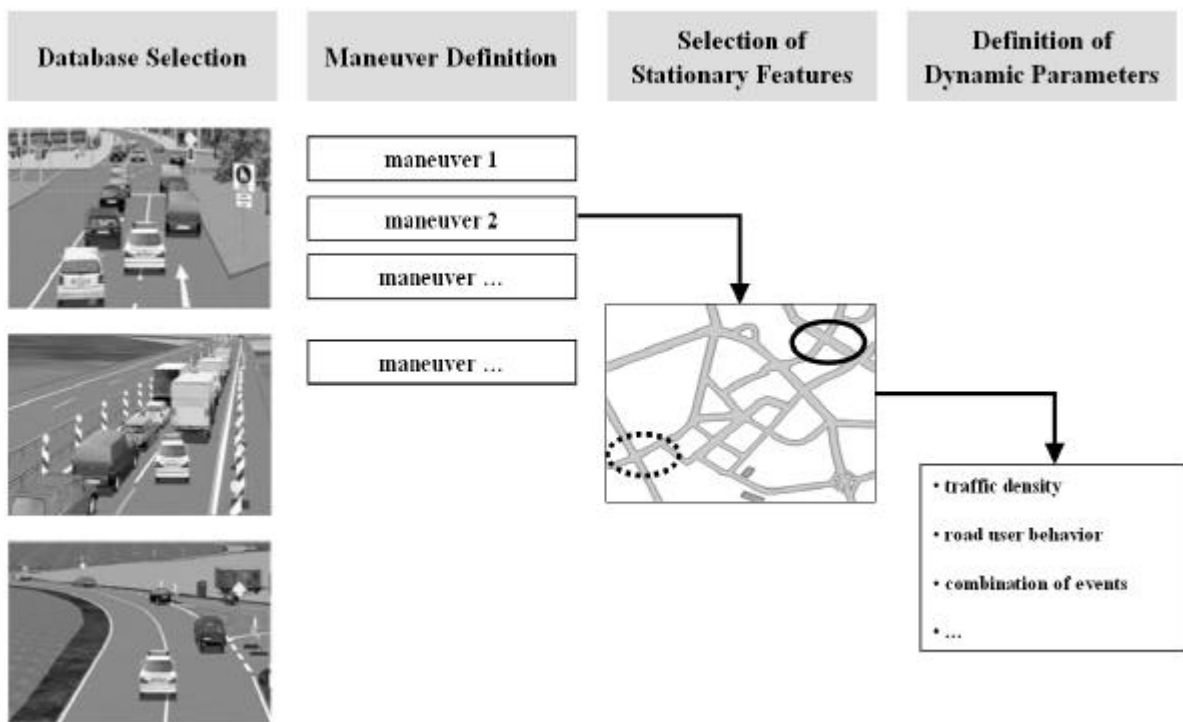

FIGURE 1: Transfer of training contents into simulation.

Traffic flow is defined by using two procedures. The first is the parameterization of the autonomous traffic, which can be varied by parameters such as traffic density and the proportion of road users with different behavioral patterns etc. Once these parameters are set, they are valid for the whole trip and cannot be altered for different scenarios. The second procedure is the definition of special events by setting parameters for a number of predefined vehicles. Subsequently, each scenario contains a combination of stochastic elements coming from the autonomous traffic and deterministic elements coming from the event definitions. In scenario design this combination sometimes leads to a kind of "trial-and-error"-procedure with much iteration. The same scenario has to be tested several times in order to achieve the desired effects. Even in the case of highly experienced instructors the design of a scenario is very time-consuming. The random component of traffic definition together with the variability introduced by the driver has the advantage that any two realizations of the same scenario will differ in their exact course. The disadvantage however is that it cannot be guaranteed that the scenario will actually occur as intended.

Step IV: Maneuver specific error analysis and definition of target behavior

As mentioned above, each driving scenario was derived from basic learning targets. As a first step toward training evaluation the degree to which the trainee has achieved the learning targets has to be evaluated. Thus, correct and

incorrect behavior for each specific scenario must be defined. For this purpose a second board of experts was appointed, and based on video material gathered from observations during the first training runs

1. the specific demands and difficulties of the scenarios were outlined, which closely correspond to the catalogue of learning goals described in Step II,

2. guidelines and standards for adequate driving behavior in each scenario were developed and

3. a list of driving errors was compiled for each scenario.

Step V: Specification of the role of the instructors

The success of simulator training fully depends on the instructor, his competence and his behavior. Therefore, the "training of the trainers" is an important task within the implementation process. Firstly, instructors must be able to handle the simulator's hardware and software. In order to ensure acceptance of the new training tool they should be engaged in the development of the training program from the very beginning. The instructors' attitude towards the simulator heavily influences the trainees' acceptance of the training.

Secondly, good didactic skills are a crucial component of teaching in the simulator. To date, commercially available driving simulators have not provided sufficient objective measures of trainee performance. An automatic assessment and evaluation of driving behavior in the simulator is still very far away and therefore substantial effort still has to be made in order to gather relevant data from the simulator concerning driving behavior, and to develop sensitive criteria for the evaluation of driving performance. These steps will provide the basis of an individual-centered training design and adaptive learning procedures. Currently however, diagnosis, documentation and evaluation of the trainees' entrance level of performance and their learning progress must be and will be carried out by the instructors. Even with automatic performance assessment, there would still remain certain aspects of the training that could not be described by objective criteria delivered from the simulator. These include for example strong emotional reactions that accompany emergency driving even in a simulated environment. Also, as mentioned before, police trainees belong to the classified group of young drivers, which means that some of them will display safety-negative driving motives as well as risky driving styles. In order to change such attitudes and behaviors it is crucial to have trainees interact with a police professional, who is able to relate training scenarios in the simulator to his own experience of the demands of emergency response driving in actual traffic.

Step VI: Structure of the simulator training

The driving simulator employed in the pilot project was manufactured by STN ATLAS Electronic GmbH. The simulator consists of a motion system with six degrees of freedom and provides a visual range of 210x40 degrees and three rear views. Fixed onto the motion platform is an original BMW cabin that in addition to the customary instrumentation, has been supplemented with police equipment (see figure 1). The simulation offers three independent fixed databases that allow the training of emergency responses to take place in rural and urban environments as well as on the motorway. Traffic simulation generates stochastic interactive traffic. The behavior of autonomous traffic can be overruled for selected vehicles in order to create critical scenarios such as violations of right of way or traffic jams.

FIGURE 2 The driving simulator and observation facilities.

Due to organizational limitations a group of 12 trainees must be trained within two days. During the training course, every trainee spends 90 minutes in the simulator (45 minutes per day). The training is carried out in teams of two (driver and co-driver), which means that every trainee spends another 90 minutes as an observer of the training outside the simulator yet connected to the driver by voice radio.

The design of the training program was devised using the following basic principles:

- A substantial prerequisite for simulator training efficiency is sufficient adaptation to the virtual environment. Therefore, a first very easy test drive in the simulator ensures that trainees are familiarized with the simulator before starting the emergency response training.

- The simulator training includes training sequences of increasing difficulty. This is achieved by using increasingly complex road environments, by raising traffic density and by increasing the number of traffic scenarios in later training sequences.

- In order to apply the behavior learned in previous training sequences and to stimulate learning transfer, the driving scenarios are repeated several times in different environments.

- Each emergency drive is replayed by the instructor and then discussed with the trainee immediately after completion of the drive.

Introduction and adaptation to the simulation environment

Before starting the simulator drive participants receive an introduction to the simulator, in which the functions and targets of the training program are outlined. In regard to training acceptance it is particularly important to point out not only the facilities, but also the limitations of the simulator. This especially applies to motion perception as it is quite different from real driving, especially in high-intensity driving situations. Therefore, two familiarization rides are included:

- An initial training sequence in the least complex environment (motorway). This is provided in order to allow the trainee to become comfortable with the simulator. The driver is asked to carry out simple steering maneuvers for instance changing lanes; however the driving style is to a large extent left to the driver. Following the recommendations from simulator sickness research this first trip is kept very short (approximately 5 minutes). The short duration and emphasis on very simple driving maneuvers without strong dynamic reactions of the vehicle, is meant to minimize the incidence of simulator sickness that has turned out to be a serious problem in simulator training (see below). During the first trip lights and sirens are not used in order to avoid additional stress.

- Secondly, a drive through rural environment is provided. Basic driving maneuvers are trained such as accurate braking, exact steering in curves and at junctions, and correct estimations of distances and the dimensions of the vehicle.

Emergency Driving Training;

Two sets of training sequences were developed; each includes the same number and kind of training scenarios, but differs in the order of scenarios and routes. Therefore, both trainees in the team have equal learning opportunities, as neither has the advantage of being familiar with the route due to having observed the drive of his team partner beforehand.

The first day's emergency training includes driving with lights and siren in the rural setting, which is then followed by a trip in urban traffic. The second day begins with motorway driving and then consists of two subsequent drives in urban settings emphasizing the negotiation of intersections and junctions, as these are particular locations responsible for a large percentage of major accidents involving emergency vehicles.

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INITIAL RESULTS OF TRAINING EVALUATION

The main aim of the pilot project is to decide whether simulation provides an efficient tool in the training of emergency driving. Thus, from the beginning of the training a comprehensive evaluation program has been conducted aiming to optimize the driving simulator training and its integration into the whole curriculum. Following the model of Kirkpatrick (1994 [9]), evaluation has to be conducted at four levels: reactions, learning, transfer and results. The program is still currently being assessed at the first two levels. Application of the practice and its benefits will be shown over the next two years of the project.

Training motivation and acceptance

The mean age of the trainees was 22 years (standard deviation 2.6, N=208). Approximately 40% of these young police officers at the time of the training had no experience with driving emergency vehicles, and 50% had already carried out up to five emergency responses during their work placement. Overall the motivation for the training can be described as being high and the attitude towards the simulator was positive. The preponderant number of trainees believed that simulator training would be a valuable preparation for negotiating real traffic. Only 7% of the participants expressed doubts beforehand. For a sample of n= 32 trainees, instructor ratings on training motivation were collected using a 5-point-scale (ranging from very poor=1 to very high=5). The mean score of ratings was m=4.09 (s=.64), showing the majority of trainees to be eager to learn. Further answers revealed that the realistic behavior of other road users plays a crucial role for the acceptance of the training.

Simulator Sickness

Simulator sickness is a well-known problem associated with exposure to virtual environments and could seriously affect both training acceptance and effectiveness. In order to assess the extent to which the training induces simulator sickness symptoms, participants were required to fill in a questionnaire at the end of each drive. The questionnaire is largely based on the Simulator Sickness Questionnaire (SSQ, Kennedy et al. 1993 [7]). In contrast to the SSQ however, six instead of four point scales are used in order to assess changes over the training course in a more sensitive way.

Results from the questionnaire study indicate that simulator sickness is a serious problem, with the reported symptoms mainly falling into the groups "nausea" and "disorientation". Oculomotor symptoms were comparably seldom reported. In accordance with the results reported in the literature large individual differences in the susceptibility to simulator sickness were found. While 23% of the participants did not suffer from nausea, about 35% of the trainees reported high to very high degrees of nausea. The high sickness scores resulted in considerable drop out rates.

Figure 1 illustrates the percentage of drop out incidents over the course of the two-day training course. 'Drop outs' were defined as training sequences that were not begun at all or prematurely terminated due to severe symptoms of simulator sickness. Data were gathered from a sample of n= 69 trainees (n= 50 men, n=19 women). The figure shows increasing rates on both training days: only the first short familiarization run was finished by all trainees, already 5% of the trainees prematurely terminated the second drive. At the end of the first day of training 'drop out' rates reached levels as high as 20%. Similar drop out rates were also observed on the second day. Self-reports and drop out rates showed that there was a remarkably higher susceptibility to motion sickness for women.
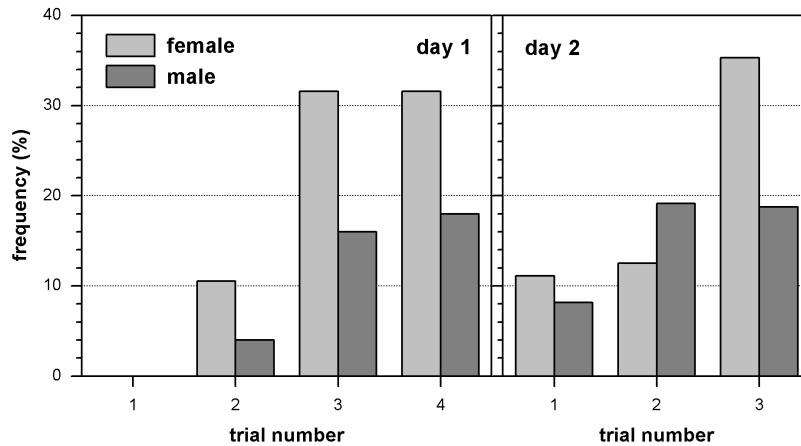

FIGURE 3 Percentage of drop outs during the course of the training.

The high 'drop out' rate might be explained by several aggravating factors that affect the incidence and degree of symptoms:

- First of all, emergency driving mainly includes maneuvers that are characterized by a high rate of linear and rotational acceleration. These high-intensity maneuvers, e.g. stops or 90-degree turns, are suspected to increase sickness scores drastically (Watson 1998, [8]).

- Furthermore, due to organizational constraints simulator training has to be accomplished within two days. Therefore, trainees are exposed not to one but to several simulator rides per day, each separated by breaks of about 15-20 minutes. Experience from pilot simulator training shows that sickness rates are highest when multiple simulator hops are carried out on the same day or one day apart (Kennedy et al. 1993) [7]. However, in the case of the emergency driving training, the tight schedule makes the optimal recommended spacing of 2 to 5 days between repeated exposures impossible.

Apart from task characteristics and exposure, features of the motion system also appeared to be an important factor. Since the implementation of the simulator based-training several engineering changes have been made to the motion system configurations, which have consequently shown significant influences on sickness scores. Furthermore, there was evidence from pilot investigations that simulator sickness might be reduced under fixed-base conditions. Further research will be conducted in this direction.

Performance assessment

Adaptation to the simulation environment

Safe simulator handling is a prerequisite for the training of adequate traffic behavior, otherwise effects related to handling difficulties will obscure the effects related to the mastering of traffic situations. In order to assess handling difficulties, self-reported ratings of simulator handling and adaptation to simulator environments were collected on a 5-point-scale with each verbally anchored category subdivided into 2 points. The scale ranged from very poor to

very good and ratings were carried out after each training sequence. The analysis only included trainees who fully accomplished the training program.

Large individual differences in adaptation to simulator environment were found. Self-reported familiarization slightly increased over the course of the four sessions on the first training day and then reached a relatively constant level. Problems with adaptation were mainly caused by unfamiliar vehicle reactions to operational input, this was particularly apparent for steering and breaking. Further investigations will put special emphasis onto the development of an assessment methodology that is based on objective performance criteria.
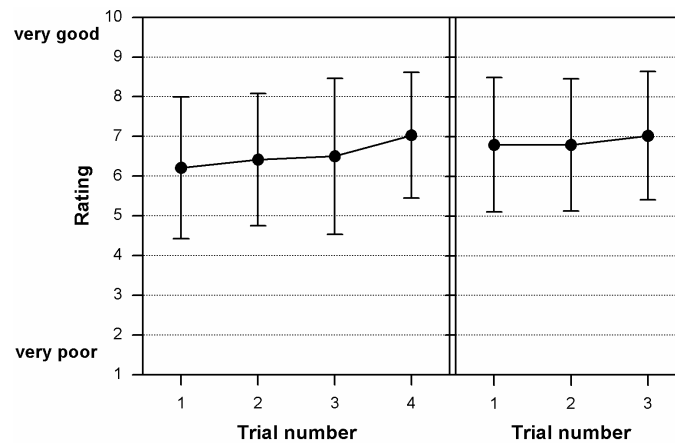

FIGURE 4 Means and standard deviations of self reported ratings for adaptation to the simulation environment (n=32).

Instructor ratings on driving performance

Since an assessment of the trainees' performance can not be performed automatically, training success has to be measured by observation and instructor ratings. For this purpose a standardized observation tool was developed. For each training sequence the trainee's performance was rated on the following dimensions:

- overtaking,
- using irregular lanes,
- clearing traffic,
- negotiating with road users that have the right of way.
- choosing speed,
- keeping distance,
- lane keeping,
- using warning devices and
- effective team working.

The rating scale consists of five verbally anchored categories (very poor to very good), each numerically subdivided twofold resulting in a 10-point scale. In addition, a global rating of overall performance was given. The instructors

were trained in observation and rating. N= 22 trainees were observed by a second independent observer to allow calculation of inter-rater-reliability.

Data from a sample of n=17 trainees who completed the whole training program is contained in figure 5. Both overall ratings of the trainees' performance in emergency driving over the course of the training (left) as well as ratings on the nine task-specific scales of comparing the first drive in an urban environment with the last one (right) are shown. The box-plot distributions of overall ratings indicate a continuous improvement of driving performance over the five emergency response rides. The large individual differences that characterize the first two emergency drives were considerably reduced by the end of the training. Thus training leads to an inter-individually high performance level. Inter-rater reliability for the global ratings was .78.

On the left side mean ratings of the task-specific performance scales in urban driving are depicted. The data is sorted by performance improvements, being highest in the subtask "clearing traffic" (improving from "average" to "very good") and improving least in "lane keeping".
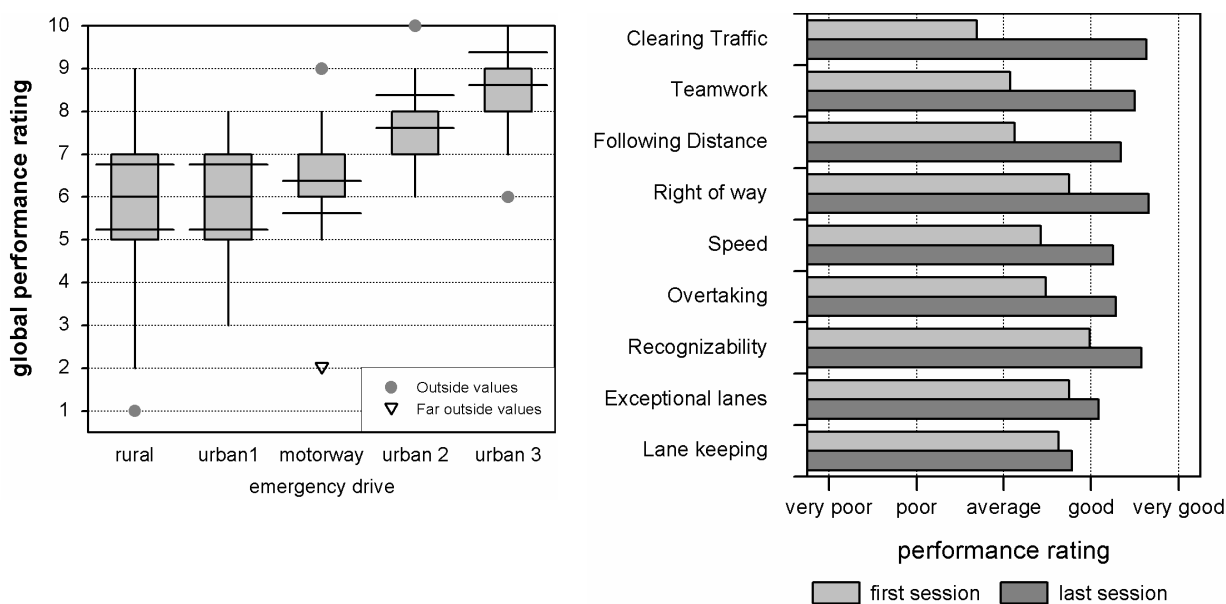

FIGURE 5 Mean task-related performance scores comparing the first and last emergency drive in an urban environment (left). Overall performance ratings in the course of the training (right).

The results indicate that simulator-based training is an efficient tool in emergency driver education, both accepted by the trainees and evaluated as helpful by the instructors. Future research will prove whether these improvements can be transferred to practice and will result in safer emergency driving.

SUMMARY AND CONCLUSIONS

The paper describes the development of a simulator-based training program for emergency driving. Initial results from evaluation show that simulator technology can be successfully integrated into a comprehensive driver training curriculum. It is important to emphasize that simulation augments rather than replaces other training methods such as track training or class-room lessons.

Simulation will without any doubt become a more and more important tool in driver training and education. In the training of young police officers it allows the practice of adequate on-the-job-behavior in a context that is very similar to the actual work environment. The trainees' acceptance of the training program is high, and indications for the training's effectiveness in terms of performance improvements have been found.

Despite the positive results however, several shortcomings of simulation have to be addressed. One is the incidence of simulator sickness. Vehicle driving in particular emergency driving is characterized by high-dynamic driving scenarios and therefore requires high performance of both the visual and the motion system. Sub-optimal performance in these domains, combined with limited training time, and subsequent insufficient adaptation to the simulation environment, will lead to intolerably high motion sickness. Although many contributing factors have been identified in recent research, our understanding in this area is still incomplete. Future research is required that focuses on the underlying mechanisms in terms of visual-vestibular coordination. Furthermore there is no satisfactory knowledge about the effects of different motion cueing characteristics. For practical purposes of training, screening systems are necessary that allow the instructor to identify trainees who are susceptible to motion sickness early on.

A second problem concerns scenario design. Common simulator technology provides fixed databases that are constructed with the objective to deliver a broad variety or a representative sample of possible roadway elements (intersections, traffic signals, highways, etc.). The result often looks very impressive, however when confronted with the problem of creating a training program guided by didactic considerations, the limitations of fixed database systems soon become evident. Many scenarios require distinct stationary road features and as a result, the design of scenarios is often constrained to very few road segments. These limitations also hinder the possibility of a wide variety of scenarios in current simulator systems, which are tailored to the needs of an individual trainee. A training sequence adjusted to the student's performance level would require more flexible databases that can easily be adapted. A first approach to this direction is provided by the simulation database architecture developed by Kaussner et al. (2001, 2003) [11, 12]. Here, generic elements of environment and traffic can be combined online during simulation. The result is a series of scenarios, which can be adapted to the actual learning state of the trainee.

The description of the instructor's task made it evident that didactic issues in driver simulator training need to receive a greater deal of attention. In current simulator training, diagnosis, evaluation and feedback fully depend on the instructor. In this respect, there is no difference to real driving lessons. To meet didactic demands and to make a simulator an "intelligent" training tool, future research and development have to focus particularly on the assessment and validation of objective measures of driving performance.

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