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Valid representation of a highly dynamic collision avoidance scenario in a driving simulator

Ilka Zöller [a,*], Alexander Betz [b], Nicole Mautes [a], Lucas Scholz [b], Bettina Abendroth [a], Ralph Bruder [a], Hermann Winner [b]

[a] Technische Universität Darmstadt, Institut für Arbeitswissenschaft, Otto-Berndt-Straße 2, 64287 Darmstadt, Germany
[b] Technische Universität Darmstadt, Fachgebiet Fahrzeugtechnik, Otto-Berndt-Straße 2, 64287 Darmstadt, Germany

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A B S T R A C T

In Germany the second-most frequent accidents in road traffic are rear-end collisions. For this reason rear-end collisions are quite important for accident research and the development of driving safety systems. To examine the functionality and to design the human–machine-interface of new driving safety systems, especially in the early development phase, subject tests are necessary. Because of the great hazard potential of such safety critical scenarios for the test persons, they are often conducted in a driving simulator (DS). Accordingly, validity is an important qualification to ensure that the findings collected in a simulated test environment can be directly transferred to the real world.

This paper regards the question of driving behavior validity of DS in critical situations. There are hardly any validation studies which analyze the driving behavior in a specific collision avoidance situation.

The validation study described in this paper aims to evaluate the behavioral validity of a fixed-base simulator in a collision avoidance situation. For this reason a field study from 2007 was replicated in a fixed-base simulator environment.

The main questions of this validation study were if the driver can notice an active hazard braking system and if the driving behavior in a static simulator can be valid in such a critical situation.

The key finding of the study states that there is no driving behavior validity in a static driving simulator for the tested dynamic scenario. The missing vestibular feedback causes a different behavior of the participants in field and simulator. The resulting absence of comparability leads to non-valid performance indicators. But these indicators are key parameters for analyzing the function and acceptance of active braking systems. So the question arises, which motion performance does a motion base have to provide in order to achieve valid acceleration simulation of such a highly dynamic collision avoidance scenario. The DS's performance is measured in workspace, velocity and acceleration.

* Corresponding author. Tel.: +49 6151 166289.
E-mail addresses: i.zoeller@iad.tu-darmstadt.de (I. Zöller), betz@fzd.tu-darmstadt.de (A. Betz), Nicole_mautes@web.de (N. Mautes), Lucas-scholz@mgc-mainz.de (L. Scholz), abendroth@iad.tu-darmstadt.de (B. Abendroth), bruder@iad.tu-darmstadt.de (R. Bruder), winner@fzd.tu-darmstadt.de (H. Winner).

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1. Introduction

According to figures from the German Federal Statistics Office (Destatis, 2013), the number of rear-end collisions (collision with a leading vehicle and/or one that is in the process of stopping, is already stopped, or is just beginning to accelerate after a stop) with 2703 accidents in February 2013 appeared relatively high. This corresponds to an equity ratio of 17% of the total number of accidents with personal injuries in this month (15,835). In February 2012 the number of rear-end collisions was 18% higher than in 2013 (3201). According to this, the accident rate is decreasing gradually, but the number of such accidents is still high. The German Automobile Club analyzed the causes of accidents and published that rear-end collisions are the second-most frequent reason for car accidents (ADAC, 2011). To avoid such accidents the automotive industry develops safety systems (such as ABS, braking assistant).

To assess and design new safety systems, driving tests in a simulation environment are often performed. The main reason for this fact is that simulators provide a secure environment for the test person (Blana, 1996) and the test vehicle. For this reason, driving simulators (DS) admit to analyze the human–machine interaction according to active safety systems already in the early phases of the engineering process of such technological systems. Particularly for critical situations, using the DS is a cost-efficient way to reach an adequate evaluation.

In addition to the mentioned benefits, it has been taken into consideration that DS are merely an attempt at reproducing reality – therefore second-rate, regardless of how exact the model is. Against this background it becomes particularly urgent to enquire whether the transferability of the data gathered in the simulator to a real driver behavior can be guaranteed. A lot of research can be found that examines this question of validity of driving behavior (e.g. Bella, 2005; Blaauw, 1982; Engström, Johansson, & Ostlund, 2005; Godley, Fildes, & Triggs, 2002; Jamson & Mouta, 2004). However, there are almost no scientific validity studies on rear-end situations with/without system intervention.

The study treated in this paper analyzes the validity of a fixed-based driving simulator with 180° FOV in a rear-end collision avoidance scenario. The analyzed question is, if a fixed-based simulator with a large FOV is realistic enough to provide valid results, or if a moving-base is needed for such a dynamic situation. Another question investigated in this paper, is how much space an adequate moving-base simulator would need.

2. Basic methodology of validation

Existing validation methods have their origin in a differentiation from Mudd (1968) and McCormick (1970), who divided validity into a physical and a behavioral aspect (Blana, 1996). The physical aspect refers to the physical correspondence between the simulator and the real vehicle. The behavioral validity refers to the aspect whether the behavior of participants driving in a DS is comparable to the behavior shown in real environment. Generally the behavioral aspect is supposed to be more important for the examination of a specific task of driving (Blana, 1996). Therefore this paper focuses on driver behavior validity and answers the question of whether drivers' behavior in a simulator can be transferred to driving behavior in the field.

The validation methodology for behavioral validity was proposed by Brown for flight simulation in 1975. According to Brown (1975), the main question is how well the task in the simulator duplicates the conditions of the real task. For analyzing this he distinguishes between quantitative indices of performance and subjective criteria. Quantitative indices are, on the one hand, the characteristics of the flight which were analyzed by comparing control performances (e.g. rate of lateral motion) in the simulator with them expected in an actual flight. On the other hand, they are physiological measurements (e.g. heart rate, skin conductance level) which provide objective and quantitative values. The subjective validation is based on the opinions of experienced pilots. Furthermore, Brown (1975) mentioned that the simulator always represented a specific aircraft.

This methodology is transferable to driving simulators, as both are human–machine-systems. The validation study described in this paper refers to the methodology from Brown (1975); two studies (field and simulator) are conducted under similar conditions (e.g. identically chosen subject groups, identical road geometry, identical programmed behavior of the leading vehicle and the same safety system). In order to validate the behavioral validity, the recorded data of both studies are then compared. The selection of the analyzed data depends on the goal of the field study. Thus the question can be answered, if data gathered in a simulated environment matches the results of the field study.

In the analysis of driving behavior validity a distinction is made between absolute and relative validity (Reed & Green, 1995). When there is a numerical correspondence between the behavior data in the simulator and in the real world (both studies under same conditions) it is called absolute validity (Reed & Green, 1995). When there is a correspondence between effects of different variations in different situations it is called relative validity (Törnros, 1998). In the present study the absolute validity is investigated, because it is more general. To analyze if the measurements show absolute validity, statistical comparisons of the means are carried out, for example, with a t-test. If there is no statistically significant difference between the means of a parameter in field and simulation ($p > 0.05$), absolute validity can be confirmed.