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Drivers' speed behaviour in real and simulated urban roads – A validation study

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ABSTRACT

Traffic accidents and injuries constitute a growing problem for Europe's urban transportation system. Driving simulators can be active support tools in the design process of urban driving environments, provided that they are appropriately validated. The aim of this study was to establish the behavioural validity, in relative and absolute terms, of the motion-base driving simulator of the Road Safety and Accident Reconstruction Laboratory (LaSIS) of the University of Florence in order to use it to evaluate the effectiveness of the urban road safety treatment design process.

The research was conducted by comparing the driving speed collected in field with those recorded in the 3D virtual reality experiments through conventional and integrative statistical methods. Speeds were recorded at twenty-one measurement sites located in homogeneous road sections characterized by a less or more demanding driving environment; thirty-four participants drove the virtual scenario which reproduced the real situation.

The results of the comparative and conventional statistical analysis established the relative validity and also revealed that absolute validity was obtained in the measurement sites in which physical constraints are imposed by engineering treatments. The integrative regression analysis confirms these outcomes and showed that the simulation system is a reliable predictor of the real speed data also in absolute terms. It was also found that the driving experience levels significantly affect the speed adopted by the motorists in the virtual environment.

These findings support the use of the driving simulator as a powerful approach to predict of the safety effectiveness of design solutions in urban areas, thus allowing important cost savings.

1. Introduction

Urban areas are very complex driving environments in which different types of road users compete continually. The constant interaction between motorized traffic and vulnerable road users creates serious implication for traffic safety.

In the last few years the problem of road crashes in urban areas has become increasingly relevant. In 2013, 26,090 people were killed in road accident throughout the European Union (EU),[2] 9923 of whom were killed in accidents on urban roads in

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[2] The European Union (EU) currently includes 28 countries and it has a population of approximately 740 million inhabitants. About 300 million passenger cars are present in the EU. The EU has almost one car for every citizens and the average annual mileage per European is 13,000 km.

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the EU. This corresponds to 38% of the road fatalities in 2013. Although the total number of fatalities within urban areas decreased since 2005, the proportion has slightly increased (from 35% to 38%) (Traffic Safety Basic Facts, 2016). In Italy the situation is even more serious. According to Italian data published by ACI-ISTAT in 2014 (ACI-ISTAT, 2015), the majority of fatal and injury accidents occurred on urban roads: 133,598 accidents, corresponding 75.5% of the total accidents with injured and/or fatalities occurred in the whole Italian road network. These accidents caused the death of 1505 people, corresponding 44.5% of the total number of victims of road traffic accidents on the Italian road network (ACI-ISTAT, 2015).

Speeding has been identified as a key risk factor in traffic accidents on urban roads, influencing both the frequency and the severity of the injuries resulting from crashes.

Many safety measures have been proposed to tackle this problem whose effectiveness depends on the characteristics of each specific urban environment and their interaction with the driver's capabilities and expectations.

The use of an interdisciplinary approach based on driving simulations is a promising method to study these interactions, to check the safety impact of the proposed interventions and to identify the most promising design alternatives.

The use of driving simulator provides important advantages in terms of experimental control, capabilities effectiveness, cost, ease of data collection and safety of the study implementation. However, it presents also limitations mainly related to the reliability of the data acquired. For this reason, any driving simulator study should be preceded by questioning whether the simulator is sufficiently valid for the task or ability to be investigated (Kaptein, Theeuwes, & Van Der Horst, 1996).

A wide range of driving parameters, environments and behaviours have been examined in driving simulator's validation studies and generally a good correspondence between performance in the real world and during driving simulator experiments was obtained. Speed is the most commonly examined parameter in safety studies concerning road tunnels (Cao, Wang, & Luo, 2015; Törnros, 1998), rural roads (Bella, 2008; Bittner Jr., Simsek, Levison, & Campbell, 2002; Godley, Triggs, & Fildes, 2002; Santos, Merat, Mouta, Brookhuis, & De Waard, 2005), highway work zones (Bella, 2005; Bham, Leu, Vallati, & Mathur, 2014; McAvoy, Schattler, & Datta, 2007), signalized intersections (Yan, Abdel-Aty, Radwan, Wang, & Chilakapati, 2008) and speed management measures (Godley et al., 2002; Riemersma, van der Horst, Hoekstra, Alink, & Otten, 1990). Few studies considered other indicators such as vehicle's lateral position (Blana & Golias, 2002; Wade & Hammond, 1998), driver's reaction time (Brown, Dow, Marshall, & Allen, 2007; Engen, 2008; Hoffman, Brown, Lee, & McGehee, 2002), time gap (Abe & Richardson, 2006; Boer, Ward, Manser, Yamamura, & Kuge, 2005) and driving errors (Meuleners & Fraser, 2015). The validity of the simulation tools for assessing driving behaviour of specific driver groups, such as young drivers (Brown et al., 2007; De Winter et al., 2009; Hoffman et al., 2002; Mayhew et al., 2011; Shechtman, Classen, Awadzi, & Mann, 2009), older drivers (Hekamies-Blomqvist, Östlund, Henriksson, & Heikkinen, 2001; Lee, Cameron, & Lee, 2003; Lee, Lee, & Cameron, 2003) and subjects with temporary or permanent disabilities (Lee et al., 2007; Lew et al., 2005) has been investigated also.

Few studies investigated the possible responsibility the drivers' characteristics in differentiating the results of the real world and the driving simulator tests. The driving experience was found to be the most crucial driver characteristic (Gemou & Bekiaris, 2014) and validation study evaluation of driving errors showed that experienced drivers had the fewest errors compared to the beginner drivers (Mayhew et al., 2011).

Gender and age also affect the behavioural validity of the driving simulator. Reed and Green (1999) found that the performance difference in terms of speed variability between young and old participants was significantly larger in simulation experiments than in the real world. Moreover, they found that the behavioural validity of lane keeping measures depends on both age and gender. In fixed-base simulators, participants older than 60 years produced a significantly larger standard deviation of the lateral position, compared to the 20–30 year-old participants, whereas in the real study no gender or age effects were observed. Additionally, they found a significant interaction between age and gender in the simulator, older females performing significantly poorer than other groups.

The validation study carried out by Yan et al. (2008) revealed that driver age and gender significantly influence the operating speed in simulator experiments. They found that the mean speed registered with male participants was slightly higher than that with females and that, after the 20–24 age group, a decreasing trend in speed with increasing age was observed. Klüver, Herrigel, Heinrich, Schöner, and Hecht (2016) found no or only marginal age and gender differences between the real study and moving-base simulators. However, they found a significant interaction between age and gender in fixed-base simulators. Specifically, older participants showed a considerably higher headway and lane keeping variability, whereas the performance of younger participants was roughly the same as in the real world.

2. Framework for driving simulator validation

Defining the validity of a driving simulator is a complicated and multidisciplinary task. The issue of transferability of results acquired on driving simulator experiments has been a concern for at least 35 years. The quality of a driving simulator is normally defined in terms of physical and behavioural validity (Blaauw, 1982). The first, often referred to as simulator fidelity, measures the degree to which the simulator reproduces the sensory stimuli present in a real driving situation, and depends on the simulator equipment (visual displays, simulator programme and dynamics – motion system). The second, also known as predictive validity, analyses the correspondence between the driver behaviour in the simulator and in the real world. In general, the physical fidelity is a prerequisite for ensuring behavioural fidelity. A recent research project carried out by Lee et al. (2013) revealed that simulators with high physical fidelity demonstrate high behavioural fidelity and likely