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► To cite this version:

Joost C F de Winter, Hervé Morvan, Frédéric Robache, Janick Naveteur, Marie-Pierre Pacaux-Lemoine. Using a high-fidelity driving simulator to predict self-reported driving style and crash involvement: a preliminary study. 30th European Annual Conference on Human Decision-Making and Manual Control, Sep 2012, Braunschweig, Germany. hal-03960445

HAL Id: hal-03960445

<https://uphf.hal.science/hal-03960445v1>

Submitted on 27 Jan 2023

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Using a high-fidelity driving simulator to predict self-reported driving style and crash involvement: a preliminary study

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Abstract

Driving behaviour in a simulator may be a powerful predictor of driving behaviour on the roads. In this study, 39 drivers completed a route in a high-fidelity driving simulator, and correlations were calculated between simulator predictor variables (speed, standard deviation of lateral position) and self-reported behaviours (driving experience, driving habits, crash involvement). Results showed that the mean speed during the drive predicted self-reported on-road risk taking and crash involvement.

Introduction

Road traffic crashes claim the lives of over 1.2 million people every year and between 20 and 50 million people suffer non-fatal injuries (World Health Organization, 2009). Crashes impose a high cost on society, estimated at about 2–3% of the gross national product (Elvik, 2000; European Transport Safety Council, 2003; SWOV Institute for Road Safety Research, 2007). It would be of considerable interest to the community to have a valid measurement tool that can distinguish between safe and accident-prone individuals.

In many countries, the on-road driving test is the primary means to screen out the safe from the unsafe new drivers. Unfortunately, on-road tests must contend variability of driving conditions (e.g., traffic density, weather conditions), variability of driving examiners (personality and individual differences, mood, alertness), and regional differences in infrastructure and test content (Baughan et al., 2005). On-road driving tests have demonstrated low test-retest reliability (Baughan & Sexton, 2001) and results are inconsistent for predictive validity with respect to crash involvement (Elvik & Vaa, 2009; Senserrick & Haworth, 2005).

A considerable number of studies have already investigated whether individual characteristics or laboratory-based test results are predictive of crash involvement (e.g., Af Wåhlberg, 2003; Arthur et al., 1991; Elander et al., 1993; Lawton & Parker, 1998; McKenna, 1983; Ranney, 1994; Visser et al., 2007). Table 1 summarises some identified categories of predictors. Several of these studies used questionnaires such as the Sensation Seeking Scale (Zuckerman, 2007) or the Driver Behaviour Questionnaire (Parker et al., 1995; De Winter & Dodou, 2010) as a predictor, giving rise to concerns about socially desirable responding (Af Wåhlberg, 2009; Corbett, 2001; Lajunen & Summala, 2003). Although questionnaires are useful aids to research, instrument-recorded data is desirable when a serious consequence, such as driving license renewal, is involved.

The Useful Field of View (UFOV) test is a well-known computerised test measuring the visual area over which information can be extracted in a brief glance without eye or head movements. UFOV is a representative predictor of on-road driving and crash involvement (Clay et al., 2005). However, computerised tests such as UFOV provide only abstractions of the tasks that are relevant to driving. Possibly, drivers with poorer visual ability will compensate for their eyesight by driving more

defensively, which in turn alleviates crash risk. It may be more effective to measure driving behaviour directly, instead of via a laboratory test that is remote from how a driver actually behaves on the roads (Medeiros et al., 2012).

Table 1
Categories of identified crash predictors.

Category	Examples
Demographic variables	gender, age, race, driving experience
Transient behaviours	fatigue, alcohol use, stress
Personality and clinical constructs	sensation seeking behaviour, social deviance, psychopathy, attitudes and beliefs, extraversion, impulsivity, social deviance, lack of conscientiousness
Medical conditions	dementia, epilepsy, use of medications, alcoholism, sleep apnoea
Hormonal and neurological responses	cortisol response, magnetic resonance imaging data
Perceptual, information-processing, and cognitive abilities	visual attention, visual acuity, field dependence perception-reaction time, general intelligence
Driving skill	observed or self-reported driving errors and hazard detection/perception test results
Driving style	observed or self-reported speed, violations, accepting short gaps and headways

This study aimed to investigate to which extent self-reported driving safety correlates with driving behaviour in a high-fidelity driving simulator. Driving simulators offer advantages compared to on-road measurements because direct measures of driver behaviour are obtained in highly controlled experimental conditions. Moreover, driving in a simulator is safe, allowing the use of scenarios that would be inappropriate to employ on the road. Today, driving simulators provide visual, auditory, and kinesthetic sensations that closely mimic actual car driving, so that driving skill and style can be measured in realistic circumstances. As Hancock, Caird and White (1990) say, “The use of simulation provides a bridge between laboratory-based artificial tasks and real-world driving that enables context selective testing.” (p. 24).

In this study, participants drove a simulated route along a highway and national road. Variables from the driving simulator were statistically associated with self-reported crash history, demographic variables, and self-reported driving style. We focused on driving speed as a possible predictor of road safety, as on-road measurements have demonstrated that speed variables are reliable over time, and associated with crash involvement (Cooper, 1997; Haglund & Åberg, 2002; West et al., 1993).

2. Method

2.1. Participants

Thirty-nine participants with full French driving licenses (i.e., not learners and not having a restricted license) were recruited from students and staff of the University of Valenciennes and the local region. The sample comprised 28 men and 11 women, with a mean age of 26.0 years, ranging from 18 to 52 years ($SD = 8.3$ years) and an average years of licensure of 7.15 years, ranging from some months to 29 years ($SD = 7.6$ years). The participants reported having driven on average 15,040 km a year, ranging from 780 to 40,000 km ($SD = 10,363$).

2.2. Driving simulator

The study used the University of Valenciennes’ driving simulator, SHERPA, an acronym for Simulateur Hybride d’Etude et de Recherche de PSA Peugeot Citroen pour l’Automobile (Fig. 1). The simulator consisted of a 6-dof (degrees of freedom) motion-base with a Peugeot 206 car mounted above it. The driving simulator was positioned in front of three angled projection surfaces. The centre

projection surface was located 3.3 m in front of the driver with two peripheral surfaces connected at a 60° angle. The projectors provided a 180° (horizontal) x 45° (vertical) forward view of the simulated road at resolutions of 1280 pixels x 1024 pixels. The centre rear view mirror and both wing mirrors were replaced with three small colour LCD screens (resolutions of 800 pixels x 480 pixels). The control devices were the steering wheel, the manual gearbox, and pedals (brake, accelerator, and clutch). Speed and engine RPM were displayed on the vehicle's dashboard. The vehicle dynamics model was based on ARHMM (Advanced Road Handling Multi-body Model; Detalle et al., 1997). The steering wheel featured force feedback. Speakers located inside the car and a sub-woofer in front of the car presented realistic engine and road noises, and speakers around the car created Doppler effects to represent crossing traffic.



Figure 1. Driving simulator of the University of Valenciennes (SHERPA)

2.3. Route and scenarios

Participants were required to drive along a route of 34 kilometres (Fig. 2), which took between 17 and 26 minutes to complete, depending on the participant. The simulated road consisted of a 27-km highway with a 130 km/h speed limit, and a 5-km national road with a 90 km/h speed limit that went through a village with a 50 km/h speed limit. At the end of the highway segment, participants were asked via telecom to enter the exit lane and come to a complete stop.

The simulation reproduced mild traffic flow during the route and to increase engagement in the task, drivers encountered two surprises: (1) On the highway, an overtaking vehicle cut in front of the participant's car, and (2) in the village, a car emerged from the right out of a junction and took right of way. At the end of the drive an unavoidable crash situation occurred: An approaching truck, followed by another truck, passed a tractor and drove onto the participant's lane. The two trucks and trees along the road made the crash unavoidable. Drivers' responses to an unavoidable crash have been studied elsewhere (Hault-Debrulle et al., 2011; Hetier et al., 2006; Morvan et al., 2007; Pacaux-Lemoine et al., 2011) and will not be investigated here.

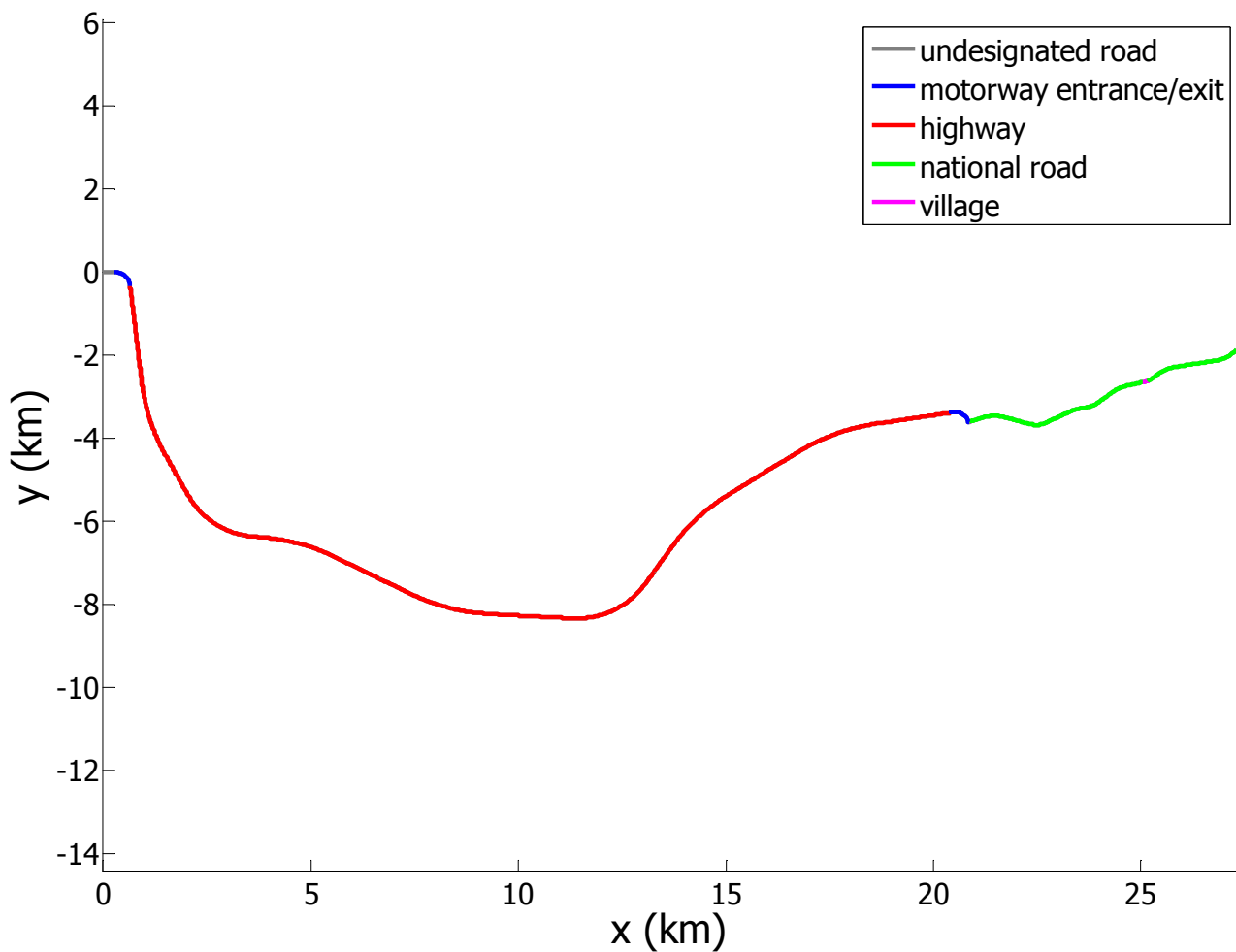


Figure 2. Top view of the trajectory

2.4. Procedure

All participants read and signed an informed consent document and were asked to fill in a brief demographic questionnaire. On their arrival, they were briefed about the drive but not told that there would be a crash at the end. Then they practiced the various functions of the driving simulator and familiarised themselves with the simulator for 20 minutes. The experimental drive took place on the second day. Participants were informed that they would be driving on highway and rural roads and that they could stop the experiment at any time. The general instructions were as follows (translated from French): “Please drive like you would in the same situation in the real world. Please adapt your speed to the driving conditions.” Following the drive, participants filled out questionnaires regarding their experiences during the drive. They also filled in an extensive questionnaire about their driving habits and crash history on the roads.

2.5. Collected data

The following dependent variables were used. Q = questionnaire data, and S = simulator data.

- Q Crash (1 = no, 2 = yes). Self-reported crash involvement as a driver, obtained from the post-experiment questionnaire.
- S Speed (km/h). Mean speed on the highway and on the national road (including village). Mean speed is regarded a measure of driving style.
- S Impact speed (km/h), representing the speed of impact with the truck.
- S SDLP (m). Standard Deviation of Lateral Position, representing lane-keeping accuracy.

SDLP is a metric of driver skill. Lane changes were excluded from the calculation of SDLP. As with the speed metric, a distinction was made between highway and national road plus village.

- Q Gender (1 = male, 2 = female), obtained from the demographic questionnaire.
- Q Age (years), obtained from the demographic questionnaire.
- Q Experience (years), representing the numbers of years of driving experience, obtained from the demographic questionnaire.
- Q Mileage (km), obtained from the post-experiment questionnaire.
- Q Video games (1 = never, 5 = very often), representing the response to the statement “Plays video games”, obtained from the demographics questionnaire.
- Q Speed (km/h), representing the free response to the statement “At what speed do you usually drive?” The question was asked separately for (a) cities, (b) winding roads, countryside, mountain, (c) regional/national roads, (d) expressways, and (e) highways. The average was used for these five categories.
- Q Risk and Q Pleasure. These scores were obtained from a 28-item post-experiment questionnaire on driving habits. A principal component analysis was performed, extracting the first two components. The highest loadings on the risk component were found for the items “you prefer accelerating” (1 = regular and light, 100 = sharp and intense), and “do you enjoy taking risks while driving” (1 = not at all, 100 = a lot), with loadings of .80 and .81, respectively. The highest loadings of the pleasure component was found for the items “For you, driving is an activity which is” (1 = very unpleasant, 100 = very pleasant) and “How much effort does it take you to drive (1 = no effort, 100 = much effort”, with loadings of .75 and $-.70$ respectively.

3. Results

Table 2 shows a correlation matrix with the collected variables. The matrix shows that crash-involved people drove on average faster than crash-free drivers. Figure 4 shows the corresponding speed profiles during the drive, illustrating large individual differences. Speed was a consistent metric during the drive, demonstrated by the positive manifold between speed on the highway, speed on national road/village speed, and impact speed. Similarly, SDLP was consistent during the drive: drivers who swerved on the highway also tended to swerve in the city environment. Age and experience were almost perfectly correlated. Older drivers had a higher SDLP, indicating poorer lane maintenance (see Figure 5). Finally, the risk-score obtained from the driver habits questionnaire correlated significantly with mean speed (Figure 6).

Table 2.

Pearson correlations between dependent variables (multiplied by 100 for convenience)

	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Q Crashes	1.21	0.41													
2 S Mean speed highway	123.82	10.33	44												
3 S Mean speed village and national road	68.59	4.47	41	74											
4 S Impact speed	71.15	11.05	24	44	68										
5 S SDLP highway	0.32	0.06	9	37	24	24									
6 S SDLP village and national road	0.35	0.05	-7	13	8	14	64								
7 Q Gender	1.28	0.46	-18	-34	-32	-18	-2	-1							
8 Q Age	25.97	8.28	4	6	-20	-16	61	49	0						
9 Q Experience	7.15	7.58	1	6	-19	-17	60	51	4	98					
10 Q Mileage	15,040	10,363	13	22	14	-2	14	23	-20	24	29				
11 Q Video games	2.59	1.14	2	2	11	9	-26	-14	-43	-29	-26	4			
12 Q Speed	91.68	6.21	8	21	7	30	5	13	-4	4	5	45	7		
13 Q Risk	0.02	1.01	9	48	50	51	8	11	-21	-18	-16	20	15	21	
14 Q Pleasure	-0.06	0.94	-10	-6	19	14	10	10	26	-1	4	20	-19	-8	-2

$p < .05$ is marked in green or red colour.

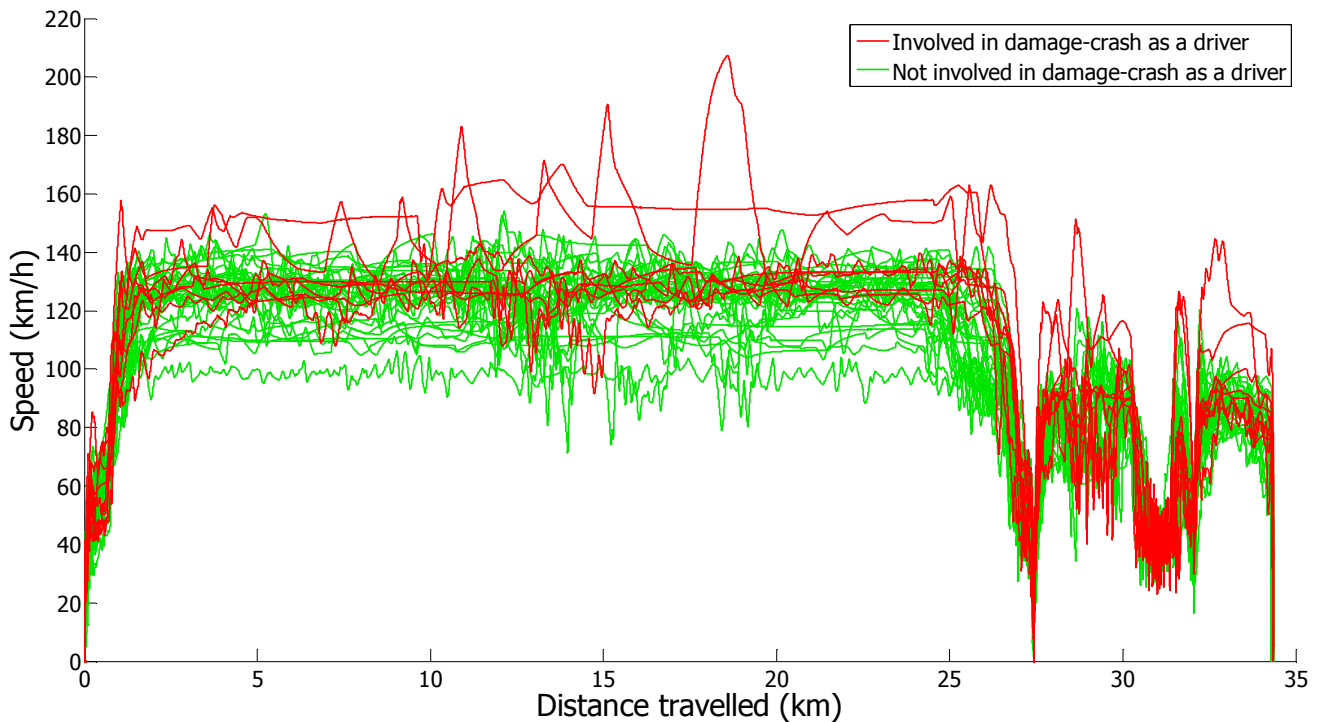


Figure 4. Speed during the drive versus travelled distance in the drive, distinguishing between crash-involved and ($N = 8$) crash-free drivers ($N = 31$).

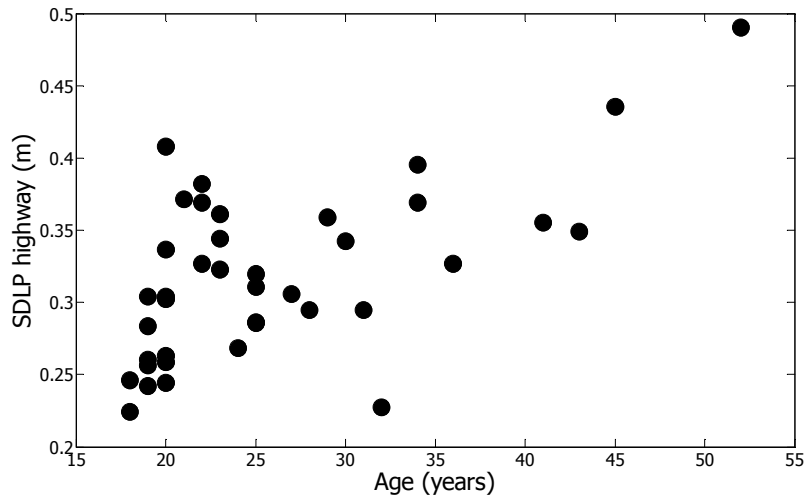


Figure 5. Standard deviation of lateral position (SDLP) on the highway versus age ($N = 39$).

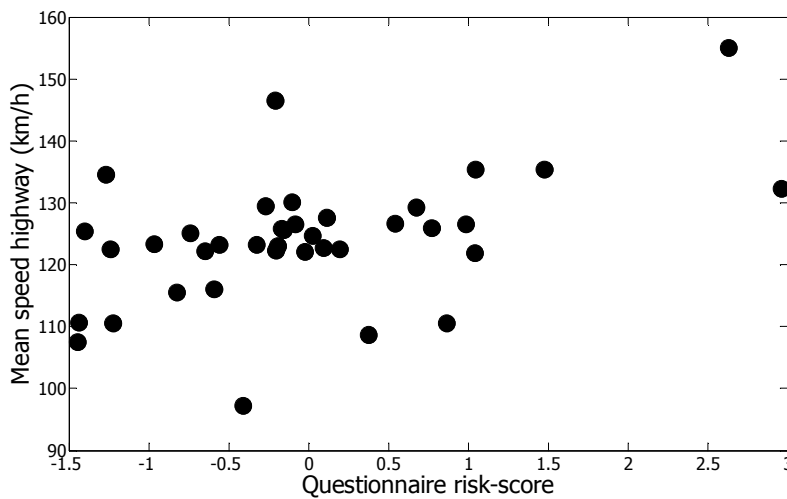


Figure 6. Mean speed on the highway versus risk score acquired from the post-drive questionnaire ($N = 39$).

Discussion

In this study, driver metrics obtained from a high-fidelity simulator were shown to be predictive of self-reported behaviours. Those who reported one or more crashes as a driver in the past drove with higher speeds than those who reported zero crashes. Those who reported riskier driving on the roads drove faster in the simulator, and older drivers were found to have a higher standard deviation of lateral position than younger drivers.

This study provides confirmation of the predictive validity of a high-fidelity driving simulator, adding to the current body of knowledge. Allen et al. (2009) previously found that driving speed in a simulator was predictive of future crash involvement, with the high-fidelity simulator configuration being most predictive. Other studies demonstrating relationships between simulator behaviour and on-road behaviour are provided by Bédard et al. (2010); Cox et al. (1999); De Winter et al., 2009, De Winter, 2012; Lew et al. (2005), and Lee et al. (2003)

An important limitation of the present study is its sample size. Thirty-nine participants provide limited statistical power, meaning that the obtained correlations are susceptible to sampling error. It would be strongly advised to use larger samples in future research. This will also make it possible to study the moderating role of variables such as driving experience and mileage on the relationship

between simulator predictor variables and criterion variables. Another limitation is that it remains uncertain whether the simulator will be truly predictive-valid in a test setting rather than a research setting. When subjects know they are being tested (e.g., as part of a driving examination), they are probably less inclined to violate the traffic rules.

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