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Relationships Between Years of Licensure and Driving Style Measured with a Short Simulator-Based Test (N = 650)

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Abstract Young and inexperienced drivers are over-involved in traffic violations and car crashes. There is a paucity of research on the use of driving simulators for assessing driving style. This study investigated the relationships between years of licensure and driving style measured with a short simulator-based test. At a motor show, 650 licensed drivers completed a 6.5-min driving style test and responded to a questionnaire about their on-road driving experience. The results showed that participants who had their driving license for a longer period adopted a less risky driving style and drove with slower speeds in the simulator. Furthermore, females and experienced drivers reported more simulator sickness than males and inexperienced drivers, respectively. The present results may be useful in the development of simulator-based driving tests.

Keywords Human factors · Driving simulator · Driving assessment

1 Introduction

On a yearly basis, road traffic crashes claim the lives of 1.25 million people and between 20 and 50 million people suffer non-fatal injuries [1]. Engineering innovations such as electronic stability control (ESC) and advanced emergency braking (AEB) have led to an impressive improvement in road safety [2]. However, the

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human remains the weakest link in driver-vehicle interaction, with human error being the primary cause of 90 % of road traffic crashes [3, 4]. Young and inexperienced drivers are overrepresented in crash statistics. An important reason is that young drivers commit a large amount of traffic violations and more often engage in risky driving behaviors than older drivers [5–7]. A driver's driving style, including violations, bad habits, and predisposition to risk, has a large effect on road safety [8].

On-road driving tests are currently the gold standard for deciding whether someone is competent to drive, both for young people obtaining their driver's license and for older people or patients whose driving needs reassessment. However, on-road driving tests suffer from issues of inter-rater reliability of driving examiners [9]. Moreover, even if examiners were always consistent and in agreement with all other examiners, there would still be limitations to the validity and fairness of on-road driving tests, due to random traffic and weather conditions as well as local differences in road infrastructure (e.g., [10]).

Psychometric tests, such as visual and psychomotor tests, are an alternative to on-road testing [8, 11–14]. A limitation of psychometric tests is that they are remote from what occurs on the road (e.g., [15]). One important aspect hard to capture in psychometric tests is the self-paced nature of driving. That is, drivers can adapt their driving style to cope with high task demands or to compensate for their own limitations. For example, although older persons are known to suffer from degraded processing speed and spatial skills [16, 17], they tend to drive more carefully and with wider safety margins than young drivers do [18, 19].

Driving simulators provide visual and auditory sensations that mimic real car driving while providing high controllability. With a simulator, hazardous driving scenarios can be offered without the physical risk of crashing [20]. Simulators are therefore reported to be "a bridge between laboratory-based artificial tasks and real-world driving that enables context selective testing" ([21, p. 24]). Another important quality of simulators is that they can measure the state of the car (e.g., speed, position) objectively. Although there is a growing body of evidence on the validity of driving simulators for predicting various types of on-road performance [5, 22–28], there is still little empirical knowledge on the suitability of driving simulators for testing the driving population. The aim of this research was to investigate the validity of a simulator-based driving style test, by measuring the extent to which the driving style in the simulator relates to drivers' years of licensure. An adjacent purpose of this research was to investigate possible bottlenecks in simulator-based testing, in particular regarding simulator sickness, which is an important topic in driving simulator development (e.g., [29–31]).

2 Methods

2.1 Simulators

Two identical portable driving simulators (Model Drive Master, Green Dino BV, 2009) were used to administer the simulator test. Each had a throttle, brake, and clutch pedal, steering wheel, horn, gear lever with five forward gears, and ignition key. Five LCD screens (resolution 1024 × 768 pixels) presented the virtual environment. A sixth screen presented the dashboard with two dials showing driving speed and engine rpm, respectively. A rear-view mirror and two side mirrors were integrated in the simulated image. The simulated field of view was 149° horizontally and 23° vertically.

The steering wheel provided force feedback derived from a combination of static and self-aligning torque through a torque engine connected to the steering shaft. Deceleration cues were simulated by a vibration unit on the steering shaft. Engine, wind, and tire sounds were audible on a speaker positioned in front of the driver. The simulated car was a mid-class vehicle with a mass of 1265 kg and a top speed of 180 km/h.

2.2 Driving Style Test

Visitors could voluntarily complete the driving style test free of charge at a demonstration stand of a driving simulator manufacturer at a motor show held in April 2009. Attended by 220,000 people, the motor show featured car manufacturers' stands with various demonstrations of innovative car products and driving simulators.

Only people with a driver's license were eligible to participate in the driving style test. The test consisted of three simulated drives and lasted about 10 min in total, including the time needed to enter and exit the simulator. The durations of the three drives were 75, 150, and 160 s, respectively.

Prior to the first drive the simulator presented a short welcome text, informing participants that the driving style test consisted of three drives after which they would be presented with their scores. The text also stated that the first drive allowed participants to get used to the simulator and that if they felt discomfort, they had to report that to the supervisor who would then alter the field of view. Following both the first and second drive, there was a short interval and the text on the screen reminded participants to report any discomfort. The supervisors could adjust the field of view by shutting down the outer two or outer four LCD screens. The simulator software provided no feedback or guidance during driving, except for spoken route instructions (recorded male voice) and a corresponding display of arrows at the bottom of the central screen.

The rationale behind the test was to expose participants to challenging driving scenarios within a short amount of time. Therefore, the test took place in a city environment with a high frequency of encounters with other road users. Furthermore, the driving style test was self-paced. That is, the test did not include scenarios where the participants would approach with fixed speed. Instead, the drivers had to choose their own pace, could violate speed limits, and had to make right-of-way decisions at intersections. Accordingly, the driving style test assessed a variety of behaviors, in particular driving speed and adherence to traffic rules.

Drive 1 took place in a city environment containing intersections without authorized priority. Curved road segments of about 200 m long separated the intersections. At each intersection, the voice instructed the participant to go straight ahead. The speed limit was 50 km/h. In Drives 2 and 3, the participant drove along a figure-of-eight route in a city environment with segregated cycle lanes on both sides of the road. Pre-programmed scenarios such as crossing cyclists and pedestrians were triggered on time-to-arrival of the participant. Traffic lights were not triggered according to the position of the participant, but changed color according to a fixed time pattern. The participant drove the route described in Table 1. In Drive 2, the participant's starting location was near the beginning of Item 1 (Table 1). In Drive 3, the participant started near the end of Item 7. In all three drives, the participant started with zero speed and with the engine off. The majority

Table 1 The route that participants had to drive in Drive 1 and Drive 2

Item	Description of environment
1	Straight ahead (275 m, speed limit 50 km/h) in a built-up area
2	Cross an intersection without authorized priority (35 m). This means that the 'right-of-way' rule (give way to the right) holds
3	Straight ahead (295 m, speed limit 50 km/h)
4	Turn right at a traffic-light-controlled intersection. A cyclist (travelling in the same direction as the participant) rides straight ahead and therefore has right of way
5	Leave a built-up area and drive through a mild 90-degree curve to the right (499 m, speed limit 80 km/h)
6	Turn right at an intersection without authorized priority. Two parallel cyclists (travelling in the same direction as the participant) ride straight ahead and therefore have right of way
7	Enter a built-up area, driving straight ahead (290 m, speed limit 50 km/h)
8	Cross an intersection without authorized priority (35 m). A scooter approaches at high speed from the left and (unexpectedly) does not give way to the participant
9	Straight ahead (42.5 m, speed limit 50 km/h), entering a residential area with three speed humps (192.5 m, speed limit 30 km/h). People are standing on the footpaths and on the street. A child crosses the street, right in front of the participant. After leaving the residential area, the participant drives along a further 55 m (speed limit 50 km/h)
10	Turn left at an intersection without authorized priority. Two parallel cyclists approach, that is travelling in the opposite direction to the participant. They ride straight ahead and therefore have right of way

(continued)

Table 1 (continued)

Item	Description of environment
11	Straight ahead (290 m, speed limit 50 km/h), passing a stationary bus on the opposite side of the road. A pedestrian standing beside the bus intends to cross the road, but pulls back
12	Turn left at an intersection without authorized priority. An approaching scooter drives straight ahead, having right of way
13	Straight ahead (285 m, speed limit 50 km/h)
14	Turn left at a traffic-light-controlled intersection. An approaching scooter turns right, that is, left from the participant's perspective

of participants completed less than 50 % of the figure-of-eight route per drive, meaning that most participants did not encounter the same scenario more than once. A degree of route overlap occurred for the fastest 5 % of the drivers. To enhance realism during the three drives, a small number of additional cars drove around, controlled by artificial intelligence.

2.3 Collected Data

The following data were collected per participant:

Driver Errors While Driving. A total of 36 errors were rated automatically. The errors were categorized into three types. In Type 1 errors (e.g., collisions, driving off the road), the number of occurrences was counted. In Type 2 errors (e.g., ignoring right of way, ignoring traffic lights), the score was calculated by dividing the number of recorded occurrences to the maximum possible number of occurrences. For example, if the participant failed to provide right of way in one out of four occasions, then the score for this error was 0.25 on a scale from 0 (*good*) to 1 (*poor*). Type 3 errors were the result of a continuous assessment on a scale from 0 (good) to 1 (poor). Examples of Type 3 errors are driving too fast, driving too slow, driving off-center, and driving too close to a car in front. Here, scores were proportional to the severity of the deviation from the norm and the total period. For example, *driving too fast* was possible on straight road segments only. A score was determined for each sampling instant (approximately 10 Hz) that the participant drove on a straight road segment. This score was 0 when the participant drove slower than a lower limit (equaling the speed limit of that road segment plus 5 %), 1 when the participant drove faster than an upper limit (30 % above the speed limit of that road segment), and between 0 and 1 when the speed was between the lower and upper limit. The score for driving too fast was calculated by averaging the score across all sampling instants.

After completing the simulator test, participants were shown their error scores on a computer outside the simulator. These scores were aggregated into various categories (safety, driving skill, risk avoidance, eco-friendly driving, vehicle control, speeding, traffic rules) and shown on a scale from 0 (*poor*) to 10 (*good*). A corresponding textual explanation was shown as well.

Measures Based on Driving Performance in the Simulator. For each completed road segment per participant, the simulator logged a number of variables, including start and end times, mean speed, standard deviation of speed, throttle position, lateral lane position, and maximum brake position. Using these segment variables, the following measures were estimated per drive: (1) mean speed (km/h), (2) maximum speed (km/h), (3) standard deviation of speed (km/h); a low value means that the participant drove at a constant speed, whereas a high value means that the participant drove with high fluctuations in speed, (4) standard deviation of lateral position (m); A low value means that the participant drove the segments at a constant distance to the center of the lane, and a high value means that the participant showed large fluctuations in lateral position, (5) standard deviation of throttle position (0–1); a low value means that the participant held the gas pedal in a constant position, whereas a high value means that the participant showed large fluctuations in pedal position, such as regularly providing full throttle and then releasing, and (6) maximum brake position (0–1); a high value means that the participant pressed the brake deeply during the drive, for example in response to a critical event, whereas a low value means that the participant did not brake hard during the drive.

The mean speed, standard deviation of speed, standard deviation of lateral position, and standard deviation of throttle position were calculated using the completion time of the road segment as a weighting factor. Maximum speed and maximum brake position were calculated using the recorded maximum of the road segments per drive. These performance measures were not shown to the participants.

Questionnaire Results. After completing the simulator test and observing their error scores, participants could fill in a single-page electronic questionnaire on a computer with touch screen. The heading of the questionnaire stated that the collected data would be used by the Delft University of Technology and treated as confidential. The questionnaire consisted of the following items (translated from Dutch): (1) Gender (possible answers: male or female), (2) How many years do you have your driving license? (any number could be typed in), (3) How many kilometers do you drive per year? (any number could be typed in), (4) Have you ever caused damage? (possible answers: yes or no). The questionnaire also included the following statements: (5) The driving simulator is a good alternative to a driving lesson on the road (Alternative), (6) My driving style corresponds to the driving style provided by the test (Agreement), (7) The next time I get into a car I will pay more attention to my driving style (Attention), (8) I suffered from car sickness (Sickness). Participants were asked to indicate the extent to which they agreed with each of these statements, using a five-point Likert scale with anchors at 1 (*disagree*) and 5 (*agree*). The questionnaire was completed by pressing the 'Submit Questionnaire' button.

It was decided to omit Question 4 from the analyses, because it asked whether the participant had *ever* caused a crash. Drivers who have their license for a longer period (Question 2) reported a higher number of crashes, giving the false impression that these drivers were less safe than younger drivers were. A positive correlation between crashes and years of licensure is self-evident because the longer you have been a driver, the greater the chance of *ever* having caused an accident.

2.4 Statistical Analyses

Descriptive statistics were calculated, and a Pearson correlation matrix amongst the simulator measures and questionnaire responses was constructed. The number of years of licensure and annual mileage were converted to ranks.

3 Results

Eight hundred and twenty-six participants (747 men, 79 women) completed the simulator test and 650 of them (598 men, 52 women) completed all items of the questionnaire, a response rate of 79 % (80 % for men, 66 % for women). Due to a data storage error, no questionnaire data were available from the second day of the motor show. Because 46 of the 826 participants completed the test on the second day of the 12-day motor show, the true response rate was therefore estimated at 83 % (i.e., 100 % * 650/(826 − 46) = 83 %).

Because the eigenvalues of the correlation matrix among the 36 error scores indicated strong unidimensionality (the first three eigenvalues were 9.84, 2.52, and 1.96, respectively), the 36 z-transformed scores were reduced into one total risk score using the item-total correlations as weights. The total risk score therefore represents a weighted average of all recorded errors. High item-total correlations for speed-related errors confirmed that the total risk score is a measure of driving style rather than driving skill.

Table 2 shows the means, standard deviations, and correlations of the obtained data. Participants who had their license for a larger number of years had lower risk scores and lower speeds in the simulator. The correlation between maximum speed and years of licensure was −0.33 (variable 2 and 10), and the correlation between mean speed and years of licensure was −0.30 (variable 2 and 9) as Fig. 1 illustrates.

Participants with a lower total risk score as well as participants with more years of licensure were more likely to agree that their error scores corresponded with their actual driving style (higher Agreement score). The corresponding correlations were −0.20 (variable 5 and 8) and 0.12 (variable 2 and 5), respectively.

Women and experienced drivers (both in terms of years of licensure and annual km) reported higher ratings of simulator sickness than males and inexperienced drivers. The relationship between years of licensure and simulator sickness is illustrated in Fig. 2 (r = 0.31; variable 2 and 7). Sixty-five percent of the participants disagreed (i.e., score = 1) with the statement ‘I suffered from car sickness’,

Table 2 Means, standard deviations, and correlations of the dependent variables ($N = 650$)

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Gender (1 = man, 2 = woman)	1.08	0.27													
2. Licensure (years)	12.6	12.7	−0.08												
3. Annual km	24,709	27,129	−0.22	0.46											
4. Alternative (1 = disagree, 5 = agree)	3.20	1.33	−0.10	0.11	0.06										
5. Agreement (1 = disagree, 5 = agree)	2.83	1.37	−0.03	0.12	0.05	0.21									
6. Attention (1 = disagree, 5 = agree)	2.64	1.33	−0.02	−0.12	−0.12	0.23	0.09								
7. Sickness (1 = disagree, 5 = agree)	1.90	1.36	0.09	0.31	0.10	−0.06	0.03	−0.07							
8. Total risk score	0	1	0.06	−0.25	−0.04	−0.09	−0.20	0.00	−0.11						
9. Mean speed (km/h)	30.89	7.17	0.01	−0.30	0.01	−0.15	−0.10	−0.01	−0.06	0.66					
10. Maximum speed (km/h)	64.23	17.12	0.04	−0.33	−0.08	−0.13	−0.19	0.01	−0.07	0.88	0.81				
11. *SD* speed (km/h)	11.35	3.19	0.06	−0.27	−0.09	−0.09	−0.19	0.00	−0.09	0.83	0.57	0.84			
12. *SD* lateral position (m)	0.19	0.11	0.08	−0.05	0.02	−0.04	−0.11	0.01	−0.08	0.57	0.28	0.46	0.40		
13. *SD* throttle (0 – 1)	0.14	0.06	0.04	−0.30	−0.11	−0.06	−0.20	0.05	−0.11	0.82	0.52	0.80	0.82	0.41	
14. Maximum brake (0 – 1)	0.41	0.17	−0.03	−0.17	0.00	−0.01	−0.07	0.00	−0.06	0.30	0.28	0.33	0.37	0.01	0.39

Note $p < 0.05$ for $|r| \geq 0.08$, $p < 0.001$ for $|r| \geq 0.13$. Variables 8–14 are averaged over the three drives. The widths of the bars linearly correspond to the correlation coefficient

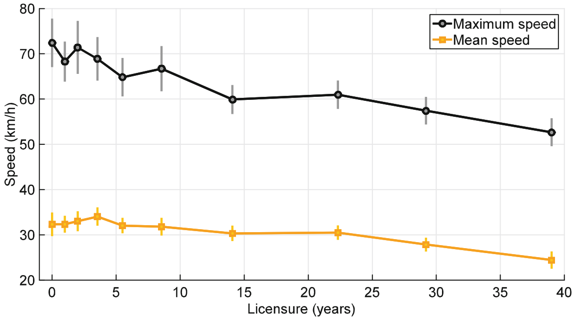

Fig. 1 Maximum and mean speed (averaged over the three drives) as a function of licensure. The participants ($N = 650$) were sorted on years of licensure in 10 groups of approximately equal size. The horizontal axis shows the mean years of licensure and the vertical axis shows the averaged speed per group. The vertical lines are 95 % confidence intervals

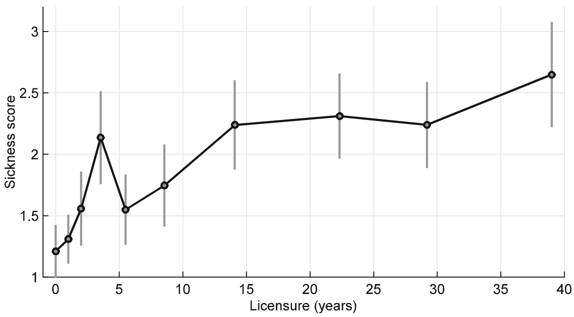

Fig. 2 Simulator sickness score (1 = disagree, 5 = agree) as a function of licensure. The participants ($N = 650$) were sorted on years of licensure in 10 groups of approximately equal size. The horizontal axis shows the mean years of licensure and the vertical axis shows the averaged sickness score per group. The vertical lines are 95 % confidence intervals

whereas 6 % agreed (i.e., score = 5). Of those who agreed, 18 % were female, while among those who disagreed, only 7 % were female. The simulator records revealed that there were 15 persons (13 men, 2 women) who did not complete the driving style test, for undocumented reasons. Three of them filled in the questionnaire, and all three disagreed with the statement 'I suffered from car sickness' (score = 1). This finding suggests that, for these participants, simulator sickness was not the cause of dropout.

4 Discussion

This study investigated how years of licensure and yearly mileage relate to driving style as measured with a short simulator-based test. The results showed that drivers who had their driving license for a longer period (thus generally also older drivers) drove more slowly and with a less risky driving style. This correlation is consistent with on-road driving data showing that young drivers are more likely to engage in risky behaviors than older drivers [7]. This study adds to a body of evidence showing that simulators are able to measure a person's driving style in a valid manner. For example, it has been found that age [32], self-reported driving style [33], and self-reported violations [5] are predictive of driving speeds in a simulator.

The use of portable simulators at a motor show allowed us to obtain a large sample size (and see [34], who tested 624 people in a simulator using a similar approach). Although our sample size was large, the present sample is not representative of the driving population, because the participants were motor show visitors; males were highly overrepresented. The unusual sample may also explain why no statistically significant gender differences in driving behavior were observed (Table 2), whereas large gender differences have been observed among learner drivers during simulation-based driver training [35]. It requires further research to investigate whether the present results are generalizable to other driving populations.

With a drive time of 6.5 min per participant, the driving style test was of short duration. According to McGehee et al. [36], experienced drivers need at least 6 min to get used to a simulator and learn how to steer the virtual car stably. A longer test is not necessarily desirable, however. Allen et al. [22] showed that the participants' (N = 488) first simulator drive was predictive of future on-road crashes; subsequent drives had no significant predictive value. A possible explanation for this finding is that individual differences in driving style may be more valid during the first simulator encounter, because the situation is new for participants and mental workload is high. In long drives, drivers may have adapted to the simulator experience, and make few errors and experience low mental workload.

It is unknown which psychological mechanisms may have caused the negative correlation between years of licensure and driving speed. Possibly, young drivers were more inclined to try out the simulator and drive as fast as possible. Another possible explanation is that the driving test provided a measure of confidence with computers (rather than actual information on how a participant drives in real traffic), and see [37–40] for the effect of age and experience on driving performance in a simulator. The motor show was not a quiet testing environment, and possibly this contributed to increased workload and distraction. It remains to be investigated how drivers would drive in a simulator-based test in a formal context, such as the hypothetical situation where a simulator test is part of the driver's license test. Most likely, drivers would then be more inclined to adhere to traffic rules, and driver behavior would be more homogenous.

People with a higher total risk score were less likely to agree with their error scores. Possibly, the simulator gave a too strict assessment for some drivers, and these drivers were therefore correct in disagreeing with their scores. On the other hand, these results may be interpreted in light of the fact that most drivers believe themselves to be better than the average driver [41]. Our study also found that the longer license-holders tended to agree more with their error scores. This may be a direct consequence of the fact that the error scores were better for the longer license-holders. This finding is also in line with work by Finn and Bragg [42] who showed that young drivers (incorrectly) perceived their chances of being involved in an accident as lower than those of their peers and older males, whereas older drivers (correctly) indicated that their chances of having an accident were comparable to those of their peers and less than those of young male drivers. The present results may point to a problem in teaching people how to drive safely, namely that those drivers who adopt the most deviant driving styles are the least willing to agree that they drive badly.

An important advantage of simulator-based testing as compared to on-road testing is the possibility to present identical scenarios to all individuals. However, car driving is a self-paced and it is crucial to assess voluntary aspects such as speeding and decision-making, for example regarding route choice. This raises the question of how to find a satisfactory balance between standardization and voluntariness of the driving task. In the present driving test, the simulator did not intervene if a participant did not follow the route instructions. If the participant drove in the wrong direction, he or she could continue driving but missed the remainder of the pre-programmed scenarios. A commonly used option is to let a simulator intervene automatically and put the car back on track with zero speed. Both aspects have disadvantages; in the first, not all participants encounter the same scenarios; in the second, the participant is interrupted and important performance measures, such as the mean speed, are distorted. A possible answer to this dilemma may be to use scripts, so that virtual agents adapt their behavior to the participant [43]. For example, if a driver makes a wrong turn, the situation can adapt so that the driver will still encounter the planned events without the need to stop and reset the vehicle [44].

The results showed that women were more susceptible to simulator sickness than men were (see also [45, 46]). The results also showed that driving experience correlated with simulator sickness and that sickness ratings systematically increased with years of licensure (Fig. 2). This systematic increase suggests that besides experience, age also contributes to motion sickness (see [47], for review on the effects of experience and age). Simulators are widely used for young driver training [48], and although simulators are not yet used for formal driving examination, this may be a logical next step. However, the present findings point to some reservations in this regard, because elevated incidences of simulator sickness should be anticipated when testing experienced (older) drivers. Severson et al. [49] proposed an interesting solution to simulator sickness in a test using a PC-based simulator with a relatively simple monitor, steering wheel, and pedals. The simulation offered an abstract visual environment in which participants had to make go/no-go decisions when approaching opening and closing gates. Severson et al.'s test was able to distinguish between healthy older drivers and older drivers with a brain disease, and there was no reported incidence of simulator sickness. Other studies have also shown that driver training and assessment can be effective with PC-based systems [25, 31].

Driving is a primary mode of transport, and driving privileges and independent mobility are critically important for most people. The introduction of new driver-testing tools is likely to meet with great skepticism and simulators will probably be accepted only when they can be shown to yield valid results. This study showed that years of licensure substantially correlates with driving speed and a total risk score in the simulator. This result corresponds to on-road-data showing that young drivers are more likely to be involved in speed-related crashes than older drivers (e.g., [7]) and to research showing that young drivers report more violations and higher sensation seeking scores than older drivers [50, 51]. However, this study provided just a first step in studying the potential usefulness of simulators for driver testing. More research will be required with alternative safety criteria, with other populations, and in other testing contexts (e.g., driver testing center instead of a motor show). Furthermore, this study highlighted challenges that must be anticipated when developing future simulator-based tests, namely issues of standardization and simulator sickness.

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