Training for the Unexpected: Enhancing Driver Preparedness Through Hazard Awareness

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Highlights

- Learning the value of hazard awareness training and testing for driving education.
- Results from 2,879 respondents show safe driving effects for driving education.
- Significant correlations between simulator performance scores, on-road training hours, exam attempts, and self-reported violations and errors after licensing.
- Females are more risk-aware than males.

Abstract

Background
Car driving education in the Netherlands is transforming, and a national curriculum has been introduced to produce safer drivers. This National Curriculum Driver Training B proposes using driving simulators to support practical training and includes hazard examinations to reinforce safe driving, which will be obligatory in Europe. This study aimed to deepen the understanding of the relationships between hazard training and testing on driving simulators and supervised (pre-licensed) and unsupervised (post-licensed) driving.

This study builds on Kuipers, De Winter, and Mulder's (2023) research, investigating the relationships between personal characteristics, pre-licence-accompanied driving, self-reported post-licence driving behaviour, and driving performance scores during simulator lessons.

Methods
We comprehensively analysed simulator data and insights from a questionnaire completed by Dutch car drivers (total n = 2,879) who underwent simulator training between 2008 and 2023. We compared the driving performance of respondents who received hazard training (HT) with the performance of a control group who did not receive HT training in four driving phases: simulator training, on-road training, examination, and post-licensed driving.

Results
We found distinct differences in performance. Simulator scores, on-road training hours, and test attempts differ significantly. HT increased practical driving education efficiency by 12.4% and reinforced the development of a safe driving style that educational experts recognised and rewarded. In contrast to this positive effect during education, we found no significant effects when driving unsupervised. Results show that whereas drivers think they are sufficiently proficient after obtaining their license, a real improvement in safety performance becomes visible after the first twelve months. This confirms the general finding that young drivers are the most vulnerable to accident involvement in the first year of driving.

Real car crashes did not affect novice drivers' awareness of their limited skills for detecting and anticipating hazards, indicating low proficiency in self-reflection/calibration.

Discussion and Conclusion

Exposure improves driving skills and stimulates self-confidence. Nevertheless, it also provokes violations and errors when driving unsupervised. Drivers are unaware that they lower their safety margins and have the highest accident risk in the first six months of driving. This study showed that, with current education curricula, risk awareness remains a more personal characteristic than a trainable skill.

We provided evidence that hazard awareness training facilitates and reinforces the development of a safe driving style that educational experts recognise. Hazard awareness training prepares students better for real-world driving, making it a valuable addition to traditional lessons. Although hazard awareness training on simulators positively affected education, no retention effect was found after licensing.

1. Introduction

In the Netherlands, the chance of being involved in a car crash is five times higher for 18–24-year novice drivers than for more experienced drivers 30-59 years old (SWOV, 2012). In the first months after licensing, the crash rates are the highest. The crash risk drops substantially over the first two years of driving, with the most significant decline during the first year (ECMT, 2006). Although education innovations like driving simulators are expected to mitigate this *young driver* problem, the Netherlands' National Scientific Institute for Road Safety Research SWOV (2019) concluded that scientific evidence is still lacking. SWOV suggested *hazard detection* training to improve viewing skills and reduce accident risk.

A broad coalition of chain partners in the Netherlands aims to innovate professional driving education to deliver safer drivers: competent drivers instead of drivers who merely show what the examiner assesses during the examination. Current driving education based on uncontrolled curricula will transform into an obligatory national curriculum for car drivers (Roemer, 2021). The educational design document of the Dutch National Curriculum Driver Training B (Roelofs et al., 2023) mentions driving simulators to support practical lessons, following the European Commission's revised Directive on driving licenses (European Commission, 2023). This EC directive recommends including driving simulators in testing *risk awareness* for novice and experienced drivers. The driver training, testing, and probation rules for all driving categories must ensure that novice drivers obtain the skills, knowledge, experience, and risk awareness needed to drive safely.

The National Curriculum Driver Training B requires the acquisition of good viewing skills (conscious awareness), which aligns with the recommendations of SWOV (2019). These viewing skills are essential for detecting the relevant information necessary to predict and recognise hazards. Literature supports this requirement. McKnight and McKnight's (2003) analyses of police reports conclude that failures in visual scanning, attention maintenance, and speed management were responsible for around 87.1% of crashes among young drivers. They concluded that hazard perception (detection and anticipation) is a crucial safety-related driving skill. Inexperienced drivers tend to scan less broadly and move their fixations less than experienced drivers and, therefore, are more inclined to fail at detecting risks on time. Owsley et al. (1998) found that the degree of visual attention was a predictive value for accident involvement of elderly drivers. They introduced the *Useful Field of View* - UFOV - metric, which explained the crash frequency of a group of older drivers as a factor. Older drivers with a UFOV reduction of 40% or more were 2.2 times more likely to crash than drivers with less UFOV reduction. The UFOV metric is widely accepted and has evolved from the active field of view size to a visual processing speed metric (Owsley, 2013). Edwards et al. (2018) conducted a systematic review and meta-analyses of UFOV training, reviewing 44 studies of UFOV training from seventeen randomised trials conducted among adults. Results indicated that UFOV training showed, among others, fair transfer to everyday function and improvements in the trained skills endured across ten years. Several studies found positive correlations between hazard detection (viewing skills) training and improved hazard detection skills directly after the training (Horswill et al., 2008; McDonald et al., 2015; Omran et al., 2023). Horswill et al. (2015) found positive correlations between hazard detection test scores and self-reported historical crash involvement. However, retention research on safe driving *after* hazard detection and anticipation training was not part of those studies.

The present study is the first to study the effects of hazard detection and hazard anticipation training on the long-term retention of safe driving skills. It aims to deepen our understanding of the role of hazard detection and anticipation skills in developing and maintaining a safe driving style after licensing. It studies the potential benefits of using simulators in driving education to support practical training, as suggested by the Dutch National Curriculum Driver Training B and the EC Directive on driving licenses.

The paper is structured as follows: The Methods section describes the processes of data generation, collection and analysis. In the Results section, we compared the driving performance of licensed car drivers who followed *Hazard Training* - HT - during driving education with a control group who did not follow HT. The Discussion section addresses performance differences between both groups from the perspective of existing knowledge and the safety goals of the Dutch National Curriculum Driver Training B and the new EC Driving license directive. The Conclusions and Recommendations section then summarises the contributions of our research to the existing knowledge concerning driving education in general and training on simulators specifically. It emphasises the importance of future research regarding the benefits of using higher safety margins in driving education.

2. Methods

Driving Simulators

The dataset[1] for this study originates from Green Dino driving simulators (Figure 1). Between 2008 and 2023, Dutch driving schools used four types of driving simulators. Whereas considerable differences existed in image projection methods (projectors or screens) and control mechanisms (car parts or Logitech products), all simulators ran identical software applications and curricula.

Figure 1: Driving simulator type “Drive Master B”.

The Green Dino simulator provides automated adaptive instruction using an AI (virtual) driving instructor, which supplies automated performance feedback (Weevers et al., 2003; Fikkert et al., 2006). The simulator substitutes both the training vehicle and the human driving instructor. The thirty-four 30-minute curriculum lessons address vehicle handling, intersection navigation, highway driving, and manoeuvring. The simulator is used early in driver training, typically before students start lessons in an on-road vehicle.

Driving school owners are advised against having an instructor present during the simulator lessons, as this decreases the economic benefit substantially. Extra support by an instructor could increase the percentile scores, giving the students a false idea of their skills compared to their peers. Two trainees with scores of 7.0 seem to be equally fast in learning, but they are not in case one needs the help of an instructor to lower faults. The opposite could also happen: De Groot et al. (2007) reported

[1] Kuipers, De Winter and Mulder (2023) used data collected in the period 2008 - 2015.

that additional attention from a human driving instructor during lessons on the Green Dino simulator (with automated instruction) decreased student performance.
The research presented in this paper used scores from one of the summary reports (Figure 2), frequently used to brief students, their parents and their instructors about their driving skill learning progress. The report includes composite scores categorised under “driving skills score” and “safety score”. In short, the driving skill score is a composite score derived from combining various task scores. These include excessive braking or collisions, improper use of turn signals, swerving or deviating from the centre of the road, and operating at inconsistent engine rpm within the simulator. The safety score is based on the degree to which the student driver exceeded speed limits or maintained an insufficient distance from the vehicle ahead in the simulator, amongst other safety-related behaviours. The scores will be explained in more detail in the Analysis Approach subsection.

Safety Report

Click on the lesson date to view the lesson results.

John Doe	
DrivingStyle	
General summary	
Driving skill	7.5
Safety score	5.8
Avoiding risks	4.6
Economical driving	7.3
Summary by categories	
Vehicle control	9.6
Observation and anticipation	5.3
Keeping safe speed	4.6
Keeping fluent speed	5.9
Keeping traffic rules	6.0
Avoiding traffic accidents	6.0
Vehicle control	
Headlights not used	5.1
High beam lights with other traffic	7.9
Possible to skip gears	0.0
Position inside lane	9.0
Smooth steering	8.9
Precise steering	6.0
Shifting up in time	9.0
Shifting down in time	6.7

Viewing	
View behaviour	4.9
* before turning left	3.5
* before turning right	6.1
* before going straight on	7.0
* before entering a roundabout	7.3
* before braking	6.8
* before changing lanes	3.4
* scanning	5.1
Observation and anticipation	
Overtaking with approaching traffic	3.2
Keeping distance to preceding car	2.0
Reacting in time	8.7
Smooth braking	6.9
Keeping safe speed	
On straight road segments	5.2
In curves	8.2
When approaching intersections	6.9
* and need to stop	6.0
* turning right	8.4
* going straight	7.1
* turning left	7.5
When crossing intersection	8.4
* turning right	5.4
* going straight	9.6
* turning left	9.9
On roundabouts	9.8

Keeping fluent speed
On straight road segments
When approaching intersection
When crossing intersection
On roundabouts
Traffic rules
Stopping for traffic lights
Indicators usage on intersections
Indicators usage on roundabouts
Obeying right of way
* On sign controlled intersections
* On trafic light controlled intersections
* On uncontrolled intersections
* On roundabouts
Accidents (number)
Collisions with other traffic
Onesided collision
Offroad
Partially offroad

Figure 2: Safety Report.

Hazard Detection Training and Testing (HDTT)
For the training and assessment of hazard detection procedures, eight fields of view are differentiated (Figure 3): straight forward, left forward, right forward, left, right, straight backwards (interior mirror), left backwards (wing mirror) and right backwards (wing mirror). These fields are related to the “driving procedures B” (= car)[2]. Figure 3 shows an example of a detection assessment for turning right; here, the driver looked at the green fields 1, 3 and 6 and did not (or not long enough) view the red fields 2, 5 and 8. Fields 4 and 7 are not needed as the task involved turning right. The white area represents the learner driver's current field of view. In the graphical user interface of the driving simulator, red regions are used with icons, text, and audio to inform the learner driver about any procedural detection faults (Figure 4).

The automated detection instruction trains the learner to release the gas pedal long before entering an intersection and scan specific areas of the surroundings related to the activated procedure. The training

[2] https://www.cbr.nl/nl/voor-rijscholen/nl/rijprocedures/rijprocedure-b-6

partly assesses the processing of the information visible in the target field, as in UFOV training[3]. Feedback about appropriate approaching speed, following distance, stopping distance and time to give right of way is provided. However, there is no direct connection between detection errors and these procedural faults because the detection of scanning errors was implemented later and not fully integrated. When approaching an intersection, feedback on the car's velocity directs the learner driver to slow down and create more time to attend to the required areas of view in the correct sequence.

The post-evaluation safety report presents scores for approaching speed and viewing procedures and integrates these into scores for driving skill, safe driving, avoiding risks, and eco driving (Figure 2).

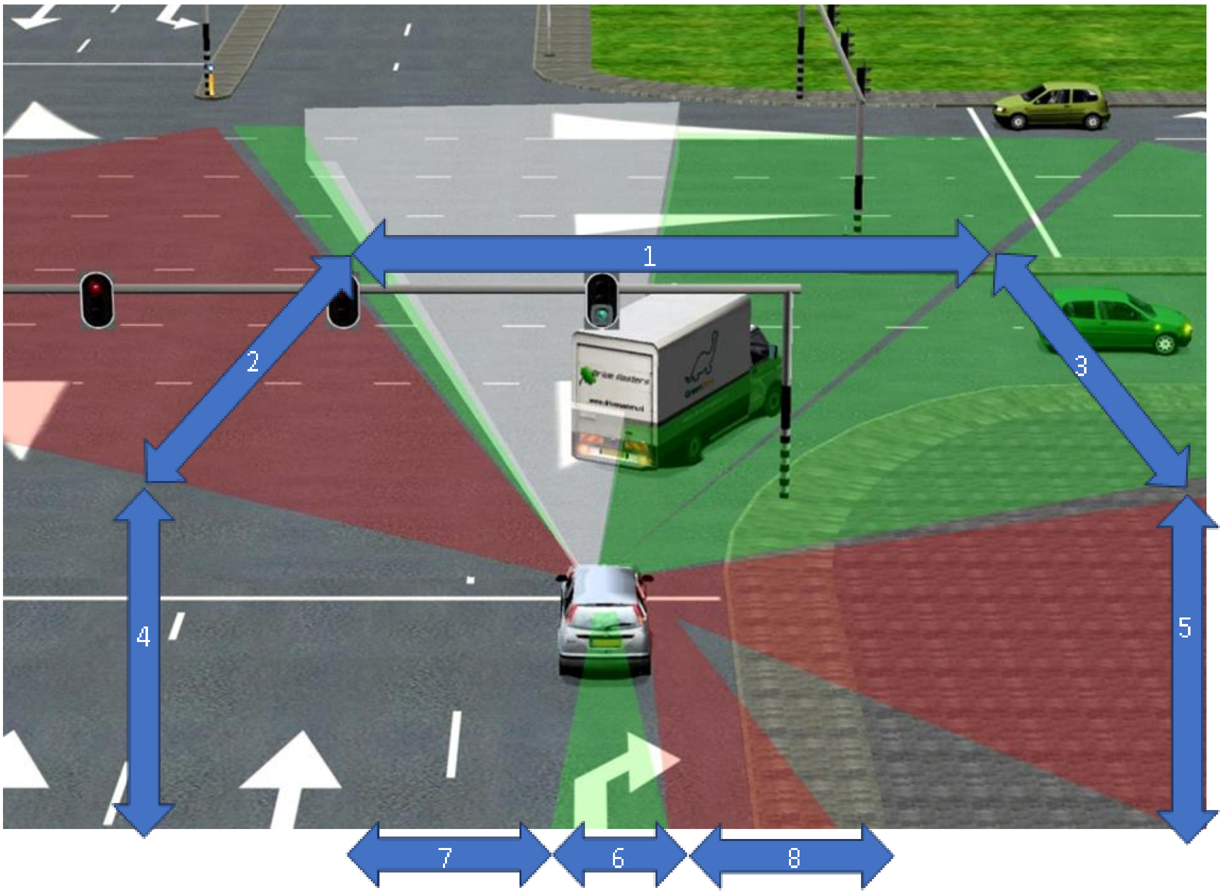

Figure 3: Detection areas: fields of view (source: Green Dino).

[3] Through combining scores of FOV, safe approaching speed, giving right of way, and use of indicators, the performance of information processing can be evaluated by the simulator operator. It is currently not yet part of the automated, adaptive instruction system.

Figure 4: Graphical user interface with red areas marking detection faults (source: Green Dino).

Hazard Anticipation Training and Testing (HATT)

In 2013, Green Dino released hazard anticipation training and testing based on Vlakveld (2011). In the HATT, five hazard scenarios are simulated which provoke crashes with other cars. The five scenarios are: 1) overtaking on an 80 km/h road, 2) covering a situation at an intersection (Figure 5), 3) covering a situation at a T-junction, 4) passing a truck on a too-narrow road, (5) two confrontations with an ambulance with alarm signals. After crashing, an explanation follows, including correct detection and anticipation instructions. Figure 5 shows a scenario where the red truck blocks the grey car driver's view of a green approaching car. The driver entered the crossing and tried to look behind the truck. A crash with the upcoming car is unavoidable. During the post-evaluation in the simulator, the driver gets an overview of the hazardous situation and is told to stop before the intersection and wait until the truck leaves. All detection and anticipation steps are mentioned and visualised. Then, in the second trial, the driver can try again, slow down and stop before entering the intersection and experience the positive effects of using higher safety margins. At the end of the Hazard Anticipation training, the learner driver follows a 6.5-minute Driving Style Test (De Winter & Kuipers, 2017) and receives safety scores related to the shown driving style. The scores support the instructor in making an education plan. Some driving schools use the Driving Style Test to determine whether the trainee can drive unsupervised.

Figure 5: Hazard anticipation training example (source: Green Dino).

HDTT and HATT *reinforce* each other. HDTT instructs the speed and viewing procedure for approaching and overtaking hazardous situations like intersections. It teaches students how to detect dangerous situations: slowing down long before entering a complex traffic situation by releasing the gas pedal (instead of braking just before entering). HATT increases knowledge about the effects of errors in executing the procedures (smooth driving) approaching potentially hazardous situations. It targets the internal motivation of the learner driver to be more careful and slow down or even stop before entering a complex situation to allow oneself more time to detect and anticipate (potential) hazards.

In this paper, the effects of HDTT and HATT will be studied in one go, labelled the 'Hazard Training' group (HT), compared to student drivers who did not follow any hazard training, the control group.

Questionnaire Distribution

Between 9 and 13 November 2015, 22,881 persons received an e-mail from Green Dino with an invitation to participate in a study and complete a survey. The survey's primary goal was to investigate the effects of simulator training on the lessons needed to obtain a driving license. The (former) learner drivers were asked to complete an online questionnaire by clicking the provided link and answering the questions. As a reward, twenty cinema tickets were raffled among interested participants. People could also indicate whether they would like to receive a summary of the results at the end of the study. The raffle and the sending of the summary took place in March 2016. Kuipers, De Winter and Mulder (2023) describe the questionnaire's content and data cleaning.

In March 2023, Green Dino sent a slightly adjusted questionnaire to study the effects of the 2013 introduced hazard anticipation training and test. Only persons who drove on a simulator between 2015 and 2023 received this second questionnaire, which contained additional questions. These questions addressed the responsibility of an accident, the self-comparison of driving skills with other drivers, and the experienced driving difficulty. Moreover, violation- and error-related questions were added for the last twelve months.

Filters were used to prepare the data sample for analysis of specific topics. Most analysis has been done using the combined data (2008-2023). Sometimes, only the latest inventory data (2015-2023) were applicable or available. In those cases, a remark is added. After filtering, data from 2,879 persons remain for analysis.

Analysis Approach

We followed Kuipers, De Winter and Mulder (2023) and divided the sample into two groups: the HT and the control groups. Then, we compared the group averages on simulator scores, training duration, exam attempts, errors, violations, and accident risk with several t-tests. We used Cohen's d to determine the effect size. Cohen's d represents the difference between two means, normalised by the standard deviation. Typically, a d value of 0.20 is interpreted as a small effect size, 0.50 represents a medium effect size, and a value of 0.80 or higher means a large effect size. In contrast to Kuipers, De Winter and Mulder (2023), the data were not transformed into ranks.

We selected four driver safety indicators to analyse the potential safety benefits of HATT (Figure 6). These indicators follow naturally from the student driver curriculum, from supervised to unsupervised driving, in four phases: simulator training, on-road training, examination and post-licensed driving. The first indicator is the simulator assessment, based on the difference between the five simulator scores obtained between the vehicle handling test at the beginning of the simulator curriculum and the intersection test, which occurred later. After the simulator training, students were trained on the road by a driving instructor. The second indicator is the driving instructors' assessment: how many on-road lessons are needed before the instructor decides the student driver can apply for the driving exam. The third indicator is the examiners' assessment, whether the student driver can drive unsupervised, for which the success on the first exam attempts and the total number of attempts are used. The fourth indicator is the drivers' self-assessment, obtained *after* the training when driving unsupervised.

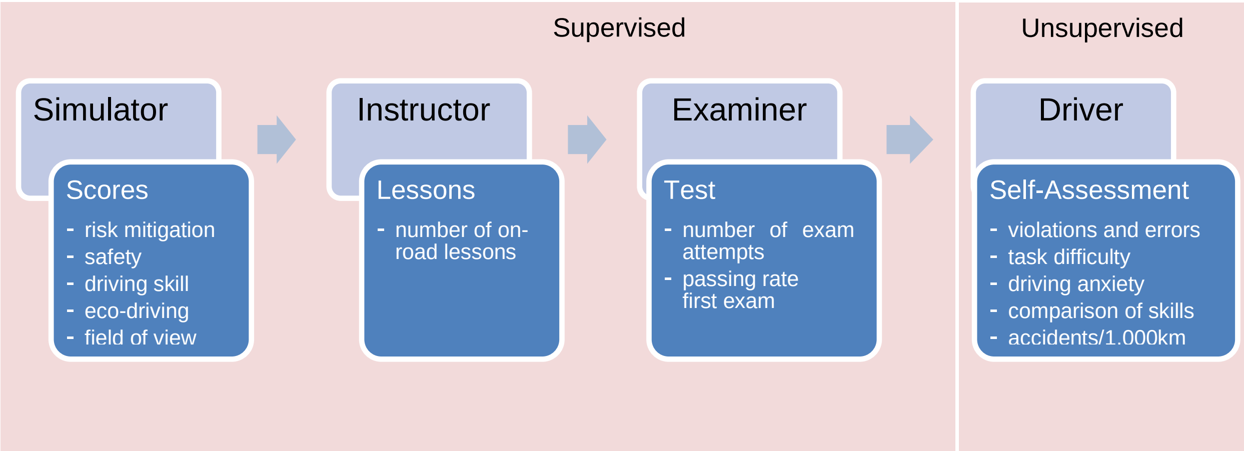

Figure 6: Driver safety indicators.

Simulator assessment measures (Figure 2)

Risk mitigation score (0-10): This score is a combined score based on scores for (1) approaching intersection too fast, (2) crossing intersection too fast, (3) driving too fast, (4) approaching intersection too slow, (5) crossing intersection too slow, (6) driving too slow, (7) ignoring right of way, (8) ignoring traffic rules, (9) inappropriate distance, (10) bad engine rpm, (11) inappropriate speed, and (12) inappropriate steering. The mean of all scores, except driving too slowly, lowers the avoiding risk score. The driving too slow score is inversed, meaning a higher score (i.e., when a trainee drives too slowly) increases the risk mitigation score. The share for driving too slow in the risk mitigation score is 50%.

Note that the 'too low' scores were designed to identify cautious drivers who did not drive smoothly, like anxious and elderly drivers. This study classifies them as the more risk-aware drivers.

Safety score (0-10): This score is a combined score based on scores for (1) bad engine rpm, (2) ignoring traffic rules, (3) inappropriate distance, (4) inappropriate speed, (5) inappropriate steering, and (6) traffic accidents. The mean of all scores lowers the safety score, including driving too slow. The score for inappropriate speed combines driving too fast and driving too slowly. The share for driving too slow in the safety score is 8.7%.

Driving skill score (0-10): This score combines scores for (1) bad vehicle control, (2) ignoring traffic rules, and (3) traffic accidents. Bad vehicle control is a combined score of bad rpm and inappropriate steering. Ignoring traffic rules is a combined score of ignoring the right of way, ignoring traffic lights, incorrect indicators usage, and incorrect indicators usage on roundabouts. Traffic accidents is a combined score of braking too hard, dynamic or static collision, driving offroad entirely or partially.

Eco driving score (0-10): This score is a combined score based on scores for (1) engine rpm too high and (2) large braking energy losses. Engine rpm too high is a combined highest and lowest max rpm score. The lowest rpm is multiplied by 1.2.

Field of view score (0-10): This score is a combination of scores for (1) inadequate scanning behaviour and (2) bad viewing behaviour for intersections. Inadequate scanning is the combined score of not observing the windscreen adequately and not observing the inner mirror before speed adjustment. Bad viewing behaviour for intersections is the combined score for not checking the windscreen, mirrors and left and right windows conform to the active driving task.

Self-assessment measures

Driving Anxiety score (1-5): The driving anxiety score is based on the respondents' answers to the question "Were you scared to drive a car when you started your driving lessons?" (not at all (1), barely (2), a little (3), quite (4), very much (5)).

Violations: The violation score is the sum of responses to five statements: How often did you? (1) drive more than 10 km/h faster than the speed limit inside city limits, (2) use your mobile phone to read/send a text, (3) (intentionally) crossed a red light, (4) drive after drinking alcohol, (5) drive without using the safety belt. Respondents could choose between seven answers: (1) never (score = 0), (2) rarely - less than one time a month (score = 1), (3) sometimes - approximately once a month (score = 2), (4) frequently - approximately once a week (score = 3), (5) very frequently - multiple times a week (score = 4), (6) almost every time I drive (score = 5), and (7) I cannot remember. The score is calculated for the first six months, second six months, first year and last twelve months of driving. Questions regarding the last twelve months were only included and distributed in the 2023 sample questionnaire, so there are no violation scores for the last twelve months in the 2015 sample. Violation scores were not generated for respondents who answered with 'I cannot remember' to one of the statements since their scores would not be representative.

The violation scores are likely to be low. It is not plausible that drivers demonstrate all these risky driving behaviours every time they get into a car. There will be drivers who sometimes drive after consuming alcohol, but they very improbably drink every time they drive. Nevertheless, differences in scores are interesting as they could demonstrate changes in risk-taking behaviour.

Errors: The error score is the sum of responses to three statements: How often did you? (1) have to make an emergency stop because you were driving too close to the car in front, (2) get off-road, for example, in the verge, against the sidewalk, or deviate into the wrong lane, and (3) not give right of way where you should have. Respondents could choose between the same seven answers, like for violations. The score is calculated for the first six months, second six months, first year and last twelve months of driving. Again, questions regarding the last twelve months were only distributed to the 2023 survey, so there are no error scores for the last twelve months in the 2015 sample. Error scores were not generated for respondents who answered with 'I cannot remember' to one of the statements since their scores would no longer be representative.

Again, these scores are not likely to be very high. It is not plausible that drivers make these errors every time they get into the car. For example, drivers are unlikely to get off the road in all their rides. Nevertheless, differences in scores are interesting because they indicate changes in driving proficiency.

Subjective driving skill competence: Two statements were used to measure subjective driving skill competence: (1) "I think I am a more skilled driver than other drivers", and (2) "I sometimes experience difficulties driving". Respondents could answer these two questions with "yes" or "no". These statements were added to the 2023 questionnaire, so this information is only available for drivers of the 2023 sample. The two statements will be labelled "Comparison driving skills" and "Subjective driving difficulty", respectively, in the following.

Accidents: Accident involvement is a binary variable with 'no' and 'yes' as answers. The accident risk was calculated to correct for exposure. The following formula was used: *Accident risk per 1.000 km = (Number of accidents/distance driven in km) * 1.000*.

Due to very small group sizes, the specifics of the accidents, such as whether more drivers were involved and whether the respondent was the offender, were not analysed.

In contrast to Kuipers, De Winter, and Mulder (2023), only simulator-trained drivers performing vehicle handling lessons and intersection tests between 2008 and 2023 were selected, mitigating the self-selection effect. Trainees who conducted the training after 2015 were selected for the HT group because head trackers functioned better after 2015 (source: Green Dino). The group of trainees who performed the intersection test on the simulator but did not receive feedback on their field of view skills and did not follow HT functioned as the control group.

By performing paired sample t-tests on the outcome variables of interest, the differences between the HT group and control group on the dependent measures were analysed. Note that the sample size differs between the various analyses due to variations in the data filters.

3. Results

The results are split into subsections, ‘Driving Supervised’ and ‘Driving unsupervised’ (see Figure 6). We first discuss the objective performance measurements obtained in the driving simulator and the (semi-objective) performance assessments of the driving instructor and examiner reported by the respondents. Then, we discuss the respondents’ subjective self-assessment measures regarding their driving after licensing.

3.1 Driving Supervised

3.1.1 Simulator

To determine the effect of HT, differences in simulator scores between the driving skill test (at the end of the first module, ‘Vehicle Operation’) and the intersection test (at the end of the second module, ‘Intersections’) were analysed. According to the simulator's skill assessment metrics, the higher these scores are, the more advanced the trainee's related driving skills are.

Table A

Table A: Means, standard deviations, sample sizes, effect sizes, and p-values for the driving skill test and intersection test of the entire sample. The coloured bar exhibits a linear scale from −1.0 to 1.0, with negative values in orange and positive values in green. Bold correlations are significant (p < 0.05).

Measurement moment	Driving skill test			Intersection test				
	Mean	*SD*	*n*	Mean	*SD*	*n*	Cohen's d_r	*p*
Simulator risk mitigation score (1 - 10)	5.04	0.65	390	5.46	0.71	236	0.53	**6.4E-13**
Simulator safety score (1 - 10)	6.32	1.34	390	7.25	0.98	236	0.58	**1.2E-14**
Simulator driving skill score (1 - 10)	6.45	1.59	390	7.94	1.00	236	0.78	**4.6E-23**
Simulator eco driving score (1 - 10)	6.26	1.14	390	7.22	1.50	236	0.64	**3.5E-17**
Simulator field of view score (1 - 10)	3.75	2.28	140	5.94	1.89	197	1.05	**2.6E-24**

The paired samples t-tests show that trainees improved on all five scores and were positively affected by the simulator intersection lessons (Table A). Compared to the vehicle handling test, trainees (1) mitigated risks better during the intersection test (d = 0.53, p < .001), (2) drove safer (d = 0.58, p < .001), (3) had more advanced vehicle handling skills (d = 0.78, p < .001), (4) drove more environmentally friendly (d = 0.64, p < .001), and (5) increased their viewing skills (d = 1.05, p < .001). The effect sizes were medium for most scores but large for the field of view score. Clearly, trainees learn and advance their driving skills in the simulator and demonstrate safer and proficient driving behaviour after following intersection lessons.

Table B shows the Pearson correlation matrix of many of the dependent measures obtained in our study. Regarding the simulator measures, items 7-11, HT training (column 1 in Table B), negatively correlates with the eco-driving score (row 10, r = -0.20) at the intersection test, indicating that the HT group trainees scored lower on eco-driving. This effect was further investigated with an independent t-test, comparing the HT and control groups (p < .001, d = 0.46, Table C). No significant differences were found between these groups for the other simulator scores, which suggests that their driving performance was comparable at this moment of the driving education.

Second, gender differences are observed (column 2 in Table B). Better safety (row 8, r = -0.24) and driving skill scores (row 9, r = -0.14) are associated with being male, whereas females show better risk mitigation (row 7, r = 0.21) and eco-driving scores (row 10, r = 0.12). Because of the weighting principles associated with these latter measures (see above), females drive more often slowly than males, driving more carefully and risk aware. Third, self-reported driving anxiety (column 4 in Table B) is negatively correlated with safety (row 8, r = -0.17) and driving skill scores (row 9, r = -0.12), demonstrating that the more anxious someone feels about driving, the lower these scores in the simulator. Risk mitigation (row 7, *r* =0.11) and eco-driving scores (row 10, *r* = 0.12) demonstrate opposite effects: the higher the feeling of anxiety, the higher these scores. No difference was observed between males or females on the simulator on the field of view score (column 2, row 11) or simulator hours (column 2, row 12).

The driving skill and safety scores at the intersection test are strongly correlated (column 8, row 9, *r* = 0.78 in Table B). The driving skill score also positively correlates with the risk mitigation score (column 7, row 8, *r* = 0.28). These correlations can be partly explained because the metrics use the same variables to calculate both scores.

Table B

Table B: Pearson correlation matrix. Bold correlations are significant ($p < 0.05$).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 HT (0 = no, 1 = yes)														
2 Gender (0 = male, 1 = female)	0.07													
3 Licencing age	**-0.12**	0.01												
4 Driving anxiety	-0.07	**0.26**	**0.21**											
5 Comparison driving skills	-0.07	**-0.23**	**-0.33**	**-0.32**										
6 Subjective driving difficulty	**0.17**	**0.23**	**0.38**	**0.47**	**-0.61**									
7 Risk mitigation score at intersection test	0.00	**0.21**	0.06	**0.11**	0.03	0.07								
8 Safety score at intersection test	-0.01	**-0.24**	**-0.11**	**-0.17**	0.11	-0.10	**0.28**							
9 Driving skill score intersection test	0.08	**-0.14**	**-0.13**	**-0.12**	0.05	0.00	**0.27**	**0.78**						
10 Eco driving score intersection test	**-0.20**	**0.12**	**0.10**	**0.12**	0.08	-0.03	**0.30**	0.00	0.02					
11 Field of view score intersection test		0.00	0.03	0.04	-0.05	0.05	0.14	**0.22**	**0.16**	0.13				
12 Simulator training hours	**0.27**	0.00	**-0.09**	0.03	-0.05	0.06	0.07	**0.18**	**0.18**	**-0.09**	0.08			
13 On road training hours	**-0.10**	**0.14**	**0.21**	**0.27**	**-0.20**	**0.26**	0.05	**-0.19**	**-0.19**	0.03	**-0.23**	0.00		
14 Total duration driving education	-0.07	**0.14**	**0.20**	**0.27**	**-0.21**	**0.26**	0.06	**-0.16**	**-0.17**	0.02	**-0.22**	**0.14**	**0.99**	
15 Number of driving exams	**-0.10**	0.07	0.01	**0.12**	-0.01	0.02	-0.01	**-0.15**	**-0.14**	0.00	-0.11	**-0.08**	**0.32**	**0.31**

3.1.2 Instructor

In this study, the measure used to quantify the instructor assessment is the number of on-road training hours needed before the instructor decides whether the student driver can apply for the driving exam (item 13 in Table B). A few variables related to the instructors' decision correlate with driving education duration. Significant positive correlations are observed between on-road training hours (row 13) and gender (column 2, *r* = 0.14), licensing age (column 3, *r* = 0.21), and driving anxiety (column 4, *r* = 0.27). This suggests that females, older trainees, and trainees with more anxiety require more on-road training hours before the instructor considers them to be sufficiently competent for driving unsupervised. In contrast, on-road training hours correlate negatively with self-reported driving difficulty (column 5, *r* = -0.20), suggesting that students who experience fewer difficulties while driving also need less on-road training.

On-road training hours and total duration driving education are nearly equal in correlations to all measures, expressed in the strong correlation in between (column 13, row 14, *r* = 0.99). The number of simulator training hours did not influence the number of on-road driving lessons and the total duration of driving education (column 12, row 13, *r* = 0.00 and row 14, *r* = 0.14), suggesting that driving instructors did not recognise, or ignored, the higher driving skills of simulator-trained trainees. Simulator students, therefore, needed more total training hours than students who only followed on-road lessons.

Some measures do not correlate at all (Table B): HT and the risk mitigation score (items 1 and 7), gender and the field of view score (items 2 and 11), gender and the simulator training hours (items 2 and 12), the subjective driving skill score and the driving skill score (items 6 and 9), the safety score and the eco-driving score (items 8 and 10), the eco-driving score and the number of driving exams (items 10 and 15), and the amount of simulator training hours and on-road training hours (items 12 and 13).

Negative correlations indicate that the instructor's judgement on driving proficiency is comparable with that of the simulator (Table B). Trainees who score higher on the safety, driving skill and field of view aspects in the simulator are considered ready for the driving exam after less on-road training hours (column 8, row 13, *r* = -0.19; column 9, row 13, *r* = -0.19; column 11, row 13, *r* = -0.23). This suggests that driving skills acquired in the simulator do indeed transfer to the road and that one can already distinguish better-performing trainees (faster learners) on the road in the simulator sessions.

Independent t-tests were done to investigate differences between the HT and control groups regarding the total duration of driving training (Table C). Significant differences indicate that HT group students followed 1.67 hours more on the simulator (7.74 versus 6.07). However, they needed 38.50 additional on-road training hours before passing the exam, compared to 43.28 on-road hours for the control group. The average duration of the driver education was 46.20 hours for the HT group and 49.36 hours for the control group, approaching significance (*d* = 0.16, *p* = .065). This demonstrates that driving instructors judge HT group students to be ready for the examination after a shorter driving education period.

Table C

Table C. Results of independent t-tests measuring differences between HT and control groups. Bold correlations are significant ($p < 0.05$).

HT	No			Yes				
	Mean	***SD***	***n***	**Mean**	***SD***	***n***	**Cohen's d_r**	***p***
Simulator risk mitigation score (1 - 10)	5.43	0.67	449	5.43	0.67	153	0.00	9.9E-01
Simulator safety score (1 - 10)	7.30	1.08	449	7.26	0.99	153	0.03	7.0E-01
Simulator driving skill score (1 - 10)	7.74	1.13	449	7.93	1.03	153	-0.17	5.2E-02
Simulator eco driving score (1 - 10)	7.75	1.52	449	7.06	1.44	153	0.46	**7.4E-07**
Simulator field of view score (1 - 10)				5.83	1.95	153		
Number of simulator training hours	6.07	2.62	496	7.74	2.31	153	-0.66	**5.1E-13**
Number of on-road training hours	43.28	19.64	494	38.50	17.36	146	0.25	**4.9E-03**
Number of total training hours	49.36	19.92	494	46.20	17.47	146	0.16	6.5E-02
Number of driving test attempts	1.78	1.02	496	1.56	0.86	152	0.23	**7.8E-03**
Passed first exam (0 = no, 1 = yes)	0.51	0.50	496	0.64	0.48	152	-0.25	**6.4E-03**
Violations first 12 months (0 - 20)	2.04	2.17	425	2.03	2.08	92	0.00	9.9E-01
Errors first 12 months (0 - 12)	1.78	1.26	415	1.65	1.25	91	0.10	3.6E-01
Driving anxiety at start of driving education (1 - 5)	2.83	1.22	496	2.65	1.23	152	0.15	9.9E-02
Violations last 12 months (0 - 20)				3.22	2.97	82		
Errors last 12 months (0 - 12)				1.31	1.33	80		
Accident involvement first 12 months(0 = No, 1 = Yes)	0.09	0.29	441	0.06	0.24	97	0.11	2.7E-01
Accident involvement last 12 months(0 = No, 1 = Yes)	0.11	0.32	331	0.10	0.30	82	0.05	7.0E-01
Accident risk first 12 months (accidents/1,000 km)	0.11	0.54	435	0.17	1.48	93	-0.08	6.8E-01
Accident risk last 12 months (accidents/1,000 km)	0.05	0.16	33	0.02	0.06	78	0.27	3.5E-01

3.1.3 Examiner

In this study, the number of exam attempts is used to quantify the examiner's judgement of the trainee's skills to drive unsupervised. Table B shows that higher levels of driving anxiety before driving education correlate positively to needing more exam attempts (column 4, row 15, *r* = 0.12) for passing. Trainees who score better on the simulator's safety and driving skill assessment require fewer exam attempts (column 8, row 15, *r* = -0.15; column 9, row 15, *r* = -0,14), which indicates that the simulator and the examiner judge driving competence similarly.

Group means for driving exam attempts and passing rate on the first exam were analysed (Table C) to study differences between the HT and control groups and see whether examiners assess HT group trainees progressing faster to sufficient skills required to drive unsupervised. Results show that control group trainees required 1.78 attempts to pass the driving test, whereas the HT group passed after 1.56 attempts (*d* = 0.23, *p* = .007). Similar results are seen for the passing rate on the first exam: The control group passing rate is 0.51, compared to 0.64 for the HT group (*d* = -0.25, *p* = .006). The examiners considered the HT group trainees to be safer drivers than the control group trainees during their first exam, i.e., during the examination, they showed better prepared to drive unsupervised (column 1, row 15, *r* = -0.10 in Table B).

3.1.4 Summary of Supervised Driving Results

The analysis of the measures of supervised driving showed several significant results: (1) The evolution of simulator scores indicates that trainees improve their driving skills during the simulator training on all measured aspects. (2) The simulator, instructor, and examiner similarly assess safe and competent driving. The trainees with higher safety, driving skills, and field-of-view simulator scores required fewer on-road training hours and passed the exam with fewer attempts. This implies that fast learners can be discovered early in driving education. (3) HT shortens the duration of driving education to become a sufficiently competent driver. The HT group drivers required less on-road training hours ($M1$ - $M2$ = 4.78) and passed the exam with fewer attempts ($M1$ - $M2$ = 0.22). This means that training hazard detection and anticipation in a simulator facilitates achieving the required driving proficiency to participate safely in traffic and thus supports the practical training as suggested by the National Curriculum Driver Training B and the new Directive on Driving Licenses. (4) No significant differences were found between the HT and control groups on most intersection test simulator scores. This suggests that whereas one cannot observe the difference in driving skills from the simulator measures yet, the hazard detection and anticipation skills developed *during* simulator training facilitate the further acquisition of safe driving skills during on-road training. Due to this facilitating effect, the HT group trainees progress faster to the required driving proficiency level.

An intermediate conclusion is that HT had a positive transfer on driver education; HT facilitated the development of safe driving skills and made practical driving education more effective.

3.2 Driving Unsupervised

After obtaining the driving license, the supervision and feedback from the driving instructor disappear. Questions to be answered are: Does the behaviour differ from the driving skills shown during supervised driving? What are the effects of personal characteristics and exposure to driving, i.e., experience, on driving behaviour? Does the HT simulator training influence this behaviour?
The results of the respondents' self-assessments are analysed to answer these questions. Over time, safe driving skills are investigated using the violation and error scores composed of self-reported violations and errors. The self-assessment is studied for four periods: (i) the first six months, (ii) seven to twelve months, (iii) the first twelve months, and (iv) the last twelve months. The last twelve months did not overlap with the other periods.

As mentioned before, the compositions of the respondents' groups differ in analysis. For the study and comparison within the first year of driving, the 2015-2023 sample is used, and for the study and comparison between the first and last 12 months, the complete 2008-2023 sample is used.

3.2.1 Violations

In the first twelve months, gender, licensing age, and driving anxiety are significantly and negatively correlated with the violation score (item 15 in Table D). This demonstrates that males, drivers who were licenced at an earlier age, and drivers who experienced less anxiety reported higher levels of risk-taking behaviour. Interestingly, a significant negative correlation occurred between violation scores and on-road training hours (column 7, row 15, $r = -0.11$). This implies that fewer on-road training hours are associated with more risk-taking in the first twelve months of driving. Drivers judged by the instructor to be ready in an *earlier* phase of driving education reported *more* violating behaviour than those considered to need more lessons. The risk mitigation simulator score (column 9, row 15, $r = -0.17$) and eco driving score (column 12, row 15, $r = -0.11$) demonstrate a negative correlation with violation scores, which suggests that trainees with better risk mitigation and eco-driving scores reported lower violation scores.
The violation score correlated positively with kilometres driven in the first twelve months (column 14, row 15, $r = 0.23$), error score (column 15, row 16, $r = 0.18$), and accident involvement in the first

twelve months (column 15, row 17, r = 0.09), indicating that drivers that had a riskier driving style in the first twelve months drove more kilometres, made more errors and were also more likely to be involved in an accident. Although this group did not have a significantly higher accident risk per 1.000 kilometres, they are identified as faster learners with lower safety margins than other drivers.

Table D

Table D: Pearson correlation matrix first twelve months of driving. Bold correlations are significant (p < 0.05).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 HT (0 = no, 1 = yes)																	
2 Gender (0 = male, 1 = female)	0.05																
3 Licencing age	**-0.12**	0.00															
4 Driving anxiety (1 - 5)	-0.08	**0.25**	**0.20**														
5 Comparison driving skills (0 - 4)	-0.04	**-0.28**	**-0.37**	**-0.35**													
6 Subjective driving difficulty (0 - 4)	0.18	**0.27**	**0.39**	**0.52**	**-0.65**												
7 On road training hours	-0.07	**0.14**	**0.18**	**0.25**	**-0.24**	**0.25**											
8 Number of driving exams	-0.03	0.06	0.00	**0.12**	-0.08	0.00	**0.28**										
9 Risk mitigation score at intersection test (0 - 10)	-0.03	**0.19**	0.07	**0.11**	0.03	0.05	**0.10**	0.02									
10 Safety score at intersection test (0 - 10)	-0.03	**-0.26**	**-0.12**	**-0.17**	0.17	-0.12	**-0.15**	**-0.11**	**0.27**								
11 Driving skill score intersection test (0 - 10)	0.04	**-0.13**	**-0.13**	**-0.10**	0.14	0.02	**-0.15**	**-0.10**	**0.29**	**0.78**							
12 Eco driving score intersection test (0 - 10)	**-0.19**	**0.09**	**0.09**	**0.12**	0.11	-0.01	0.05	0.00	**0.31**	-0.01	0.01						
13 Field of view score intersection test (0 - 10)		0.03	0.01	0.07	0.02	0.00	**-0.30**	-0.10	**0.27**	**0.22**	0.11	0.14					
14 Km driven first twelve months	-0.03	**-0.18**	**0.09**	**-0.13**	0.19	**-0.20**	**-0.09**	-0.02	-0.02	**0.09**	0.06	0.00	0.04				
15 Violation score first twelve months (0 - 20)	0.00	**-0.15**	**-0.14**	**-0.15**	0.15	-0.12	**-0.11**	-0.02	**-0.17**	0.08	0.04	**-0.11**	-0.04	**0.23**			
16 Error score first twelve months (0 - 12)	-0.04	0.00	0.00	**0.14**	0.10	-0.04	0.03	0.07	0.02	-0.05	**-0.11**	0.02	0.02	**0.13**	**0.18**		
17 Accidents first twelve months (0 = no, 1 = yes)	-0.04	0.01	0.08	0.02	-0.02	0.12	0.00	-0.02	-0.03	0.00	-0.01	0.08	-0.11	0.05	**0.09**	0.07	
18 Accident risk first twelve months (accidents/1,000 km)	0.03	0.05	0.01	0.05	-0.05	0.14	0.01	-0.01	-0.02	-0.04	0.00	0.05	0.01	-0.07	0.03	0.03	**0.49**

The drivers in this sample indicate an *increase* in violation scores from the first (M = 1.97) to the last (M = 2.69) year of driving (Table E). A similar effect shows when the first twelve months are further divided into two groups (Table F): drivers licenced for less than six months report a significantly *lower* violation score (M = 1.74) compared to drivers that have their licence between six and twelve months (M = 2.26).

Table E

Table E: Results of paired samples t-tests measuring differences in driving between the first and last twelve months. Bold correlations are significant (p < 0.05).

Months licenced	First 12 months			Last 12 months				
	Mean	***SD***	***n***	**Mean**	***SD***	***n***	**Cohen's d_r**	***p***
Violation score (0 - 20)	1.97	2.08	789	2.69	2.60	796	-0.39	**2.7E-25**
Error score (0 - 12)	1.44	1.29	786	1.15	1.20	802	0.30	**1.3E-15**
Accident involvement (0 = no, 1 = yes)	0.10	0.30	1543	0.08	0.28	1536	0.04	1.1E-01
Accident risk (accidents/1,000 km)	0.16	1.20	1489	0.07	1.37	600	0.03	5.2E-01

Table F

Table F: Results of independent t-tests measuring differences between drivers licensed less than six months and drivers licensed between six and twelve months. Bold correlations are significant (p < 0.05).

Months licenced	<6 months			6-12 months				
	Mean	***SD***	***n***	**Mean**	***SD***	***n***	**Cohen's d_r**	***p***
Comparison driving skills (0 - 4)	1.88	0.87	110	2.16	0.73	71	-0.34	**2.4E-02**
Subjective driving difficulty (0 - 4)	1.95	1.07	110	1.76	1.08	71	0.17	2.6E-01
Violation score first 12 months (0 - 20)	1.74	1.70	265	2.26	2.39	275	-0.25	**3.7E-03**
Error score first 12 months (0 - 12)	1.51	1.36	270	1.51	1.23	275	0.00	9.9E-01
Km driven first 12 months	1486.94	2987.40	264	2955.43	5303.76	277	-0.34	**7.7E-05**
Accident involvement first 12 months (0 = No, 1 = Yes)	0.06	0.24	277	0.08	0.27	283	-0.06	4.5E-01
Accidents risk first 12 months (accidents/1,000 km)	0.24	2.20	263	0.15	0.95	277	0.05	5.3E-01

The significant correlations found in the first twelve months (Table D) do not copy 1:1 to the correlations in the last twelve months (Table G). While the violation score is still negatively correlated with licensing age (column 3, row 15, r = -0.21), we see that gender (column 2, row 15) and driving anxiety (column 4, row 15) are no longer related to the violation score in the last year. Additionally, subjective comparison of one's driving skills (column 5, row 15, r = 0.33) and subjective driving difficulty (column 6, row 15, -0.24) correlate with the violation score in the last twelve months of driving.

Drivers who obtained their licenses at a younger age were more confident, had more exposure, and reported more risk-taking behaviour. They also found themselves better drivers, which aligns with the simulator, driving instructor, and examiner assessments.

Table G

Table G: Pearson correlation matrix for the last twelve months of driving. Bold correlations are significant ($p < 0.05$).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 HT (0 = no, 1 = yes)																	
2 Gender (0 = male, 1 = female)	0.04																
3 Licencing age	**-0.11**	0.03															
4 Driving anxiety (1 - 5)	-0.08	**0.22**	**0.21**														
5 Comparison driving skills (0 - 4)	-0.02	**-0.27**	**-0.38**	**-0.35**													
6 Subjective driving difficulty (0 - 4)	0.18	**0.26**	**0.38**	**0.56**	**-0.64**												
7 Risk mitigation score at intersection test (0 - 10)	-0.05	**0.16**	0.06	**0.12**	-0.01	0.08											
8 Safety score at intersection test (0 - 10)	**-0.13**	**-0.33**	-0.07	**-0.19**	0.19	-0.13	**0.25**										
9 Driving skill score intersection test (0 - 10)	0.01	**-0.20**	**-0.13**	**-0.13**	0.18	0.02	**0.27**	**0.81**									
10 Eco driving score intersection test (0 - 10)	**-0.28**	**0.11**	**0.10**	**0.15**	0.12	0.03	**0.29**	-0.03	-0.03								
11 Field of view score intersection test (0 - 10)		0.03	0.04	0.09	-0.01	0.04	**0.23**	**0.22**	0.17	0.12							
12 On road training hours	-0.08	**0.13**	**0.19**	**0.28**	**-0.27**	**0.23**	**0.10**	**-0.18**	**-0.20**	0.07	-0.21						
13 Number of driving exams	0.01	0.09	0.01	**0.16**	-0.12	0.06	0.06	**-0.16**	**-0.11**	0.05	-0.08	**0.33**					
14 Km driven last twelve months	-0.16	-0.10	0.01	**-0.19**	**0.32**	**-0.41**	-0.18	-0.11	-0.09	0.12	-0.02	-0.05	0.00				
15 Violation score last twelve months (0 - 20)	0.06	0.00	**-0.21**	-0.09	**0.33**	**-0.24**	-0.14	-0.03	-0.12	0.14	0.03	-0.07	-0.02	**0.39**			
16 Error score last twelve months (0 - 12)	0.10	0.13	0.00	0.10	-0.05	0.07	-0.03	-0.01	-0.10	0.02	-0.08	-0.05	0.00	-0.02	**0.32**		
17 Accidents last twelve months (0 = no, 1 = yes)	-0.02	-0.07	0.02	0.00	0.08	0.01	0.07	-0.02	-0.03	0.03	0.02	0.01	-0.05	0.14	0.08	0.04	
18 Accident risk last twelve months (accidents/1,000 km)	-0.12	-0.06	-0.13	-0.05	0.04	0.07	0.00	-0.17	-0.03	0.13	0.16	0.01	-0.15	-0.10	0.01	0.08	**0.71**

There was no difference in violation score between HT (M = 2.03) and the control group (M = 2.04) in the first twelve months (Table C). This suggests that drivers demonstrate comparable low-level risk-related behaviour, regardless of the type of training. The difference in the last twelve months could not be calculated because the control group's violation score sample size was too small.

The violation score increases with the number of months of licensing (Tables E and F). In the last year, no significant correlation was found between violation scores and the number of months licensed (r = 0.02, p = 0.85). This indicates that risk-seeking driving behaviour increases after one is licensed and *stabilises* after one is licensed for more than 24 months. Correlations with other variables are not calculated.

3.2.2 Errors

The error score (item 16 in Table D) in the first twelve months positively correlates with driving anxiety (column 4, row 16, r = 0.14), meaning that the more anxious before driving education, the more likely to make errors in the first year. Furthermore, a negative correlation with the driving skill simulator score (column 11, row 16, r = -0,11) suggests that error-prone drivers can already be detected during simulator training. Positive correlations are observed with kilometres driven (column 14, row 16, r = 0.13) and violation scores (column 15, row 16, r = 0.18). The positive correlation between the error and violation scores was the only correlation maintained in the last twelve months (column 15, row 16, r = 0.32 in Table G).

Error scores of all drivers are similar between the first and second half years (M = 1.51 in Table F). The error score decreased significantly from the first to the last twelve months ($M1$ - $M2$ = 0.29 in Table E), which implies that after the first twelve months of driving unsupervised, the more experience is gained, the fewer errors are made. HT training did not affect safety margins related to making errors (Table C). Neither group made more or fewer errors than the other, indicating equal driving proficiency in the first twelve months of driving unsupervised. The difference in the last twelve months could not be calculated because the control group sample size was too small.

3.2.3 Comparison driving skills

Significant negative correlations were found between the self-comparison of driving skills and gender (column 2, row 5, r = -0.23 in Table D), licensing age (column 3, row 5, r = -0.33), and driving anxiety (column 4, row 5, r = -0.32) (Table B). A significant negative correlation is found with subjective driving difficulty (column 5, row 6, r = -0.61). This means that males, drivers licensed at a younger age, and less anxious drivers see themselves as more competent drivers. Those who experience more driving difficulty assess their driving skills to be lower. Fewer on-road driving training hours are associated with higher driving skills judgement (column 5, row 13, r = -0.20) and lower subjective driving difficulty (column 6, row 13, r = 0.26). The self-judgement of this group aligns well with that of the simulator and the driving instructor, but not the examiner, as correlations with the number of driving exams are near zero (column 6, row 8 in Table D).

In the first year of driving, no significant correlations were observed between the comparison of driving skills and distance driven, violation/error score and accidents (Table D). The subjective driving difficulty was negatively correlated with kilometres driven in the first twelve months (column 6, row 14, r = -0.20), suggesting that drivers who report higher driving difficulty drive less in the first year. In the last twelve months, comparisons between driving skills and subjective driving difficulty demonstrate significant correlations with the violation score (column 5, row 5, r = 0.33, and column 6, row 15, r = -0.24 in Table G). Drivers with higher violation scores think they are better drivers than others and experience low driving difficulties. Reporting lower subjective driving difficulty correlates with higher distance driven in the last twelve months (column 5, row 14, r = -0.41) and judgement of having higher driving skills than others (column 5, row 6, r = -0.64). The higher trust drivers have in their driving skills, the more they report violating behaviour (column 5, row 15, r = 0.33 and column 6, row 15, r = -0.24).

The self-assessment of own driving skills compared to others increases from 1.88 in the first six months to 2.16 in the second six months (Table F, sample 2015-2018) on a scale of 0-4 (p = 0.02, d = -0.34). Driving difficulty decreased from 1.95 to 1.76 in the same period (Table F). Additionally, months of license possession positively correlates with comparison of driving skills (r = 0.30, p < .001) and negatively with perceived difficulty of driving (r = -0.22, p < .01). This demonstrates that, after a few months of driving unsupervised, drivers intensify their opinion that they are better drivers than others. This reinforcement continues with gained experience: the longer one is licensed, the more advanced one judges their driving competence.

3.2.4 Accidents

Accident involvement did not significantly differ between the first and second half years of driving (Table F, sample 2015-2023) or between the first and last year of driving (Table E, sample 2008-2023). This suggests that accident involvement remains approximately the same over the unsupervised driving years. The annual distance driven, however, affects the risk of being involved in an accident. Drivers involved in an accident drove more kilometres than those not involved in the first twelve months (p = .029, d = -0.17) and the last twelve months (p = .002, d = -0.52). The risk of being involved in an accident dropped between the first six months and second six months with 37.50% ($M1 – M2$ = 0.09 in Table F) and between the first year and last year with 56.25% ($M1 – M2$ = 0.09 in Table E), both nine accidents per 100.000 kilometres. These differences were insignificant, mainly due to large deviations in reported kilometres.

In the first twelve months, a positive correlation between accident involvement and reported violation score (column 15, row 17, r = 0.09, Table D) demonstrates that drivers with riskier driving behaviour were more likely to be involved in an accident. Additional independent t-tests indicate that drivers involved in an accident have a higher violation score than drivers not involved in an accident in both the first (p = .003, d = -0.27 in Table H) and the last twelve months (p = .015 d = -0.47 in Table I). Moreover, a significant difference in error scores in the last twelve months (p = .002, d = -0.58) indicates that drivers involved in an accident make more errors than those not involved. This effect was not observed for accident risk (column 15, row 18 in Tables D and G).

We found no significant differences in the violation scores and the subjective driving skill scores between drivers involved and not involved in an accident in the first twelve months and last twelve months (Tables H and I), suggesting that experiencing an accident does not affect one's risk-taking behaviour and subjective driving proficiency.
Interestingly, the drivers involved in an accident in the last twelve months were the drivers that required most on-road training hours ($M1 - M2 = 4.55$, $p = .044$, $d = -0.25$). This might indicate that trainees with more difficulty acquiring driving skills during education still have trouble performing the driving task unsupervised. In contrast, faster learners can perform the task with less difficulty since they have already automated certain aspects of driving and, therefore, suffer less from driving with lower safety margins. An explanation could be that slower learners experience a higher mental load because of making errors and did not learn how to adjust safety margins to compensate for it.

The HT group had a *higher* accident risk (0.11 – 0.17 = -0.06) in the first year and a *lower* accident risk (0.05 – 0.02 = 0.03) in the last year of driving compared to the control group (Table C); no significant effects were observed between accident risk and HT in the first (column 1, row 18, $r = 0.03$ in Table D) and last year (column 1, row 18, $r = -0.12$ in Table G).

Table H

Table H: Results of independent t-tests measuring differences between drivers involved in an accident and those not involved in an accident in the first twelve months. Bold correlations are significant ($p < 0.05$).

Accident in the first twelve months	No			Yes				
	Mean	*SD*	*n*	Mean	*SD*	*n*	Cohen's d_r	*p*
HDTT/HATT (0 = no, 1 = yes)	0.56	1.17	491	0.38	1.01	47	0.01	
Gender (0 = male, 1 = female)	0.61	0.49	1784	0.65	0.48	190	0.01	
Licencing age	21.12	4.97	1772	21.95	6.00	191	0.01	
Driving anxiety before driving education	2.75	1.25	1786	2.69	1.28	192	0.01	
Comparison driving skills	2.34	0.91	595	2.39	0.77	52	0.01	
Subjective driving difficulty	1.50	1.19	596	1.58	1.21	52	0.01	
Simulator risk mitigation score (1 tot 10)	5.50	0.67	806	5.44	0.61	97	0.01	
Simulator safety score (1 tot 10)	7.37	1.05	806	7.44	0.87	97	0.01	
Simulator driving skill score (1 tot 10)	7.87	1.09	806	7.96	1.04	97	0.01	
Simulator eco driving score (1 tot 10)	7.58	1.52	806	7.88	1.47	97	0.01	
Simulator field of view score (1 tot 10)	5.53	2.06	91	4.60	1.73	6	0.01	
Number of simulator training hours	5.93	3.06	1396	6.22	2.86	149	0.01	
Number of on-road training hours	40.93	18.93	1733	39.57	14.52	191	0.01	
Number of total training hours	47.46	19.12	1371	46.62	15.04	149	0.01	
Number of driving test attempts	1.68	0.98	1785	1.65	0.95	192	0.01	
Passed first exam (0 = no, 1 = yes)	0.57	0.50	1785	0.58	0.49	192	0.01	
Violations first 12 months (0 - 20)	1.99	2.11	1699	2.57	2.56	185	-0.27	**3.4E-03**
Errors first 12 months (0 - 12)	1.57	1.22	1678	1.71	1.15	180	0.01	
Km driven first 12 months	4224.64	6940.86	1735	5385.41	6771.49	183	-0.17	**2.9E-02**

Table I

Table I: Results of independent t-tests measuring differences between drivers involved in an accident and those not involved in an accident in the last twelve months. Bold correlations are significant ($p < 0.05$).

Accident in the last twelve months	No			Yes				
	Mean	*SD*	*n*	Mean	*SD*	*n*	Cohen's d_r	*p*
HDTT/HATT (0 = no, 1 = yes)	0.60	1.20	368	0.53	1.16	45	0.01	
Gender (0 = male, 1 = female)	0.61	0.49	1404	0.55	0.50	128	0.01	
Licencing age	21.23	5.21	1396	21.13	4.66	128	0.01	
Driving anxiety before driving education	2.75	1.25	1408	2.62	1.34	128	0.01	
Comparison driving skills	2.35	0.89	528	2.33	0.90	42	0.01	
Subjective driving difficulty	1.49	1.18	529	1.41	1.21	42	0.01	
Simulator risk mitigation score (1 tot 10)	5.53	0.65	622	5.48	0.59	69	0.01	
Simulator safety score (1 tot 10)	7.49	1.02	622	7.63	0.94	69	0.01	
Simulator driving skill score (1 tot 10)	7.94	1.08	622	8.08	1.07	69	0.01	
Simulator eco driving score (1 tot 10)	7.70	1.50	622	7.60	1.65	69	0.01	
Simulator field of view score (1 tot 10)	5.47	1.84	74	5.15	2.43	8	0.01	
Number of simulator training hours	6.02	3.03	1053	6.00	2.62	93	0.01	
Number of on-road training hours	40.00	17.40	1364	44.55	24.46	125	-0.25	4.4E-02
Number of total training hours	46.94	17.98	1034	50.57	22.67	92	0.01	
Number of driving test attempts	1.67	0.96	1407	1.73	1.03	128	0.01	
Passed first exam (0 = no, 1 = yes)	0.57	0.50	1407	0.56	0.50	128	0.01	
Violations last 12 months	2.85	2.65	517	4.12	3.12	41	-0.47	1.5E-02
Errors last 12 months	1.06	1.12	518	1.71	1.25	41	-0.58	2.3E-03
Km driven last 12 months	7911.20	9483.73	568	12862.98	9842.51	47	-0.52	1.6E-03

3.2.5 Summary of unsupervised driving results

In the first results summary, section 3.1.4, our analyses showed that receiving HT in the simulator facilitates the driving skill-acquiring process: HT trainees demonstrate the desired safe driving behaviour in a shorter time than the control group. In this second section, we examined whether these positive effects continue after drivers obtain their licenses. We investigated whether the HT group developed a safer driving style than the control group and whether it was maintained over the unsupervised driving years. The influence of personal characteristics and exposure was also studied to determine the contribution of HT more precisely. The results are divided into four sections: Violations, Errors, Comparison driving skills and Accidents.

The analysis of self-reported **Violations** yielded significant correlations for personal and exposure measures but *not for HT*: (1) A higher violation score in the first 12 months correlated positively with being male, younger licensed, less anxious, less fuel-consuming, and less risk mitigating. (2) Drivers judged by the instructor (not the examiner) to be ready for driving unsupervised in an earlier phase of education (they needed fewer lessons) reported more violations. (3) Drivers with a higher violation score drove more kilometres, made more errors and were more likely to be involved in an accident. (4) Violation scores increased from the first to the second half year and the first and last year of driving. This effect is reinforced by the number of months of licensing. (5) Early-age licensees reported more violations in the last 12 months. So, in this study, the *age* of starting unsupervised driving matters in the long run (not gender, anxiety, etc.). (6) Drivers who consider themselves as more competent and experience less effort operating a vehicle reported more violating behaviour.

Analysing **Errors,** we did not find an effect of HT. Effects for other measures were: (1) A higher error score correlated with higher driving anxiety, more kilometres and lower driving skills. (2) A higher violation score means a higher error score, independent of months licensing. (3) Errors decreased from the first 12 to the last 12 months.

HT did not affect the self-reported **Comparison driving skills**. Nevertheless, significant effects were found: (1) Males and early-age licensees saw themselves as more competent than their peers. They experienced less anxiety and followed fewer on-road training hours, suggesting their instructors' judgment aligns with their feeling of having better driving skills. This also aligns with the simulator measures but *not* with the examiner. (2) The comparison driving skills score correlates negatively with the subjective driving difficulty score in the first 12 months. Drivers who reported higher driving difficulty drove less in the first year (3) No correlation was found with kilometres, violations, errors and accidents in the first 12 months. (4) Higher comparison driving skills and lower subjective driving difficulty scores correlate with more violations in the last 12 months of driving. (5) Comparison driving skills scores increased, and subjective driving difficulty decreased in the last 12 months. (6) The longer one is licensed, the more advanced one judges their driving skills.

HT did not affect **Accidents**. Significant effects: (1) Accident involvement remains the same over the first and last years of unsupervised driving. (2) Drivers reporting accidents drove more kilometres in the first and second years. (3) The risk of being involved in an accident dropped from the first six months to the second six months and from the first twelve to the last 12 months. (4) Drivers reporting more risk-taking (higher violation score) had more accidents, independent of the first or last year of driving. (5) Drivers involved in accidents report more errors. (6) No significant differences are found in violations and subjected driving skill scores between drivers who are or are not involved in an accident: experiencing an accident did not affect risk-taking behaviour and self-calibration. (7) Drivers reporting accidents in the last 12 months required more on-road training hours. (8) Faster learners (less on-road training hours) were less involved in accidents.

The lack of differences in violation scores, error scores, subjective driving skills, and accident involvement between the HT group and control group trainees in the first twelve months agrees with the expectation that newly licensed drivers have a similar driving proficiency level directly after passing the exam. The pronounced facilitating effect of HT on driving education *disappears* after licensing. This study ascertains *experience* (distance driven and years of licence possession) as the most influencing factor: drivers' estimation of one's driving skills and safe driving style change with experience. Reported violations increase with higher annual mileage and with more extended licence possession. Drivers who drove more annual kilometres and possessed a driving licence longer reinforced their belief in being skilful drivers. These shifts towards a more violating and confident driving style were already observable after six months of driving. They continued reinforcing within the first year and the rest of the unsupervised driving years. Moreover, these shifts amplified the correlation between reported violations and subjective driving proficiency in the last twelve months of driving: drivers who considered themselves as 'better drivers' also showed riskier driving behaviour, tentatively because they felt more confident in their driving capabilities.

The shift towards higher confidence in one's driving competence, in combination with a riskier driving style, has negative consequences. Subjective and objective skill proficiency grow further apart. Subjective driving skills proficiency estimation intensified after six months of unsupervised driving. However, a decrease in reported errors was only detectable after the first year. Whereas drivers thought they were becoming better at an early stage, our results demonstrate that this improvement only starts *after* the first twelve months, making young drivers *more* vulnerable to accident involvement in the first year of driving.

Errors are associated with violations in the first and last twelve months, meaning drivers who reported more violations also tend to make more errors. Drivers who reported being involved in an accident also reported a more risk-seeking driving style. It is striking that accident involvement did not result in behavioural changes: no differences were found in the comparison of driving skills scores and subjective driving difficulty scores between drivers involved in an accident and those not involved.

Our results show that although driving instructors and examiners judge learner drivers to be able to drive safely unsupervised, licenced drivers still experience the *highest* accident risks during the first year of driving. Furthermore, being involved in an accident does *not* affect drivers' valuation of their driving skills, indicating *low proficiency* in self-reflection/calibration.

4. Discussion

This study aimed to contribute to the Dutch National Driver Curriculum B regarding the revised EU Directive on driving licenses by understanding the relationships between hazard training and testing (HT) on driving simulators and supervised (pre-licensed) and unsupervised (post-licensed) driving. It builds on earlier research by Kuipers, De Winter, and Mulder (2023) into understanding the relationships between personal characteristics, pre-licence accompanied driving, self-reported post-licence driving behaviour, and driving performance scores during simulator lessons.

The educational value of HT is investigated using six assessment moments in four consecutive driving phases. The first moment is the simulator intersection test, which gives insights into sufficient driving skills before driving in a driving school car. The second moment is when the driving instructor decides the trainee has enough skills to drive unsupervised and can apply for the driving test. The third moment is when the trainee gets official permission from an examiner to drive unsupervised. The fourth, fifth and sixth moments are after six months, one year and the last year of driving unsupervised.

Many factors affect the number of on-road training hours necessary to get permission to drive unsupervised (Kuipers et al., 2023). This study showed that the HT group needed significantly fewer on-road training hours (38.50). The total education hours (46.20) were also lower. The number of on-road driving hours differed by 4.78 hours, and the total education hours differed by 3.16 hours, proportional to 12.4% and 6.8%, respectively. In addition, trainees passed the driving exam in fewer attempts (1.56) than drivers who did not get HT (1,78), proportional to 12.5%. The HT group's success rate on the first driving exam was higher (0.64) than that of the control group (0.51), proportional to 24.1%, respectively. This demonstrates that the instructors' and examiners' judgements about safe driving performance are in line: both were convinced earlier in driving education that the HT group had sufficient, safe driving skills for unsupervised driving compared to the control group. Following Andersons' learning theory (1982), instructors and examiners judge the HT group to have cognitive skills at a procedural level sooner than the control group. We conclude that HT simulator training facilitates and reinforces the development of a safe driving style that educational experts recognise.

We found that HT trainees did *not* show a safer driving style than the control group in the simulator intersection test. Both groups profited equally from the instructed safety margins. Performance in the early phase is identified as slow and error-prone (Fitts & Posner, 1967). Additionally, Anderson (1982) stated that cognitive task performance is still relatively unstable early in driving education since the focus is consciously on isolated components of the driving task and possible strategies are tested and rejected. Once associations between the isolated components are formed and strengthened, procedures are generated that can be applied in traffic situations that are recognised as similar. This development takes time. Differences observed between the HT and control groups in on-road training hours and exam attempts suggest that the HT trainees can proceed to the subsequent phases in a shorter time frame. However, this facilitating effect is not observable sooner than on the road. Lastly, the HT scenarios were only practised once, which implies fewer benefits. The benefits of learning increase rapidly due to repetition and stabilise after a certain period (Fits and Posner, 1967). The positive effects of HT training observed in our study could be reinforced through repetition and differentiation of the traffic scenarios.

One can assume that Dutch driving trainees should have some pre-knowledge of monitoring behaviour at intersections that they can apply when driving a car: They did learn the viewing procedures in primary school for crossing intersections as pedestrians and cyclists and must pass a test. However, the difference in field-of-view monitoring performance after the intersection lessons is considerable. The effect size of the field-of-view score difference between the vehicle operation and intersection tests was large (d = -1.05, Table A). The significant increase in the field-of-view score demonstrates that feedback is essential to maintaining and increasing these skills. However, the viewing score is still relatively low after the training (M = 5.94 out of 10), suggesting that these skills are still in the early stage of development. It is unclear whether HT contributed to it since no field-of-view score is available for the control group (who had not received feedback on viewing skills). A randomised experiment measuring trainees' field of view scores with or without HT is necessary to gain more insight and knowledge.

This study found that possession time of the driver's license and driving kilometres correlated positively with violations and errors. On average, respondents lowered their safety margins as they became more experienced. The violation scores positively correlated with the error scores in the first year of driving, suggesting a more accident-prone driving style (Table D). Overconfidence is more apparent in the last year of driving (Table E). Drivers feel less anxious, are more skilled, and experience less driving difficulty. The correlation between the violation and error scores is more pronounced in the last year of driving, indicating decreased safety margins (Table E). These results suggest that risk awareness is a *character trait* rather than a trainable skill, as De Craen (2010) suggested. It is, therefore, challenging to be affected by driving curricula.

During driving education on the Green Dino simulator, the AI instructor acts as an external supervisory control system and continuously reminds the trainee of faults in task execution. In the case of severe faults, the AI instructor takes over control by warning the student of the danger ahead and demanding a risk mitigating action. This external supervisory control continues during the on-road training phase by the human instructor and examiner. After licensing, the young drivers become their own supervisors. The high accident risk directly after licensing found in this study and reported by SWOV (2014) indicates that novice drivers are *not yet* competent in supervising themselves and critically reflecting on their driving performance. The accident risk was 0.24 accidents per 1,000 kilometres in the first 6 months, 0.15 for the second 6 months and 0.07 in the last 12 months (Tables E and F).

Our results show that drivers *generally* have problems with self-reflection. Violation behaviour increases with experience, and the experience of an accident did not change the self-assessment of task difficulty and safety performance. Koppel et al. (2022) replicated a study by Svenson (1981) and confirmed that drivers overestimate their driving skills and find themselves less risky than their peers. Learning novice drivers to self-reflect (calibration) seems very difficult, which aligns with the findings of De Craen (2010) and Kruger and Dunning (1999).

Our study supports Kuipers, De Winter and Mulder (2023), who concluded that smooth (flued) driving does not facilitate driving education. Smooth driving aims not to disturb other traffic; go with the flow. However, the simulator safety score penalises a smooth driving style, because smooth driving stimulates closer distances and higher speeds at intersections, lowering hazard awareness. We found that the safety score correlated negatively with the number of on-road training hours and driving exams (Table E), meaning that instructors and examiners recognised a safer driving style for students who drove less smoothly and more carefully, applying higher safety margins. Currently, driving instructors prepare their students to pass the driving test (Roemer, 2021) and instruct them to drive smoothly, confirming the national Driving Procedure B (car) guideline. This changes the risk-avoiding driving style learned in the simulator to a more accident-prone one, lowering the time to react by all traffic participants (including the instructor and examiner) in case of task execution errors or violations and increasing the impact of a crash. We illustrated this with the *risk mitigation score* of the simulator Intersection Test: trainees with a cautious driving style, using higher safety margins, scored higher on risk mitigation and reported a less violating driving style and fewer errors driving unsupervised. Teaching and awarding lower safety margins (e.g., lower following distance, higher speed and a smaller field of view at intersections) might reinforce violating behaviour while driving unsupervised. Following Kruger and Dunning (1999), it could also be possible that instructors and examiners *overestimate* the risk detection and anticipation skills of the trainees because of their high *own* competencies in driving safely with lower safety margins.

5. Conclusions and Recommendations

This study investigated the effects of hazard awareness training and testing on simulators in driving education. We compared a group of car drivers who followed hazard detection and anticipation training and testing (HT) with those who followed simulator training without these specific types of training and testing. Results show that HT simulator training facilitated driving education. HT trainees needed fewer practical lessons to get the instructor's and examiner's permission to drive unsupervised: HT training reinforced developing a safe driving style that educational experts recognised. The results align with the National Curriculum Driver Training and the European Commission's recommendation to use driving simulators for hazard awareness training and testing in driving education. Simulators with AI can teach and test trainees like instructors and examiners.

Stimulating risk awareness with virtual car crashes had only a noticeable effect on a safe driving style during education. We found no significant differences between the HT and non-HT groups. A striking finding was that our data suggest that even *real* car crashes did not trigger any changes in risk awareness after licensing. Hazard awareness appears to be a personal character trait rather than a trainable skill. Therefore, training and testing *higher safety margins* could be a more promising way towards safer driving than teaching and testing so-called higher-order skills. Making them more cautious during education will delay violating behaviour after licensing and hopefully bridge the most dangerous driving period in the first six months of unsupervised driving.

The benefits of HT are distinct when comparing the numbers of simulator training hours and on-road training hours between both groups. HT made the on-road lessons more efficient by 12.4% and the total number of educational hours by 6.8%. Nevertheless, it should not be a goal for learner drivers and driving instructors to minimise education's duration (and costs). Hazard awareness training prepares students better for real-world driving, making it a valuable addition to traditional lessons. Although hazard awareness training on simulators positively affected education, no retention effect was found after licensing.

6. Limitations

Our study had several limitations, such as uncontrolled conditions, self-reporting/ self-selection biases and the overrepresentation of females and higher-educated individuals in the study sample. Due to the extensive period between the start of the driving education and the moment of answering the inventory, the accuracy of memories decreases, especially when indicating the number of training hours on-road and kilometres driven in the first months of driving. Respondents were asked about their certainty of the indications. Still, the deviations were high. A more frequent (monthly) inventory following a respondent could increase the accuracy of those measures.

Beanland et al. (2013) summarised obstacles to proving safety effects, such as the availability of suitable datasets, the noise in the data, the subjectivity of the data and the poor research design. The low number of accidents and the responsibility for accident involvement are examples of obstacles in this study, mainly because it is highly questionable whether drivers can properly judge their own responsibility. Conducting experiments with drivers involved in police-documented accidents could help to determine biases and improve significance.

For cost-efficiency and privacy reasons, available datasets frequently come from questionnaires like those used in this research. One problem with self-reported performance is the considerable deviation in reported kilometres, which influences the reliability of the accident risk rates, making it hard to research accident risk. The instrument of self-reported driving behaviour has been disputed (Bailey & Wundersitz, 2019). However, we found correlations between objective assessment measures of the driving simulator, semi-objective[4] measures of the driving instructor and examiner, and unsupervised self-reported risky driving behaviour.

Moreover, our work remains cross-sectional, and a randomised controlled trial, as in the classical DeKalb study (Lund et al., 1986; Stock et al., 1983), is still lacking and exceedingly tricky nowadays due to strong regulations and ethical considerations. Consequently, our research could uncover no evidence indicating that hazard detection and hazard anticipation on simulators enhance driving safely unsupervised. Despite the potential of stimulating risk awareness with simulated car crashes, more research is needed to understand the safety benefits.

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8. Declaration of Competing Interest

Kuipers is the owner and director of the simulator manufacturer Green Dino. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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