Simulator-based driving training: The effect of speed-episodes on acquiring driving skills

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Abstract

Driver crash rates are highest immediately after licencing, determining it as a risk-prone period. Hence, driving training is required to prepare novices for driving safely and so decrease their crash risk. This study examined the potentials of simulator-based driving training, with a specific focus on the use of speed-episodes and differences between experience levels of the drivers. It was expected that participants performing the speed-episode would drive more accurate in the end, and that experienced drivers in general would perform better. Participants were divided in two groups performing different training methods (accuracy training and speed training) and had to complete three blocks of 12 trials. The focus in the first and last block was on driving accurately. The focus in the second block differed between the groups: the accuracy training group executed the same task, but the speed training group performed a speed-episode in which they had to speed up and did not have to focus on driving accurately. Results showed a significant within-difference between block 1 and 3 on time on task and number of lane departures. No significant main and interaction effects were found between training methods and driver experience. So, it can be concluded that driving skills can be trained within a simulator, making it a potential training method to implement in driving training. However, with the results of this study, it cannot be said that speed training is superior to accuracy training, or that experienced drivers perform better than inexperienced drivers. Future research could consider making the speed-episode more error-prone and making the difference in experience more distinctive to detect the expected results.

Keywords: driving training, simulator-based training, speed-episodes, driver experience

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1. Introduction

Worldwide, the amount of road traffic deaths has been increasing for several years. In 2015, 1.25 million people died in a traffic crash, which has rapidly climbed up to 1.35 million fatal crashes in 2016 (WHO, 2015; WHO, 2018). Around 90% of these accidents are partially due to human errors which might be caused by insufficient professional skills of drivers (European Commission, 2016; WHO, 2015). Especially fatal traffic crashes of young novice drivers, compared to other groups, are overrepresented. All around the world, over 1000 individuals under the age of 25 years die in traffic crashes every day, making it one of the leading causes of death among this age group (WHO, 2007).

Driver crash rates for all ages are highest immediately after licensing and decrease substantially over the first two years of driving, with the highest decline in the first six months (Mayhew, Simpson, & Pak, 2003). However, after 18 months, this crash rate is still approximately three times higher than that of more experienced drivers (Lee, Simons-Morton, Klauer, Ouimet, & Dingus, 2011). These numbers indicate that the first years of driving unsupervised are most risk-prone and that it is important to properly prepare novices through driving training for this moment.

1.1. Current driving training

Current driving training aims to prepare novices to drive independently on public roads. The Goals for Driver Education (GDE) framework (Figure 1) identifies four components that should be addressed within driver education programs: vehicle manoeuvring (operational), mastery of traffic situations (tactical), driving goals and context (strategic), and goals for life/skills for living (e.g., control over how life-goals and personal tendencies, such as peer pressure and sensation seeking, affect driving behaviour) (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002).

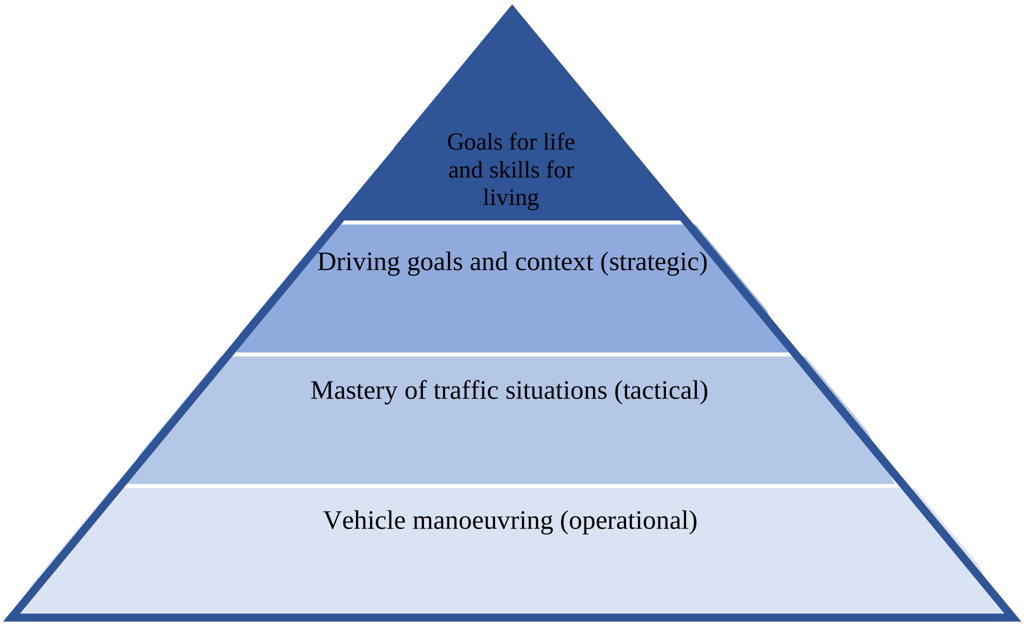

Figure 1. The Goals for Driver Education (GDE) framework adapted from Hatakka et al. (2002). The operational level contains basic skills such as braking, steering and switching gears. The tactical level includes interaction with objects and other traffic users (e.g., manoeuvring around obstacles and merging into traffic). The strategical level comprises the route and time of driving that are chosen by the driver. Goals for life and skills for living contain the control over how life-goals and personal tendencies, such as peer pressure and sensation seeking, affect driving behaviour. The framework operates as a hierarchy ranging from basic operational vehicle driving skills to higher-order skills which means that operational skills should be developed sufficiently to support executing higher-order skills.

Nevertheless, the focus of practical driving education is mainly on the lowest level (vehicle manoeuvring) of this hierarchy and on traffic rule knowledge within common traffic situations (Beanland, Goode, Salmon, Lenné Michael, 2013; Dols, Pardo, Falkmer, Uneken, & Verwey, 2001; Simons-Morton & Ehsani, 2016; SWOV, 2019). However, to drive safely, drivers should also train the higher levels of the hierarchy, which entail the development of higher-order perceptual and cognitive skills (Pardo & Dols, 2003). These skills support in detecting potential hazards: based on a deliberate evaluation of all the different information that is incoming during driving, drivers can efficiently judge on how to act in dynamic and complex traffic situations (Pardo & Dols, 2003; Simons-Morton & Ehsani, 2016). However, scenarios involving the performance of higher-order skills are risky for novice drivers and only happen rarely (Dols et al., 2001). Therefore, they cannot systematically be handled in practical training and are predominantly taught in a more theoretical way.

However, this does not seem to be sufficient since a large extent of novice driver accidents can be attributed to failure of higher-order skills (Dols et al., 2001; SWOV, 2016). Additionally, the development of these higher-order skills require time and much practice, which makes it unknown whether these skills are learned as part of driver training (Pollatsek, Narayanaan, Pradhan, & Fisher, 2006; Simons-Morton & Ehsani, 2016). Accordingly, higher-order skill acquisition is considered to be a critical part of driver education and should be better developed before licencing.

1.2. Driving skill acquisition

Fitts and Posner (1967, as cited in Groeger & Banks, 2007) determined three distinct stages for general skill acquisition: the cognitive, associative, and autonomous stage. Within the cognitive stage, performance is slow, deliberate and error-prone because learners consciously try to understand the task. In the following stage, the associative stage, performance gets more accurate. Gross errors are eliminated and patterns or sequences of sub-skills emerge. Skill acquisition ends with the autonomous stage, in which task performance is reliable, efficient, fluent, and less likely to be affected by distracting factors since it has become more unconscious.

Driving trainees can reach the autonomous stage for their operational skillset in approximately fifteen hours of training (Hall & West, 1996). However, driving is categorised as a complex high-performance skill requiring a variety of perceptual-motor skills, procedural skills, and cognitive skills that have to be time-shared (Van Emmerik, 2004; Groeger, 2000). In addition to that, the dynamic traffic situations make it difficult to reach the autonomous stage for the entire skillset. For that reason, practice and experience are important in learning how to drive.

1.3. Development of driver experience

It takes experience to get to the autonomous stage of operational driving, but it takes even more experience to get close to this stage for higher-order driving skills. Car crash rates for all ages are highest immediately after licensing (Mayhew et al., 2003), so experience plays an important role (Pardo & Dols, 2003; Simons-Morton & Ehsani, 2016).

Inexperienced drivers are less likely to detect potential hazards than experienced drivers because they scan less holistically, quickly, and efficiently (Deery, 1999; Pollatsek et al., 2006; Vlakveld, 2011). Experienced drivers can see patterns and perceive underlying structures of situations that novices cannot. After gaining more driving experience and encountering various traffic scenarios, drivers are thought to develop mental models that can easily be retrieved from memory when facing similar scenarios (Simons-Morton & Ehsani, 2016). Subsequently, these mental models evoke a specific sequence of actions and will help the driver to react in this situation (Shallice, 1988). With more experience, these mental models get more elaborate and flexible, behaviour becomes more automated and cognitive demands decline (Vlakveld, 2011).

1.4. Simulator-based training

The high cognitive demands driving entails and the on-road training difficulties that are presented make simulators potential learning resources for driving training. Simulators offer some possibilities that could tackle skill acquisition problems encountered while learning how to drive. Also in other domains where complex high-performance skills are acquired, such as aviation (Martin, Murray, Bates, & Lee, 2016) and medicine (McGaghie, Issenberg, Petrusa, Scalese, 2010), simulator-based training has become a prominent part of education, giving positive expectations for application within driver education. Furthermore, promising results regarding the integration of a simulator in driving training are provided by De Winter et al. (2009). They showed that good performance in the simulator improved real road driving skills, indicating that acquired skills in the simulator transfer to real-life driving.

However, there is yet no consensus around the world about integration of simulator-based training into the driving domain. The Netherlands are currently world leaders in using simulator-based driving training, with having around 100 simulators in operation spread over the country (Beanland et al., 2013; Kappé & Van Emmerik, 2005). These simulators are initially used to teach the basic operational driving skills such as steering, braking, and switching gears. Subsequently, these operational skills, as well as tactical skills like interaction with other traffic, are further developed during on-road driving training.

1.4.1. Advantages of applying the simulator in driving training

When acquiring skills, Roscoe (1991) states that optimal conditions for learning might not be the most favourable conditions for the actual skill operation. For example, on the real road, trial-and-error might have fatal consequences. Simulator-based training presents some advantageous possibilities that consider these optimal learning conditions for skill acquisition.

Firstly, the simulator documents individual performance data allowing to measure learning progress (Käppler, 2008; Dongen, 2010). Performance can be assessed objectively and accurately by the simulator (de Winter et al., 2009).

Secondly, it is possible to adapt the training to the performance level of the trainee. Different levels of complexity and cognitively demanding situations can be displayed to meet the needs of the trainee (Käppler, 2008). For instance, the environment can be programmed in a low cognitively demanding way in the beginning, to allow the trainee to solely focus on acquiring the operational skills. Traffic intensity can gradually be increased the moment skills get more automated (Van Emmerik, 2004).

Thirdly, simulators are not limited to situations encountered during formal training, but offer a broad variety of possible realistically presented scenarios that can be selected. Within simulators, trainees can experience situations to an extent that would be impossible in reality (De Groot, Centeno Ricote, de Winter, 2012; Van Emmerik, 2004; Käppler, 2008; van Leeuwen, Happee, de Winter, 2014; Zhao, Xu, Ma, & Gao, 2019). For example, rare traffic situations do not have to be bounded to an occasional encountering by only a few trainees, but can be experienced by everyone. Additionally, certain skills of the total performance can be practised exclusively and to a different extent than other skills (De Groot et al., 2012; Van Emmerik, 2004; Käppler, 2008). A particular skill sequence, both operational (e.g., braking, steering, and switching gears) and higher-order (e.g., hazard perception, situation planning, and response planning) important for total performance can be trained isolated several times in a row. Therefore, a certain level of a specific skill sequence can be achieved without having to focus on other interfering skills.

Lastly, undoubtedly one of the greatest benefits of simulator-based driving training is the safe environment in which it takes place, eliminating severe consequences of errors. This makes it possible to provide error-based training from direct feedback on driver errors. Errors prompt learners to stop and think about the error, facilitating the development of adaptive expertise (Ivancic & Hesketh, 2000). Subsequently, the error scenario and its reasoning are stored in memory, facilitating retrieval when similar situations occur. Research on error-based training in driver education by De Groot et al. (2012) and Ivancic and Hesketh (2000) has shown that eliciting errors during driving training has the potential to improve driving performance on the long-run.

1.5. Speed-episodes

An example of error-based training is the use of speed-episodes. Speed-episodes are moments within the training that force people to perform faster, making them more error-prone because their performance is challenged to their limits (Dyre, Tabor, Ringsted, & Tolsgaard, 2016). These episodes are reflected by the speed-accuracy trade-off: the influence of time on error rate (Gas, Buckarma, Cook, Farley, & Pusic, 2018; Weimer, 2019). This phenomenon represents the complex relationship between an individual's willingness to perform slowly to be less error-prone in contrast to their willingness to perform quickly and thus be more error-prone.

The influence of speed-episodes is not yet extensively investigated within the driving training context. However, Ivanic & Hesketh (2000) and De Groot et al. (2012) had promising results regarding error-based training and driving. Therefore, one might indicate that speed-episodes will also have a positive effect on acquiring driving skills since trainees are being triggered to make errors. Additionally, research on simulator use within the laparoscopy domain provides evidence regarding positive effects of speed-episodes within simulated environments. Weimer (2019) used speed-episodes to investigate the effect of time pressure on performance of a laparoscopic task. Results showed that the estimated performance of learning after experiencing a speed-episode, compared to the initial training phase, was faster and had lower error rates. This indicates that more errors lead to an active exploration and deeper understanding of the task, and therefore to better performance. Trainees actively have to search for solutions on how to recover from the mistake or what to do the next time to avoid this mistake. Gas et al. (2018) strengthen these results by stating that medical students kept improving their accuracy when instructed to increase their speed.

1.6. The present study

The present study aims to develop guidelines for simulation-based driving training by exploring the acquisition of operational skills. Kappé & Van Emmerik (2005) state that there are indications that simulator-based training facilitates skill acquisition. Due to the various advantages the simulator offers (e.g., decreasing of traffic complexity and training of one specific skill sequence), operational skill acquisition becomes less cognitively demanding and might be automatized faster (ST Software Simulator Systems, 2010). This would leave more time and cognitive capacities of the trainee to develop higher-order skills (which are proven to be essential for driving safely) without extending the training hours (Dols et al., 2001).

This is done by exploring the effect of speed-episodes on the development of operational driving skills. By speeding up, trainees are stimulated to make mistakes and actively form mental models containing error-recovery or error-avoidance strategies on their operational skillset (Ivancic & Hesketh, 2000; Simons-Morton & Ehsani, 2016; Weimer, 2019). Furthermore, the difference in performance between experienced and inexperienced drivers will be explored. Specific focus is on exploration of the effect on inexperienced drivers since they represent the group of real driving trainees the best.

Based on these findings the main research question is formulated as: *To what extent is simulation-based speed training a potential method to facilitate the development of operational driving skills?*. It is expected that trainees performing a speed-episode both show a greater learning progress and drive more accurately in the end than trainees within accuracy training (De Groot et al., 2012; Ivancic & Hesketh, 2000; Weimer, 2019).

Exploratory sub research questions are formulated as: *Will experienced drivers outperform inexperienced drivers in their learning progress and performance outcome?* and *Do inexperienced drivers benefit more from speed training than experienced drivers?*. Based on research of Simons-Morton & Ehsani (2016) and Vlakveld (2011), it is expected that experienced drivers will overall perform better than inexperienced drivers, since their mental models are more developed. However, inexperienced drivers might therefore show more progress within their learning because they are still forming these mental models.

2. Methods

2.1. Participants

For this research, 42 individuals (18 males and 24 females) were recruited. Their age ranged from 17 to 32 years old (M = 20.19, SD = 2.63) and most of them were from the Netherlands (Netherlands = 61.9%, Germany = 23.8%, Other = 14.3%). Participants either signed up via the institution's Sona Systems webpage or were recruited through the personal networks of the researchers. Some of them had experience with VR-glasses, but none of them had ever been in a driving simulator. Due to worsening signs of simulator sickness (nausea, dizziness, etc) while performing the experiment, 9 participants dropped out and their data was excluded. Therefore, the final sample consisted of 33 participants (15 males and 18 females) with their age ranging between 17 and 25 years old (M = 19.67, SD = 1.88). Most participants were still from the Netherlands (Netherlands = 72,73%, Germany = 15,15%, Other = 12,12%).

Participants were divided into two categories: experienced drivers (*n* = 15) and inexperienced drivers (*n* = 18). Mayhew et al. (2003) state that crash rates drop over the first two years after licencing. So, to qualify as an experienced driver, participants had to have their driving licence for a minimum of two years (*n* = 10). Participants that were licenced for four or more years were instantly considered as experienced (*n* = 5). To ensure that driving is actively practised within the experienced drivers category, an extra criterion was included: Participants that are licenced between two and four years should drive a minimum of two times per week. The inexperienced drivers category consisted of drivers who had their driving licence for less than two years (*n* = 9), people that were taking part in drivers training at the moment of participating (*n* = 6), and people that had no driving experience (*n* = 3).

2.2. Task

The total experiment consisted of 3 blocks of 12 trials lasting approximately 1-1.5 minutes, in which the time varied depending on the time a participant used to complete the track. The track was fixed for all trials (Figure 2). Barricades placed on the road guided the participants along the route. There were no other road users presented to reduce complexity, so participants only had to focus on operational skills such as steering and braking. A start/finish checkpoint was included, indicating the end of the trial.

Figure 2. The route participants had to complete in one trial

All participants started with an accuracy block in which the main task was stressed as driving accurately. Subsequently, the experimental group did a speed training block in which they were told that making mistakes was no issue and that they should solely focus on reaching the finish as fast as possible. The control group did again an accuracy training block. The last block consisted for both groups of an accuracy training.

2.3. Measures

This research used two components to assess driving performance: speed and accuracy. The driving simulator collected different performance parameters for each component during the simulations. With regards to the speed component, the parameter Time on Task (ToT) represented the number of seconds a participant needed to complete one trial. The accuracy component was assessed by measuring the number of lane departures of the driver and the number of collision events with objects. Lane departures were represented by the number of moments participants crossed the line of the lane they were instructed to drive in. The collision of events parameter represented the number of collisions the participant had caused during all single trials of one accuracy block. Collisions include hitting the curb as well as bumping into objects like traffic lights, trees, and buildings. The parameters belonging to the accuracy component were not measured in the speed block since participants were allowed to make these mistakes within this training.

Within the accuracy training blocks, the data on ToT, the number of lane departures, the number of collisions determined the level of performance per individual. Low amounts of lane departures and collisions paired with a low ToT accounted for the best possible results. To ensure that the speed block functioned as speed-episode, the ToT was used to determine whether the participants actually sped up.

During all blocks, the researchers noted the ToT of the simulator and the ToT measured with a stopwatch. Means of these times were calculated to correct for errors either from the simulator or stopwatch, to get a time as accurate as possible. Within the accuracy training blocks, the researchers also tallied the lane departures and collisions to determine how accurate the performance was.

2.4. Materials

The pre-questionnaire used to gather demographic information (e.g., gender and nationality) and to determine the level of expertise was self-developed by the researchers (Appendix A). The informed consent form consisted of the outline of the study, stated potential risks (feelings of motion sickness), and mentioned the possibility to withdraw from the study at any moment (Appendix B). A tally scheme allowed the researchers to note the measurements during the experiment (Appendix C).

2.4.1. Driving simulator and environment

The driving simulator consisted of three pedals (accelerator, brake, and clutch), a steering wheel, and a gear stick held together by a base around a driving chair (Figure 3). However, since the vehicle was programmed to be automatic, participants did not have to use the clutch pedal and gear stick. Participants could see the environment through VR-glasses (Varjo VR-2), allowing them to have a 360° view. This set-up can be considered as a moderate fidelity driving simulator (Caird & Horrey, 2011).

Figure 3. Driving simulator set-up. Participants could accelerate and brake by pressing the pedals and could manoeuvre by turning the steering wheel. The gear stick was not used.

The environment that participants drove in was programmed and displayed via Unity Hub. The route of the accuracy training trials was located in a city-like scenery, whereas all surroundings such as buildings, traffic lights and trees were removed in the speed training trials. In both scenarios, there were no other road users represented. The participants were virtually seated in the car as if they would sit in a real car. They could see the steering wheel, dashboard, and mirrors within their visual field while focussing on the road (Figure 4). When participants moved their heads, they could also see other features of the car such as the radio, gearing stick and the back seat.

Figure 4. Driving environment within the accuracy blocks. Within the speed-episode, surrounding buildings, traffic lights, and trees were removed, but the car had an equal appearance.

2.5. Design

The study used a 3 (Block 1 2 3) x 2 (Group: control and experiment) x 2 (Experience: experienced and inexperienced drivers) mixed-design to observe effects of training methods and experience on the dependent variables time on task (ToT), number of collisions, and number of lane departures. The within-subjects design focused on the development of the dependent variables within block 1 and block 3. The measurements of the first accuracy block were compared with those of the last accuracy block to see whether participants were able to improve themselves during the training. The between-subjects design focused on the difference between training methods (accuracy training vs. speed training) to investigate whether the use of speed-episodes made a difference in developing driving skills. Additionally, between-subject differences for the independent variable experience (experienced vs. inexperienced drivers) were studied to examine whether experience played a role in developing driving skills.

2.6. Procedure

The experiments consisted of one session of approximately 1,5 hour and took place in the simulator room of the University of Twente. Participants started the experiment by reading and signing an informed consent form. Additionally, they filled out a pre-questionnaire and were asked whether they suffered from motion sickness.

Next, participants were asked to sit down in the simulator. Instructions on how to operate the simulator and the VR-glasses were given. Then they were asked to put on the VR-glasses. The researchers adjusted the simulated viewpoint of the participants to personal preference to enable them to see the speedometer and simultaneously see the road. Then they were instructed to drive a test trial to get used to driving in the simulated vehicle. This test trial was also used to detect unknown motion sickness among them, which was monitored afterwards.

Subsequently, the trials used for analysis started. Participants of both groups were instructed about the set-up of the experiment (“You will drive 36 trials divided into three blocks, so three times 12 trials. If everything goes well, there will be a break after each block.”) and told that they would start with 12 accuracy training trials. They were instructed that they “Should drive as accurate as possible”, meaning that they “Should drive as they would in real life on a normal road”, and that lane departures and collisions would be counted. Furthermore, they were notified about some technical aspects (e.g., how to drive backwards and how to react when flipping over) and the lack of speed limit. The participants were also told that they should start driving the moment they saw something on the VR-glasses, because the simulator would begin counting the time the moment the programme had started. Lastly, it was stressed that motion sickness symptoms (nausea, etc.) should be reported immediately to the researchers.

After the first block of 12 trials, participants that felt no or minor symptoms of motion sickness had a break of approximately 5-10 minutes. They could take off the VR-glasses and rest. Before the planned break, some participants already had a few additional breaks if they requested for it. Participants that felt motion sick were asked whether they thought they could continue for 24 more trials. For those participants that did not feel fit to continue, the experiment stopped.

The participants that felt confident to continue were then divided in two groups: accuracy training group (control group, n = 16) or speed training group (experimental group, n = 17). They were assigned by the researchers to get a good division of people representing the different categories (experienced vs. inexperienced, and male vs. female) within the two conditions. Furthermore, participants that indicated experiencing minor feelings of simulator sickness in the first block of the experiment were assigned to the control group to protect them from worsening of sick feelings. This led to four sub-groups: experienced drivers performing speed training (n = 8), experienced drivers performing accuracy training (n = 7), inexperienced drivers performing speed training (n = 9) and inexperienced drivers performing accuracy training (n = 9). The control group continued with 12 trials of the accuracy training and were instructed to do the exact same task as in the first block. The experimental group was told that they would continue with a speed training. They were instructed to reach the finish line as fast as possible and were allowed to make mistakes (i.e., lane departures and collisions). Collidable objects were removed and participants could use all lanes present.

Both groups ended the experiment with another accuracy training block (see Table 1 for a summary of the experimental set-up). After the last trial, participants were thanked for participating. Participants recruited via the Sona System received two credits afterwards.

Table 1. *Summary of the experimental procedure.*

Condition 1 (Accuracy Training)	Condition 2 (Speed Training)
Practice trial	Practice trial
Block 1: Accuracy1	Block 1: Accuracy1
Trials #: 12	Trials #: 12
Instruction: “You will now drive 12 trials in the simulator. Please, drive as you would normally drive in real life.“	Instruction: “You will now drive 12 trials in the simulator. Please, drive as you would normally drive in real life.”
Block 2: Accuracy2	Block 2: Speed1
Trials #: 12	Trials #: 12
Instruction: “You will now drive 12 more trials. Please drive as you would normally drive in real life.”	Instruction: “We are now interested in your driving behaviour in a new environment where the risk of collisions is removed and were you do not have to stay in one lane. Please, try to reach the finish as fast as possible. You will again complete 12 trials in this new environment.”

Block 3: Accuracy3	Block 3: Accuracy3
Trials #: 12	Trials #: 12
Instruction: “You will now drive your last 12 trials. Please drive as you would normally drive in real life.”	Instruction: “You will now drive your last 12 trials. Please drive as you would normally drive in real life.”

2.7. Data analysis

The final data set was explored after exclusion of the data of participants that withdrew due to motion sickness. Descriptive statistics were analysed and mean scores for measurements functioning as dependent variables (ToT, number of lane departures, and number of collisions) per block per individual were computed. Additionally, the individual differences between the means of all measurements of block 1 and 3 were calculated. This new variable represented the learning progress of the individuals. Finally, the ToT of the speed-episode was compared to the ToT of block 1 to verify whether participants in speed training actually sped up.

The analysis started with testing the assumptions for different statistical analyses such as homogeneity of variances, distribution of data, and multicollinearity. Furthermore, the means of all groups were compared to get an overview of the possible differences that could be found.

Subsequently, three repeated measures ANOVAs between block 1 and 3 were conducted on the dependent variables to measure the general effect of training on driving performance. Each measurement was tested independently since the assumptions for conducting a repeated measures MANOVA were not met.

Differences between conditions and experience were measured through independent factorial ANOVAs. Three separate independent factorial ANOVAs were conducted to look for differences in learning progress between the categories (speed vs. accuracy, experienced vs. inexperienced, and a combination of those). The three prior calculated differences on each measurement between the blocks functioned as dependent variables in these first three tests. Differences between learning outcomes among the categories were also tested. Three independent factorial ANOVAs between categories were computed on each measurement of block 3.

3. Results

The gained data showed a good variance of homogeneity and there were no extreme outliers presented, so all 33 participants that finished the experiment were included. Additionally, the ToT in block 2 of participants performing speed training differed enough from their ToT in the other blocks to indicate that it functioned as a speed-episode. However, the data was not normally distributed for all dependent variables and two dependent variables showed multicollinearity.

The Shapiro-Wilk test of normality showed that only the variables ToT of block 1 and 3 independently, and the prior computed differences between block 1 and 3 in number of lane departures and number of collisions were normally distributed ($p > .05$). However, Blanca, Alarcón, Arnau, Bono & Bendayan (2017) state that, in terms of Type I error, the F-test is robust against violation of normality. Furthermore, correlation tables demonstrated that the ToT measures of block 1 and block 3 were too highly correlated ($r = .992$), which is problematic when performing a MANOVA (Tabachnick & Fidell, 2012). After consideration of these results, it was decided to still conduct repeated measures ANOVAs and independent factorial ANOVAs, since the violation of normality can be accounted for.

The data gathered for block 2 will not be used within this analysis since it is too different between training methods. Participants got different tasks in block 2, depending on the training method they were assigned to. For instance, accuracy parameters were not measured for participants in speed training because their focus was on decreasing their ToT. Subsequently, their ToT in block 2 was much lower than that of participants performing accuracy training. This makes it difficult to compare learning progress and performance between the groups within this block.

3.1. Training effect

The observed significant within-difference in the means on ToT in seconds between block 1 and 3 ($F(1,32) = 43.561$, $p < .001$) indicated that training had a positive effect on the time to complete the task. Participants were on average able to complete one trial faster in block 3 ($M = 66.182$, $SD = 5.458$) than in block 1 ($M = 71.012$, $SD = 6.676$) (see Figure 5).

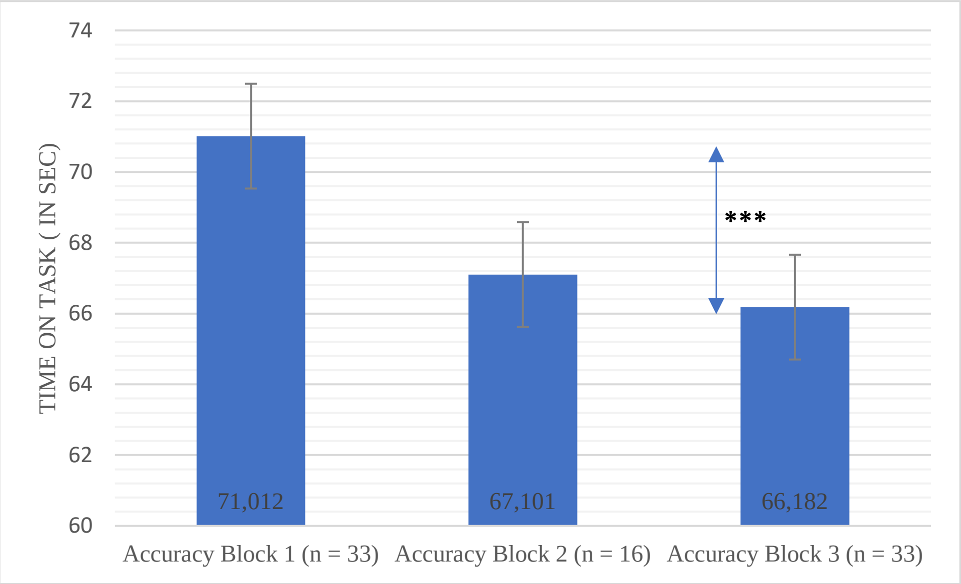

Figure 5. A representation of the significant within-difference of ToT between Accuracy block 1 and 3. Data of the participants performing accuracy training in block 2 is added to this figure to illustrate the development better.
*** p <.001

A significant within-difference in means on number of lane departures between block 1 and 3 ($F(1,32) = 8.576$, $p < .009$), indicated that participants made in general fewer lane departures in block 3 than in block 1. Whereas participants made on average 2.326 (SD = 1.579) lane departures per trial in block 1, they only made 1.774 (SD = 1.303) lane departures in block 3 (see Figure 6).

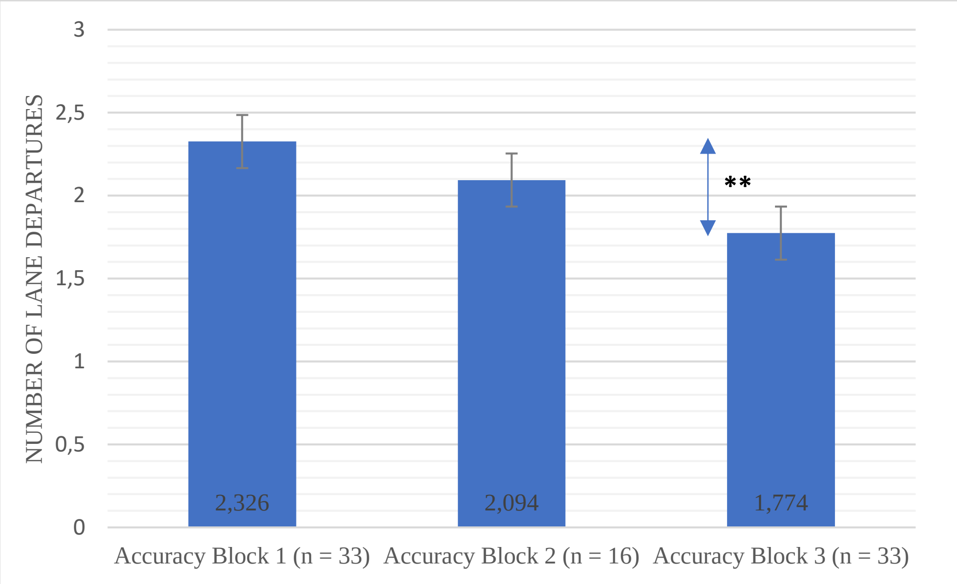

Figure 6. A representation of the significant within-difference of number of lane departures between Accuracy block 1 and 3. Data of the participants performing accuracy training in block 2 is added to this figure to illustrate the development better.
** $p < .009$

Lastly, there was no significant within-difference in means on number of collisions between block 1 and 3 ($F(1,32) = .802$, $p = .377$). So, practice did not lead to fewer collisions.

3.2. Differences between training methods: Accuracy vs. speed training

3.2.1. Learning progress

An independent factorial ANOVA on all 3 learning progress measurements separately showed that there was no significant between-subjects main effect observed on the differences between block 1 and 3. Firstly, the non-significant main effect of training on differences of ToT between block 1 and 3 ($F(1,29) = 1.006$, $p = .324$) suggested that a certain training method did not support participants to complete the trial faster than the other. Secondly, the non-significant main effect of training on the difference of number of lane departures between block 1 and 3 ($F(1,29) = 0.944$, $p = .339$) demonstrated that participants performing one type of training were not able to reduce their number of lane departures more than the other group. Lastly, a non-significant main effect of training on the difference on number of collisions between block 1 and 3 ($F(1,29) = 1.823$, $p = .187$) indicated that one group was not able to decrease their moments of colliding more than the group performing another training method. So, no group showed a higher learning progress compared to the other. See Table 2 for an overview of all observed learning progress means for both training methods.

Table 2. *Mean scores of the learning progress measures for the training methods.*

Category	Mean differences in ToT between block 1 and 3	Mean differences in number of lane departures between block 1 and 3	Mean differences in number of collisions between block 1 and 3
Accuracy training	4.05 (*SD* = 3.49)	0.76 (*SD* = 1.09)	0.17 (*SD* =0.39)
Speed training	5.57 (*SD* = 4.77)	0.36 (*SD* = 1.08)	-0.03 (*SD* = 0.51)

Note. These observed means did not result in significant main effects. Therefore, it cannot be concluded that the observed differences are caused by differences in training method.

3.2.2. Performance outcomes

An independent factorial ANOVA was conducted to measure the effect of training method (accuracy or speed) on the scores of all 3 performance outcome measurements. All between-subjects main effects were statistically non-significant. Firstly, the non-significant main effect of training on ToT ($F(1,29) = 0.007$, $p = .932$) showed that neither the accuracy nor the speed group performed better than the other at the end of the experiment. Secondly, a non-significant main effect of training on number of lane departures ($F(1,29) = 0.012$, $p = .912$) indicated that a particular training method did not cause more or less lane departures than the other. Lastly, there was a non-significant main effect of training on number of collisions observed ($F(1,29) = 1.212$, $p = .280$), suggesting that the performance outcome on number of collisions is not better for one training group compared to the other. Therefore, neither participants performing speed training nor participants within accuracy training were able to outperform the other group. See Table 3 for an overview of all observed performance outcome means for both training methods.

Table 3. *Mean scores of the performance outcome measures for the training methods.*

Category	Mean ToT in Accuracy block 3	Mean number of lane departures in Accuracy block 3	Mean number of collisions in Accuracy block 3
Accuracy training	66.05 (*SD* = 5.69)	1.85 (*SD* = 1.64)	0.30 (*SD* = 0.29)
Speed training	66.31 (*SD* = 5.40)	1.71 (*SD* = 0.92)	0.51 (*SD* = 0.72)

Note. These observed means did not result in significant main effects. Therefore, it cannot be concluded that the observed differences are caused by differences in training method.

3.3. Differences between experience: experienced vs. inexperienced drivers

3.3.1. Learning progress

An independent factorial ANOVA on all 3 learning progress measurements separately did not show any between-subjects main effects of experience on differences between block 1 and 3. Firstly, a non-significant main effect of experience on the difference of ToT between block 1 and 3 ($F(1,29) = 1.460$, $p = .237$) suggested that differences in experience did not cause differences in improvement of time to complete a trial. Secondly, the non-significant main effect of experience on the difference of number of lane departures between block 1 and 3 ($F(1,29) = 0.542$, $p = .467$) indicated that experience did not influence the progress of lane departures made. Lastly, a non-significant main effect of experience on the difference of number of collisions between block 1 and 3 ($F(1,29) = 0,571$, $p = .456$) demonstrated that the difference in experience did not cause drivers to improve themselves more on times of colliding. Thus, overall, neither experienced and nor inexperienced drivers showed more improvement within their driving behaviour than the other. See Table 4 for a representation of the observed means for learning progress within the different experience groups.

Table 4. *Mean scores of the learning progress measures for experience.*

Category	Mean differences in ToT between block 1 and 3	Mean differences in number of lane departures between block 1 and 3	Mean differences in number of collisions between block 1 and 3
Inexperienced drivers	3.99 (*SD* = 4.01)	0.69 (*SD* = 1.06)	0.13 (*SD* = 0.55)
Experienced drivers	5.84 (*SD* = 4.34)	0.39 (*SD* = 1.13)	0.00 (*SD* = 0.32)

Note. These observed means did not result in significant main effects. Therefore, it cannot be concluded that the observed differences are caused by differences in experience.

3.3.2. Performance outcomes

An independent factorial ANOVA on all 3 performance outcome measurements separately did not show any significant between-subjects main effects of experience on the performance outcomes of block 3. Firstly, the lack of significant main effect of experience on ToT in block 3 ($F(1,29) = 0.373$, $p = .546$) demonstrated that the experience level of drivers did not cause a faster or slower performance on the trials. Secondly, the non-significant main effect of experience on number of lane departures in block 3 ($F(1,29) = 2{,}571$, $p = .120$) suggested that one group was not able to make less lane departures than the other group. Lastly, a non-significant main effect of experience on number of collisions in block 3 ($F(1,29) = 2{,}164$, $p = .152$) indicated that more or less collisions are not paired with differences in driving experience. Therefore, it cannot be concluded that - in general - one group performed better in the end than the other group. The following table (Table 5) represents all observed means for the performance outcomes measures within both experience groups.

Table 5. *Mean scores of the performance outcome measures for experience.*

Category	Mean ToT in Accuracy block 3	Mean number of lane departures in Accuracy block 3	Mean number of collisions in Accuracy block 3
Inexperienced drivers	66.75 (*SD* = 5.14)	2.08 (*SD* = 1.58)	0.54 (*SD* = 0.69)
Experienced drivers	65.50 (*SD* = 5.93)	1.40 (*SD* = 0.75)	0.26 (*SD* = 0.31)

Note. These observed means did not result in significant main effects. Therefore, it cannot be concluded that the observed differences are caused by differences in experience.

3.4. Differences between training methods (accuracy vs. speed) and experience (inexperienced vs. experienced)

3.4.1. Learning progress

An independent factorial ANOVA on all 3 learning progress measurements separately did not show any significant interaction effects of experience and condition on differences between block 1 and 3. Firstly, the non-significant interaction effect on differences in ToT between block 1 and 3 ($F(1,29) = 0{,}051$, $p = .822$) demonstrated that neither experienced nor inexperienced drivers in both training methods showed more progress in time needed to complete the trial. Secondly, a non-significant interaction effect on differences in number of lane departures between block 1 and 3 ($F(1,29) = 0{,}182$, $p = .673$) indicated that no sub-group improved themselves more by means of lane departures made than the other sub-groups. Lastly, the non-significant interaction effect on differences in number of collisions between block 1 and 3 ($F(1,29) = 1{,}509$, $p = .229$) suggested that there was no particular sub-group that showed most progress in times of colliding. Therefore, it cannot be concluded that either experienced or inexperienced drivers improved more within the different training methods. See Table 6 for a representation of the learning progress means for the different sub-groups.

Table 6. *Mean scores of the learning progress measures for conditions and expertise combined.*

Experience	Condition	Mean differences in ToT between block 1 and 3	Mean differences in number of lane departures between block 1 and 3	Mean differences in number of collisions between block 1 and 3
Inexperienced	Accuracy	3.41 (*SD* =2.15)	0.96 (*SD* = 1.30)	0.14 (*SD* = 0.48)
	Speed	4.56 (*SD* = 5.38)	0.41 (*SD* = 0.72)	0.12 (*SD* = 0.64)
Experienced	Accuracy	4.87 (*SD* = 4.79)	0.51 (*SD* = 0.76)	0.22 (*SD* = 0.25)
	Speed	6.69 (*SD* = 4.03)	0.30 (*SD* = 1.43)	-0.19 (*SD* = 0.25)

Note. These observed means did not result in significant interaction effects. Therefore, it cannot be concluded that the observed differences are caused by differences in training method or experience.

3.4.2. Performance outcomes

An independent factorial ANOVA on all 3 performance outcome measurements separately did not present any significant interaction effects of experience and condition on the performance outcomes of block 3. Firstly, the non-significant interaction effect on ToT in block 3 ($F(1,29) = 0.532$, $p = .472$) demonstrated that none of the sub-groups were able to significantly complete one trial faster on average than the other sub-groups. Secondly, a non-significant interaction effect on number of lane departures in block 3 ($F(1,29) = 2.868$, $p = .101$) indicated that no sub-group made less lane departures than the others at the end of the training. Lastly, the non-significant interaction effect on number of collisions in block 3 ($F(1,29) = 0{,}055$, $p = .816$) showed that no sub-group was able to outperform the other groups on collisions made. Thus, it cannot be said that one particular sub-group benefitted more from a certain training method, and therefore performed better at the end of the experiment. See Table 7 for an overview of all observed means for all sub-groups (experienced drivers in accuracy and speed training, and inexperienced drivers in accuracy and speed training) on the performance outcome measurements.

Table 7. *Mean scores of the performance outcome measures for conditions and expertise combined.*

Experience	Condition	Mean ToT in Accuracy block 3	Mean number of lane departures in Accuracy block 3	Mean number of collisions in Accuracy block 3
Inexperienced	Accuracy	65,94 (*SD* = 4.16)	2,48 (*SD* = 1.92)	0,41 (*SD* = 0.34)
	Speed	67,55 (*SD* = 6.11)	1,69 (*SD* = 1.14)	0,67 (*SD* = 0.92)
Experienced	Accuracy	66,18 (*SD* = 7.60)	1,03 (*SD* = 0.68)	0,17 (*SD* = 0.12)
	Speed	64,91 (*SD* = 4.46)	1,73 (*SD* = 0.69)	0,34 (*SD* = 0.40)

Note. These observed means did not result in significant interaction effects. Therefore, it cannot be concluded that the observed differences are caused by differences in training method or experience.

4. Discussion

This study aimed to develop guidelines for implementation of simulation-based training within the current driving training curriculum. The effect of speed-episodes on developing operational driving skills was explored, aiming to match the results of Ivancic and Hesketh (2000), De Groot et al. (2012), and Weimer (2019). Therefore, the main research question was formulated as: *To what extent is simulation-based speed training a potential method to facilitate the development of operational driving skills?* Furthermore, differences between experienced and inexperienced drivers on the development of driving skills were explored. Additional research questions were formulated as: *Will experienced drivers outperform inexperienced drivers in their learning progress and performance outcome?* and *Do inexperienced drivers benefit more from speed training than experienced drivers?*.

A significant difference within the entire sample between block 1 and 3 in both the means on ToT and number of lane departures was found. Generally, disregarding their individual differences (e.g., experience, age, and gender), participants were able to improve themselves on their ToT and the number of lane departures made. These results are in line with research on skill acquisition (De Winter et al., 2009; Fitts & Posner, 1967) which shows that with increasing experience, trainees shorten their time required to finish a procedure and become less error-prone. Therefore, it can be concluded that certain components of driving behaviour can be trained through a simulator. This means that it could be useful to implement simulator-based training within the current driving training curriculum. Trainees can repeatedly practise specific skills and situations at their performance level and so gain experience in a safe way (De Groot et al.; Van Emmerik, 2004; Käppler, 2008; Van Leeuwen et al., 2014; Zhao et al., 2019). However, the question remains which training method is most successful and who benefits most from the training.

It was expected that trainees performing speed training would both show a greater learning progress and would drive more accurately in the end than trainees performing accuracy training (De Groot et al., 2012; Ivancic & Hesketh, 2000; Weimer, 2019). Results showed that these expectations were not confirmed: There was no significant main effect found between the two training methods (speed training vs. accuracy training). Therefore, it cannot be concluded that speed training is superior to accuracy training when acquiring operational driving skills within a simulated environment. However, error training is still considered to be a useful training method for complex tasks where the major training goal is transferring skills (Keith & Frese, 2008), which is the case in learning how to drive. Therefore, also because trainees significantly improved themselves within the simulated environment, speed training might still be a potential training method after some adjustments.

Within this experiment, it might have been possible that the speed-episode did not completely function as error training. Firstly, participants did not experience consequences after making mistakes (i.e., no haptic or auditory feedback after an error), which might have caused a lack of error recognition. However, error recognition is determined to be an important factor in forming mental models and thus on the effectiveness of error training (Heimbeck, Frese, Sonnentag, & Keith, 2003). Secondly, it is not clear whether the speed-episode evoked enough opportunities for the trainees to make errors. Keith & Frese (2005) state that trainees within effective error training should be provided with enough opportunities to make errors and recover from them.

So, this limitation should be accounted for in future research. It should be considered to develop a speed-episode in which trainees easily recognise their mistakes and have enough opportunities to make errors. This can be done by adding haptic and auditory feedback and by making the traffic situations more complex (e.g., adding other traffic users or traffic rules) to ensure that the speed-episode truly operates as error training.

Moreover, it was expected that experienced drivers would perform better than inexperienced drivers since their mental models are more developed, but that inexperienced drivers would therefore show a greater learning progress (Simons-Morton & Ehsani, 2016; Vlakveld, 2011). Nevertheless, there was no significant main effect represented between experienced and inexperienced drivers on learning progress and performance outcome. A factor that could have caused this lack of difference is that the sample division might not have been distinctive enough in this study. The sample mainly consisted of students, which made it difficult to define experienced drivers. It was decided to categorise participants licenced for less than two years as inexperienced (Mayhew et al., 2003) and participants licenced for more than two years with a regular driving habit as experienced. However, it cannot be ensured that people who have their licence for less than two years are less experienced than people who are licenced for slightly longer than two years. In this respect, it cannot be concluded that an individual that is licenced for 1,5 year and drives five to six times a week is less experienced than an individual that is licenced for 2,5 years and drives just two to three times a week.

However, it might be possible to detect the expected differences in experience when this limitation is removed. When a more distinctive division is represented, the extensive developed mental models of different traffic situations and the (nearly) autonomous driving skillset experience drivers possess (Deery, 1999; Dols et al., 2001; Simons-Morton & Ehsani, 2016; Vlakveld, 2011) might become more explicit. To get this desired sample division in future research, it is recommended to categorise drivers that are licenced for more than five years as experienced (Rijksoverheid, 2020), and participants without a licence as inexperienced.

Lastly, results did not show a significant interaction effect between the two training methods and experience level of the participants. Therefore, it cannot be concluded that one sub-group benefitted more from speed training than the other groups. Future research could dive further in exploring from which training method inexperienced drivers learn the best, since they will represent the ones that eventually will perform the training when learning how to drive.

4.1. Relevance and recommendations for further research

Although the effect of speed-episodes on training operational driving skills was not as expected within this study, it is still relevant to dedicate further research to it. Many crashes among inexperienced drivers seem to rise from badly developed higher-order cognitive skills (Dols et al., 2001; SWOV, 2016). This could be caused by the primary focus of training being on the acquisition of operational driving skills and traffic rule knowledge (Beanland et al., 2013; Dols et al., 2001; SWOV, 2019). Therefore, being able to shorten required training hours for certain elements of driving (e.g., operational skills like braking or steering) might leave more time to develop other critical skills like higher-order skills (e.g., hazard perception, situation planning, and response planning). Error-based training (i.e., speed-episodes) still appears to be a promising method since other research shows that it facilitates skill acquisition (de Groot et al., 2012; Ivancic & Hesketh, 2000; Weimer, 2019).

Accordingly, a suggestion for future research would be to study the effect of speed-episodes not only on acquiring operational driving skills, but also on higher-order skills and rare and risky traffic situations. Positive results on either one of them can lead to an improved driving training curriculum. To illustrate, positive effects of error-based training on acquiring operational skills leave more room for developing higher-order skills within the same amount of training time. Meanwhile, positive effects on developing higher-order cognitive skills and awareness of different traffic situations might offer more possibilities to practise these skills within a simulated environment.

5. Conclusion

The present paper aimed at developing guidelines on how to use simulators within driving training, with a specific focus on the effect of speed-episodes on acquiring operational skills. Whereas results showed that it is possible to improve performance on ToT and number of lane departures within a simulator, there were no differences found between types of training (accuracy vs. speed training) and driver experience (experienced vs. inexperienced drivers). Future research is needed to account for the limitations in this study and explore the use of speed-episodes more within driving training.

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Appendices

Appendix A

Pre-questionnaire

Pre-questionnaire
We are happy that you want to participate in this study. Note that all information you provide within this questionnaire will only be linked to your participant number (not your name) and no third parties will have access to your information.

Demographic information

1. What is your age?
   ____

2. What is your gender?
a. Male
b. Female
c. Other: _____________________
3. What is your nationality?
. Dutch
a. German
b. Other: ________________________

Driver experience

1. Do you have a driver's license?
   1. Yes, for how long?_____________________________
   2. No
- If Yes: go to question 3
- If No: go to question 2

2. Have you ever had a driving lesson?
a. Yes
b. No
- If Yes: go to question 3
- If No: this is the end of the questionnaire

3. How often do you drive? Please give an indication how much you drive per week and per month
____________ times a week
____________ times a month

4. Do you own a car? (Note: this car should be yours, not the car from your parents)
a. Yes
b. No

5. Have you ever driven in other countries than the country you are from?
a. Yes, which countries? _____________________________________
b. No.

6. Please tick all situations in which you have driven:
a. Heavy rain
b. Stormy (very strong winds, heavy rain, hail, etc.)
c. Snow (both snow on the road and snowing)
d. Icy/slippery roads
e. Thick fog

7. Do you have a crash-history?
a. Yes
b. No
c. Not willing to share

8. Do you tend to keep the speed limit?
a. Yes, perfectly
b. No, I mostly go somewhat faster
c. No, I mostly go somewhat slower
d. Not willing to share

9. What is the highest speed you have driven by yourself?
____

Appendix B

Informed consent form

Informed Consent Form

Human Factors and Engineering Psychology

I give my consent to participate in the Driving Simulator Study that investigates individual learning behaviour and is run by the department of Psychology at the University of Twente in Enschede.

I have been informed about the nature of the experiment. I understand that my participation is voluntary. I may withdraw from the study at any time without further justification. I have the right to a debriefing about the general results of the study and I may obtain my individual results upon request. I give my consent knowing that all aspects of my participation will remain confidential and that I will not be subjected to any harm or deception.

I understand that the experiment has potential benefits in understanding individual learning behaviour and processes that might facilitate these. The aim of this study is to comprehend how humans interact with technology and how this interaction can be improved and optimized. The results might provide a basis for future studies in the field of Human Factors and Engineering Psychology.

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Name of Participant Date

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Signature of Participant

Appendix C

Tally scheme

Participant no: Group:

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