Transfer of Skills Learned on a Driving Simulator to On-Road Driving Behavior

Article *in* Transportation Research Record Journal of the Transportation Research Board · January 2017

DOI: 10.3141/2660-01

2 authors:

Pierro Hirsch
Virage Simulation

François Bellavance
HEC Montréal - École des Hautes Études commerciales

Pilot Project to Validate the Transfer of Training of Driving Skills Learned on a Mid-Range High Fidelity Driving Simulator to On-Road Driving Performance

Final Report

Pierro Hirsch, Virage Simulation
François Bellavance, HEC Montréal, RRSR, CIRRELT et GERAD

February 2016

Table of Contents

Introduction
- Problem
- Study Goals
- Literature Review
  - Novice Drivers
  - Professional Drivers

Method
- Study Design
- The Quebec Driver Licensing System
- Driving Simulator Scenarios
  - Goals and Content of Training
  - Feedback to Learners
  - Scenario Testing and Validation
  - Driving Simulator Platform and Visual System
  - Scenario Selection and Integration into ToT Study
  - Adjustments to PESR
- Driving School Participation
- Teacher Training
- Data Sources
- Sample / Driving Simulator Training
  - Sample Sizes for the Study Data
  - Comparison Group

Results
- Implementation of Driving Simulator Scenarios
  - Driving Simulator Sessions
- Learner Perceptions of Simulator Training
  - Immediate Perceptions of Simulator Training
  - Retrospective Perceptions of Simulator Training
- Teacher Questionnaire
- Associations with SAAQ Records
  - Road Exam Results
  - Driving Infractions

Crash Rates
Motor Vehicle Ownership – A Proxy for Driving Exposure
Logistic Regression

Discussion
Limitations
Conclusion
Acknowledgments
References
Appendixes

List of Appendixes

Appendix A VS500M Driving Simulator
Appendix B Recommended Requirements for a Driving Simulator Visual System
Appendix C CAA-Québec Letter of Support
Appendix D SAAQ Approval Letter 2008-03-13
Appendix E SAAQ Approval Letter 2009-11-26
Appendix F SAAQ Extension of Study to 2015 and AQTR Permission for Back-to-Back Simulator and On-Road Lessons
Appendix G Obligations of Participating Driving School Letter
Appendix H Consent Form and Three Questionnaires
Appendix I Teacher Questionnaire
Appendix J Frequency List of Driving Simulator Scenario Usage
Appendix K Direct Comparison of Simulator vs. On-road Training

List of Tables

Table 1. Suitability of different driving simulator visual systems and fields of view to train and evaluate basic driving skills

Table 2. Participating driving schools by city and city population

Table 3. Frequency of the top 50% scenarios selected by driving teachers

Table 4. Driving skills in decreasing ranking of perception by learners as more efficiently learned on a driving simulator than on the road

Table 5. Sample sizes for data analyses on road exam results, infractions and crashes for the different driving time periods

Table 6. Number of female drivers in each group with at least one infraction in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 7. Number of male drivers in each group with at least one infraction in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 8. Number of female drivers involved in one or more crash without injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 9. Number of male drivers involved in one or more crash without injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 10. Number of female drivers involved in one or more crashes with injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 11. Number of male drivers involved in one or more crash with injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 12. Number of female drivers involved in one or more crashes in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 13. Number of male drivers involved in one or more crash in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 14. Number of female drivers owning at least one vehicle for one day or more in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 15. Number of male drivers owning one or more vehicle for one day or more in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

Table 16. Results of logistic regression models for female crash rates controlling for vehicle ownership and age.

Table 17. Results of logistic regression models for male crash rates controlling for vehicle

ownership and age.

List of Figures

Figure 1. Number of self-reported driving simulator sessions
Figure 2. Number of estimated sessions on simulator
Figure 3. Perceptions of learning on the driving simulator
Figure 4. Opinions of the learning objectives of each scenario
Figure 5. Learners' evaluation of the scenario's organization and learning advantages
Figure 6. Learner perceptions of the driving simulator teacher
Figure 7. Motivation to become an excellent driver following simulator session
Figure 8. Perceptions of easiness of lessons in the simulator and on-road
Figure 9. Perceptions of driving lessons as relaxing in the simulator and on-road
Figure 10. Perceptions of enjoyment learning on the simulator and on-road
Figure 11. Perceptions of stimulation on the simulator and on-road
Figure 12. Direct comparison of perceived efficiency of simulator vs. on-road training
Figure 13. First time pass rates on road test by sex for simulator and comparison groups
Figure 14. Female infraction rates for simulator and comparison group drivers by permit type and length of licensure
Figure 15. Male infraction rates for simulator and comparison group drivers by permit type and length of licensure
Figure 16. Female rates of crashes without injury for simulator and comparison group drivers by permit type and length of licensure
Figure 17. Male rates of crashes without injury for simulator and comparison group drivers by permit type and length of licensure
Figure 18. Female rates of injury crashes for simulator and comparison group drivers by permit type and length of licensure
Figure 19. Male rates of injury crashes for simulator and comparison group drivers by permit type and length of licensure
Figure 20. Female crash rates for simulator and comparison group drivers by permit type and length of licensure
Figure 21. Male crash rates for simulator and comparison group drivers by permit type and length of licensure
Figure 22. Percentage of females owning at least one car during the time periods under study
Figure 23. Percentage of males owning at least one car during the time periods under study

Introduction

Problem

Novice, adolescent driver overrepresentation in road crashes is a well-documented, robust phenomenon that Evans (1991) contends is "almost like a law of nature." Driver education (DE) is a controversial intervention that has rarely demonstrated safety benefits (Brown, Groeger, and Biehl, 1987; Christie, 2001; Lonero and Clinton, 2006; Helman, Grayson, and Parkes, 2010; Hirsch, 2005; Mayhew and Simpson, 2002; Mayhew, Simpson, Williams, and Ferguson, 1998; Vernick, Li, Ogaitis, Mackenzie, Baker, and Gielen, 1999). Nevertheless, there appears to be continued support for DE among policy makers (Maryland Government; Société de l'assurance automobile du Québec).

In an effort to improve DE interventions, Hatakka, Keskinen, Gregersen, Glad, and Hernetkoski (2002) proposed the Goals for Driver Education or GDE-matrix as a holistic, multi-level and comprehensive model to explain driver behavior. This model has been widely acknowledged by the traffic research community as a promising theoretical starting point when developing driver training (Peräaho, Keskinen, and Hatakka, 2003). The GDE-matrix attempts to integrate driver knowledge, skill and motivation across the five distinct, interactive levels of vehicle maneuvering, mastery of traffic situations, goals and context of driving, goals for life and living and social environment. Motivation and self-awareness are identified as key factors that influence driver behavior within and across these five levels. The GDE model has also been criticized for its lack of operational detail (Peräaho et al., 2003). A basic assumption of this transfer of training (ToT) study is that driving simulation is a tool that can help program developers and driver trainers to operationalize training goals as a means of improving training outcomes.

Flight simulators have proven to be effective training tools for enhancing aviation safety through pilot and crew training (Blickensderfer, Liu, and Henrandez, 2005; Hays, Jacobs, Prince, and Salas, 1992; Salas and Cannon-Bowers, 2001). In recent years, due to the combination of decreasing costs of computer hardware and software and increasing quality and fidelity of image production, the option of driving simulator-based training for novice drivers has become more feasible. Blickensderfer et al. (2005) emphasized that simulation is a tool, not a panacea, that requires: (1) the identification of training needs; (2) proper design of scenarios; (3) appropriate performance measurement and feedback, and; (4) consideration for trainee characteristics, work environment characteristics and the transfer environment. Based on the fourth criterion, comparisons between a rigorous program of flight simulator training for commercial pilots and driving simulator training for non-professional drivers are problematic. Nevertheless, since most drivers receive some formal on-road training prior to obtaining a license to drive on public roads, the potential training benefits of driving simulators still hold promise for improving public safety. Compared with on-road training, driving simulators allow learners to:

- Practice any maneuver, even dangerous ones, in a realistic and safe environment;
- Practice maneuvers in distant or difficult-to-access locations at any time, e.g. expressways for learners who live an hour away from one;
- Experience the virtual consequences of their driving behaviors under a variety of realistic conditions (i.e. any weather, road and traffic condition, alone or in combination);
- Learn faster due to lower stress, better feedback and less wasted time;
- Control their learning pace (e.g. pause for a break at any time, do extra practice drills for any skill);
- Develop appropriate levels of self-confidence as they progress from easy to difficult and from simple to complex skills;
- View instant replays of their performances including overhead views;
- Practice complex visual and psychomotor skills until they can be performed automatically, e.g. lane changes;
- Receive computer-enhanced performance challenges and real-time feedback unavailable during on-road training;
- Receive reliable, objective performance scores, and;
- Improve their hazard anticipation, perception and response skills.

Study Goals

This study adopts the practical approach suggested by Parkes (2005) that affirms that there are three important elements that should drive decisions on simulator provision within the training process: the efficiency and acceptability of the learning in the simulator; the transfer of the learning to the real world, and the retention of skills or knowledge learned. To respond to the first element, this study aimed at developing and testing a reliable method for implementing driving simulator-based training in driving schools and measuring how learner drivers perceived their driving simulator training. Transfer of learning, the second element, was objectively measured by performance on the probationary permit road exam. The third element, retention of skills or knowledge related to legal and safe driving behavior, was objectively measured by driver records of infractions and crashes during the first months and years of unsupervised and relatively unrestricted driving.

Literature Review

Blanco, Hickman, Hanowski, and Morgan (2011) observed that although the first vehicle simulations were developed to study driver behavior in the 1960s, it has only been in the last decade that they have been used for driver training. Relatively few studies have measured the transfer of training of driving skills learned on a driving simulator to on-road driving. This literature review is divided into two sections: novice drivers and professional drivers.

Novice Drivers

Several studies have shown that basic vehicle control skills and traffic management skills can be successfully learned on driving simulators. Hoskovec and Stikar (1971) studied ten beginner drivers who learned to brake and to shift gears on a manual transmission in a fixed-base simulator and found that these skills transferred successfully to real car driving. He also recommended the use of a moving-base simulator for future training. De Groot, Centeno, Ricote, and de Winter (2012) observed that reducing tire traction in the simulator during training sessions led to drivers reducing their speed when driving on rural roads in the simulator with normal tire traction both in the session immediately following training and in a later transfer session on the simulator the next day. Moe (personal communication, March, 2007) found that novices who learned driving skills on the driving simulator compared favorably with novices who learned with on-road lessons. Interestingly, the simulator sessions were only 30 minutes in duration compared with the 45-minute on-road session and the repetition of different exercises in the simulator outnumbered the on-road exercises by a ratio of three to one. Cox, Wharam, and Cox (2009) conducted a controlled study of novice driver training using a high-fidelity driving simulator with a 180-degree forward field of view. In this study, novices trained on the simulator, compared to those trained on road, received significantly better on-road scores on seven performance measures ranging from "steering" to "attention to driving" and "attitudes toward driving". Rosenbloom and Eldror (2014) studied 280 newly licensed drivers, half of whom received simulator-based driving lessons prior to licensing. Of the initial sample, 40 drivers had their on-road driving evaluated by expert driving instructors and in-vehicle data recorders (IVDRs). There was no significant difference between the two novice driver groups according to the driving instructors but the IVDRs indicated that the drivers who had received simulator-based lessons braked more often and were less prone to headway events, suggesting a more responsive driving style. Weirda (1996, cited in Vlakveld, 2005b) demonstrated that it was possible for some individuals to pass the government road test after just nine hours of simulator training and 30 minutes of on-road practice. Korteling, Helsdingen, and von Bayer (2000) reports that driving schools in the Netherlands that use driving simulators to assess and train their students have claimed a 10% increase in pass rates since the introduction of the driving simulator lessons. Instructors in those schools claim that 20 minutes of instruction in the simulator is equivalent to one hour of on-road training.

Several more studies have shown promising results for transfer of training of drivers' visual attention, scanning behaviors and hazard perception and response learned on a driving simulator. Vlakveld (2005a) found that novices trained in visual discrimination skills in a simulator environment learned to make difficult discriminations in real traffic faster than learners who only had on-road driving training. Fisher, Pollatsek, and Pradhan (2006) found that novice drivers trained in a simulator to scan for information that will reduce their likelihood of a crash are more likely to perform the same scanning while driving a real car than novice drivers who did not receive the simulator-based training. Pradhan, Masserang, Divekar, Reagan, Thomas, Blomberg, Pollatsek, and Fisher (2009) found that, compared to controls, drivers trained on a simulator exhibit better visual scanning ability and are more likely to fixate on areas of the driving environment containing potential hazards during on-road driving. Goode, Salmon, and Lenné (2013) conducted a literature review on simulator-based training and reported that several studies show that in a driving simulation evaluation, simulator-trained participants, compared to control groups, are more likely to perceive and respond appropriately to hazards as assessed by driving instructors and objective measures of driving performance, including braking patterns, speed selection and eye-movement measures. Moreover, these benefits generalized to scenarios not encountered during training and were evident when retested in the driving simulator four weeks after initial training. However, the authors cautioned that although these results are encouraging, no published studies have yet directly examined the association between simulation-based hazard perception training and crash risk - therefore, it remains unclear whether these results persist and lead to safety benefits over time.

Allen, Park, Cook, and Fiorentino (2007) conducted a post-training crash analysis on adolescent drivers in California who were trained on three different simulator configurations: an instrumented cab with wide-angle projected display; a wide field-of-view desktop system with a three monitor display, and; a single monitor, narrow field-of-view desktop system. The researchers compared the crash rates of all three training groups with the adolescent driver crash rates in the first two years of independent driving for California and found that the crash rate of the adolescents trained in the instrumented cab simulator configuration was only one third that of the general adolescent driver population. The crash rate of adolescent drivers trained with the desktop wide field of view configuration was 77% of the adolescent driver accident rate and the crash rate of the adolescent drivers trained on the single monitor desk top system was about equal to that of the general adolescent population. Due to methodological limitations, these results are considered inconclusive (Beanland, Goode, Salmon, and Lenne, 2013). Nevertheless the study supports the hypotheses that driving simulator-based training could possibly produce safer drivers and that the degree of driving simulator fidelity has some effect on its potential training effectiveness. Ekeh, Herman, Bayham, Markert, Pedoto, and McCarthy (2013) published findings on a randomized prospective study of a forty high school students, half of whom took ten modules of driver training on a driving simulator (DS), who recently obtained their driver's license. Driving records for the study sample were collected at 6 months, 12 months, and 18 months after licensing and comparisons were made. The DS group and the control group were similar in age and the DS group was 69% male compared to the 89% male control group. None of the differences in driving records collected at different time intervals were statistically significant but the trend in the data allowed the study authors to conclude that adolescent novice drivers who underwent structured simulator-based training showed consistent trends toward fewer infractions and crashes.

Professional Drivers

Professional drivers receive advanced skills training because they represent increased crash risk during their normal work practice, e.g. police drivers in high-speed pursuit or truck drivers managing heavy loads on slippery roads. Two sets of studies are reported in this subsection. The first concerns findings about the transfer of training from driving simulators for professional drivers learning to drive emergency vehicles. The second set reports findings about the transfer of training from truck simulators for professional drivers learning to drive heavy vehicles.

Coutermarsh, MacDonald, and Shoop (2011) conducted a two-year study as a proof-of-concept test for driving simulator-based emergency vehicle training. In the first year, they compared performances in a real car in an emergency maneuver exercise between ten drivers trained on a driving simulator and ten untrained drivers. The following year, they gave refresher or sustainment training to five of the simulator-trained drivers and compared their performances in a real car with five untrained drivers. The researchers measured vehicle control aspects of the training to determine if the trained drivers had acquired the necessary muscle memory to correctly implement the various vehicle control steps involved in each maneuver. The trends in the data analysis seemed to indicate that the trained drivers exhibited a better execution of the tasks than ones with no training. Lindsey and Barron (2008) assessed the effectiveness of adding a driving simulator to a traditional training program for emergency medical services drivers. In their study, 52 participants in the control group received classroom and closed circuit training and 50 participants received training in a driving simulator in addition to the classroom and closed circuit prior to the standard competency course test. On the first run of the competency course, compared to the control group, the simulator-trained group took significantly less time to complete the drive and acquired significantly fewer penalty points. The authors concluded that driving simulators can be effective training tools for teaching emergency vehicle drivers and observed that driving simulators would also reduce: expensive repairs when vehicles are damaged during training; the time emergency vehicles are out of service, and; the risk of injury to drivers. In addition, simulator training, compared to closed circuit training, significantly reduces time and staffing requirements, is unaffected by weather and can be done at any time. Falkmer and Gregerson (2003) compared vehicle control skills across three groups of drivers: those trained on a low-cost simulator (40-degree field-of-view screen and no motion feedback); those trained on a medium-cost driving simulator (120-degree field-of-view screen and simple movement feedback), and; an untrained control group. Results showed that drivers trained on the medium-cost simulator had better lateral control of their vehicle, drove more slowly through fog, left longer headways and had greater minimum time-to-collisions than the driver in the other two groups. Turpin, Welles, and Price (2007) report findings from a two-year study of police trainees in which driving simulator-based training for emergency driving skills was inserted between the classroom theory and test track training. In the first year, 355 simulator-trained drivers demonstrated a 67% reduction on the test track of critical errors related to collisions. In the second year, the training was repeated with 598 new trainees with similar results. Analysis of the data reveals that improvement in driver performance was independent of the trainer(s), and that the training benefit is a function of the sequence and number of exercises on the driving simulator. Neukum, Lang, and Krueger (2003) report that the results of their implementation study indicate that simulator-based training is an efficient tool in emergency driver education, that the trainees accepted it and the instructors evaluated it as helpful. Welles and Holdsworth (2000) report anecdotal findings that strongly suggest that driving simulators "can reduce accidents, improve driver proficiency and safety awareness, and reduce fleet operations and maintenance costs". In particular, hazard perception training delivered on a driving simulator to a particular police force reportedly led to reductions in intersection accidents of around 74%, and overall accident reductions of around 24% in a six-month period following training. Heinrich and Wieland (1997, cited in SWOV, 2011) report that professional drivers who did part of their training on a driving simulator had a 22% reduction in crash rates compared to a control group who only practiced with real cars.

The next set of studies report findings about the transfer of training from truck simulators for professional drivers learning to drive heavy vehicles. These studies focus on two main questions: Do basic vehicle control skills learned in a truck simulator transfer to the real world and, if so, does truck simulator-based training reduce training time? Morgan, Tidwell, Medina, and Blanco (2011) evaluated the training and testing of entry-level commercial motor vehicle (CMV) drivers on truck simulators and found that learners who spent 60% of their time on a truck simulator performed equally well to drivers who were trained for the same length of time in a real truck. The authors concluded

> "providing longer, more structured training for CMV drivers offers distinct benefits that may increase operational safety on public roads. Beyond this, simulators could potentially be used to replace some of the time normally spent training in an actual vehicle. If structured correctly, this could result in cost savings for an organization and

allow for novice CMV drivers to be introduced to a heavy vehicle in a safe and controlled manner."

Two evaluation studies of the effectiveness of simulator-based training on the acquisition of gear-shifting skills for learner truck drivers using the self-paced Golden Shifter learning program without an instructor reduced training time by 50% or more (Hirsch, Pigntatelli, and Bellavance, 2011; Hirsch and Bellavance, 2013). Uhr (2003) found that training of truck backing skills on a truck simulator transferred to the real truck. Choukou, Hirsch, and Bellavance (2014) conducted two tests of the efficiency of the self-paced Golden Mirror program for learning backing skills. The first test used the Golden Mirror program for 20% of the total training and the second used the program for 50% of the total training. The results of both tests showed that training on the truck simulator produced skill levels equal to those learned in the truck after equal hours of training.

In summary, the transfer of training studies that have been done for novice automobile and professional drivers for basic and advanced vehicle control skills as well as hazard perception training have demonstrated that overall, within the limits of each study design, driving simulator-based training appears to have many positive effects on skill acquisition and driving safety and few, if any, negative effects.

Method

Study Design

The *Pilot Project to Validate the Transfer of Training of Driving Skills Learned on a Mid-Range High Fidelity Driving Simulator to On-Road Driving Performance*, or ToT study, is a long-term, prospective cohort, naturalistic study of the transfer-of-training from the programmed scenarios on the VS500M driving simulator to on-road driving performance and behavior. Learner perceptions of driving simulator-based training and how it compares to on-road instruction were collected through two questionnaires, one distributed near the start and the other at the end of the several month-long driving course. Within the ToT study, one driving simulator hour can replace one hour of on-road training for up to 47% of the SAAQ on-road curriculum. Driving-school teachers were free to determine, in consultation with their students, which on-road session(s) would be replaced by driving simulator sessions. On-road performance is measured by the results on the SAAQ probationary permit road test. The potential behavioral effects of simulator–based training are measured by driving infractions and police-reported crashes in the first months and years of unsupervised driving.

The Quebec Licensing System

The SAAQ regulations for access to a driver's permit changed during the planning of this study. In 2006, the ToT study was conceived and designed in the context of the Quebec government policy in effect between 1997 and 2009 that regulated access to driver's permits for new drivers. During this period, driving courses were not mandatory but probationary permit candidates who presented a certificate attesting to the successful completion of twelve hours of in-car lessons at driving school approved by the CAA-Quebec or the AQTR could apply for their road test four months early. This twelve-hour, on-road driver-training program was based on the curriculum developed by the SAAQ in 1991. In 2007, the Quebec Minister of Transport announced that all novice drivers in Quebec would be required to take a mandatory driving course. The SAAQ produced a new driver-training curriculum, the *Programme d'éducation à la sécurité routière pour une nouvelle génération de conducteurs* (PESR). The PESR consists of 24 hours of in-class interactive learning activities and 15 hours of in-car training given over a minimum period of one year. Twelve two-hour long theory modules are alternated with 15 on-road driving sessions consisting of 13 hours of lessons, one hour of observation and one hour of evaluation. Novices can apply for a learner's permit at the age of 16. Graduates of the PESR who pass their SAAQ theory and road exams receive a probationary driver's permit which allows unsupervised driving, but imposes certain restrictions on driving privileges for two years, after which they receive a Class 5 permit without further testing. Lower limits for the maximum number of demerit points and for blood alcohol content apply in an age-specific manner until the driver reaches 25 years of age.

Driving Simulator Scenarios

Prior to the ToT study, extensive work was completed to create a library of training scenarios for the VS500M driving simulator. According to Kearney and Gretchkin (2011)

> "A scenario specifies the dynamic characteristics of a simulation. Thus, it binds together activities and places. A scenario is typically defined as a series of episodes with tightly controlled critical events interspersed with periods of free driving." p. 6-10

In the development of driver training scenarios, three elements identified by Blickensderfer et al. (2005) were considered. The goals and content of the scenario lessons were based on the identification of training needs and the proper design of scenarios. There was also a strong focus on appropriate performance measurement and feedback for the learner. In addition to these elements, three more were added. The driving simulator platform and visual system were adapted for maximum compatibility to training goals. For example, blind spot monitors were added to permit training a more complete range of driving maneuvers. The training scenarios were informally tested and validated for their acceptability to learners and teachers and their transfer to on-road driving. Finally, for the purposes of this study, the training scenarios were integrated into the PESR.

Goals and Content of Training

The information relevant to driving is likely to be predominantly visual (Sivak, 1996). Vision skill training for drivers is considered essential for the achievement of basic and advanced vehicle control and consistent safe driving outcomes (Lee, 2005). One can safely assume that the vast majority of a driver's behavior is based on decisions and automatic habits initially formed and continuously informed by visual information from the driving environment. Therefore, the development of competent vision skills for driving is the primary and explicit instructional goal of almost all the driving simulator scenario programming for novice drivers.

Initially, learning content for the scenarios was derived from two sources, the basic vehicle maneuvering and mastery of traffic situations referred to in the GDE matrix (Hatakka Keskinen, Glad, and Gregersen, 1999) and the maneuvers listed in the 1991 Quebec government novice driver curriculum (Société de l'assurance automobile du Québec, 1991). The instructional design focus was on exploiting all the pedagogical advantages of driving simulator technology to help novices learn where and when to look before and during all driving maneuvers and to train their expectations of what to look for and how to interpret information from visible and latent hazards. Scenarios were designed to allow learner drivers to develop hazard perception skills and greater self-awareness about their own behavioral contributions to crash risk situations. Scenarios were also designed to create the conditions that maximize the amount and variety of experiential learning opportunities, e.g. the potential to practice forty or more consecutive lane changes during one ten-minute scenario. The more often that basic vehicle control skills are practiced, the sooner they become automatic, i.e. able to be performed without conscious effort (Fitts and Posner, 1967). A high rate of deliberate practice in a concentrated time period is ideal for developing automaticity in complex maneuvers but this form of training is too difficult and potentially dangerous for on-road lessons. Eco-driving training exercises with objective feedback were also included to help learners understand the influence of the physical forces that affect fuel consumption. Scenario programming followed proven pedagogical principles, e.g. segmentation of tasks and then progression from the simple and easy to the complex and difficult.

Feedback to Learners

An integral part of the design and creation of a driving-simulator training scenario is the determination of the type, timing and frequency of the feedback the learner receives during and after a programmed scenario. Programmers made extensive use of the technological advantages of simulation, e.g. performance replays, overhead views, augmented feedback, i.e. sounds, images and interactive models or diagrams to help learners understand the learning content of a particular lesson. Experiential learning, or learning by doing, is most effective when each action produces clear feedback, that is, unambiguous consequences from the road or simulator environment that inform the learner's brain and shapes his subsequent decisions and actions. According to Kuiken and Twisk (2001), feedback from real driving experience is inconsistent and of poor quality. Real world feedback can range from overwhelming and confusing, e.g. downtown traffic at rush hour with road construction, to nearly absent and of low learning value, e.g. suburban or rural roads with no traffic. During on-road lessons, a learner who is still struggling to master basic operational control skills may not have sufficient attention and cognitive resources to perceive and properly interpret the meaning of the available feedback. Crash risk may potentially increase in the absence of negative or corrective feedback for a dangerous act, e.g. driving too fast for conditions, or for a dangerous omission, failure to scan the intersection before crossing. Without corrective feedback, the brain of the adolescent novice driver may conclude that his actions were not, in fact, dangerous, despite the warning words of the driving teacher, thus increasing the probability that these risky behaviors will be repeated in the future. Driving simulators can deliver correct and objective feedback to help learners understand particular lessons. Augmented feedback is also used to evaluate the learner's performance. When appropriate, objective and precise feedback is provided during or after a scenario from within the simulation. At the end of each specific scenario and again at the end of the entire session, the teacher provides his own subjective assessment of the learner's progress.

Scenario Testing and Validation

During the planning stage (2007-2010), driver-training scenarios in the Virage Simulation library were validated by the scenario designers through an informal process at the company learning laboratory. Later these scenarios were field-tested with actual students in a driving school. From early 2006 until April 2008, licensed or learner drivers of both sexes and all ages in the Montreal area were invited to drive the simulator scenarios. Their driving teachers accompanied some learner drivers. Driving teachers were invited to teach their own students using the driving simulator scenarios. Throughout this process, the behavior and responses of the drivers and their teachers on the driving simulator was observed. Feedback from participants was elicited before, during and after each simulator session. Whenever possible, transfer of training was observed during post-session on-road drives. In some cases, learner drivers or driving teachers reported their reflections on the simulator experiences several days after the simulator sessions. Lessons learned through this validation process were applied to fine-tune the scenarios in order to increase their effectiveness. On average, during that time period, there was one validation session per week. Field-testing occurred from April 2008 until January 2010, when the driving simulator scenarios were used to teach novice drivers in a driving school. Driving school teachers reported good to excellent transfer of simulator training to on-road driving and one new scenario was suggested that was programmed and added to the library.

Driving Simulator Platform and Visual System

The high-fidelity driving simulator used in this study is the VS500M, (Appendix A). This driving simulator provides a geometrically accurate 180-degree forward field-of-view (FOV), inset mirrors and two additional displays to show the driver's blind spot areas exactly where they are located in real life. Wider fields of view allow for more accurate speed perception (Andersen, 1986) and, according to Stoner, Fisher, and Mollenhauer Jr. (2011), a 180-degree field of view in a driving simulator is ideal for teaching safety at intersections, where drivers must scan left and right looking for potential hazards and checking for traffic. Proper scanning requires that a driver turn his head a full 90 degrees to the left and a full 90 degrees to the right. Therefore, the driving simulator's visual system needs to display a geometrically accurate 180-degree FOV in order to minimize negative transfer, i.e. the unintentional development of incorrect vision habits and psychomotor reflexes that could increase the risk of dangerous mistakes in traffic. A real car cockpit mounted on a motion / vibration platform with three degrees of freedom, i.e. pitch, roll and heave, and a sound system further increase the perceived realism of the driving experience. This driving simulator configuration can simulate visual, auditory and haptic feedback on driving speed similar to what novice drivers receive on the road from observing the motion of all the surface elements in the driving environment (i.e. optic flow) and from the noise and vibration of their vehicle.

In the future, every car on the road will have a blind spot detection system. Until then, drivers still need to verify that no other vehicles or cyclists are inside their blind zones in order to safely turn at intersections, change lanes in traffic or merge on expressways. Blind spot verification must be performed automatically to most effectively reduce crash risk. Therefore, blind spot verifications need to be taught at the start and practiced each and every time a driver deviates from straight line driving. To accomplish this in a driving simulator, blind spot displays need to be placed in the same locations where the pertinent information would be found on real roads. Table 1 lists the range of driving skills that can be learned in relation to two types of driving simulator visual systems (see Appendix B for a more detailed, technical explanation).

Table 1. Suitability of different driving simulator visual systems and fields of view to train and evaluate basic driving skills

Driving skills	A minimum 180-degree geometrically accurate forward field of view with blind spot displays	Less than 180-degree forward field of view or distorted geometric representations and no blind spot displays
Speed control	Yes	Yes
Brake reactions	Yes	Yes
Lane keeping	Yes	Yes
Lane changes (with shoulder checks)	Yes	No
Crossing intersections safely	Yes	No
Turns (with shoulder checks)	Yes	No
Expressway merges (with shoulder checks)	Yes	No

In relation to the present ToT project, it is critical to understand that in order to create learning scenarios to help learners develop correct vision habits and hazard perception skills, the driving simulator configuration must be able reproduce as accurately as possible the same visual information in the same locations relative to his forward gaze that the driver will need to correctly and efficiently access on real roads.

Scenario Selection and Integration into ToT Study

The first selection of driving simulator scenarios for this ToT project was based upon a comprehensive task analysis of the twelve-hour training curriculum developed by the SAAQ in 1991. Appropriate scenarios were selected from the Virage Simulation library and organized into six one-hour sessions. The CAA-Quebec, a non-profit consumer protection group mandated by the SAAQ to certify driving schools, accepted an invitation from Virage Simulation to conduct a comprehensive review of the proposed curriculum. On August 28, 2007, the CAA-Quebec approved the curriculum (Appendix C). That six-hour curriculum was then submitted for approval to the SAAQ in September 2007 and formally accepted by the SAAQ on March 7th 2008 (Appendix D).

To meet the new requirements of the PESR, the original ToT set of approved scenarios from March 7th 2008 were reviewed, adapted and augmented to emphasize the four principal themes of the new program: a) autonomous driving; b) the strategy of observe-evaluate-act (OEA); c) eco-driving, and; d) special road and weather conditions and challenging driving maneuvers. Sixteen additional simulator-based training scenarios were selected from the Virage Simulation library, including observation challenges designed to aid learners develop correct vision habits and hazard perception training to sensitize learners to hidden traffic dangers. In addition, based on on-going research (Bureau de l'efficacité et de l'innovation énergétiques, 2011), a set of ecodrive scenarios was selected to provide learners with precise real-time graphic feedback on how natural forces that act upon vehicles in motion are affected by their driving decisions and how these driver-vehicle interactions directly influence fuel consumption. All the teaching PowerPoint slides that appear at the start of each simulator scenario as well as the Instructor Guide accessible in the operator station of the simulator were updated for the PESR and revised in both French and English. The revised selection of driving-simulator learning scenarios, each one on average 10 minutes long, was distributed and organized into six (6) one-hour sessions according to the PESR curriculum. Note that within the guidelines of the study, seven (7) of the 15 on-road driving lessons (47%) could be substituted by driving simulator lessons. The final curriculum for the PESR study was approved by the SAAQ on November 26, 2009 (Appendix E).

Adjustments to PESR

Due to the unique pedagogical advantages of driving simulator-based training and the high-quality feedback provided by the simulator training scenarios, two rules of the PESR were modified for participants in this ToT study. First, under the normal PESR rules at the time of the study, during the first four hours of the 15-hour training program, only one on-road session of one-hour duration was permitted per day, after which any sessions could be combined into two-hour sessions. However, during preliminary experiences with driving simulator-based training, teachers observed better transfer of skills learned on the driving simulator to the road and greater appreciation by the learners of the value of their simulator lessons when the first driving simulator session, usually taken in the first four hours of the program, were immediately followed on the same day by an on-road session. The SAAQ permitted this practice to continue during the actual study (Appendix F).

Driving School Participation

In 2010, the planning stage of this project ended and Quebec driving schools were invited to participate in the pilot study to validate the transfer of skills learned on programmed scenarios delivered on the VS500M driving simulator training to on-road driving performance and behavior. Participating driving school owners were required to respect the ToT study protocol as outlined in the letter of agreement when they acquired the driving simulator (Appendix G). Their commitments included obtaining signed consent forms from learner drivers that gave researchers access to government driving records. Driving school owners were also required to distribute and collect the questionnaires and return them by post to the principle investigator of the ToT study. Under these conditions, participating learners were permitted to substitute from one to seven hours of driving simulator training for an equal number of on-road hours within the PESR. In addition, participating driving school owners voluntarily and without compensation liberated their teachers and paid their salaries and expenses during the three-day teacher training and the subsequent annual one-day teacher workshops.

Teacher Training

The study methodology took into account the fact that teachers accustomed to training novice drivers on-road in uncontrolled, dynamic road and traffic environments would need to adjust their methods to train novice drivers within the programmed environment of a driving simulator. To increase the probability of successful adaptation and to maximize the pedagogical advantages of the programmed training scenarios, driving teachers at the participating driving schools received two training courses from Virage Simulation. The first was a one-day course oriented to making teachers proficient on the technical aspects of operating the driving simulator and covered topics like procedures for simulator start-up and shut-down, start-up of a training session, selection of individual training scenarios and trouble shooting. The second training course was a three-day program that included the following topics and activities:

1. History of driving simulators;
2. Driving simulator strengths, i.e. immersion, improved control of learning, environment, reduced stress, part-task training, drill, replay, alternative view points;
3. Driving simulator challenges, i.e. negative transfer, simulator adaptation syndrome;
4. The research project with the SAAQ;
5. The Instructor Guide and the scenario-based curriculum;
6. Review of all training scenarios;
7. Practice teaching with teachers as proxy students and discussion;
8. Practice teaching with volunteer driving school students.

Additional support was provided to teachers through: a written instructor's guide accessible at all times on the screen of the driving simulator operator station; annual trainer workshops for the first two years, and; on-line support from the scenario designers.

Data Sources

There are three data sources in this study: questionnaires; driving simulator data, and; SAAQ records. A total of three questionnaires were distributed to learners at different times during their training (Appendix H). The first learner questionnaire was given at the time of or soon after registration at the driving school, when learners and their parents were informed of the details and conditions of the ToT study. If they agreed to participate, consent forms were signed and learners completed a questionnaire measuring computer use, past traffic experience on any type of motorized or non-motorized vehicle, risk perceptions, and lifestyles. The second questionnaire was given after the first driving simulator lesson to collect impressions of that learning experience. The third learner questionnaire was given after the 15th and final on-road evaluation near the end of the mandatory twelve-month driving school program to assess the learning experiences of simulator-based and on-road lessons and to compare the efficiency of both training methods across 15 specific driving skills. At the same time, driving teachers completed the fourth questionnaire rating their respective students' driving competence (Appendix I). Questionnaire items specific to driving-simulator use were developed for the ToT study and tested with actual students during the planning phase of the project. The remaining questionnaire items on the learner questionnaires were taken from an extensive study of adolescent drivers by Hirsch (2005). The items on the driving teacher questionnaire were taken from an earlier study by Hirsch (1997). Driving simulator records contained the ID number, the date, the start and end times of each scenario and the names of the student and teacher. SAAQ records provided the dates when the learners' attempted their theory and road tests and their success or failure as well as their infraction and crash records.

Sample / Driving Simulator Training

Four Quebec driving schools participated in this study. Table 2 lists the schools, the cities where they are located and the populations of each city.

Table 2. Participating driving schools by city and city population

Driving School	Location	Population[1]
Permis Plus	Thetford Mines	25,700
Permis Plus	St-Georges de Beauce	31,200
CFA	Sherbrooke	154,600
Pilote	Rivière-du-Loup	19,400

[1] Statistics Canada 2011 census

Sample Sizes for the Study Data

Between January 2010 and May 2015, the total number of names of students that were entered into the four driving school simulators as study participants and who drove at least one driving simulator scenario is 4,265. From that group, the researchers did not receive a consent form or a questionnaire for 2,078 names. After May 2015, the researchers received a consent form and/or a questionnaire for 117 of these names but this data was not entered and included in our analyses.

Researchers received at least one of the four questionnaires or/and the consent form from 2,187 participants. From that group of 2,187, consent forms to access SAAQ data was received for 1,805 participants. Of those 1,805, we were not able to match the names and driver's permits for 15 participants, leaving a final sample size of 1,790. From that group of 2,187 participants, 186 had no driving simulator data either because we were unable to match their names with one of the other 2,078 names entered (see above) or they simply did not use the simulator at all or they had not yet started their practical driving lessons. Note that study participants enroll in driver schools at different times and are at different stages of their training programs.

From the group of 2,187, 1,956 participants completed and returned the first questionnaire distributed at or close to the time of registration, 1,297 participants completed and returned the second questionnaire distributed immediately after the first driving lesson on the driving simulator and 649 completed and returned the third questionnaire distributed at the end of the 15 hours of mandatory driver training.

One probable explanation for the missing consent sheets and questionnaires is as follows. The participating driving schools introduced the research project and the rules of participation during theory module six in the PESR, which parents of adolescent learner drivers are encouraged but not obligated to attend. At that time, if learners decided that they wanted to participate in the study and replace one or more of the mandatory on-road sessions with simulator sessions, they are presented with the consent sheet and the first questionnaire. If a parent was present, the consent sheet may have been signed immediately. Some parents returned home with their consent sheet in order to reflect further or discuss the decision with a partner. When no parent was present, many learners declared their intention to participate and then returned home to explain the project and ask for a parental signature.

To collect data on the simulator driving sessions, each learner driver had to be registered in the simulator. Due to chronic understaffing and the high turnover of office personnel in driving school offices, there was a need to facilitate and streamline the driving school's daily operations. One method was to register the names of every student who verbally consented to becoming a study participant into the simulator files in a batch process during non-peak business hours, even if the consent forms had not yet been collected. After module 6, tracking and continually reminding learners to return their consent forms and to complete and remit all three questionnaires became an extra and a low priority administrative duty that did not serve the paying customer's immediate needs. As a result, the often inexperienced and unsupervised driving school personnel were not consistent or efficient in collecting consent forms and questionnaires. Also, given the four and one-half year time span of this data collection, it is reasonable to imagine that efforts made by driving school staff to remind students to complete and return their second and third questionnaires diminished over time. Another reason for the missing second and third questionnaires is that participants are at different stages of their training programs and some of them have not yet have taken their first simulator lesson, after which they answer the second questionnaire, or completed their year-long training program, after which they answer the third questionnaire.

The average age of the final sample (n=2,187) was 17.6 years, the median age was 16 years and the gender distribution was 53.8% female and 46.2% male.

Comparison Group

The comparison group used in the data analysis for this study consisted of all new drivers in Quebec who obtained a “Class 5” learner’s permit between January 2010 and December 2014 and who had never had before a permit to drive other motor vehicles such as a motorcycles or mopeds.

Results

Implementation of Driving Simulator Scenarios

In this naturalistic study of driving simulator use for novice driver training, driving teachers were trained in the proper use of a wide range of simulator scenarios organized into individual sessions on the driving simulator operator station menu in conformity with the requirements of the PESR curriculum. After the training, the driving teachers used their own judgment to select the simulator session that would replace the on-road session and to select the approved scenarios from the menu to be used within that session. The Table in Appendix J presents all the scenarios and their frequency of use with the study group (2,001 of the 2,187 with simulator data) between January 2010 and May 2015 from four driving simulators located in four cities in Quebec. Table 3 displays the titles of the twelve most frequently selected scenarios, comprising 50% of all the scenarios used in this study. The majority of these scenarios focus upon the development of vision skills related to: steering control at high speeds; understanding the proper use of mirrors and blind spots during lateral maneuvers; visual exploration, and; hazard perception.

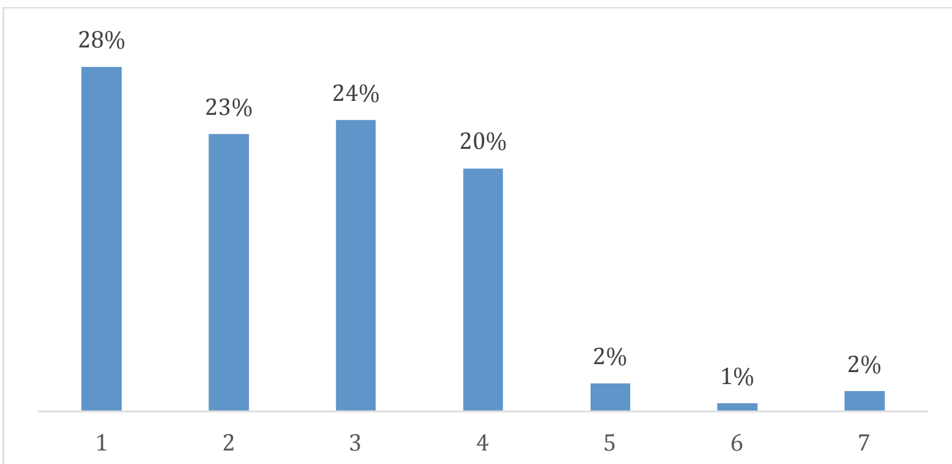
Table 3. Frequency of the top 50% scenarios selected by driving teachers

Ranking	Scenarios	Frequency	%	Cumulative Percentage
1	Aiming and Steering - Expressways	1465	6.1	6.1
2	Observation Challenge 1	1385	5.7	11.8
3	Aiming and Steering - Basic Turns	1302	5.4	17.2
4	Blind spot and Mirrors - Expressway	1110	4.6	21.8
5	Hazard Perception - City Intersection	969	4.0	25.8
6	Hazard Perception - Pedestrians 2	909	3.8	29.5
7	Merging on Expressways - Practice I	903	3.7	33.3
8	Observation Challenge 2	854	3.5	36.8
9	Speed Adjustment - Reduced Traction - Winter	853	3.5	40.3
10	Lane Change - Practice I (Expressway)	770	3.2	43.5
11	Left Turns - Practice I	768	3.2	46.7
12	Lights and Controls	729	3.0	49.7

Driving Simulator Sessions

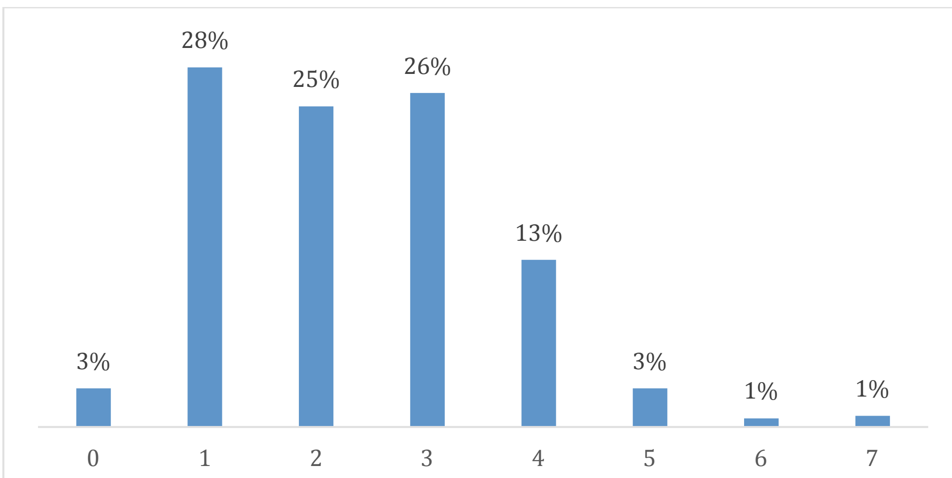
Data on the number of sessions on the driving simulator that were used to replace on-road training sessions derives from two sources, self-report and driving-simulator records. In the questionnaire at the end of the driving course, learners were asked how many sessions they remembered having taken on the driving simulator. Their responses are reported in Figure 1. Note that the majority of learners reported taking between one and four sessions on the driving simulator and that a tiny percentage claim to have taken as many as seven sessions. Most likely, these participants remembered incorrectly or were offered additional training sessions, in excess of the PESR mandatory 15 sessions.

Figure 1. Number of self-reported driving simulator sessions (n=600)



The driving simulator recorded the time that each scenario was used from the moment it was loaded or started to the moment it was closed or ended. For various reasons, a single scenario may have been started and ended more than once during a single session. For example, the scenario may have been used for a theory class or a demonstration or the teacher may have repeated the exercise. Each scenario was designed to be used for an average of approximately ten minutes. However, due to a multitude of factors prevalent in any naturalistic study, driving teachers were inconsistent in their operational use of the driving simulator and the driving simulator data required a few rules of interpretation in order to produce estimates of the duration of each scenario and the total number of driving simulator sessions per participant. Upon consultation with the participating driving school owners, it was determined that a valid scenario would be defined as having a minimum duration of three minutes and a maximum duration of 20 minutes, even if the scenario had not been closed on the simulator after this time limit expired. If the duration of a scenario was less than three minutes, it was removed from the simulator data. If the duration of a scenario was greater than twenty minutes, it was replaced by 20 minutes. The sum of the duration of the scenarios per learner per day was computed. A session was defined as having a total duration of simulator use of 20 minutes or more in a single day. By applying these rules of interpretation, the number of estimated sessions taken on the driving simulator by study participants ranged from zero to seven (Figure 2). Three percent of the study participants who completed the driving course[1] do not have any days with a total recorded simulator use of 20 minutes or more. The Spearman correlation coefficient between self-reported sessions, Figure 1, and their estimated number of sessions is 0.69 (n=600[2]).

Figure 2. Number of estimated sessions on simulator (n=1,572)



Learner Perceptions of Simulator Training

Data on study participants' immediate and retrospective perceptions of their experiences learning to drive on the driving simulator was collected in two questionnaires, one immediately after the first driving lesson on the simulator and the other retrospectively after the completion of the 15th on-road driving session (questionnaires 2 and 3, Appendix H).

[1] Among the 2,187 participants, we identified 1,572 who completed their driving course and had at least one recorded scenario on the driving simulator. Completion of the driving course was demonstrated either by the receipt of the completed third questionnaire, or, for participants with signed consent forms and missing third questionnaires, confirmation from the SAAQ data of obtention of a probationary permit.

[2] The Spearman correlation coefficient can be computed only for the 600 participants for whom we have the self-reported and the estimated number of simulator sessions.

Immediate Perceptions of Simulator Training

This questionnaire collected learner perceptions of their first experience learning to drive on the driving simulator. Figures 3 through 7 report learners' responses to the items on that questionnaire. Figure 3 shows that in response to four questions about the how "easy", "relaxing", "enjoyable" and "stimulating" the simulator experience was, the vast majority responded positively. The highest levels of complete agreement were reported for the enjoyable and the stimulating categories. The highest levels of moderate agreement were reported for the easy and relaxed categories but when these are added to the responses for complete agreement, the combined agreement percentage exceeds 85% for easy and 73% for relaxed.

Figure 3. Perceptions of learning on the driving simulator (n=1,297)

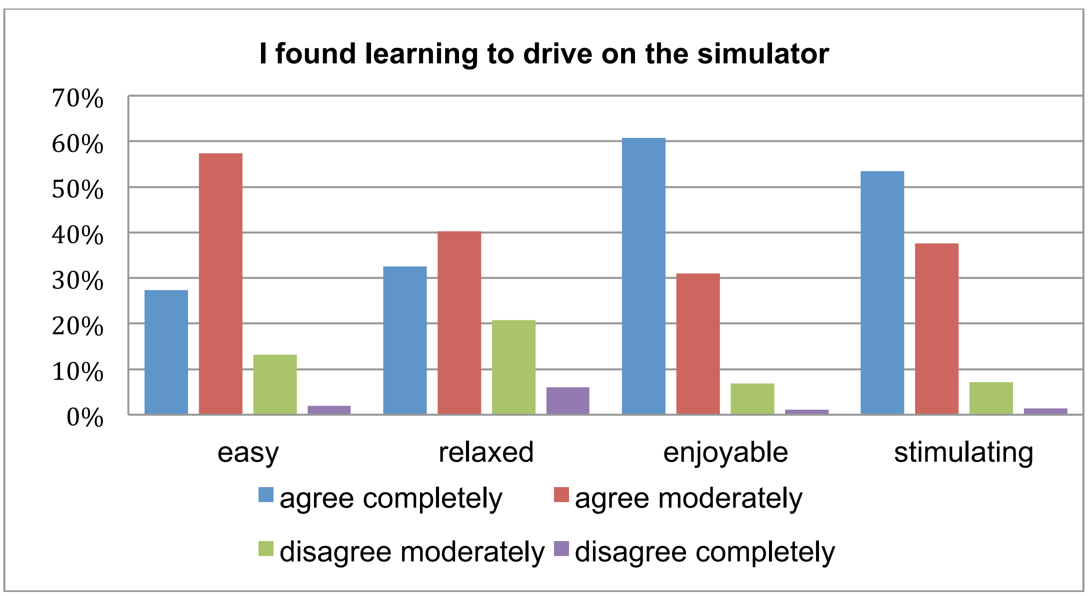


Figure 4 reports almost total agreement by learner participants that the objectives of each scenario were clear and concise. One reason for this perception is probably related to the fact that each scenario on the driving simulator begins with a PowerPoint slide explicitly detailing the intended driving competencies to be learned in that particular scenario. Another probable reason may be that driving teachers were trained to ask each learner to read aloud the text on the introductory PowerPoint slide to assure understanding before proceeding with the lessons and then to refer to these learning goals when providing feedback to the learners after each scenario.

Figure 4. Opinions of the learning objectives of each scenario (n=1,297)

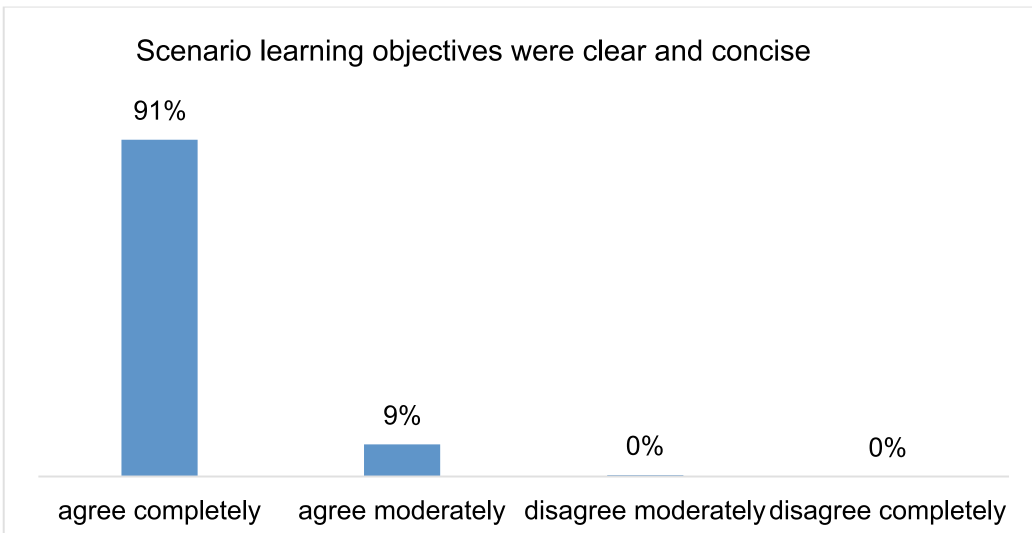
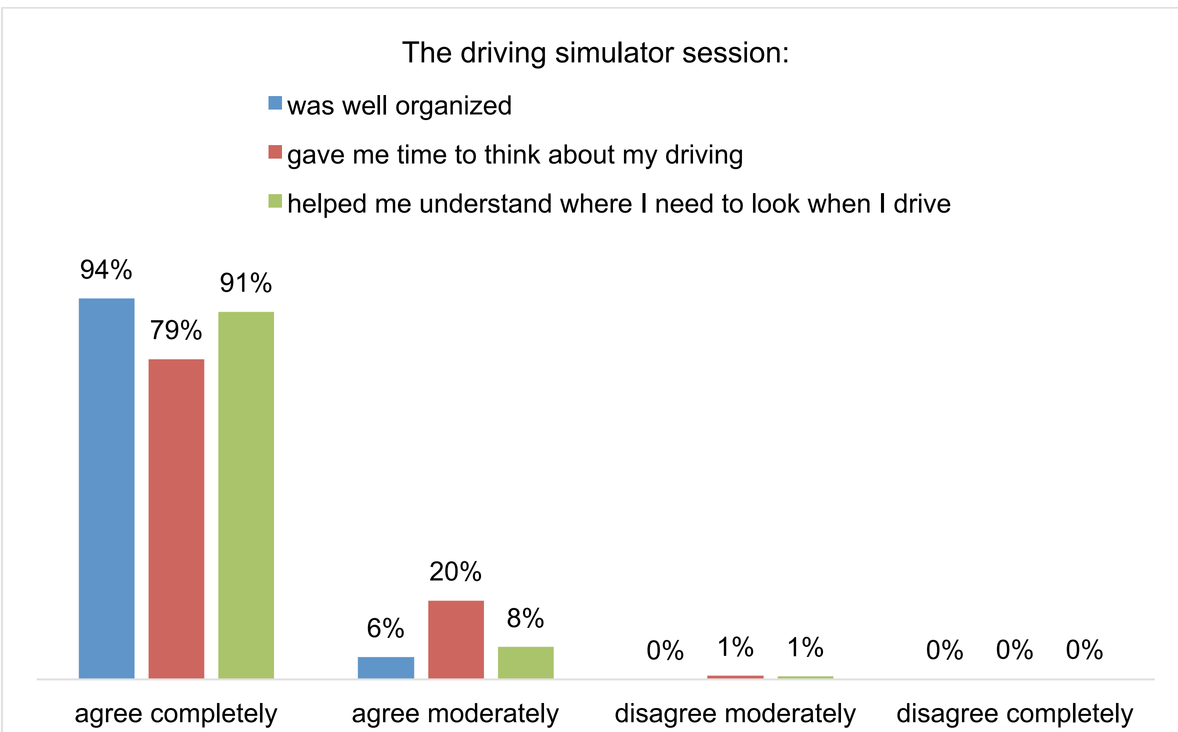


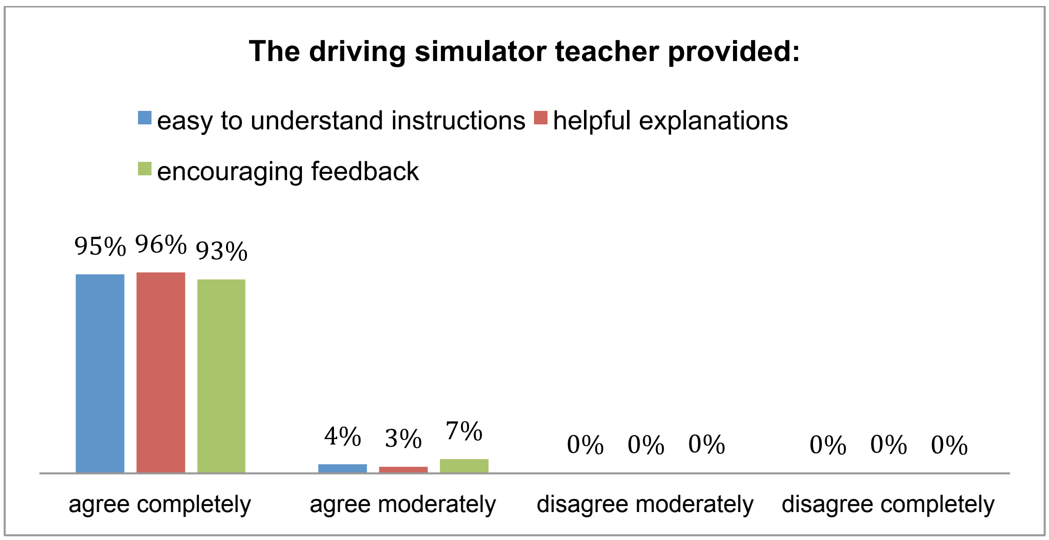
Figure 5 reports the learners' appreciation of the scenario organization and learning advantages. In relation to three items: how well organized the scenarios were; if they gave learners time to think about their driving, the self-reflective dimension of the GDE (Peräaho et al., 2003), and; helped them learn where to look when they drive, the percentage of learners who responded that they agreed completely were 94%, 79% and 91% respectively. The percentages of learners who reported moderate agreement to these three items were 6%, 20% and 8% respectively. In total, nearly 100% of the responses to these three items were positive, indicating that the teachers who used these scenarios were able to implement them according to the intentions of the scenario designers.

Figure 5. Learners' evaluation of the scenario's organization and learning advantages (n=1,297)



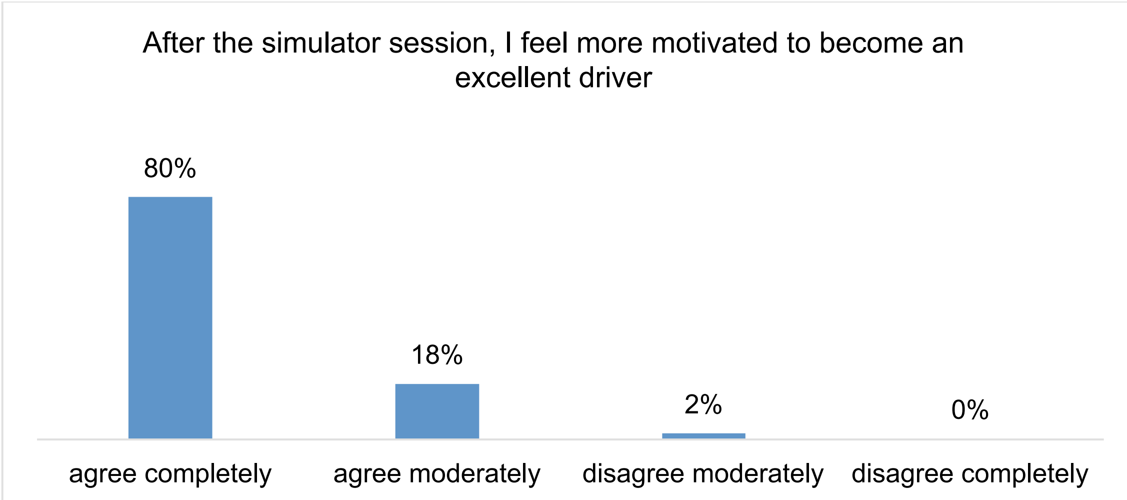
The performance of the driving teachers in terms of providing easy-to-understand instructions, helpful explanations and encouraging feedback was assessed by learners (Figure 6). The percentages of learners who responded that they agreed completely were 95%, 96% and 93% respectively. The percentages of learners who reported moderate agreement to these three items were 4%, 3% and 7% respectively. In total, almost 100% of the responses to these three items were positive.

Figure 6. Learner perceptions of the driving simulator teacher (n=1,297)



One of the reasons for developing the GDE-matrix was to attempt to understand and support the development of methods to address motivational factors in driving (Hatakka et al., 2002). The last item of the questionnaire administered immediately after the first driving simulator session asks directly if the learning experience on the simulator increased the learner's motivation to become an excellent driver. Figure 7 indicates that 80% agreed completely and 18% agreed moderately. Only 2% disagreed moderately. This response indicates that there is a potential for driving simulator-based training programs to effectively address motivational factors in driving.

Figure 7. Motivation to become an excellent driver following simulator session (n=1,297)



Retrospective Perceptions of Simulator Training

The last questionnaire for learner drivers administered after the 15th and final on-road driving session reports the learners' retrospective appreciation of the overall experience of learning to drive on-road and on the driving simulator (questionnaire 3, Appendix H). This questionnaire, in contrast to the previous questionnaire administered immediately after the first simulator session, aims to discover how learners appreciate driving simulator lessons after they have completed all their lessons on-road and in the simulator and have a good basis for comparing their experiences with both methods. The results of three questions from that retrospective questionnaire completed by 618 learners are reported here.

One question asks if the learners found their driving simulator lessons to be easy, relaxing, enjoyable and stimulating (questionnaire 3, item 14 in Appendix H). A second question asks if the learners found their on-road driving lessons to be easy, relaxing, enjoyable and stimulating (questionnaire 3, item 10 in Appendix H). The answers provided by learners for these two distinct questions are reported side by side in relation to the four categories of easy, relaxing, enjoyable and stimulating in Figures 8 to 11.

Figure 8 shows that over 47% of the learners agreed completely with the statement that learning to drive on the simulator was easy compared to 31% for the on-road lessons. Moderate agreement with the statement that learning to drive on the simulator was easy was reported by 41% compared with 60% for on-road lessons. Total positive responses for easiness of learning on the driving simulator were 88% compared with 91% for learning on the road. Overall, it appears that the learners found learning to drive to be easy in the driving simulator and in the car with a slightly higher appreciation for the simulator compared to on-road training in the category of complete agreement and a slightly lower overall score when complete and moderate answers are combined.

Figure 8. Perceptions of easiness of lessons in the simulator and on-road (n=618)

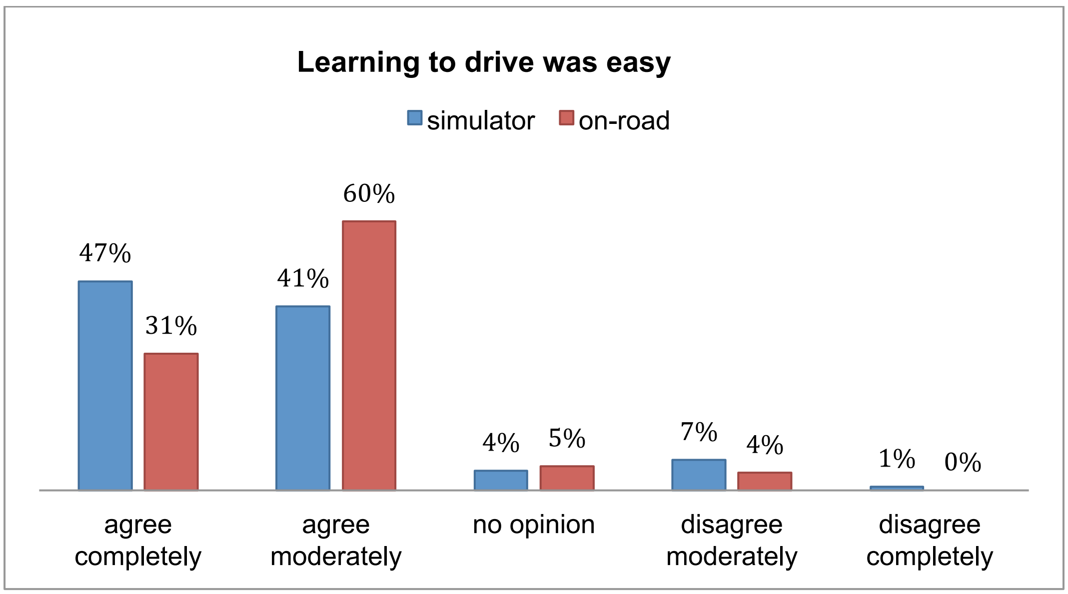


Figure 9 shows that over 41% of the learners completely agreed with the statement that learning to drive on the simulator was relaxing compared to 23% for the on-road lessons. Moderate agreement to this question was reported by 33% for simulator lessons compared with 40% for on-road lessons. Figure 9 shows a total positive responses to this item about learning in a relaxed manner on the driving simulator were 74% compared with 63% for learning in a relaxed manner on the road. Overall, it appears that learners found learning to drive on the simulator to be more relaxing than learning on the road by a margin of 11%. For the response categories of “no opinion” and “moderate disagreement”, fewer learners expressed no opinion regarding the simulator lessons than the on-road lessons, 14% compared to 19%, and fewer learners expressed moderate disagreement regarding the simulator lessons than the on-road lessons, 10% compared to 16%.

Figure 9. Perceptions of driving lessons as relaxing in the simulator and on-road (n=618)

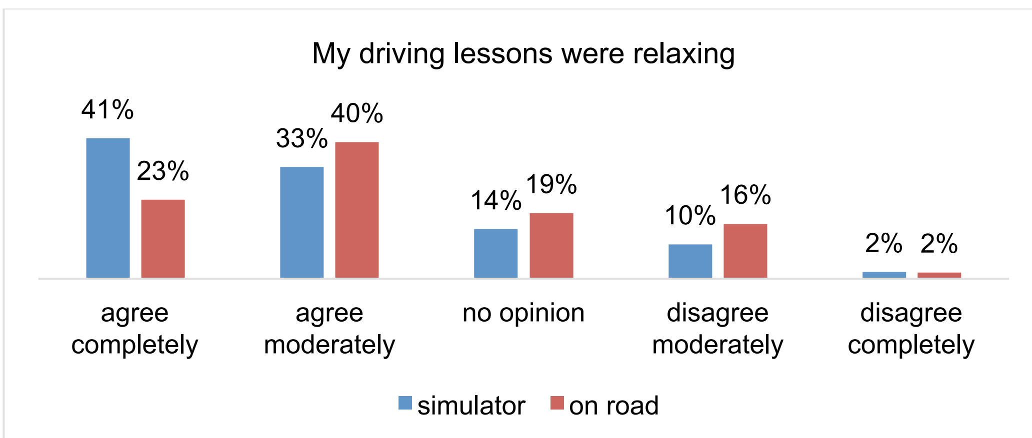


Figure 10 shows that 49% of the learners agreed completely with the statement that learning to drive on the simulator was enjoyable compared to 50% for the on-road lessons. Moderate agreement to this question was reported by 30% of the simulator compared with 36% for on-road lessons. Total positive responses to this item on learning being enjoyable on the driving simulator were 79% compared with 86% for learning being enjoyable on the road. For the response categories of "no opinion" and "moderate disagreement", more learners expressed no opinion regarding the simulator lessons being enjoyable than the on-road lessons, 11% compared to 10%, and more learners expressed moderate disagreement for simulator lessons than the on-road lessons, 7% compared to 4%. It appears that while slightly more learners enjoyed their on-road lessons compared to their simulator lessons, slightly more learners had no opinion and 5% more of the learners indicated that they did not enjoy their simulator lessons compared to their on-road lessons. Overall, it appears that the learners found learning to drive to be an enjoyable experience and that on-road lessons were perceived as slightly more enjoyable than driving simulator lessons.

Figure 10. Perceptions of enjoyment learning on the simulator and on-road (n=618)

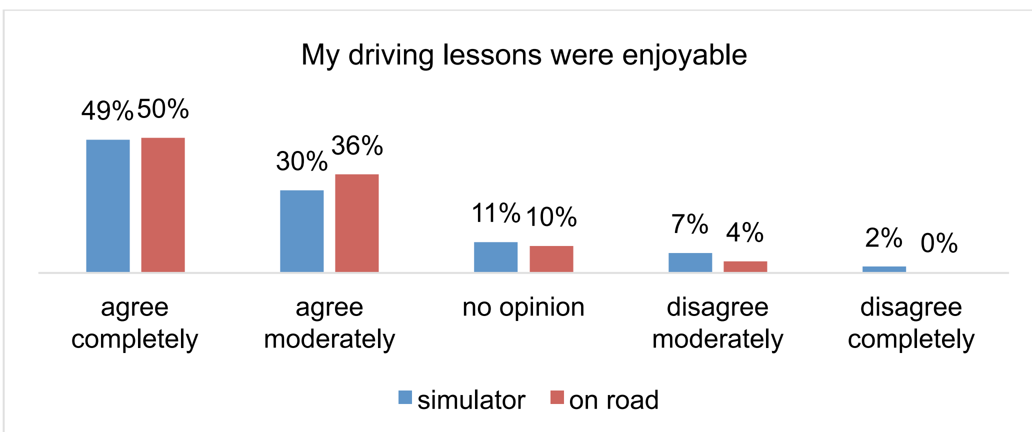
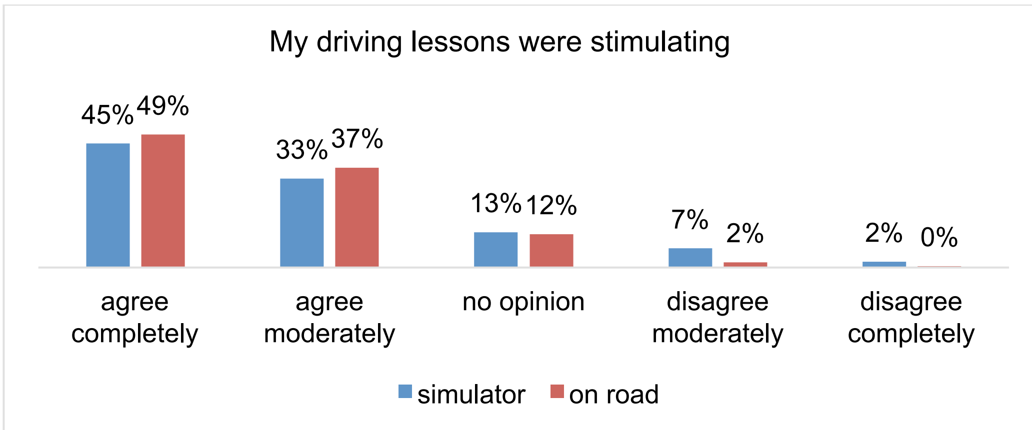


Figure 11 shows that 45% of the learners agreed completely with the statement that learning to drive on the simulator was stimulating compared to 49% for the on-road lessons. Moderate agreement to this question was reported by 33% of the simulator compared with 37% for on-road lessons. Total positive responses to this item on learning being an enjoyable experience on the driving simulator were 78% compared with 86% for learning being a stimulating experience on the road. For the response category of "no opinion", 13% had no opinion on this question in reference to their simulator lessons compared to 12% in reference to their on-road lessons. In the category of "moderate disagreement", a slightly higher percentage of learners indicated that driving simulator lessons were not stimulating, 7%, compared to those who responded the same way regarding on-road lessons, 2%. Overall, it appears that the learners found learning to drive to be a stimulating experience and that the driving simulator lessons were perceived as slightly less stimulating than on-road lessons.

Figure 11. Perceptions of stimulation on the simulator and on-road (n=618)



The last question on the final questionnaire asks learners to directly compare one hour of instruction on the driving simulator with one hour of on-road instruction in terms of efficiency for learning 15 specific driving skills (questionnaire 3, item 15 in Appendix H). An efficient method of learning is generally understood as one that achieves maximum productivity with minimum wasted effort or expense. This question attempts to go beyond the typical adolescent experience of simulators as gaming devices and to determine if and to what extent learners perceived the simulator as an effective learning platform in comparison to on-road lessons. The question offers five possible responses: much more efficient; a little more efficient; equally efficient; a little less efficient, and; much less efficient. The "much more" and "a little more" responses were combined to produce the three categories, (more efficient, equally efficient and less efficient); these are presented in Figure 12 in graphic form in the same order that the 15 skills were listed in the original question (see Appendix K for the results with the original five possible responses). Across all 15 skills, learners rated driving simulator lessons, compared to on-road lessons, to be on average 37% more efficient, 40% equally efficient and 23% less efficient.

Figure 12. Direct comparison of perceived efficiency of simulator vs. on-road training (n=618)

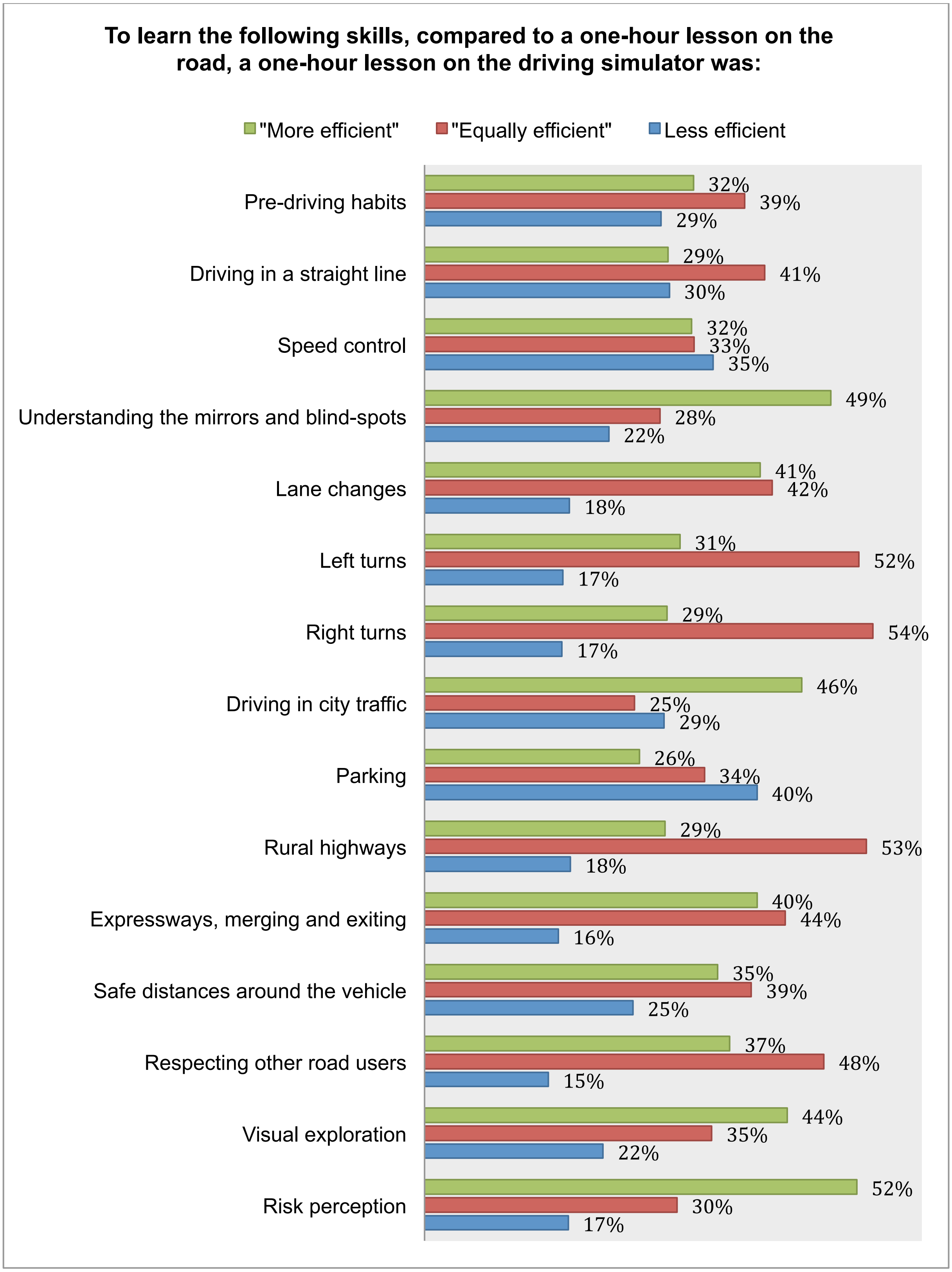


Table 4 presents the 15 driving skills ranked in descending order of which skills learners perceived to be more efficiently taught on the driving simulator than on the road. The driving skills with an asterisk in Table 4 correspond to the learning content covered in the top 50% most frequently used scenarios listed in Table 3. Note that for all 15 driving skills listed, the combined percentages for the choices of driving simulators as more efficient or equally efficient exceed the percentages for the choice of the on-road lessons as being less efficient. With the exception of speed control, driving in a straight line and parking, the percentages for the choice of driving simulators as more efficient exceed the choice of driving simulators as less efficient. For five of the 15 driving skills, understanding mirrors & blind-spots, visual exploration, lane changes, merging and exiting expressways, and respecting other road users, the choice of more efficient exceeds the choice for less efficient by 200%. For one driving skill, risk perception, the choice of more efficient exceeds the choice for less efficient by 300%.

Table 4. Driving skills in decreasing ranking of perception by learners as more efficiently learned on a driving simulator than on the road

	Compared to a one-hour lesson on the road, a one-hour lesson on the driving simulator was:		
Learning content	More efficient (%)	Equally efficient (%)	Less efficient (%)
Risk perception * [3]	52	30	17
Understanding mirrors & blind-spots * [2]	49	28	22
Driving in city traffic *	46	25	29
Visual exploration * [2]	44	35	22
Lane changes * [2]	41	42	18
Expressways, merging and exiting * [2]	40	44	16
Respecting other road users * [2]	37	48	15
Safe distances around the vehicle *	35	39	25
Pre-driving habits	32	39	29
Speed control *	32	33	35
Left turns *	31	52	17
Right turns	29	54	17
Rural highways *	29	53	18
Driving in a straight line *	29	41	30
Parking	26	34	40

* Same content is covered in top 50% most frequently used scenarios (see Table 3)
[3] Perception of greater efficiency three times greater than perception of lower efficiency
[2] Perception of greater efficiency two times greater than perception of lower efficiency

Teacher Questionnaire

To date, relatively few driving teachers completed the questionnaire designed for them (see Appendix I). The data that was analyzed did not reveal any statistically significant relationships between teachers' predictions about their learners and driving performance outcomes.

Associations with SAAQ Records

The main concern of this pilot project mirrors the concern of all evaluations of driver training interventions, how does the intervention influence driver performance and safety? This concern is operationalized as a comparison between the simulator-trained group and a comparison group regarding (1) performance on the probationary permit road exam and (2) driver records of infractions and crashes with and without injury during their first months and years of driving. Table 5 describes the sample sizes in the simulator and the comparisons groups used for analyzing rates of infractions and injury and non-injury crashes by permit type and length of licensure. For comparisons of road test performance, infractions and crashes with a learner's permit, age was restricted to less than 25 years at the time of obtention of "Class 5" learner's permit. For the same comparisons with probationary permit, age was restricted to less than 25 years at the time of obtention of the "Class 5" probationary permit. A driver had to hold its driver permit for the entire period considered to be included in the analysis. That is why the sample sizes are decreasing as the driving time period is increasing in Table 5. Recall that rivers who obtained their learner's permit between January 2010 and December 2014 were at different stages at the time of the statistical analyses.

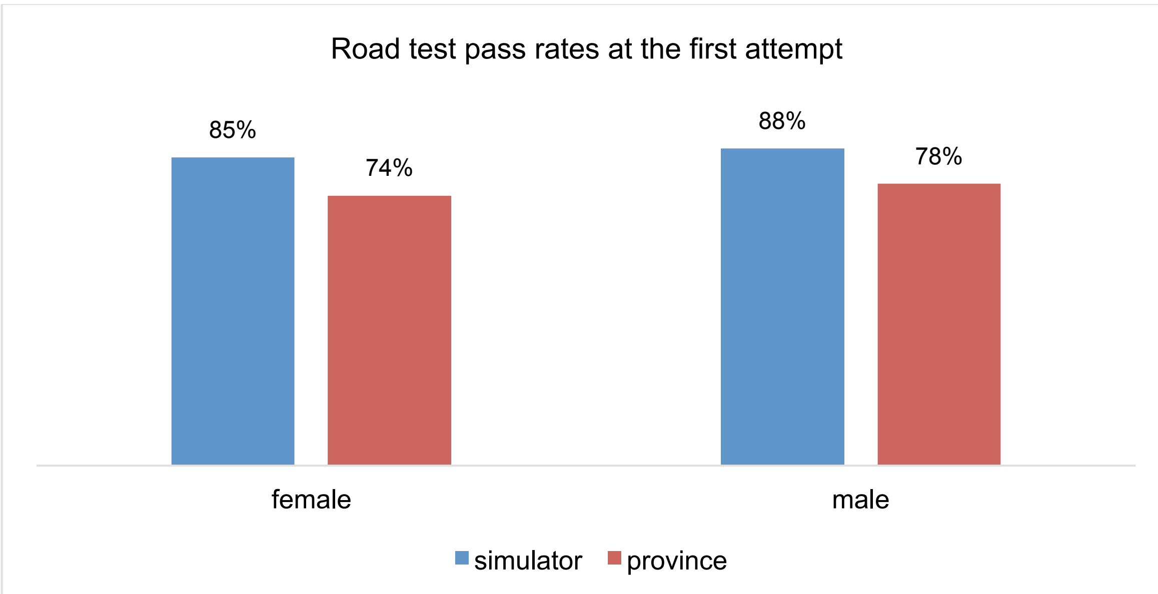
Table 5. Sample sizes for data analyses on road exam results, infractions and crashes for the different driving time periods

Driving time period	Females		Males	
	Simulator	Province	Simulator	Province
Learner's permit and have done the road exam at least once	772	142,956	682	135,022
Learner's permit up to the date they obtained probationary permit	757	132,764	667	127,439
Probationary permit 0 to 6 months	696	115,753	625	111,265
Probationary permit 6 to 12 and 0 to 12 months	618	99,332	553	95,724
Probationary permit 12 to 18 months	512	82,220	460	79,498
Probationary permit 18 to 24 and 0 to 24 months and have obtained regular permit	397	65,336	345	60,839

Road Exam Results

In relation to the road exam results, the study data show statistically significantly different higher first-time pass rates on the probationary permit road exam for females and males in the simulator group in relation to the comparison group (Figure 13).

Figure 13. First time pass rates on road test by sex for simulator and comparison groups



female: $\chi^2(1)= 44.4$, $p < .0001$; male: $\chi^2(1)= 37.7$, $p < .0001$

Driving Infractions

The study data shows statistically significant lower rates for females and males in the driving simulator group who had at least one infraction while driving with a probationary permit in relation to the comparison group. Figure 14 shows the female rates of occurrence of at least one infraction for simulator and comparison group drivers by permit type and length of licensure. Table 6 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. For the simulator and comparison groups, when female novices are driving with a learner's permit under adult supervision infraction rates are negligible. However, during unsupervised driving by females with a probationary permit, the occurrence of at least one infraction in the simulator group was statistically significantly lower for each six-month time segment and for the cumulative one- and two-year time periods.

Figure 14. Female infraction rates for simulator and comparison group drivers by permit type and length of licensure

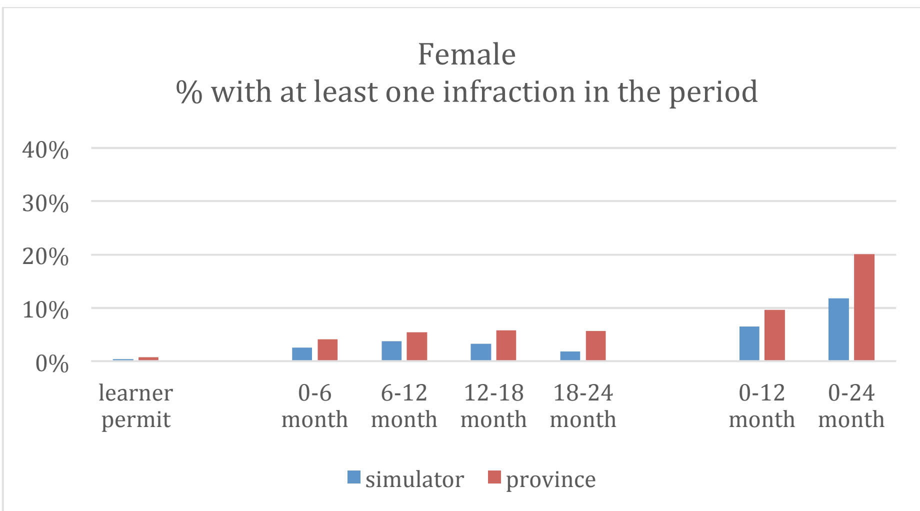


Table 6. Number of female drivers in each group with at least one infraction in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	3	18	23	17	7	40	47
province	1,056	4,749	5,405	4,767	3,716	9,511	13,135
$\chi^2(1)$	1.523	4.052	3.536	5.732	11.37	6.840	16.81
p-value	0.2171	0.0441	0.0600	0.0167	0.0007	0.0089	<0.0001

Figure 15 shows the male rates of occurrence of at least one infraction for simulator and comparison group drivers by permit type and length of licensure. Table 7 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. For the simulator and comparison groups, when male novices are driving with a learner's permit under adult supervision and also during the first six months of unsupervised driving with a probationary permit, there was no statistically significant difference in the occurrence of at least one infraction between the simulator and the comparison groups. However, compared with the comparison group, the occurrence of at least one infraction for males in the simulator group was statistically significantly lower in each successive six-month time segment and for the cumulative one- and two-year time periods.

Figure 15. Male infraction rates for simulator and comparison group drivers by permit type and length of licensure

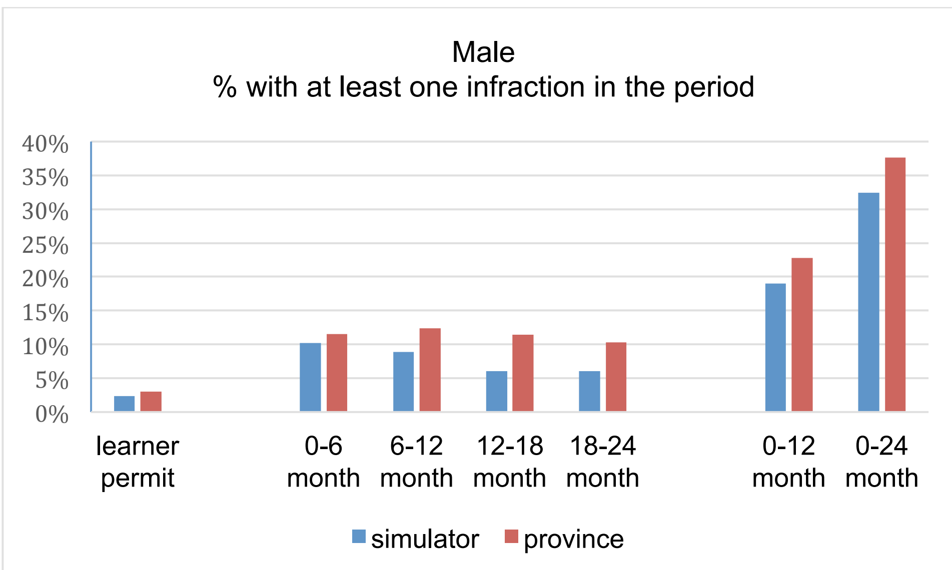


Table 7. Number of male drivers in each group with at least one infraction in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	16	64	49	28	21	105	112
province	3,801	12,844	11,826	9,129	6,265	21,838	22,915
$\chi^2(1)$	0.782	1.034	6.205	13.13	6.598	4.574	3.954
p-value	0.3764	0.3090	0.0127	0.0003	0.0102	0.0325	0.0468

Crash Rates

Figure 16 shows the female rates of occurrence of at least one crash without injury for simulator and comparison group drivers by permit type and length of licensure. Table 8 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. Compared with females in the comparison group, females in the simulator group had a statistically significant higher rate of crashes without injury only when they were driving with a learner's permit under adult supervision. During each of the subsequent time periods with a probationary permit, there was no statistically significant difference in crashes without injury between females in the simulator group and females in the comparison group.

Figure 16. Female rates of crashes without injury for simulator and comparison group drivers by permit type and length of licensure

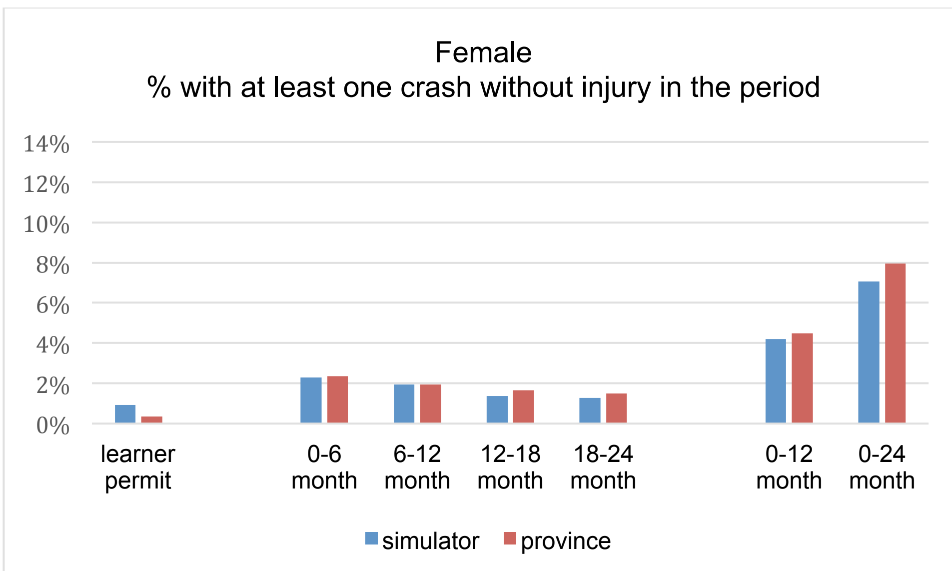


Table 8. Number of female drivers involved in one or more crash without injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	7	16	12	7	5	26	28
province	459	2,743	1,932	1,352	984	4,463	5,197
$\chi^2(1)$	7.254	0.015	0.0	0.242	0.161	0.117	0.438
p-value	0.0071	0.9025	0.9954	0.6228	0.6874	0.7323	0.5080

Figure 17 shows male rates of occurrence of at least one crash without injury for simulator and comparison group drivers by permit type and length of licensure. Table 9 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. There are no statistically significantly differences in rates of crashes without injury for males in the simulator and comparison groups.

Figure 17. Male rates of crashes without injury for simulator and comparison group drivers by permit type and length of licensure

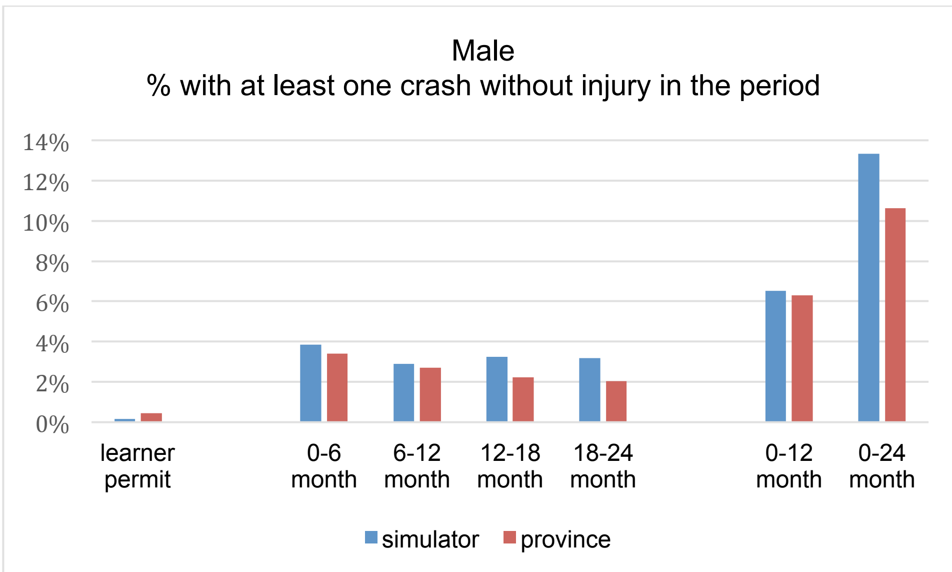


Table 9. Number of male drivers involved in one or more crash without injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	1	24	16	15	11	36	46
province	585	3,774	2,594	1,768	1,233	6,041	6,475
$\chi^2(1)$	1.392	0.380	0.070	2.255	2.324	0.036	2.607
p-value	0.2380	0.5373	0.7911	0.1331	0.1274	0.8478	0.1063

Figure 18 shows the female rates of crashes with at least one injury for simulator and comparison group drivers by permit type and length of licensure. Table 10 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. There are no statistically significantly differences in rates of crashes with injury for females in the simulator and comparison groups.

Figure 18. Female rates of injury crashes for simulator and comparison group drivers by permit type and length of licensure

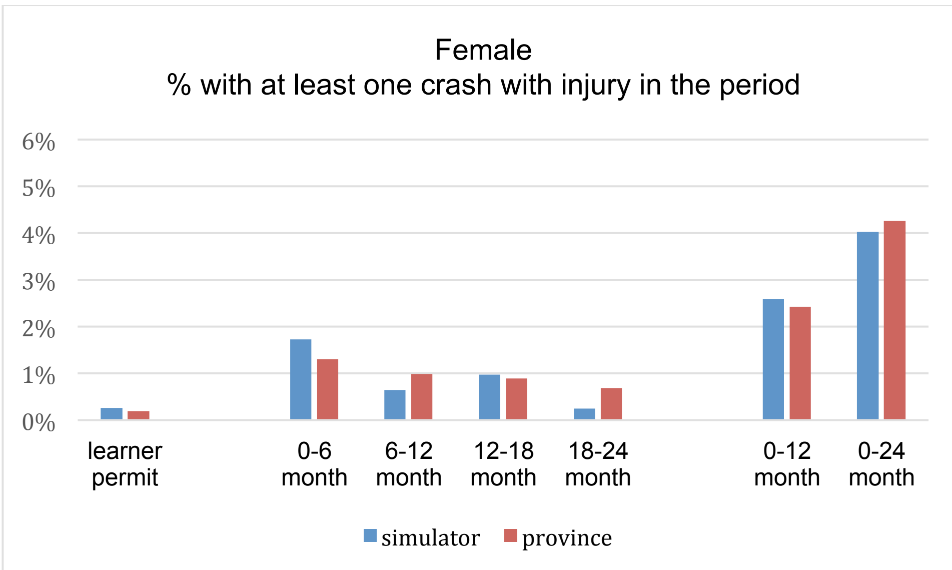


Table 10. Number of female drivers involved in one or more crashes with injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	2	12	4	5	1	16	16
province	252	1,508	986	732	448	2,415	2,780
$\chi^2(1)$	0.219	0.953	0.747	0.042	1.094	0.064	0.048
p-value	0.6395	0.3288	0.3874	0.8359	0.2955	0.7997	0.8250

Figure 19 shows the male rates of crashes with at least one injury for simulator and comparison group drivers by permit type and length of licensure. Table 11 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. There are no statistically significantly differences in rates of crashes with injury for males in the simulator and comparison groups.

Figure 19. Male rates of injury crashes for simulator and comparison group drivers by permit type and length of licensure

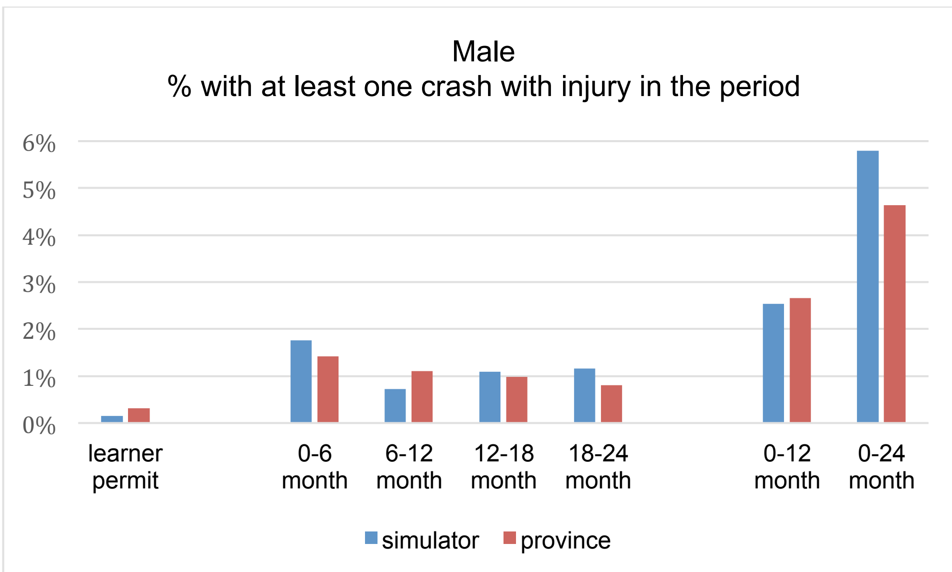


Table 11. Number of male drivers involved in one or more crash with injury in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	1	11	4	5	4	14	20
province	400	1,586	1,055	780	494	2,543	2,820
$\chi^2(1)$	0.571	0.494	0.7252	0.052	0.513	0.033	1.046
p-value	0.4496	0.4819	0.3944	0.818	0.4739	0.8554	0.3064

Figure 20 shows the female rates of crashes (without or with injury) for simulator and comparison group drivers by permit type and length of licensure. Table 12 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. Compared with females in the comparison group, females in the simulator group had a statistically significant higher rate of crashes only when they were driving with a learner's permit under adult supervision. During each of the subsequent time periods with a probationary permit, there was no statistically significant difference in crashes between females in the simulator group and females in the comparison group.

Figure 20. Female crash rates for simulator and comparison group drivers by permit type and length of licensure

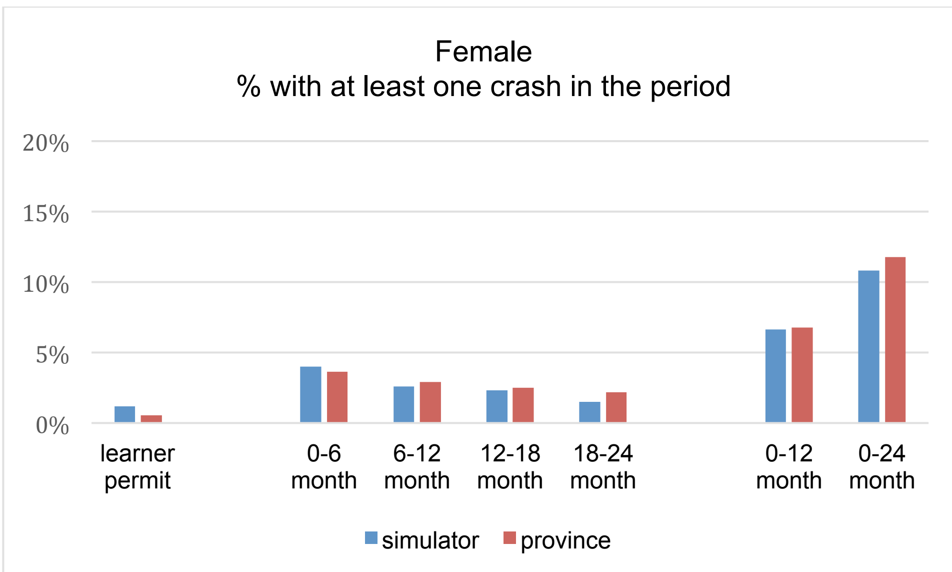


Table 12. Number of female drivers involved in one or more crashes in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	9	28	16	12	6	41	43
province	709	4,199	2,898	2,069	1,418	6,734	7,679
$\chi^2(1)$	6.035	0.309	0.234	0.0619	0.808	0.020	0.323
p-value	0.0140	0.5781	0.6285	0.8036	0.3686	0.8863	0.5695

Figure 21 shows the male rates of one or more crashes (without or with injury) for simulator and comparison group drivers by permit type and length of licensure. Table 13 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. During the probationary driving permit period, relative to males in the comparison group, males in the simulator group had higher rates of crashes that approached statistical significance ($.05 < p < .10$) between the 18th and 24th months and over the 24 month duration of their probationary permit.

Figure 21. Male crash rates for simulator and comparison group drivers by permit type and length of licensure

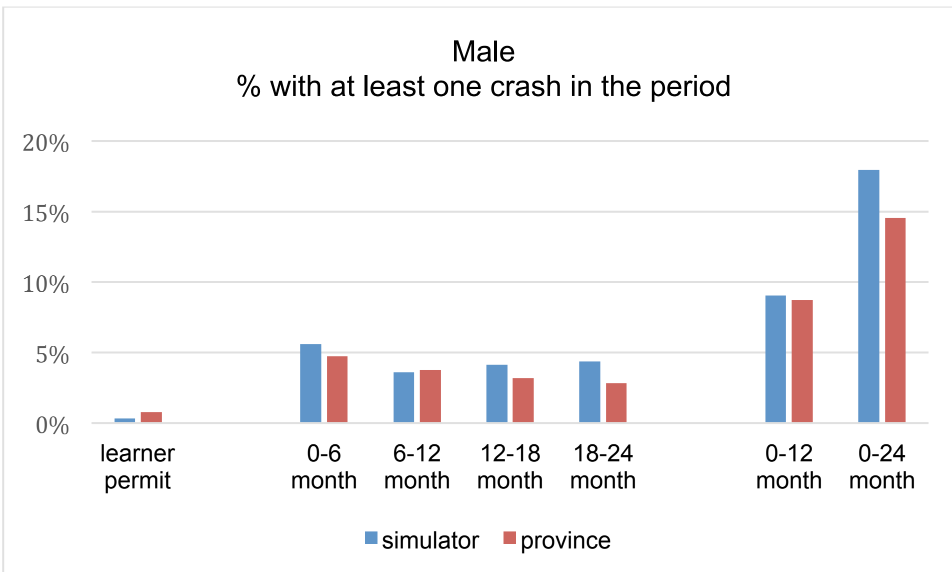


Table 13. Number of male drivers involved in one or more crash in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	2	35	20	19	15	50	62
province	981	5,275	3,605	2,520	1,710	8,347	8,851
$\chi^2(1)$	1.924	1.014	0.033	1.372	2.958	0.071	3.229
p-value	0.1654	0.3138	0.8540	0.2414	0.0854	0.7892	0.0723

Motor Vehicle Ownership – A Proxy for Driving Exposure

Figure 22 shows the rates of females in the simulator and comparison groups who owned at least one registered motor vehicle for at least one day during the time periods considered for the data analysis. Table 14 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. Table 14 shows that there were no statistically significant differences in vehicle ownership between the females in the simulator group and the provincial comparison group during any of the time periods under study.

Figure 22. Percentage of females owning at least one car during the time periods under study

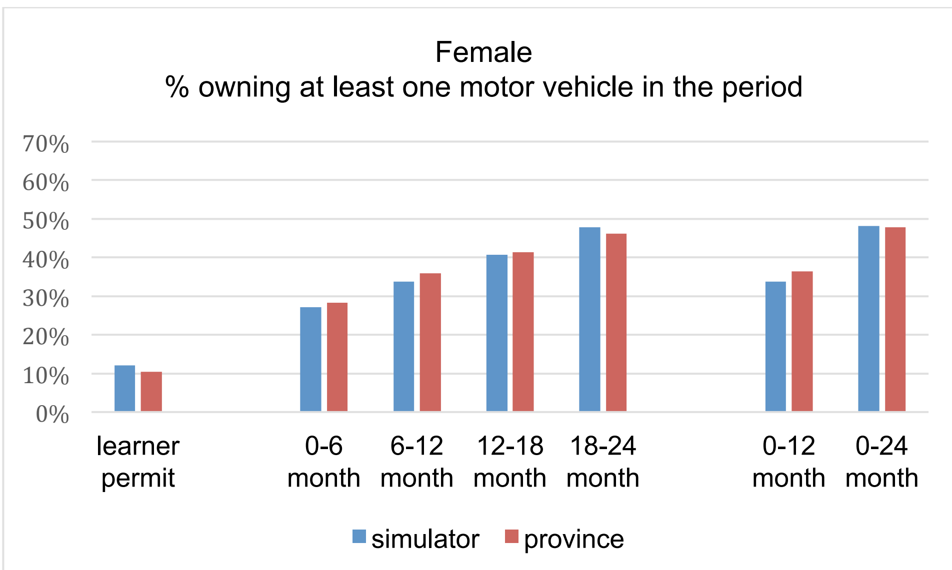


Table 14. Number of female drivers owning at least one vehicle for one day or more in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	91	189	209	208	190	209	191
province	13,805	32,753	35,686	34,074	30,137	36,184	31,284
$\chi^2(1)$	2.126	0.443	1.184	0.140	0.476	1.805	0.008
p-value	0.1448	0.5054	0.2764	0.7082	0.4899	0.1791	0.9274

Figure 23 shows the rates of males in the simulator and comparison groups who owned at least one registered motor vehicle for at least one day during the time periods considered for the data analysis. Table 15 shows the results of chi-square tests of the hypothesis of equality of the percentages between the two groups. Table 15 shows that for each of the time periods under study, except during the first six months with a probationary permit, the males in the simulator group had a statistically significant higher rate of vehicle ownership than the males in the provincial comparison group.

Figure 23. Percentage of males owning at least one car during the time periods under study

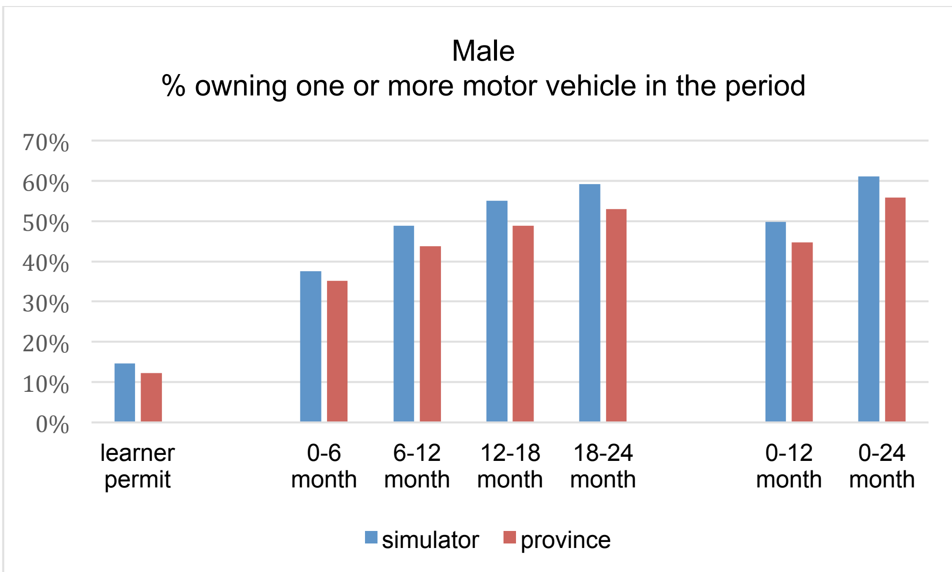


Table 15. Number of male drivers owning one or more vehicle for one day or more in the period and the chi-square test to test the hypothesis of equality of the % between the two groups

	Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
simulator	98	235	270	253	204	275	211
province	15,622	39,165	41,830	38,871	32,217	42,814	33,943
$\chi^2(1)$	3.652	1.569	5.871	6.820	5.252	5.564	4.008
p-value	0.0560	0.2103	0.0154	0.0090	0.0219	0.0183	0.0453

Logistic Regression

Tables 16 and 17 show results for females and males respectively for the logistic regression used to model the probability of novice drivers in the simulator group compared to novice drivers in the province of Quebec of having at least one crash (without or with injury) in each time period under study, controlling for motor vehicle ownership and age at licensing. Note that the analyses are restricted to novice drivers who met the following criteria: they obtained their learner's permits after January 1, 2010 and were between 16 and 24 years old at time of licensing for their learner permits, and; they obtained their probationary permits before the age of 25 years old for the analyses of the other driving periods with their probationary permits.

Table 16 shows that for females: (1) during the learner's permit period only, membership to the simulator group is positively associated with crash risk after controlling for vehicle ownership and age (p= .0151); (2) for each time period in the analysis, vehicle ownership is positively associated with crash risk controlling for group membership and age, and; (3) for each time period with a probationary permit, younger ages are positively associated with crash risk controlling for group membership and vehicle ownership; however we observed the reverse for the learner permit period, i.e. the odds of having at least one crash increases by 7% for each year older than 16 at age of learner permit licensing.

Table 16. Results of logistic regression models for females for the probability of having at least one crash in the period controlling for vehicle ownership and age at licensing

Effect estimates		Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
province vs simulator	odds ratio	0.44	0.93	1.16	1.10	1.50	1.04	1.13
	95% CI	0.22; 0.85	0.63;1.36	0.70;1.91	0.62;1.96	0.67;3.37	0.75;1.44	0.82;1.55
	p-value	0.0151	0.7149	0.5593	0.7367	0.3228	0.7945	0.4501
vehicle ownership (yes vs no)	odds ratio	1.95	2.29	2.19	2.15	2.00	2.17	2.03
	95% CI	1.62; 2.36	2.15;2.44	2.03;2.36	1.96;2.35	1.80;2.23	2.06;2.28	1.93;2.13
	p-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
age at licensing	odds ratio	1.07	0.89	0.89	0.90	0.90	0.90	0.90
	95% CI	1.02; 1.11	0.87;0.91	0.86;0.91	0.88;0.93	0.86;0.94	0.88;0.91	0.88;0.91
	p-value	0.0018	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table 17 shows that for males: (1) membership to the simulator group is not associated with crash risk after controlling for vehicle ownership and age; (2) for each time period in the analysis, vehicle ownership is positively associated with crash risk controlling for group membership and age, and; (3) for each time period with a probationary permit, younger ages are positively associated with crash risk controlling for group membership and vehicle ownership; however we observed the reverse for the learner permit period, i.e. the odds of having at least one crash increases by 8% for each year older than 16 at age of learner permit licensing.

Table 17. Results of logistic regression models for males for the probability of having at least one crash in the period controlling for vehicle ownership and age at licensing

Effect estimates		Learner permit	0-6 month	6-12 month	12-18 month	18-24 month	0-12 month	0-24 month
province Vs simulator	odds ratio	2.57	0.89	1.12	0.82	0.67	1.04	0.82
	95% CI	0.64; 10.3	0.63;1.26	0.71;1.76	0.51;1.30	0.40;1.14	0.77;1.39	0.62;1.09
	p-value	0.1821	0.5315	0.6082	0.4034	0.1451	0.7978	0.1790
vehicle ownership (yes Vs no)	odds ratio	2.66	2.32	2.37	2.13	2.03	2.34	2.26
	95% CI	2.13; 3.07	2.19;2.45	2.22;2.54	1.96;2.32	1.83;2.25	2.24;2.46	2.15;2.37
	p-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
age at licensing	odds ratio	1.08	0.90	0.93	0.91	0.91	0.92	0.92
	95% CI	1.04; 1.12	0.88;0.92	0.91;0.95	0.88;0.94	0.87;0.94	0.90;0.93	0.90;0.93
	p-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Discussion

This naturalistic, non-randomized study looked at different aspects of allowing between one and six hours of programmed training scenarios on a high-fidelity driving simulator to be substituted for an equal number of hours of on-road instruction during the mandatory novice driver training program. The research questions addressed how driving simulation-based training was implemented in the driving schools, how novice drivers appreciated it and what were the effects on driver performance as measured by first-time pass rates on the government probationary permit road test and driver behavior as measured by infractions and crashes during the first months and years of unsupervised driving. The study protocol did not prescribe the exact number of one-hour simulator sessions to be taken by each learner driver other than to set the limit to six hours of the 15-hour on-road training program. Driving teachers used their own judgment, with the consent of their students, to determine which and how many on-road sessions would be substituted with driving simulator.

Due to constraints on the experimental design, no data was collected on the factors influencing why students did or did not volunteer to participate in this study or what factors influenced the total number of simulator sessions per participant. Results from the two sources of data on driving simulator use per study participant, self-report and simulator records, were not in 100% agreement. Nevertheless, we can state with some confidence that about 28% of the participants had only one simulator session, 23% to 25% had two simulator sessions, 24% to 26% had three simulator sessions, 13% to 20% had four simulator session and 5% of the study participants had more than four sessions. In total, it appears that 95% of the study sample had less than five hours of driving simulator-based training out of the 15 mandatory training hours in the PESR.

After their first session on the driving simulator, several factors might reduce the likelihood that the learner would return for additional driving simulator sessions. These factors range from the policy of the driving school, e.g. one driving school owner initially restricted each learner to only one simulator session, to scheduling conflicts related to individual circumstances, to the limited availability on the driving simulator. The fact that every driving school had several practice vehicles but only one driving simulator may have been a factor when scheduling lessons at peak hours during evenings and weekends. Other factors that might reduce the likelihood that the learner would return for additional driving simulator sessions could be the availability of driving practice opportunities with family and friends outside the driving school course. Learners with limited access to driving practice outside the driving school might be reluctant to substitute more than one or two driving simulator hours for needed on-road driving hours.

There are other factors to consider that might influence the number of sessions voluntarily taken on the driving simulator that are arguably less likely. There is the well-known tendency for a small percentage of individuals to develop simulator adaptation syndrome (SAS). SAS is characterized by symptoms of dizziness and nausea that disappear soon after the simulator session ends. However, SAS is relatively rare among adolescents and it can be greatly reduced with an adequate introduction to the driving simulator, even among a susceptible population of older, experienced drivers (Muncie, 2006). The driving teachers who participated in this study were all trained on methods to reduce and mitigate SAS and the reported incidence by participating driving schools of SAS among adolescent learners since the first introduction of driving simulators to Quebec driving schools in 2008 is nearly zero. Another factor that might affect a learner's likelihood to return for additional simulator sessions is their level of satisfaction with the first lesson and the attitudes towards driving simulator sessions expressed by driving teachers who are more accustomed to and may be more comfortable with on-road lessons. However, these explanations appear to be less probable because the learners' responses to the questionnaire about their first simulator session and their perceptions of the driving teachers during that first session were almost entirely positive. In addition, during the annual teachers' workshops, driving teachers consistently expressed positive attitudes towards driving simulator-based training.

It should be noted that even when a learner indicated that he appreciated the first driving simulator session, at that time he might not have fully appreciated the advantages of the driving simulator compared to the on-road lesson because he would have had little or no basis for comparison. After driving schools began scheduling simulator lessons and on-road lessons back-to-back on the same day, driving teachers reported that learners exhibited more enthusiasm to return to the driving simulator for further training because they had directly experienced the advantages of immediately applying lessons learned in the driving simulator to their on-road driving.

In summary, regardless of the reasons for the number of simulator sessions taken by study participants, it is important to keep in mind when discussing the results of this transfer of training research that for the vast majority of participants, driving simulator sessions were substituted for 27% or less than the mandatory 15-hours of on-road driving sessions.

Regarding the perceptions of novice drivers about their driving simulator training collected by questionnaires after the first simulator session and after the final on-road driving session, the learner responses indicate a strong positive reception for simulator-based training. Learners appeared to have appreciated the relative ease and relaxed atmosphere of driving simulator lessons without reporting relatively less enjoyment or stimulation. After the first simulator lesson, between 73% and 90% of novice drivers agreed that learning on the driving simulator was “easy”, “relaxing”, “enjoyable” and “stimulating”. The pedagogical advantages of the driving simulator and training scenarios were well appreciated by the learner drivers both immediately after the first simulator session and in retrospect several months later. After the first simulator session, the learners were almost unanimous in their agreement that the scenarios were well organized, the scenarios gave them time to think about their driving and helped them learn where to look when they drive. The programmed scenarios that focused on the most safety-critical driving competencies, i.e. vision and hazard perception skills, were also among the ones most frequently selected by the driving teachers and the ones that were most highly appreciated by the learner drivers. Motivational factors are recognized as critical to safe driving outcomes (Hatakka et al., 2002) and 98% of the learners in this study agreed that the learning experience on the driving simulator increased their motivation to become an excellent driver. This response rate indicates a potential for driving simulator-based training programs to effectively address motivational factors in driving.

When learners were asked to directly compare the efficiency of learning 15 specific driving skills on the driving simulator to the on-road lessons, the combined percentages for the choices of driving simulators as more efficient or equally efficient exceed the percentages for the choice of the on-road lessons as being less efficient. These results are consistent with the findings from previous research that repetition of training exercises in the simulator outnumbered on-road exercises by a ratio of three to one Moe (personal communication, March, 2007) and two to one (Hirsch et al., 2011), that 20 minutes of instruction in the simulator is equivalent to one hour of on-road training (Korteling et al., 2000) and that successful training is a function of the sequence and number of exercises (Turpin et al, 2007). The positive perceptions of learner drivers for the driving simulator-based training delivered in this pilot project hold promise for future adaptations of this educational technology, particularly regarding the development of a more structured and comprehensive driving simulator-based program to train and test hazard perception and response skills (Goode et al., 2013).

The critical question in evaluating any form of training is simply, does it work? Did the skills learned on the driving simulator transfer to the road? Data from SAAQ indicate that simulator-based training may have had a positive impact on driver performance as measured by first-time pass rates on the probationary permit road exam. The pass rates at the first attempt at the road exam were statistically significantly higher for both sexes in the driving simulator group in relation to the comparison group, 85% vs. 74% for females and 88% vs. 78% for males. This result is consistent with anecdotal evidence that the substitution of driving simulator hours for on-road hours increases road exam pass rates Weirda (1996, cited in Vlakveld, 2005b).

Evans (1996) considers that, compared to driver performance, i.e. what a driver can do on a road test, it is driver behavior, i.e. what a driver does when he is unobserved, that plays the dominant role in road safety. One indicator of driving behavior is legal infractions. The data from this study show that infraction rates were statistically significantly lower for both sexes in the driving simulator group in relation to the comparison group. During unsupervised driving by females with a probationary permit in the simulator group, the occurrence of at least one infraction was statistically significantly lower for each six-month time segment and for the cumulative one- and two-year time periods than for females in the comparison group. During unsupervised driving by males with a probationary permit in the simulator group, the rate of occurrence of at least one infraction was statistically significantly lower for all but the first of the six-month time segments analyzed and for both the cumulative one- and two-year time periods than for males in the comparison group. These results are in line with previous research. Ekeh et al. (2013) found weak evidence in a randomized control study that a group of predominately male high school students who had taken ten structured training sessions on a driving simulator recorded non-statistically significant lower rates of infractions than the control group drivers after 6 months, 12 months, and 18 months of licensed driving.

Another indicator of driving behavior is crash rates. Empirical findings from detailed crash investigations indicate that driver behavior is the sole or contributory factor in about 80% of traffic crashes according to some estimates (Sabey & Taylor, 1979; Streff, 1991) and between 94% and 99% according to others (Rumar, 1985). This study examined crash rates without injury, with injury and total crashes during the learner's permit period and during the probationary permit period in successive six-month time segments and for cumulative one- and two-year time periods. Without exception, during the probationary permit period, the crash rates of females in the simulator group were not statistically different from the crash rates of females in the comparison group. However, during the learner' permit period of supervised driving when the crash rates of all drivers are at their lowest, females in the simulator group recorded a statistically significantly higher rate of non-injury crashes than females in the comparison group. There was no statistically significant difference in crash rates with injury between females from the simulator and comparison groups but a statistically significant higher crash rate for females in the simulator group during the learner's permit was present when all crashes were analyzed.

Crashes occur less frequently than infractions and infraction rates are positively associated with crash rates (Hirsch, Maag and Laberge-Nadeau, 2006; Peck and Kuan, 1983). Therefore, the combination of findings for females during the learner's permit period of supervised driving of a statistically significant lower rate of infractions and a statistically significantly higher rate of non-injury and total crashes rates appears somewhat anomalous. One potential explanation is that driving simulator-based training might have produced a type of overconfidence typically associated with advanced driver training (Katila, Keskinen, Hatakka, and Laapotti, 2004). If so, the effect seems to have disappeared as soon as the females from the simulator group passed their probationary permit tests and began driving without supervision.

For males in the simulator group, compared to males in the comparison group, there were no statistically significant differences in non-injury or injury crashes. However, males in the simulator group, compared with males in the comparison group, had a weak statistically significant higher rate for all crashes during the 18-24 month time segment of the probationary permit and for the cumulative two-year duration of the probationary permit ($p < .10$). Like the females in the simulator group, the combination of findings for males in the simulator of a statistically significant lower rate of infractions and a weakly statistically significantly higher rate of total crashes appears anomalous. Unlike the females in the simulator group whose increased crash risk might be the result of early over-confidence, the elevated crash risk for males only appears towards the end of two years of unsupervised driving. This contradicts previous research indicating that novice drivers are at their highest crash risk during their first six months of driving (Curry, Pfeiffer, Durbin, and Elliott, 2015; Lee, Simons-Morton, Klauer, Ouimet, and Dingus, 2011).

As noted by Ehsani, Bingham, Shope, Sunbury, and Kweon (2010), understanding novice driver crash risk requires a good measure of driving exposure, e.g. kilometers or time travelled, time of day, average speeds, road environments etc. Chipman (1982) found that young male drivers remained at high risk for all types of exposure denominators. In this study, exposure data was not collected. However, SAAQ data allowed access to information about vehicle ownership. Females in the simulator group were not statistically significantly different than females in the comparison group in vehicle ownership rates during any of the time periods under study. However, males in the simulator group, relative to males in the comparison group, had statistically significantly higher rates of vehicle ownership for each of the time periods under study except during the first six months with a probationary permit.

Vehicle ownership is arguably a valid proxy for increased driving exposure and the types of behaviors associated with young novice driver crashes. Scott-Parker (2012) reports on research that consistently demonstrates that young novices who own their own vehicle also report greater driving exposure, more risky driving, greater crash involvement (Cammisa et al., 1999) and more driving violations (Williams, Leaf, Simons-Morton, and Hartos, 2006). Diverse methodologies, e.g. surveys, interviews, instrumented vehicles and log books, in cross-sectional and longitudinal studies have shown that car ownership is associated with: more risky driving behaviour such as speeding (e.g., Cammisa et al., 1999; Garcia-Espana, Ginsburg, Durbin, Elliott, and Winston, 2009), higher overall crash rates (e.g., Williams et al., 2006); higher crash rates specifically associated with anti-social behavior like speeding and street racing (e.g., Palk, Freeman, Gee Kee, Steinhardt, and Davey, 2011), more traffic offences (e.g., Hirsch et al., 2006), and greater mileage (e.g., Leaf, Simons-Morton, Hartos, and Northrup, 2008). Moreover, greater duration of ownership corresponds to more offences by and crashes involving young novice drivers (Williams et al., 2006). Klauer, Simons-Morton, Lee, Ouimet, Howard, and Dingus (2011) studied data from instrumented vehicles and found that teenage drivers who owned their vehicles, relative to those who shared a vehicle, sped four times more frequently overall and more frequently at night and with multiple teen passengers.

Logistic regressions examining total crashes were done for both sexes in relation to three variables, membership either to the driving simulator or the comparison group, vehicle ownership, and age. The results showed that female crashes during the learner's permit period only in the driving simulator group remained statistically significantly higher than in the comparison group, even after controlling for vehicle ownership and age. The logistic regression results also showed that vehicle ownership and younger ages were independently associated with increased crash risk for both groups of females for each of the time periods analyzed with a probationary permit. The logistic regression done for males showed that the weak statistically significant association for increased crash risk for the driving simulator group noted above disappeared when vehicle ownership and age were considered. As for the females, for the males the logistic regression results showed that vehicle ownership and younger ages were independently associated with increased crash risk for both groups of males for each of the time periods analyzed with a probationary permit.

It is interesting to note that the study finding of a statistically significant lower infraction rate for males in the driving simulator group, relative to males in the comparison group, is even more impressive when one considers that vehicle ownership is associated with quantitatively more and qualitatively riskier driving exposure, and that the higher rate of vehicle ownership in the male driving simulator group would normally lead to the expectation of a relatively higher, not a lower, rate of infractions.

In summary novice drivers who substituted between one to four hours of driving simulator training for an equal number of on-road driver training hours appeared to appreciate the pedagogical advantages of the driving simulator relative to on-road training. They considered that driving simulator to be more efficient for learning almost all of the driving skills lists, especially the safety critical skills of vision training and hazard perception. Perhaps more importantly, after their first and in many cases their only lesson on the driving simulator, novice drivers almost unanimously agreed that the simulator lesson gave them time to think about their driving and increased their motivation to become excellent drivers. These self-reflective and motivational dimensions have been identified as critical to learning to drive safely within the GDE (Peräaho et al., 2003). In relation to the comparison group, the simulator group performed statistically significantly better on the probationary permit road exams, and during their learner's permit period and probationary permit driving periods, had statistically significantly lower rates of infractions and, after controlling for vehicle ownership, an equivalent risk of crashes.

Limitations

The naturalistic aspect of the study allowed researchers to gather information on how driving simulator-based training can be successfully implemented in commercial driving schools. However, the non-randomized design potentially introduced one or more selection biases and confounding variables. A volunteer bias among the study participants may have skewed the data on learner perceptions of driving simulation. The rate of vehicle ownership is relatively higher among males in the driving simulator group. This may be associated with differential qualities and quantities of driving exposure between the simulator and the control groups. An important limitation in this study is that the unique combination of elements in the implementation of this particular driving simulation-based training, i.e. specially designed learning scenarios focused on vision skills, a specific configuration of driving simulator hardware and software, e.g. with blind spot displays that complements that training scenario design, and the initial and recurrent training for driver trainers, may not generalize to other driving simulator configurations, training scenarios or applications of driving simulator-based training.

Conclusion

This pilot study examined the three elements proposed by Parkes (2005) to be important regarding the use of driving simulators within novice driver training: the acceptability and efficiency of the learning in the simulator; the transfer of the learning to the real world, and the retention of skills or knowledge learned. The data from this study indicate that the first and second of these elements were successfully achieved. Novice drivers appreciated their lessons on the driving simulator and rated them to be more efficient than on-road lessons for learning vision and hazard perception skills, arguably the most safety-critical skills for driving. Regarding transfer of driving skills learned on the driving simulator to the real world, the anecdotal data from driving teachers reported at annual teachers workshops and the superior results on the Quebec government probationary permit road exam relative to the comparison group indicate successful transfer of learning to the real world.

The question of long-term retention of skills or knowledge learned on the driving simulator to the real world is deceptively difficult to answer because so many events and factors can intervene after training is completed. It is worth remembering that the process of learning to drive is a complex area of study that is underdeveloped in relation to its potential impact on adolescent novice driver safety. After multiple evaluations spanning decades, driver education programs have rarely been able to unequivocally demonstrate the long-term retention of skills or knowledge related to safety benefits. Therefore, it is somewhat surprising and encouraging that our analysis of the impact of a limited number of simulator sessions on road exam performance and driving infractions showed a clear and positive indication of benefits from driving simulator training. The risk of driving simulator training producing over-confident and riskier driving may have manifested itself for females during the learner's permit period only but there was no indication of this arising for males. In fact, the opposite seems to have occurred. Males in the driving simulator group, relative to males in the comparison group, had a higher rate of vehicle ownership and a lower rate of infractions. Infractions reflect intentional behavior that is largely under the driver's control. Crashes are multifactorial events that do not necessarily reflect driver intentions (Hirsch, 2003). Nevertheless, there is no indication from the study data that driving simulator training had any negative effects on crash risk during the first two years of unsupervised driving.

In conclusion, it is undeniably clear that the introduction of programmed learning scenarios delivered on realistic driving simulators into novice driver training allows trainers to exercise control over environmental variables during a driving lesson and that the driving simulator-based training tested in this pilot project was positively perceived by the learner drivers. There is good evidence of positive transfer of driving skills to road exam performance and possibly a positive long-term effect on the reduction of driving infractions. Moreover, there is no indication of adverse effects on crash risk due to overconfidence. There are also other long-term and broader benefits from driving simulator training for novice drivers. Programmed learning scenarios can provide researchers and program developers with reliable data that may lead to measureable improvements in driver training and evaluation for novice as well as other groups of drivers, e.g. professional and aging drivers.

Acknowledgments

This study was made possible by the Société de l’assurance automobile du Québec (SAAQ) that allowed driving schools to use the driving simulator and programmed scenarios as a substitute for up to 47% of the mandatory on-road lessons and that provided some financial support to conduct the study. The researchers also wish to thank the personnel at SAAQ for their work in extracting the data on driving exam performance, infractions and crashes and the valuable contributions of the participating driving school owners and professional driving teachers who supported the introduction of a novel learning technology into their profession and who continue to contribute their expertise to optimize the use of driving simulators in novice driver training.

References

Åberg, L. & Rimmö, P.A., 1998. Dimensions of aberrant driver behaviour. Ergonomics. 41(1), 39–56.

Allen, R. W., Park, G. D., Cook, M. L., & Fiorentino, D. (2007). The Effect of Driving Simulator Fidelity on Training Effectiveness. Paper presented at the DSC 2007 North America, Iowa City.

Andersen, G. J. (1986). Perception of Self-Motion. Psychophysical and Computational Approaches. Psychological Bulletin, 99(1), 52-65.

Beanland, V., Goode, N., Salmon, P. M., & Lenne, M. G. (2013). Is there a case for driver training? A review of the efficacy of pre- and post-licence driver training. Safety Science 51, 127-137.

Blanco, M., Hickman, S. J., Hanowski, R. J., & Morgan, J. F. (2011). The commercial driver. In D. L. Fischer, Rizzo, M., Caird, J.K., Lee, J.D. (Eds.) (Ed.), Driving Simulation for Engineering, Medicine and Psychology. Boca Raton, FL.: Taylor and Francis.

Blickensderfer, B., Liu, D., & Henrandez, A. (2005). Simulation-Based Training: Applying lessons learned in aviation to surface transportation modes. Retrieved from

Brown, I. D., Groeger, J. A., & Biehl, B. (1987). Is Training Contributing Enough To Road Safety? In J. A. R. a. R. A. deBruin (Ed.), Road Users and Traffic Safety. Assen/Maastricht: Van Gorcum.

Bureau de l'efficacité et de l'innovation énergétiques. (2011). Eco-Driving Training Pilot Project for Light Vehicles: Summary Findings. Ministère des Ressources naturelles et de la Faune. Québec.

Cammisa, M. X., Williams, A. F., & Leaf, W. A. (1999). Vehicles driven by teenagers in four states. Journal of Safety Research, 30, 25-30.

Chipman, M. L. (1982). The Role of Exposure, Experience and Demerit Point Levels in the Risk of Collision. Accident Analysis and Prevention, 14(6), 475-483.

Choukou, M.-A., Hirsch, P., & Bellavance, F. (2014). Effectiveness of Training with a Truck Driving Simulator in Performing Backing Maneuvers in Real World. Poster presentation at the AUTO21 Final Annual Conference.

Christie, R. (2001). The effectiveness of driver training as a road safety measure: A review of the literature.

Coutermarsh, B., MacDonald, K., & Shoop, S. (2011). Assessing the Transfer of Simulator Trained Skills to Real Vehicle Control. Paper presented at the Proceedings of the

Sixth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Lake Tahoe.

Cox, C. V., Wharam, R., & Cox, D. J. (2009). Does virtual reality driving simulation training transfer to on-road driving in novice drivers? A pilot study. Chronicle for Driver Education Professionals, 57(1).

Curry, A. E., Pfeiffer, M. R., Durbin, D. R., & Elliott, M. R. (2015). Young driver crash rates by licensing age, driving experience, and license phase. Accident Analysis & Prevention, 80(0), 243-250.

de Groot, S., Centeno Ricote, F., & de Winter, J. C. F. (2012). The effect of tire grip on learning driving skill and driving style: A driving simulator study. Transportation Research Part F: Traffic Psychology and Behaviour, 15(4), 413-426.

Ehsani, J. P., Bingham, C. R., Shope, J. T., Sunbury, T. M., & Kweon, B. (2010). Teen driving exposure in Michigan: Demographic and behavioral characteristics. Accident Analysis & Prevention, 42(4), 1386-1391.

Ekeh, A. P., Herman, Kyle, Bayham, Dustin, Markert, Ronald, Pedoto, Michael, and McCarthy, Mary C. (2013). Pilot evaluation of the short-term effect of driving simulation on novice adolescent drivers. Journal of trauma and acute care surgery, 75(1), 83-87.

Evans, L. (1991). Traffic Safety and the Driver. New York: Van Nostrand Reinhold

Evans, L. (1996). Comment: The dominant role of driver behavior in traffic safety. American Journal of Public Health, 86(6), 784-786.

Falkmer, T., & Gregersen, N. P. (2003). The trainer project - The evaluation of a new simulator-based driver training methodology. In L. D. (Ed) (Ed.), Driver Behaviour and Training. Ashgate.

Fisher, D., Pollatsek, A., & Pradhan, A. (2006). Can novice drivers be trained to scan for information that will reduce their likelihood of a crash? Injury Prevention, 12((Suppl 1)), i25-i29.

Fitts, P. M., & Posner, M. I. (1967). Human Performance. Belmont, CA: Brooks/Cole.

Garcia-Espana, J. F., Ginsburg, K. R., Durbin, D. R., Elliott, M. R., & Winston, F. K. (2009). Primary access to vehicles increases risky teen driving behaviors and crashes: National perspective. Paediatrics, 124, 1069-1075. doi: 10. 1542/peds.2008-3443

Goode, N., Salmon, P. M., & Lenné, M. G. (2013). Simulation-based driver and vehicle crew training: Applications, efficacy and future directions. Applied Ergonomics, 44(3), 435-444.

Hatakka, M., Keskinen, E., Gregersen, N. P., Glad, A., & Hernetkoski, K. (2002). From control of the vehicle to personal self-control; broadening the perspectives to driver education. Transportation Research Part F: Traffic Psychology and Behaviour, 5(3), 201-215.

Hatakka, M., Keskinen, E., Hernetkoski, K., Glad, A., & Gregersen, N. P. (1999). Theories and aims of educational and training measures. In S. S. (ed.) (Ed.), Learning to become a driver - What can be done? Assessment of existing and possible measures. GADGET report.

Hays, R. T., Jacobs, J. W., Prince, C., & Salas, E. (1992). Flight Simulator Training Effectness: A Meta-Analysis. Military Psychology, 42, 63-74.

Heinrich, H. C., & Wienand, M. (1997). Neuere Entwicklungen bei Fahsimulatoren - Dokumentation. Retrieved from Bremerhaven: Wirtschaftsverlag.

Helman, S., Grayson, G. B., & Parkes, A. M. (2010). How Can We Produce Safer New Drivers? A Review of the Effects of Experience, Training and Limiting Exposure on the Collision Risk of New Drivers (Insight Report INS005).

Hirsch, P. (1997). An Exploration of the Predictive Assessement Abilities of Professional Driving Teachers Regarding the Safety of16 to 19 Year Old Drivers. (Maitrise en sante communautaire), Université de Montréal.

Hirsch, P. (2003). Adolescent driver risk taking and driver education: Evidence of a mobility bias in public policymaking. Journal of Safety Research, 34(3), 289-298.

Hirsch, P. (2005). The Relationship between Markers of Risk-Taking Tendencies and the First Year Driving Records of Young Drivers. (PhD), Université de Montréal.

Hirsch, P., Maag, U., & Laberge-Nadeau, C. (2006). The Role of Driver Education in the Licensing Process in Quebec. Traffic Injury Prevention, 7(2), 130-142.

Hirsch, P., Pignatelli, S., & Bellavance, F. (2011). An Evaluation of the Effectiveness of Simulator- Based Training on the Acquisition of Gear-Shifting Skills for Learner Truck Drivers. Proceedings of the 21st CMRSC. Halifax, Nova Scotia.

Hirsch, P. & Bellavance, F. (2013). [Transfer-of-Training Efficiency Study]. Unpublished raw data.

Hoskovec, J., & Stikar, J. (1971). Validity of driving simulator training. Ceskoslovenska Psychologie, 15(2), 158-162.

Jonah, B. A. (1997). Sensation Seeking and Risky Driving: A Review and Synthesis of the Literature. Accident Analysis & Prevention, 29(5), 661-665.

Katila, A., Keskinen, E., Hatakka, M., & Laapotti, S. (2004). Does increased confidence among novice drivers imply a decrease in safety?: The effects of skid training on slippery road accidents. Accident Analysis & Prevention, 36(4), 543-550.

Kearney, J. K., & Gretchkin, T. F. (2011). Scenario Authoring. In D. L. Fisher, M. Rizzo, J. K. Caird, & J. D. Lee (Eds.), Handbook of Driving Simulation for Engineering, Medicine and Psychology. Boca Raton, London. New York: CRC Press.

Klauer, S. G., Simons-Morton, B., Lee, S. E., Ouimet, M. C., Howard, E. H., & Dingus, T. A. (2011). Novice drivers' exposure to known risk factors during the first 18 months of licensure: The effect of vehicle ownership. Traffic Injury Prevention, 12(2), 159-168.

Korteling, J. E., Helsdingen, A., & von Bayer, A. (2000). Handbook Low-cost Simulators (Technical Report, ELS-DEL/5-HB, index 8, 2000.).

Kuiken, M. J., & Twisk, D. A. M. (2001). Safe driving and the training of calibration: A literature review.(R2001-29). Institute of Road Safety Research.

Laberge-Nadeau, C., Maag, U., Bourbeau, R., Desjardins, D., Messier, S., & Hirsch, P. (1999). Le lien entre performance aux examens (théorique et pratique) pour l'obtention d'un permis et le taux d'implication dans les accidents. Rapport final. (CRT-9-56).

Lawton, R., Parker, D., Manstead, A., Stradling, S.G., 1997. The role of affect in predicting social behaviours: the case of road traffic violations. Journal of Applied Social Psychology 27, 1258–1276.

Leaf, W. A., Simons-Morton, B. G., Hartos, J. L, & Northrup, V. S. (2008) Driving miles estimates by teen drivers: How accurate are they? Injury Prevention, 14, 59-61.

Lee, J. D. (Ed.) (2005). Chapter 4. Driving Safety: Reviews of Human Factors and Ergonomics, Sage. http://rev.sagepub.com/content/1/1/172

Lee, S. E., Simons-Morton, B. G., Klauer, S. E., Ouimet, M. C., & Dingus, T. A. (2011). Naturalistic assessment of novice teenage crash experience. Accident Analysis and Prevention, 43, 1472-1479.

Lindsey, J. T., & Barron, A. E. (2008). Effects of Simulation on Emergency Vehicle Drivers' Competency in Training. Prehospital and Disaster Medicine. July – August.

Lonero, L., & Clinton, K. M. (2006). Evaluating Driver Education Programs. Management Overview. AAA Foundation.

Martinussen, Laila M., Hakamies-Blomqvist, Liisa, Møller, Mette, Özkan, &Türker Lajunen, Timo (2013). Age, gender, mileage and the DBQ: The validity of the Driver Behavior Questionnaire in different driver groups

Maryland Government. Rookie Driver. Maryland's Graduated Licensing System. Retrieved December 15, 2015, from http://www.mva.maryland.gov/_resources/docs/DL-060.pdf

Mayhew, D. R., & Simpson, H. M. (2002). The safety value of driver education and training. Injury Prevention, 8(Suppl 2), ii3-7; discussion ii7-8.

Mayhew, D. R., Simpson, H. M., Williams, A. F., & Ferguson, S. A. (1998). Effectiveness and Role of Driver Education and Training In a Graduated Licensing System. Journal of Public Health Policy, 19(1), 51-67.

Moe, D. (2007). [Transfer of training study with novice drivers] personal communication, March, 2007.

Morgan J. F., Tidwell, Scott, Medina, Alejandra, and Blanco, Myra (2011). On the Training and Testing of Entry-level Commercial Motor Vehicle Drivers. Accident Analysis and Prevention, 43. 1400-1407.

Muncie, H. (2006). Design and Development of a Bus Simulator for Bus Driver Training. (PhD), Cranfield University.

Neukum, A., Lang, B., & Krueger, H.-P. (2003). A Simulator-Based Training for Emergency Vehicle Driving. Driving Simulator Conference North America. Dearborn, Michigan.

Palk, G., Freeman, J., Gee Kee, A., Steinhardt, D., & Davey, J. (2011). The prevalence and characteristics of self-reported dangerous driving behaviours among a young cohort. Transportation Research Part F, 14, 147-154.

Parkes, A. M. (2005). Improved realism and improved utility of driving simulators: are they mutually exclusive? . Paper presented at the HUMANIST Workshop Brno.

Peck, R. C., & Kuan, J. (1983). A statistical model of individual accident risk prediction using driver record, territory and other biographical factors. Accident Analysis & Prevention, 15(5), 371-393.

Peräaho, M., Keskinen, E., & Hatakka, M. (2003). Driver Competence in a Hierarchical Perspective; Implications for Driver Education.

Pradhan, A., Masserang, Kathleen M., Divekar, Gautam, Reagan, Ian J., Thomas, F. Dennis, Blomberg, Richard, Pollatsek, Alexander, Fisher, Donald (2009). Attention maintenance in novice drivers: assessment and training. Proceedings of the International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 5, 349-355.

Reason, J.T., 1990. Human Errors. Cambridge University Press, Cambridge.

Rimmö, P.-A., & Hakamies-Blomqvist, L., (2002). Older drivers' aberrant driving behaviour impaired activity, and health as reasons for self-imposed driving limitations. Transportation Research Part F: Traffic Psychology and Behaviour 5 (1), 47–62.

Rosenbloom, T., & Eldror, E. (2014). Effectiveness evaluation of simulative workshops for newly licensed drivers. Accident Analysis and Prevention, 63, 30-36.

Rumar, K. (1985). The role of perceptual and cognitive filters in observed behavior. In L.Evans and R.C. Schwing (Eds.). Human Behavior and Traffic Safety, (pp. 151-65). New York: Plenum Press.

Sabey, B. E. & Taylor, H. (1979). The known risks we run: the highway. (Report PA 660/79). U.K. Transport and Road Research Laboratory Report.

Salas, E., & Cannon-Bowers, J. A. (2001). The Science of Training: A Decade of Progress. Annual Review of Psychology, 52, 471-499.

Scott-Parker, B. J. (2012). A comprehensive investigation of the risky driving behaviour of young novice drivers. Queensland University of Technology, School of Psychology and Counselling, Centre for Accident Research and Road Safety – Queensland (CARRS-Q). Retrieved from http://eprints.qut.edu.au/view/person/Scott-Parker,_Bridie.html

Sivak, M. (1996). The information that drivers use - is it indeed 90-percent visual? Perception, 25(9), 1081-1089.

Société de l'assurance Automobile du Québec. Road Safety Education Program for a New Generation of Drivers. Retrieved December 15, 2015 From Http://www.SAAQ.Gouv.Qc.Ca/Publications/Prevention/Safety_Program.Pdf

Société de l'assurance Automobile du Québec. Mandatory Driving Course. Retrieved December 15, 2015, From Http://www.SAAQ.Gouv.Qc.Ca/En/Driver_Licence/Access_Driving/Index.

Société de l'assurance automobile du Québec. (1991). Course Program for the Driving of a Passenger Vehicle: Program for practical lessons.

Stoner, H. A., Fisher, D. L., & Mollenhauer Jr., M. (2011). Simulator and Scenario Factors Influencing Simulator Sickness. In D. L. Fisher, M. Rizzo, J. K. Caird, & J. D. Lee (Eds.), Handbook of Driving Simulation for Engineering, Medicine and Psychology. Boca Raton, London. New York: CRC Press.

Streff, F. M. (1991). Crash avoidance: New opportunities for behavior analysis. Journal of Applied Behavior Analysis, 24, 77-79.

SWOV. (2001). PROMISING. Promotion of Measures for Vulnerable Road Users. Institute for Road Safety Research, the Netherlands.

Turpin, D. R., Welles, R. T., & Price, C. (2007). Simulator-Based Learning: Achieving Performance Improvement Independent of Instructors. Paper presented at the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Stevenson, Washington.

Uhr, M.B.F., Felix, D., Williams, B.J., Krueger, H. (2003) Transfer of Training in an Advanced Driving Simulator: Comparison Between Real World Environment and Simulation in a Manoeuvring Driving Task. Driving Simulation Conference, North America 2003 (DSC-NA 2003). Dearborn MI, USA

Vernick, J. S., Li, G., Ogaitis, S., MacKenzie, E. J., Baker, S. P., & Gielen, A. C. (1999). Effects of high school driver education on motor vehicle crashes, violations, and licensure. American Journal of Preventive Medicine, 16(1 Suppl), 40-46.

Vlakveld, W. P. (2005a). The use of simulators in basic driver training. SWOV, Institute for Road Safety Research.The Netherlands.

Vlakveld, W. P. (2005b). Will Simulator Training in Basic Driver Education Help Enhance Road Safety? SWOV, Institute for Road Safety Research.
The Netherlands.

Welles, R. T., & Holdsworth, M. (2000). Tactical driver training using simulation. Paper presented at the I/ITSEC 200 Conference. Nov. 30th. 2000, Orlando, Florida, USA.

Williams, A. F., Leaf, W. A., Simons-Morton, S. G., & Hartos, J. L. (2006). Vehicles driven by teenagers in their first year of licensure. Traffic Injury Prevention, 7(1), 23-30.