



How would changing driver training in the Queensland licensing system affect road safety?

Deliverable 2: Simulators for skill acquisition training and assessment, and their impact on road safety

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Executive summary

This report is the second of three reports in a program of research that examines driver education and training with a focus on how education and training interact with Graduated Driver Licensing systems, particularly Queensland's. This second report reviews driving simulators for driver training and assessment, with a focus on novice drivers. The report initially considers the practicalities and issues relating to the use of driving simulators, then considers the role and effectiveness of simulators for novice driver training and novice driver assessment, followed by a case study of an on-going study investigating simulator based novice driver training. Finally, an overall conclusion is presented.

Driving simulators are a potentially useful training tool for novice driver training and education as they may enable novices to develop and practice a range of skills without any crash risk or the distraction of maintaining vehicle control. Two large scale European projects (EU-TRAINER and EU-TRAIN ALL) have created a comprehensive foundation for the study of how simulators are used for driver training and assessment. This work has included a comprehensive review of simulators currently being used across Europe for novice driver training and a classification system of simulators for training. The term "driving simulator" within the context of driver training and assessment is necessarily broad to encompass the wide variety of simulation interfaces. These range from high fidelity real car interfaces mounted on high end motion platforms, to low fidelity standard PC interfaces (single screen, mouse and keyboard) with no motion. While the fidelity of a simulator has some potential to influence results, a maximum fidelity simulator is not always the best option for training or assessment, given the potential complexities in programming and maintaining such a device. Additionally, errors in fidelity may affect the handling of a simulator to the extent that it no longer mimics a real car. It is possible that this could result in incorrect learning of procedural skills by novice drivers. In the context of novice driver training, simulator validity is of greater importance than fidelity. That is to ensure the transferability of trained skills to real road driving.

Role and effectiveness of simulators for novice driver training

To date, simulators have been used to train procedural skills and higher order cognitive skills in novice drivers. The use of simulators for training higher order cognitive skills is more common and widely practiced than procedural skills (with the exception of the Netherlands). Research conducted in the Netherlands has identified that it is possible to teach learner drivers the necessary procedural skills required to drive, through a simulator delivered curriculum. Analyses of learner performance records during simulator training (followed by on-road training) has shown that superior steering control, fast progression through training and few simulator violations and crashes are associated with passing the practical driving test on the first attempt. Research in this area is still relatively new. There is currently no conclusive evidence as to whether simulator training in procedural skills translates to safer unsupervised on-road driving compared to novices who learned to drive without simulators.

Hazard perception is the skill most widely trained using a simulator, in part due to its convenience and relatively low cost. Since hazard perception relies on observation and visual scanning, this skill is particularly amenable to training via low fidelity simulators. Hazard perception training is widely undertaken in Australia, Europe and the United States of America. Training is generally delivered via

a web or CD Rom based tool on a computer at the user's home or driving school. The standard format involves driving scenarios presented via pictures or video from the driver's perspective. The trainee is required to interact with the simulator via clicking on hazards and/or responding to questions. Overall, research evidence suggests that simulator training in hazard perception results in skill improvement, at least in the short term. However, few studies have undertaken longer term follow up or investigated the transfer of skill from the simulator to on-road, naturalistic driving. Furthermore, limiting simulator based higher order skill training to hazard perception in isolation has resulted in a general weakness in the literature whereby the entire training/education context which the novice is engaging in as a whole is almost never considered.

Role and effectiveness of simulators for novice driver assessment

To date, simulators are not used to assess the procedural skills of novice drivers. However, precedence has been set within the context of heavy vehicle driver training in Ecuador where experienced drivers may complete their assessment for a truck driving licence on a simulator (instead of a closed circuit). Simulators are used for the assessment of hazard perception in Australia and in the United Kingdom. A similar method has been undertaken by both jurisdictions to development their hazard perception tests. Potentially hazardous driving scenarios are derived from in car videos of actual driving and specifically represent common situations in which accidents occur in the novice driver population. While there is limited research on the road safety benefits of the hazard perception test, a longitudinal study has shown that since the introduction of the hazard perception test in Great Britain, crash risk of novice drivers has decreased.

Conclusion

Overall, research evidence suggests that simulators are effective at training and assessing higher order cognitive skills of novice drivers, particularly hazard perception. There are still gaps in the literature regarding long term on-road safety benefits. However, safer driving practices are apparent immediately following training, as has been shown in Great Britain where crash risk is lower in novice drivers (in the first year of unsupervised driving) for those who pass a hazard perception test, compared with those who do not complete such an assessment. In contrast, there is less evidence for the effectiveness of simulators for procedural skills training and assessment. The evidence which is available suggests that simulators are effective for training driving skills, although evaluation of such skills is usually undertaken a short time after learning, and by artificial context (simulated drive or practical test). It is largely unknown whether the skills gained transfer to naturalistic settings where novices are required to handle the procedural and cognitive tasks of driving, as well as other physical, psychological and environmental factors of the driving context. Further, it should be remembered that the simulator itself is a tool, therefore the outcomes of training will be as much (if not more) influenced by the processes and goals of the education program as a whole as it is by the type (i.e. fidelity) of the physical simulator used.

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List of Abbreviations

AMAP	Attention Maintenance Assessment Program
ANWB	Algemene Nederlandse Wielrijders Bond; the Dutch Automobile Association
CARRS-Q	Centre for Accident Research and Road Safety - Queensland
DATS	Driver Assessment and Training System
FOCAL	Forward Concentration and Attention Learning
GADGET	Guarding Automobile Drivers through Guidance Education and Technology
GDE	Goals for Driver Education
GDL	Graduated Driver Licensing
HPT	Hazard Perception Test
OECD	Organisation for Economic Cooperation and Development
RAPT	Risk Awareness and Perception Training
TMR	Queensland Department of Transport and Main Roads
SAAQ	Société de l'assurance automobile du Québec (Quebec Government Insurance Board)
ToT	Transfer-of-Training

1 Background

The Queensland Department of Transport and Main Roads (TMR) called for responses to a tender to investigate how changing driver training in the Queensland licensing system would affect road safety. Following successful application by the Centre for Accident Research and Road Safety – Queensland (CARRS-Q), a program of work was developed. The project has three objectives:

- Inform decision makers and policy developers of the ways in which different types of driver education and training for novice car drivers might be incorporated into the Queensland Licensing System, and the likely effects on road safety;
- Consider the potential for simulator use in novice driver education, training and assessment; and
- Identify the policies and practices related to driver education and training, with a particular focus on jurisdictions comparable to Queensland.

2 The program of research

The current Report is the second deliverable within the program of research. The central aim of this literature review is to evaluate the use of simulators for:

1. Training in complex skill acquisition;
2. Assessment of complex skill acquisition; and
3. Their impact on road safety,

Findings from this second Report (and those from Report 1) will be used to inform Deliverable 3 of the project. The other deliverables within the project are listed below:

Deliverable 1: Approaches to driver education and training in jurisdictions that are comparable to Queensland.

Deliverable 3: Evidence-based driver education considerations for policy options. This report will draw upon the research reviewed in Reports 1 and 2, considering how existing research results could be generalised to the Queensland context. It will aim to inform decision makers and policy developers of the ways in which different types of driver education and training for novice car drivers might be incorporated into the Queensland Graduated Driver Licensing (GDL) System, and the likely effects on road safety.

To ground the context of the findings from the literature review, the current report initially defines the key terms of, 'driving training', 'driver assessment' and 'simulator'. It is important that these terms are clearly understood to contextualise the remainder of the report. This is followed by a general evaluation of the advantages and disadvantages of driving simulators. The literature is then reviewed in terms of potential for road safety benefits for simulator based driver training and using simulators for assessment. Next, there is a case study detailing an on-going naturalistic driver training program using a driving simulator. Finally, a brief discussion is presented, on the potential impact for driving simulators on road safety.

3 Method

The primary objective of the report is to critically review the scientific research literature evaluating evidence of the efficacy of simulators for training and assessment of novice drivers. The majority of evidence is in regard to skill acquisition, however, where possible, impacts on road safety are discussed. Report two covers two main issues:

1. Simulators for training in complex skill acquisition; and
2. Assessment of complex skill acquisition using simulators.

3.1 Project outcomes

1. Theoretical basis of training and assessment tools;
2. Evaluation of simulators as training tools;
3. Evaluation of simulators as assessment tools;
4. Evaluation of simulator based training as an effective road safety intervention for novice drivers; and
5. Canadian case study of simulators for novice driver training.

3.2 Scope

The literature review focused on the more recent developments (within the past 10 years) in simulator training and assessment due to advancing technology. However, where deemed appropriate, older literature was accessed and considered. Throughout the report, the main focus is on literature relating to novice drivers. Where limited information is available, research from other driving populations may be sampled to illustrate possible applications for novice drivers.

3.3 Literature search

The systematic search for literature was conducted using the following search engines and databases: "Science Direct", "Web of Knowledge", "TRID online" and "Google Scholar". Due to time constraints, the search was focused on TRID online.

Additionally, relevant conference proceedings were examined (e.g. Australian road safety, policing and education conference) and cross referencing of obtained studies undertaken.

The search terms used were:

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" driv* "training" criteria"  
" driv*"assessment" criteria *"  
" driv* "training" necess* "  
" driv*"assessment" necess  
" driv* "training" theory "  
" driv*"assessment" theory "  
"driv* "training" content"  
"driv*"assessment" content"  
"(training OR trainer) AND Simulat* AND "procedural skills"  
"(training OR trainer) AND Simulat* AND "higher order  
thinking"
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"(training OR trainer) AND Simulat* AND "higher order
 cognitive skills""
 "(training OR trainer) AND Simulat* AND application"
 "(training OR trainer) AND Simulat* AND "real world""
 "(training OR trainer) AND Simulat* AND naturalistic"
 "(training OR trainer) AND Simulat* AND efficacy"
 "(training OR trainer) AND Simulat* AND driv*"
 "teach* And Simulat*"
 "educat* And Simulat*"
 "learn* And Simulat*"
 "assess* AND Simulat* AND driv*"
 "assess* AND Simulat*"
 "assess* AND Simulat* AND application"
 "assess* AND Simulat* AND "real world""
 "assess* AND Simulat* AND naturalistic"
 "assess* AND Simulat* AND efficacy"

A search of article titles and abstracts for relevance was initially undertaken. From the studies found, those most relevant to the aims of the review were selected for further review and investigation. The review only included literature published in English. The main focus was on peer reviewed scientific literature, however, grey literature was also considered if it came from a reputable source (e.g. websites of recognised road safety organisations). Research published since the year 2003 was given highest priority although, as indicated earlier, earlier publications were included where appropriate.

3.4 Outcomes of interest

Clear identification of outcome measures is key to understanding the actual and potential impact of driver education and training programs. The most common outcome measure reported by novice driver training literature is skill acquisition. This is an informative measure which quantifies the degree to which the training has achieved its purpose. However, skill acquisition may not reflect the real world impact of training on road safety. A more rigorous outcome of interest is crash rate/crash risk and traffic offences. These outcomes are both robust objective measures. If a training program is successful at training skilled and safe drivers it would be expected that participants would have fewer crashes and traffic offences than control participants with similar levels of driving exposure. However, there are issues associated with the use of this outcome measure. These issues include the relative rarity of crashes which makes it difficult to detect differences between drivers that have undertaken driver training and those that have not. Not all crashes are reported to police and thus are not included in administrative databases (Beanland, Goode, Salmon & Lenne, 2013). There is some concern that self-reported crashes by participants may lead to the under-reporting of crashes (Bates, Watson, & King, 2009), although recent research suggests that self-reported crashes by novices are comparable to administrative data from licensing authorities (Boufous, Ivers, Senserrick & Stevenson, 2010). Finally, novice driver crashes are caused by a range of factors (Bates, Watson & King, 2009). It is unlikely that driver education and training is able to address the full range of factors related to novice driver crashes (Beanland et al., 2013). Furthermore, a true control group (resulting

from random assignment to treatment conditions) is rarely used. Within the novice driver literature it is more common to use a comparison group (e.g. training as usual, resulting from group self-selection). This leads to an inability to control for individual differences, such as driving exposure and innate driving ability. Such individual differences will influence the self-selection to participate and subsequent crash risk, making it difficult to identify the true impact of training.

An alternative outcome measure is whether the behaviour of novice drivers has changed as a result of their education and training. For instance, previous research has considered the impact of education and training on self-reported driving related attitudes, self-reported and observed dangerous driving behaviours, self-reported perceptions of enforcement and self-reported and police reported crash risk (Senserrick & Swinburne, 2001). Additionally, other outcome measures for driver education and training could include the impact of driver education and training on simulated driving performance (Beanland et al., 2013; Dorn & Barker, 2005) or on their naturalistic driving behaviour within a vehicle using unobtrusive recording devices (Beanland et al., 2013). However, the degree to which simulator recorded driving behaviour corresponds to on-road recorded driving behaviour or how either driving behaviour recording options relate to crash risk remains unclear. Perhaps the most thorough way to evaluate training may be by monitoring driving behaviour change (e.g. simulator/on-road evaluation drive) but also to follow up real world driving behaviour (e.g. observation studies) and crash/traffic offence history.

In reviewing the literature it must be noted that reported outcome measures will differ between studies. Consequently, it can be hard to generalise findings from one study to those of another and in cases of less robust outcome measures, practical road safety benefits may be hard to quantify.

4 Defining simulators, training and assessment

The aviation domain has a long history of using simulators for training. Flight simulators have been utilised for over 80 years to train pilots (Teteris, Fraser, Wright & McLaughlin, 2012). The earliest simulators consisted of a frame with a seat and basic control system. The novice pilot would sit and attempt to “control” the “plane” as assistants would lift the entire frame and move it to simulate a plane tipped back and forth. Parkes (2012) describes one of the first automated flight simulators, from 70 years ago, which replicated aerodynamic characteristics. Although, basic motion was simulated from relatively early on, there was no means of creating a visual landscape in early simulators. Over time simulators have been introduced to other modes of transport as well as some application in the medical field. Both transport and medicine share the commonality of requiring trainees to operate in an environment in which an error could prove costly or even fatal. The lack of danger within a simulated environment makes simulators an attractive option for training in both domains. Simulators enable control over the learning or testing situation and present an opportunity to experience situations which are both potentially dangerous and rarely encountered in real life. However, despite the attractions there are also strong limitations. By their very nature, simulators seek to “emulate” real life but the extent to which this is achieved will have implications for the validity of results. The advantages and disadvantages of simulators are discussed in section 5 of the current report.

Before the effectiveness of simulators for driving training and assessment can be evaluated it is first important to have a clear understanding of each of the three concepts; driving simulator, driver training and driver assessment. Each of these is defined below. Further, the nature of the simulators themselves will also have implications for how their use can potentially fit within the novice driver training domain.

4.1 Driving simulator

For the purposes of this report, a driving simulator will be functionally defined as: Any dynamic interactive form of technology that is intended to teach or assess driving skills in learner or novice drivers relating to any aspect(s) of the driving task. This definition of a driving simulator is purposefully broad in order to encompass a range of simulator related training tools. For instance, under the broad definition, PC based interactive video tasks (such as those used in hazard perception training/assessment) can be included. It is recognised that there is no set definition of simulators, and others have distinguished between simulators and multimedia tools. In such cases PC based training (such as hazard perception training/assessment) and low fidelity simulators are included as multimedia tools rather than a simulators (Hoeschen et al., 2001; Lang et al., 2007). Within the current review, PC based training, multimedia tools and low fidelity simulators will be considered alongside higher fidelity simulators.

Fisher, Caird, Rizzo & Lee (2011) note that there is a wide range of driving simulators available, in part due to recent technological advancements and lowering costs of dated technology. Driving simulator programs are now available for smartphones and PC computers, and in more sophisticated forms that aim to emulate real driving experience as much as possible. Such smart phone apps will not be included in the current review. The great variety of simulators available creates some difficulty in generalising results of one simulator study to those of another. As such, when

interpreting the results from one driving simulator study it should not be assumed that the same results would be obtained if a different simulator was used for the same study protocol.

4.2 Novice driver training and education

Novice driver training and education refers to the provision of courses that aim to provide a new driver with a range of procedural and cognitive skills associated with driving. It may also include components that focus on driving safely as well as developing an awareness of how their personality and characteristics may influence their driving (Bates, Filtness, Fleiter, Watson, Tones & Williamson, 2013). Models and theoretical frameworks of driver training and driver behaviour illustrate the complexity of skills and requisite attitudes novice drivers must learn in order to implement safe driving on the road. For a review of theoretical perspectives on driver training and education, see Bates et al. (2013).

When evaluating the effectiveness of any driver training tool it is important to understand the breadth of skills a novice driver must acquire. Driver training should aim to address all skills required for driving, which may be greater than those required for assessment. This range of necessary skills for driving is demonstrated by the results of an extensive EU project, where four levels of Goals for Driver Education (GDE) were defined (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002). The project was not an empirical study but instead the necessary skills were identified through a combined approach including literature and theory evaluation. Initially, the developers sought to understand driver behaviour and the theory behind adaption of behaviour in order to formulate a new framework for driver education and training that emphasised new goals and directions for driver education. In direct relation to driver education and training they then reviewed the relevant theoretical background and the current situation of driver training in Europe, and for non-European jurisdictions using GDL systems. However, whilst empirical evidence pertaining to driver behaviour change under GDE application is positive, driver behaviour change and crash risk outcomes are not uniformly reported and as such there is greater theoretical evidence for GDE than empirical evidence. Nonetheless, the GDE appears to offer the most comprehensive model against which to assess driver training and education programs. At the lowest level is vehicle manoeuvring, which requires mastery of vehicle operation under varied driving conditions, followed by mastery of traffic situations, which refers to interaction with other road users and following road signage and regulations (Christ et al., 1999). Next is driving goals and context, while the highest level is goals for life and skills for living, which places driving within the context of the driver's life. Whilst the GDE (otherwise known as the GADGET matrix; Guarding Automobile Drivers through Guidance Education and Technology) represents an ideal situation, in reality the lower two levels are typically overemphasised in training and research (Hoeschen et al., 2001; Bates et al., 2013). Additionally, while skill development at the upper levels of the GADGET matrix may be occurring via conventional training, these attributes are often not measured or reported in novice driver training and education evaluations.

Findings from the EU TRAINER project (Hoeschen et al., 2001), which reviewed driver training and education primarily in the European Union indicated several recommendations for what driver training and education should offer in order to reduce crash risks in novice drivers. In short, learning to drive is cognitively demanding, and a focus on training at the lower levels of the GDE has led to drivers skilled in vehicle operation and capable of passing a driving test. However, many novice drivers lack the ability to apply their operational skills safely, which is evident in the overconfident,

aggressive or risky behaviour of some novice drivers. This includes inaccurate self-appraisal of driving skills and poor identification of driving hazards and risks. This is potentially an unintended negative outcome of training focussing on vehicle manoeuvring skills. Hoeschen et al. (2001) suggest that simulators could be used to train driving skills at both the lower level of the GDE matrix, as well as to develop cognitive skills important in automation and decision making. For instance, it would be possible to use simulator training to enable drivers to safely experience risky driving scenarios such as driving while fatigued or under the influence of alcohol, thereby demonstrating the resulting impaired performance. Multimedia tools were also acknowledged as valuable in training very basic vehicle control skills, hazard perception, as well as risks and self-awareness at all levels of the GDE, particularly via self-assessment and instructional feedback (Hoeschen et al., 2001).

In addition to ensuring that training results in the desired skill acquisition, three further things which should be considered when assessing a driver training approach are: training time, skill retention and transfer of training to non-training environment (Mitsopoulous-Rubens, Lenne & Salmon, 2013). It is important that skills can be obtained in a timely fashion, that the skills learned will be remembered long term and that the skills are relevant to the real world which will be encountered post training. The latter is particularly important in the context of driving simulator training (Mitsopoulous-Rubens et al., 2013).

4.3 Driver assessment

Driver assessment refers to the evaluation of drivers' competency to control a vehicle. Assessment may focus on one specific skill, such as a hazard perception skills or may consider a range of skills required for competent driving. When considering driving assessment as a component of a licensing system that allows an individual to be able to legally drive unsupervised on the road, the assessment process should be standardised, meaning that each examinee should be evaluated against common benchmarks. Regulating the objectives and process of legal driving assessment within a jurisdiction allows all those undertaking the assessment to be appraised against the same criteria. Consequently, the proficiency of those who pass the assessment should be at the same minimum level throughout the particular jurisdiction. Regulation in this manner provides guidance to examiners, facilitating impartial judgement of driving ability in relation to theoretical best practice and not personal comparison to other examinees. Many jurisdictions publicise the components of driving that may be assessed. For example, the Queensland State Government provides information regarding their driver assessment processes on their webpage (TMR, 2013). Driver assessment aims to evaluate driver competency but is unlikely to be able to assess all skills required to drive competently and safely within one assessment. One approach to address this difficulty is to use multiple assessments. For instance, a separate hazard perception test focussing only on hazard perception skills is often used in conjunction with other assessment types such as theory tests and practical on-road driving tests (Bates et al., 2013). It is also possible to select a range of skills for assessment for an examiner to deduce overall driving competency without evaluating each skill individually.

Simulator based training is not a mandatory prerequisite for simulator based assessment. However, if using a simulator for driver training, there is potential to include an assessment component as part of the training, using the training simulator. Lang et al. (2007) reported in the TRAIN ALL project that 28% of multimedia tools and 65% of simulators had assessment features. The EU TRAIN-ALL project reviewed and evaluated how training simulators were actually being used in Europe. In total, 25 multimedia tools and 20 simulators were evaluated. The assessment processes the authors used

within the multimedia tools was not clear, although it was likely that feedback in terms of scoring of correct responses was intended to serve as the assessment process. In the case of simulators, eight of the twenty that were evaluated enabled assessment of the trainee's performance by both the trainer and simulator; by the simulator only in five of the cases and in just one case by the instructor only.

The majority of simulator tools enabled the learner to replay their performance. While reviewing performance was not explicitly linked to self-assessment or awareness of one's own skills, this feature could be applied to self-awareness training facilitated by the instructor. Self-awareness training aims to address deficiencies in learners' accurate self-appraisal of their driving ability. The ability to accurately perceive driving ability is an important skill with respect to reducing overconfidence, as overconfidence has been found to be correlated with increased crash risk for novice drivers, and calibration between driving ability and the level of challenge encountered in real life driving situations (e.g. Weiss, Petzoldt, Bannert & Krems, 2013). According to Hoeschen et al., (2001), recommendations from the TRAINER study suggest that self-assessment of performance compared to a correct demonstration could also serve as a useful training and assessment outcome to generate awareness of strengths and weaknesses in one's own driving repertoire. However there is some evidence that even when feedback is provided following simulator based hazard perception tests, drivers are more likely to mistrust the feedback given than re-evaluate and adjust their perception of their own skill level (Dogan, Steg, Delhomme & Rothengatter, 2012). Transparency of assessment criteria and raw simulator data on learner performance was also considered valuable (as opposed to summary reports). Access to all simulator data allowed both the learners themselves and those administering the training to gain an insight into training objectives and progress of the learner (Lang et al., 2007).

5 Advantages and disadvantages of driving simulators

Caird and Horrey (2011) outline the advantages and disadvantages of using a driving simulator (listed below). The most obvious advantage of driving simulators is that simulators offer a fully controlled environment without the risk of the participant experiencing an actual crash (Flach, Dekker, & Stappers, 2008). This means that users avoid exposure to potentially distracting or dangerous stimuli such as severe weather or heavy traffic or at least experience these conditions in a situation with limited negative consequences (Vlakveld, 2005). Furthermore, visual or perceptual information is easily reproducible, often at lower cost, and low fidelity simulators can be used to investigate important driving skills such as attention maintenance and hazard perception. In the case of training, simulators can be programmed to offer targeted driving exercises in sequence to reduce the time spent on unproductive driving, such that it is claimed by driving instructors that one hour of instruction in a simulator may cover the same learning content obtained in three hours of practical driving (Kappé, van Emmerik, van Winsum & Rozendom, 2003). In the context of assessment, simulators are capable of examining driver performance and can offer identical test conditions to each participant, thus potentially offering a highly standardised form of assessment (Evans, 2004).

However, even the highest fidelity (degree of exactness with which on-road driving is replicated) simulator currently available cannot fully replicate the driving experience (Kappé, 2005). Consequently, there is potential that any benefits obtained from simulator training/assessment may not be realised on the real roads. The potential impact of fidelity is discussed in section 5.1. A further limitation is that errors in simulation are more likely to occur in higher fidelity simulators (Greenberg & Blommer, 2011; Andersen, 2011). A simulator of any level of fidelity cannot possibly account for all potential on-road driving environments within its program, such as unpredictable behaviours of road users that may be encountered in real life. Regardless of fidelity, simulators could be used to increase the range of driving environments a trainee is exposed to. For example, those living in remote areas may obtain their driving licence without experiencing urban road environments (e.g. roundabouts). Simulators provide a potential opportunity to specifically expose a trainee driver to environments they are not likely to encounter during their on-road practice. The effectiveness of simulators may also be dependent on how authentic the user believes the simulator to be. While some users may become engrossed in the simulator exercise and behave as though they are driving a real car, other users may not take the simulator exercise seriously and behave differently as a result (Ranney, 2011). Fundamental to simulator authenticity are the consequences of a crash. While the absence of crash risk is an advantage in that injury or property damage is avoided, it may be a disadvantage to teach or measure driving performance exclusively in this context as the effects of a crash in a simulator on users is unknown (Caird & Horrey, 2011). A less obvious disadvantage is the difficulty in describing and replicating simulator protocols (Fisher et al., 2011).

Following a review of the literature, Caird & Horrey (2011) have identified nine advantages and nine disadvantages of using driving simulators for training, assessment and research. These are quoted below:

Advantages

1. *Simulators have the capability to place drivers into crash-likely situations without harming them, such as when they are using drugs, fatigued, engaging in police pursuits, during extreme weather, using new technologies, among other dangerous activities.*
2. *Many confounding variables that occur in on-road driving can be controlled when driving simulation is used (e.g., weather, traffic, lighting, frequency of vulnerable road users, wind, potholes, proportion of vehicle types, irrational or unexpected behaviour of other drivers, and so forth).*
3. *All of the sensory details of the real world are not used by drivers anyway. Those aspects which are specifically required for driving (perceptual information) and can be faithfully reproduced using simulators.*
4. *Events or scenarios can be identically repeated for each participant.*
5. *Simulators offer cost savings through flexible configurability so that a wide range of research questions can be addressed (research specific).*
6. *Even low-cost, low-fidelity simulators can address a wide variety of interesting research questions (research specific).*
7. *Driving simulation is compelling and elicits emotional reactions from drivers that are similar to those of actual driving.*
8. *Simulators are good tools for assessing driver performance or what a driver can do.*
9. *A structured driver training curricula can be set up and run.*

Disadvantages

1. *Simulated crashes do not have the same consequences as a real crash and may affect subsequent behaviour. Crashes in a simulator may have an unknown psychological impact on participants.*
2. *Confounding or interacting variables (such as driver behaviour) that occur in the real world are not fully understood and, since they cannot be fully recreated in simulators, are not necessarily amenable to testing (as yet).*
3. *The real world can never be perfectly reproduced. The specific combinations of real-world information and feedback that are important to driving are not completely known.*
4. *Each exposure or trial affects responses to subsequent exposures (research specific).*
5. *High-end simulators require considerable hardware and software development.*
6. *Low-cost simulators can be imprecise and inflexible and therefore do not address all needs.*
7. *If drivers do not believe in the authenticity of the simulation at a fundamental level, responses will be affected based on this perception.*
8. *Simulators are not able to address questions of driver behaviour, which is, what a driver does do in their own vehicle.*
9. *The extent that the driver training transfers to on-road skills is not known nor is the relative cost-effectiveness of such programs.*

5.1 Simulator fidelity

Simulator fidelity refers to how well the driving simulator replicates the physical and perceptual aspects of driving. Physical fidelity relates to aspects of engineering, which is beyond the scope of this report (Greenberg & Blommer, 2011). Rather, Fisher et al. (2011) argue that theoretically the functional fidelity of a simulator is most important in terms of the driving simulator's capacity as a training or assessment tool. Functional fidelity is the extent to which a simulator behaves in a manner applicable to the real world, regardless of how realistic it looks and feels physically.

Kappé (2005) provides an example of the variety of fidelity levels between simulators and their functions for use in learner driver training in the Netherlands. Simulator aspects considered

included: the vehicle interface, replication of perceptual information related to visuals and motion, the traffic modelling and scenarios in the simulator program, and the instructional components. The vehicle interface and responsiveness of instruments such as pedals or steering were in many cases found to be very advanced in simulation, as the engineering of these elements is borrowed from car manufacturers (Kappé, 2005). For a simulator to be considered high fidelity, faithful reproduction of visual and motion stimuli are necessary precursors to basic operations of vehicle control such as steering, braking and management of speed as well as hazard identification (Andersen, 2011). Together with the control instruments, representation of vision and motion constitute the main physical aspects of a high fidelity training simulator. Additionally, Groot et al. (2001) suggest that realistic sounds may add to user immersion in the driving experience. Lastly, Kappé (2005) notes that instructions provided by the simulator to the driver enable learner drivers to practice in isolation or participate in group lessons with a single instructor.

Although high fidelity simulators may closely replicate on-road driving, they may not always be the best option for driver training. Fisher et al. (2011) cautioned against the use of higher fidelity simulators when it is unnecessary for the driving task due to the specialised skills required to program and maintain the simulator, as well as expenses to run the simulator. Additionally, some argue that lower fidelity simulators can be more beneficial for training than high fidelity simulators because they remove the extraneous (distracting) aspects of the target skill being acquired (Vlakveld, 2006). Furthermore, the fidelity of the simulator itself may not be as influential as the training curriculum in which it is embedded (Mayora, 2008). Simulator modelling and scenarios contribute to the efficacy of the simulator as a training tool (Kappé, 2005). Simulators require an artificial intelligence to replicate human behaviour in the case of computer generated pedestrians and motorists. This is challenging to realistically generate due to the highly variable nature of human behaviour in real life (Kearney & Grechkin, 2011). Nonetheless, the ability to program specific scenarios is a significant advantage of driver training simulators (Caird & Horrey, 2011). High fidelity simulators are more likely to result in “simulator sickness” than low fidelity simulators. Simulator sickness is the physical discomfort which may be experienced when driving a simulator. It results from incompatible signs from the bodies visual, auditory and motion systems. The symptoms of simulator sickness are similar to motion sickness including; restlessness, cold sweat, nausea, excessive salivation and vomiting (Classen et al., 2011). This may result from the excessively wide field of vision (Fisher et al., 2011) or errors in replicating the vehicle’s motion (Kappé, 2005). Furthermore, design flaws such as too small a field of vision, or poorly calibrated steering or brake control may undermine the efficacy of the simulator in training as the learner may not be able to scan the scenario properly and experience difficulty in developing vehicle control skills. Driving simulators also carry a higher risk of erroneous learning of procedural tasks due to inaccurate emulation of the driving experience, such as reduced mirror scanning due to learning on a simulator with a single screen and narrow field of view, or poor vehicle control due to limitations in steering, brake or motion functionality (Greenberg & Blommer, 2011). Despite this, both low and medium level simulators have been considered as acceptable tools to train drivers in basic vehicle operation (Jamson, 2011).

Evaluating the impact of fidelity on novice driver training is difficult, in part because there is no specific definition of high and low fidelity simulation. Many driving simulators are described as “high fidelity” in the literature further adding to the confusion (Greenberg & Blommer, 2011). A detailed five level classification system for training simulators has been developed by the EU TRAIN-ALL

project (Lang et al., 2007 [p. 11]), although subsequently it has not been widely used. The TRAIN-ALL project systematically reviewed and evaluated training simulators being used across Europe. The review covered all types of simulator based driver training. The project distinguished between simulators and multimedia tools. Multimedia tools were PC based training approaches. The five simulator classification levels were developed after rating each of the simulators included in the report on their performance at six criteria: the replication of vehicle features, visual system, motion rendition, interactivity and quantity of simulated motorists, sophistication of simulated environment including road map and environment, and complexity of learning opportunities provided. In the EU TRAIN-ALL project (Lang et al., 2007) multimedia tools (including PC based training) was considered separately and form no component of the classification. The following levels of simulator fidelity were identified, images of simulators from each level are reproduced from Lang et al. (2007):

- Level A: The most simplistic simulators consisting of a single screen and a joy stick or steering wheel and pedals, with a low number of motorists and minimal road environments and conditions. This type of simulator would be typical in computer games or as an instructional tool designed to entertain or raise awareness.



Figure 1 Examples of Band A simulators

- Level B: These simulators consisted of Level A features with the addition of a fully instrumented cab and slightly more complex scenarios. This level is used for learning basic operational control and procedures to comply with some road rules.



Figure 2 An example of a B band driving simulator

- Level C: These simulators include the features of Level A and B plus greater realism of car controls and simulated scenarios, sometimes with a wider field of vision and motion system. This level is used to develop skills in basic manoeuvring and tactical decision making.



Figure 3 Green Dino's Dutch Driving Simulator, an example of a C band driving simulator

- Level D: These are typically high fidelity simulators with a fully instrumented cab including front, rear and side view visual stimuli, motion system, the potential for changes to the vehicle interface (e.g. potential to switch between a car and a truck), and highly complex simulator scenarios that enable the interaction and influence of artificial road users. This level of simulator permits the development of skills in complex manoeuvres that require interaction with road users, and hazard perception, as well as eco-driving (adaptation of driving behaviour in such a way as to minimise fuel consumption and reduce carbon dioxide emissions).



Figure 4 Thales' Trust 3000 Simulator, an example of a D band driving simulator.

- **Level E:** This is the highest level of simulator and has all of the above features, with the addition of forward and backward motion rails and extremely high level scenario interactivity to enable complex training. Level E simulators may provide greater realism in manoeuvring tasks due to more faithful motion replication.



Figure 5 Examples of band E driving simulators.

Observations from the EU TRAIN-ALL study (Lang et al., 2007) provide insight into how driving simulators are used in training. All 20 simulators were observed to have steering, pedals and an instrument panel, and present a motorway and cars as part of the scenario suggesting that simulators possessed at least level B complexity. The presence of a vehicle cab and mirrors in 75-80% of simulators suggests that a C or possibly D level of complexity is fairly common. Weather

conditions such as fog or mist (85%) or darkness (75%) were frequently included in the simulator program, while rain, storms or snow (60%) were also used often. At least half of the simulators featured some sort of light or sound to add to the realism of the experience, with the most common of these being headlights (70%), brake/ reversing lights (55%), hazard/ parking lights (50%) or tyre sounds (55%). Forty percent of simulators were reported to have control aids or other features such as power steering, anti-lock braking systems or manual transmission. However, the failure to mention simulators that contained motion features indicates that Level D or E fidelity simulation was not found. Kappé (2005) reports that motion is one of the most challenging aspects of driving to reproduce in a simulator.

Simulator environments typically included rural (95%) and/or urban (90%) roads, with bridges and serpentine roads being less common (55%), and features such as hills, service stations, car parks, road works or rail crossings included in less than half the simulators. The mean number of other road users in simulators was 34, with a range of 3 to 80, and road users included drivers of cars (100%), trucks (70%), motor cycles (60%), or emergency vehicles (40%), as well as pedestrians (80%) and animals (25%). There was limited information about the behaviour of road users. However, findings suggested that attempts had been made to put novice drivers in challenging or risky situations by presenting illegal or unpredictable road behaviours in simulated traffic.

5.2 Simulator validity

Simulator validity refers to the transferability of simulator experience (including vehicle and driver behaviour) to on-road driving. When considering simulator validity distinction is often made between *absolute* and *relative* validity (Kaptein, Theeuwes & Van Der Horst, 1996). Absolute validity is achieved if the exact effect created in a simulator is equal to the effect on real roads. Relative validity, which can also be termed ecological validity, relates to an effect or behaviour which is equivalent in a simulator to on-road driving although not identical. Investigation of simulator validity has primarily been conducted in relation to research rather than training/assessment. A review of several driving simulator validity studies by Mullen, Charlton, Devlin and Bedard (2011) showed that simulators are capable of measuring the relative driver performance for objective tasks such as speeding, road position, braking, divided attention, as well as traffic violations or crashes. Only one group of studies was identified that investigated the validity of simulators for novice drivers, these studies by Allen and authors investigated the validity of simulators for hazard perception and are discussed in section 6.2.2.

Beyond fidelity, there are two further key differences between simulators and real world driving that may influence the validity of simulators for driver training. These are the omission of driving risk, and the fact that there often is not any purpose to the simulator trip beyond the documentation of driving performance for research, training or assessment objectives (Ranney, 2011). Psychological fidelity refers to the congruence between the risks and rewards of the simulator task and the risks and rewards of real life driving (Ranney, 2011). Some of the disadvantages of driving simulators actually relate to the lack of psychological fidelity in this medium. In the case of driver training or assessment, the lack of journey reward may be less problematic as the objective of driving either in a simulator or on a road would be to satisfy training or assessment requirements. It may be possible that learner drivers with less driving experience may be less affected by the lack of psychological fidelity, although it is unknown whether other non-driving experience such as media and race car computer games may affect their conduct in driving simulators.

6 Role and effectiveness of simulators for novice driver training

One of the largest investigations into simulator training for novice drivers is the EU TRAINER project (Groot et al., 2001). This project intended to explore the potential application of simulators and computer based instruction to novice driver training. At its inception in 2000, driving simulators were used sparingly in Europe, with many countries not using simulators at all. Early in the study a survey of 60 key experts, ministry representatives and other authorities related to the transport industry reported that simulator training could have numerous applications to training learner drivers. The greatest level of agreement between experts was that approximately 20% of the experts felt that simulators had potential for use in both learning to drive in bad weather and learning risk awareness. The next greatest agreement was between 10% of the experts who believed that simulators could also be of use in both the training of using telematic aids while driving and training overtaking. A secondary report in the EU TRAINER project (Hoeschen et al., 2001) identifies that simulators and computer based training may be especially beneficial to training higher order cognitive skills in learner drivers due to the possibility that learners can experience hazardous driving situations and the consequences of their behaviours without any actual risk of injury.

The more recent EU TRAIN-ALL project involved a survey of 25 multimedia tools and 20 simulators, aiming to provide data on how training simulators were actually being used (Lang et al., 2007). The multimedia tools were overwhelmingly intended for novice car (light passenger vehicle) drivers, although some tools were applicable to other vehicle types, such as motorcycles or trucks, or other driving groups such as experts and instructors. Some of the programs were intended to be applicable to multiple vehicle types and driver groups. The multimedia tools were mostly aimed at manoeuvring in traffic (80%), the second level of the GDE. Equal proportions of tools were aimed at vehicle control (56%), the lowest GDE level, or goals for driving (52%), the second highest GDE level. Only 40% of multimedia programs addressed goals for living, the highest level of the GDE matrix. All multimedia tools required users to observe a traffic scene, while the majority required some form of response from the learner such as anticipation of next event (76%), answering a question (76%), making a decision (84%), or naming a hazard (72%). Video footage was common to all tools, while photos (84%), text (80%), speech (68%) and animation (60%) were also widely used. All tools provided feedback as to whether the learner had provided the correct answer or made the right choice, while showing the consequence (64%) or hazard (72%) were also common, along with a trainee score (68%). Lang et al. (2007) note that the majority of multimedia tools had not been evaluated (84%).

The simulators reviewed in the EU TRAIN-ALL project were understandably more complex in their features than the multimedia tools, and could be classified into five categories, outlined in section 5.1 of the current report (Lang et al., 2007). In regards to the training aspects of the EU TRAIN-ALL simulators, almost all simulators were deemed appropriate for novice drivers (95%), while many were also suitable for experts (85%). Fewer were suitable for instructors (35%), and elderly drivers or drivers with disabilities (30%). In line with the wider novice driver literature, the majority of training offered via simulators was at the lower levels of the GDE, being vehicle control (95%) and manoeuvring in traffic (90%), while goals for driving and goals for life were addressed by 40% and 20% of simulators respectively. Only 30% of the simulators included in the project had undergone any form of evaluation. Lang et al. (2007) note that current simulators have focused on replicating

on-road driving and to date have generally not assessed the third and fourth levels of the GDE. Given that multimedia tools were reportedly being used to address goals and motives surrounding driving (high level GDE) there may be potential for future simulators to incorporate training strategies currently used in some of the multimedia tools or alternatively the multimedia tools could be seen as complementary to other aspects of driver training.

Simulator based training for novice drivers can broadly be considered as addressing either procedural or higher order cognitive skills. Predominantly simulator based novice driver training has historically been targeted towards modifying driver behaviours associated with crash risk (Ouimet, Duffy, Simons-Morton, Brown, & Fisher, 2011), such as simulated drives while talking or listening (e.g. Gugerty, Rakauskas, & Brooks, 2004; Kubose, Bock, Dell, Garnsey, Kramer, & Mayhugh, 2006), driving when affected by alcohol (e.g. Harrison & Fillmore, 2005), speed (Taubman Ben-Ari, Florian, & Mikulincer, 1999; Taubman Ben-Ari, Florian, & Mikulincer, 2000), or hazard perception (Fisher et al, 2007; McKenna, Horswill, & Alexander, 2006; Pollatsek, Narayanaan, Pradhan, & Fisher, 2006; Pradhan, Fisher, & Pollatsek, 2006). Consequently there is more evidence regarding use of simulators for training higher order cognitive skills than procedural skills. In their literature review of simulator interventions to reduce crash risk in novice drivers, Ouimet et al. (2011) identified 37 randomised control studies published between 1950 and 2008 which satisfied their criteria. All participants were aged under 25 years, with the majority aged 19-21 years. Twenty-nine studies included a mix of males and females, while eight studies recruited male participants only. Just under half (49%) of the studies included 30 or more participants in each experimental group. Such commonly used small sample sizes make it difficult to generalise results. Simulator interventions were classified as games or simulation techniques, both of which correspond to Level A simulator fidelity as designated by Lang et al. (2007), or as driving simulators, which would be expected to meet the standards of a level B simulator or higher as stipulated by Lang et al. (2007). Overall, studies tended to focus on the training of driving skills such as hazard perception (30%), talking or listening during driving tasks (19%), driving following alcohol consumption (13%), and the impact of psychological, perception or physiological factors such as stress or tiredness on driver performance (38%; Ouimet et al., 2011). The majority (90%) of randomised control trial studies investigated the effects of hazard perception training on driver performance in a simulator task. Training with respect to driver skills was generally positive, with trained drivers demonstrating safer driving performance in the simulator task following training compared to the control groups, although follow up tests were generally conducted less than a month after training and only three studies applied training to other contexts such as on-road driving (Chapman, Underwood & Roberts, 2002; Pradhan, Fisher & Pollatsek, 2006; Regan, Triggs & Godley, 2000). Ouimet et al. (2011) note that many of the studies provided limited information regarding the randomised control trial design.

Of the three studies which included a follow up in a different context, two did so a short time after training using a simulator (Regan et al., 2000; Pradhan et al., 2006) and one used a longer term follow up of on-road driving and a hazard perception test (Chapman et al., 2002). Pradhan et al.'s (2006) study utilised the Risk Awareness and Perception Training, version 2 (RAPT-2, see section 6.2.2) and a follow up time of only four days. The study consisted of two groups who either completed RAPT-2 simulator training or did not. All participants completed an evaluation simulated drive four days after the training session for the experimental group. At follow up those who had completed training had better hazard perception performance during the evaluation drive. Regan et al.'s (2000) study utilised the DriveSmart training (see section 6.2.1) and a four week follow up

period. In this study half of the participants received the DriveSmart simulator training and the other half were exposed to a flight simulator. Immediately following training, an evaluation drive was conducted in an advanced driving simulator. At this point the DriveSmart trained group demonstrated more cautious driving behaviour in eight out of 16 presented scenarios. Four weeks later this difference was sustained in seven out of 16 scenarios. Chapman et al. (2002) utilised hazard perception training and a 3 to 6 month follow up evaluation on-road drive as well as a hazard perception test (see section 6.2.3). The follow up results demonstrate no impact of training on on-road driving. Regardless of training, travel speed increased and following distance decreased. Those who had completed the hazard perception training showed a greater visual scanning pattern during the follow up hazard perception test, but not on on-road driving.

Since the publication of Ouimet et al.'s (2011) research, two other studies (Carpentier et al., 2012; Thomas, 2011) have examined the retention of simulator training up to four weeks later. Carpentier et al. (2012) used the RAPT training program and a simulator based evaluation with a two to four week follow up period (see section 6.2.2). A total of 29 novice drivers were randomly assigned to the training group or a control group, and the design included an evaluation immediately after training (or control) and a retention evaluation two to four weeks later. Hazard perception skills were superior amongst trained drivers immediately following training in terms of hazard detection time, correct hazard perception and mirror use. In the retention test, hazard detection time was found to decline, while percentage of hazards detected and use of mirrors increased within the trained group, suggesting continued improvement in hazard perception skills over time. Untrained drivers also became quicker at identifying hazards over time. Thomas (2011) included both an on-road driving task with a passive driving instructor (for legal requirements) and a simulator evaluation (see section 6.2.2). The main focus was driver distraction and eye gaze behaviour. Participants who had completed the simulator training glanced away from the road for shorter periods of time during distraction tasks than non-trained drivers.

6.1 Procedural skills

Procedural skills training involves teaching novice drivers how to undertake a sequence of actions that may become automatic after practice. This could include manoeuvring or operating the vehicle (Beanland et al., 2013). Research on driver simulation in the training of basic operational skills is limited as simulators are not widely used in this area, and there is a debate about whether driver simulators possess sufficient fidelity and validity to accurately teach these skills (de Winter, Wieringa, Dankelman, Mulder, van Paassen & de Groot, 2007a). If simulators are used for procedural skills training (for instance, in rehabilitation for the neurologically impaired), it is common that set scenarios are developed targeting a specific procedure, such as negotiating a corner which is undertaken with concurrent feedback (Goode, Salmon & Lenne, 2012). The training of procedural skills can address vehicle manoeuvring and mastery of traffic aspects of the GDE.

A barrier to the use of simulators for procedural training is poor validity. This is partly associated with the high costs of faithfully replicating the driving experience and the maintenance from highly skilled professionals that is required. As such, driver training is focused towards on-road training as, in many cases, it is considered more cost effective to teach basic skills in a real car (Pollatsek et al., 2011).

One exception is the Netherlands, where the first stage of learner driver training involves the use of a medium fidelity simulator (classified as Level C by the EU TRAIN-ALL project; Lang et al., 2007) outfitted with a screen displaying a wide field of view and basic vehicle instrumentation (de Winter, de Groot, Mulder, Wieringa, Dankelman & Mulder, 2009). Kappé et al. (2005) describe the simulator driving curriculum developed by ANWB (Algemene Nederlandse Wielrijders Bond; the Dutch Automobile Association) which covers basic vehicle operation and interacting with traffic across 18 lessons of 20 minutes duration. The lesson content is structured with transparent learning goals, scenarios in which to develop and practice those skills, which are then assessed against learning goals. Initially, this format of training may be more cost effective than on-road driving given that learners can develop their skills in small groups with an instructor present who can monitor progress and give complex feedback that a 'virtual instructor' would not be able to provide (Kappé, 2005). Fisher et al. (2011) report that there are now 30 driving simulators at the ANWB driving school and instructors report that they are able to focus on higher order cognitive skills and spend less time on basic procedural skills during driving lessons.

The limited research on driving simulators to teach operational skills has been conducted by de Winter and colleagues (de Winter, Wieringa, Kuipers, Mulder & Mulder, 2007b; de Winter et al., 2009) in the Netherlands. The first study involved 520 participants undertaking a 15 lesson simulator training program. Lessons covered vehicle control and urban driving (including intersections and roundabouts) as separated into 20 different tasks. Participants then continued with on-road driving training and driving performance was finally assessed 8 months after the initial simulator lesson. Driving performance during the simulator lessons was recorded and factor analysis applied to distinguish between violations (intentional deviations from normative performance) and errors (unintentional deviations from normative performance). Overall, male participants committed more violations and females made more errors. To investigate driving performance, distinction was made between forced-paced tasks (simulated tasks where participants had minimal influence on task completion times) and self-paced (simulated tasks where participants could influence task completion time by adjusting their travel speed). Forced-paced tasks were associated with fewer errors and violations. During self-paced tasks the quicker participants generally committed more violations however, made fewer errors. The authors suggest that being quick is therefore a sign of having good vehicle-handling abilities (de Winter et al., 2007b). The second study determined the influence of learner driver performance in simulator training on the pass rate for the practical driving test (de Winter et al., 2009), which was reported to be 48.6% in 2005. Feedback data was collected on 804 learner drivers (no comparison group used) and compared to test performance six months later. Just over half of the participants (54%) who had experienced simulator training passed their driving test on the first attempt. Superior performance on the simulator tasks was associated with an increased likelihood of passing the practical on-road driving test. A higher score on the mandatory theory test was also associated with the practical on-road driving test pass rate. The regression analysis considered: duration of time between first and last simulator lesson and each test attempted, gender, age, theory test score, proportion of simulator training completed, duration of simulator learning, general on-road practical test pass rates by region, and simulator measures (speed, violations, steering errors). Although, both the number of simulator hours of training and the duration of time between simulator training and test passing were controlled for, on-road practice exposure was not. However, the authors acknowledge that passing the practical on-road driver test and superior simulator driving performance may not translate to safer driving skills.

Vlakveld (2005) described a hypothetical and extreme example of the efficiency of simulators in teaching practical driving skills. Specifically, a case study of six learner drivers in the Netherlands completed nine hours of simulator training, followed by approximately 30 minutes on-road training, no other driving practice was undertaken. The short on-road training was necessary as the transfer of vehicle handling skills from the simulator training to real vehicle control was quite poor. Immediately after this on-road training five participants undertook a replica driving test on real roads with a qualified driving examiner. If this had been the official Dutch driving test two participants would have passed. However, passing the practical test without ever driving in a real car on the road is likely to greatly increase crash risk due to a lack of practical experience and reduced learning exposure for developing the higher order cognitive skills which are also necessary to avoid a crash (de Winter et al, 2009).

Vlakveld (2004) reviewed the literature in relation to driver training in the Netherlands and noted that some driving schools offered an accelerated driving course where students could obtain a licence in a fixed period of days, the shortest being 10 days. The authors note benefits of learning to drive during a fixed period learning course compared to an ad-hoc lesson pattern over a longer period of time as; easy to monitor trainee progress, structured learning objectives, and possibility to easily incorporate simulator learning. However, intensive learning allows little time for rest and consolidation of learning. Those undertaking shorter intensive learning have greater crash risk than those completing longer learning courses. It is not possible to say if the course itself leads to higher crash risk or if the type of person who is more likely to attend an intensive course is more likely to have crashes. The option of intensive learning is most commonly taken by young men who are already at an elevated crash risk compared to young women. Intensive courses are also more likely to be undertaken by those who attach more importance to driving and who consequently may also have greater on-road exposure than those completing learning over a longer duration. Such confounders make it hard to accurately evaluate the use of intensive learning courses. One particular aspect of interest is that the driving schools offering intensive learning report that one hour of simulator learning is equivalent to three hours of practical learning. As a result of these findings, Vlakveld (2004) suggested that driver training, including that via simulation, take place over a longer period of time interspersed with practical lessons, as well as some form of training in higher order cognitive skills such as hazard perception and insight (understanding of the dangers and risks associated with driving). Vlakveld (2004), suggested that despite the reported benefits of simulator learning, the claim by driving instructors that one hour of simulator learning is equivalent to three hours of practical learning has no factual basis.

Vlakveld (2005) notes that simulators have been used in training for other modes of transport, the most obvious being flight simulators to train pilots. However, the context of flying greatly differs from driving in that operating a modern plane is primarily a monitoring task (due to advanced autopilot technology) as opposed to the manual involvement required in operating a car, and additionally, pilots function as part of a team whereas the driver generally operates alone (Wheeler & Triggs, 1996). Consequently, the literature pertaining to procedural skills training in aviation is not transferable to driving.

There are potential economic benefits of using simulators for training drivers as a more condensed learning program is possible with a structured curriculum delivered via a simulator (Blanco, Hickman, Hanowski & Morgan, 2011). For instance, the Federal Motor Carrier Safety Administration is

currently conducting a trial of a simulator delivered training program for novice tractor-trailer drivers, which will explore entry level training and advanced skills training with a view to evaluating the potential for using simulation in assessment for commercial driver licensing (Robin, McFann, Knipling, Derrickson, Tidwell & Antonik, 2005).

Research into simulation training for truck drivers has traditionally focused on subjective data (Mitsopoulous-Rubens et al., 2013), until the recent SimVal study (Morgan, Tidwell, Medina & Blanco, 2011). This recent work compared three groups of novice truck drivers (experienced car drivers) undertaking three different training programs. The first group completed conventional training involving classroom learning and practical on-road driving, the second group followed the same protocol as the conventional training except 58% of the practical driving occurred in a simulator while the third group completed a shortened version of the conventional training designed only to train the skills necessary to pass the licence test. At the conclusion of training all participants completed an on-road assessment that was examined by independent experts, who had not previously been involved with the study. Comparison of assessment performance showed that the simulator-based training group performed no differently than those who were conventionally trained. Those trained in the conventional manner and with the simulator performed better than those completing the condensed training course. This finding indicate that training exposure (the amount of time being trained), and/or the aim of the training (safety vs., test passing), is more important than the mode of training. Further research is needed to confirm this finding. It remains unclear as to the relationship between test performance and subsequent crash risk. The potential for using simulators to expose drivers to a variety of situations has been recognised by the EU in relation to drivers wishing to obtain a vocational Certificate of Professional Competence to drive large goods vehicles. Precedence has been set so that simulators may be used as part of training (maximum of eight of 20 required training hours) (European Parliament 2003, p24). Although, it should be noted that the wording of the directive is vague so as not to recommend or require simulators to be used as part of training (Parkes, 2005). The applicability of findings relating to truck driving to novice drivers is unclear as those training to operate commercial vehicles will not be novice vehicle operators. They will already possess driving skills which through training, they will apply to a new type of vehicle.

6.2 High order cognitive skills

This section discusses key studies of hazard perception training for novice drivers. Such training addresses mastery of traffic situations within the GDE framework. According to de Winter et al. (2007b) lower fidelity simulators may serve as good pedagogical tools for facilitating the development and refinement of higher order cognitive skills in learner drivers, which would otherwise improve at a slower organic pace with increasing driving experience. There is an abundance of training tools towards this end, partially due to the availability and cost of technology required to distribute such software. These programs can be developed for a low fidelity platform which the user would have access to, such as a home computer, tablet or smart phone. The design of such tools is comparable to the multimedia training aids described in the EU TRAIN-ALL study (Lang et al., 2007) described earlier, and typically involves the use of video clips, photos, text, animation and sound to deliver the program. The programs do not require driving hardware for their use, rather users are required to observe, anticipate, make decisions, identify hazards, or answer questions to progress through the training. These activities are actually examples of part task

training, which is a typical strategy in teaching hazard perception (Beanland et al., 2013). These programs may be available either for home or driving school use, although instructors suggest that the driving school environment would enable an instructor to address any problems experienced by the user and ensure the training is completed correctly (Groot et al., 2001). Given the large number of low fidelity simulators aimed at developing hazard perception and related cognitive skills in novice drivers' programs, evaluation studies will be reviewed in groups by jurisdiction.

6.2.1 Australia and New Zealand

DriveSmart is an Australian CD-Rom program designed to train learner drivers in hazard perception, attention maintenance, time sharing and calibration (Senserrick & Haworth, 2005) across rural, highway and urban driving conditions using videos or simulated 3D environments (Pollatsek, Vlakveld, Kappé, Pradhan, & Fisher, 2011). The program is based on the pedagogical strategy of Incremental Transfer Learning, meaning that it was specifically aimed to address near transfer (ability to apply learning to similar scenarios) and far transfer (ability to apply learning to scenarios which are dissimilar to those used during learning) of learning (Regan, Triggs & Godley, 2000). The program was evaluated by changes to performance in the Victorian Hazard Perception Test and driving performance in a high fidelity simulator with motion features. Participants included 116 learner drivers aged 17 years (52 female) with 40 to 110 hours driving experience (Regan et al., 2000a,b). Participants were screened to exclude visual problems and epilepsy, and completed several questionnaires to control for a variety of driving related variables including the a demographic questionnaire about driving experience, the NASA-Task Load Index, the Situation Awareness Ratings Technique, Driving Confidence Questionnaire and the Simulator Sickness Questionnaire (Regan et al., 2000a,b). The experimental group consisted of 58 participants who completed the DriveSmart program over four sessions, ensuring that the program was completed at approximately the same pace for the entire group. Remaining participants completed training on a flight simulator which was not relevant to driving. It was not stated how participants were assigned to groups.

All participants completed pre and post-test sessions in a driving simulator before and after training, and four weeks after training. The simulator exercises initially familiarised participants to the simulator and obtained a measure of driver caution for pre and post training comparison. Cautiousness was assessed in relation to five everyday traffic events where some degree of caution would be expected (e.g. approaching a signalised intersection). The initial drive provided a baseline of caution for each participant. Speed on approach and exit from each traffic event was the main measure of caution. Participants also completed an exercise where they viewed a video from the driver's perspective of a near miss collision, following which they were asked to what degree they believed they would have been able to prevent the crash had they been driving. The immediate post-test session involved further simulator practice, a divided attention task and a risk perception task. The divided attention task required participants to follow road signage related to speed while they completed an arithmetic task. During the risk perception task participants were confronted with four hazards, two of which were similar to those taught in the DriveSmart program (near transfer; testing scenarios closely resembling those seen in training), and two of which were dissimilar (far transfer; testing scenarios dissimilar to those seen in training). To assess cognitive workload during the risk perception task, the arithmetic task was also completed when two of the four hazards were presented. The task where participants witnessed a near miss collision was

repeated, and again participants were asked whether they believed they could prevent the crash. The final battery of tests, four weeks later, replicated the very first session with the exception that the task was modified to allow participant response. The required response was first by pushing a button when they believed the situation had become unsafe and the second time by controlling the car in the simulator. This was contrasted with their response to the passive viewing scenario in the first and second last sessions (Regan et al., 2000a,b). Results indicated that experimental (DriveSmart trained) and control group (flight simulator exposure) participants reported similar levels of driving experience. Entry and exit simulator drives revealed that participants who had completed DriveSmart drove significantly slower in the post-test evaluation compared to the control group. Attention maintenance was superior in participants who completed DriveSmart, who were better able to maintain speed control in the dual task compared to the control group. The DriveSmart trained group also demonstrated safer performance around hazards in risk perception drives compared to the control group, in about half of the drives. Findings on the passive crash viewing task indicated that experimental and control group participants were comparable in their beliefs about avoiding the crash pre and post-training test, and very few participants actually avoided the crash when they were given the opportunity to intervene. The authors (Regan, Triggs & Godley, 2000b) determined from this that training did not impact driver confidence, and most importantly, did not lead to overconfidence. In summary, participants who completed the entire DriveSmart program demonstrated safer driving skills during general driving and hazard perception and improved attention maintenance as assessed via a driving simulator immediately before and four weeks after training.

The New Zealand based online eDrive program (Isler & Starkey, 2011; Isler & Starkey, 2012) is a computer based training program which is intended to teach situation awareness, hazard perception and risk management to learner drivers. The program offers video based output of driving scenarios filmed from within a car. A 360 degree view is facilitated via the inclusion of the windscreen, driver and passenger seat windows, dashboard and mirrors in the film to represent a realistic driving view, albeit on a smaller scale. Training modules are sequenced according to complexity and cover five key areas: visual search, hazard anticipation, risk management, road commentary and speed choice, plus an extra module on night driving (Isler & Starkey, 2011). Visual search requires participants to look at a video scene taken from inside a simulated vehicle looking out at the traffic environment to identify potential hazards. Hazard anticipation training requires participants to click on potential hazards presented during a video. Risk management requires participants to identify if a risky situation is occurring and then to take appropriate action. Road commentary requires the participant to speak their thoughts aloud while watching the scenarios. Finally, speed choice requires participants to decide on an appropriate speed, based on the road conditions which are presented. An assessment component is also included in the form of a self-evaluation exercise and hazard anticipation tests which are completed before and after the training program (Isler & Starkey, 2011). Hazard perception test scores were collected for 634 users. It was observed that from pre to post test, the number of hazards detected increased by 10% while the speed of hazard detection increased by 11% (Isler & Starkey, 2012). This study suggests that internet delivery of driver training may have a positive effect on hazard perception skills on some participants. However, control of design and methodology were virtually absent making it almost impossible to generalise results. There was no control group, participants self-selected into the study and completed the program in their own

home at a self-selected time. No demographic data was collected which would have provided valuable information about confounding factors such as age, gender and driving experience.

6.2.2 United States of America and Canada

The *Driver ZED* (Zero Error Driving) is a CD-ROM-based program that trains learner drivers in situation awareness: that is visual scanning skills, hazard perception, risk awareness and decision making (Blank & McCord, 1998). The training program features a video output of driving scenarios shot from inside a car similar to the *eDrive* program described above. However, *Driver ZED* enables the user to include a virtual passenger to create extra distractions. A variety of training methods are used, including: evaluation questions at the end of the scenario to determine whether the user detected hazards, clicking on hazards during the scenario, questions part way through a scenario to determine subsequent driving actions, and clicking the mouse to indicate the point at which evasive action should be taken to avoid a crash (Fisher, Laurie, Glaser, Connery, Pollatsek, Duffy, & Brock, 2002). An evaluation study was conducted to determine whether *Driver ZED* training translated to greater caution in risky driving scenarios where the risk was either hidden from view or visible. Participants included 30 high school drivers aged 16-17 years who were partaking in high school driver education and 15 college students who were licensed bus drivers and spent 10-20 hours per week in this occupation. Half of the high school students completed the *Driver ZED* program in one 1.5 hour session and served as the 'trained' experimental group, the remainder of high school students and college bus driving students served as 'inexperienced untrained' and 'experienced' comparison groups, respectively. It is not stated if the high school drivers were learner drivers or provisional drivers and no details of on road exposure are given.

All participants completed a series of driving tasks in a medium fidelity (similar to Level B EU TRAIN-ALL classification) driving simulator consisting of an instrumented cab and high resolution visual display, but no motion features. Accompanied by an experimenter to provide driving directions, the participants completed a total of six simulated driving tasks, two depicting hidden hazards, two with visible hazards, and two with hazards in the context of procedural driving skill demands (Fisher et al., 2002).

Analysis of simulated driving performance revealed that 'trained' inexperienced drivers responded to hidden hazards with the same level of caution as the 'experienced' group. 'Trained' and 'experienced' drivers braked and altered their road position in response to the hazards, while 'untrained inexperienced' drivers were less likely to perform these manoeuvres, suggesting they missed the hidden hazards. Where visible hazards were presented, 'trained' younger drivers tended to slow down more approaching hazards than 'untrained' drivers, who braked more suddenly than 'trained' or 'experienced' drivers. In two conditions which required participants to execute a vehicle manoeuvre (overtake a stationary truck and make a left turn with on-coming traffic) in addition to responding to hazards, 'experienced' drivers approached the scenarios more cautiously and performed the manoeuvres more smoothly than either group of inexperienced drivers (Fisher et al., 2002).

These findings suggest that hazard perception skills had been trained in the group who completed the *Driver ZED* course, however there were several limitations. The sample size was small at 15 participants per group, the assessment took place one day to one week after training, and it is unknown whether inexperienced drivers were randomly assigned to the trained or untrained group

or how much on-road driving exposure they had. Despite improved hazard awareness, newly licensed novice drivers may find themselves distracted by the procedural demands of operating the vehicle and as a result their attention to visual scanning is reduced making them less likely to perceive risky situations. For instance, Prabhakaran, Molesworth & Hatfield (2013) found that novice drivers' ability to manage speed in a simulated drive was reduced during the completion of a mental arithmetic task, suggesting that performing non-automated tasks may reduce attention to the driving environment. These findings suggest that the outcomes of simulator based training may be influenced by the timing of when it is to be implemented within the licensing process. The timing should be optimised to reflect the purpose of the simulator training. For instance, during the earliest phases of learning, drivers have least automated vehicle control. This could be considered an optimal time for simulator based training as it provides a safe setting for higher order skill development. Conversely, if vehicle control is considered necessary prior to the skill development of interest it would be preferable for simulator training to occur late in the learning process.

More recently, the Risk Awareness and Perception Training (RAPT) was developed and tested on inexperienced novice drivers who were either learner drivers or newly licensed provisional drivers (Fisher, Pollatsek & Pradhan, 2006). This program was intended to produce deep learning (the concept that the deeper the level of processing of an event, the more likely the event is to be stored in long term memory) in users and enable them to apply trained scenarios to similar, but not identical, real life situations. Rather than simply requiring users to detect a hazard, training scenarios required users to view a scenario and report on (1) areas which should be scanned continuously while driving through the scene and (2) areas where hidden hazards could present themselves. The RAPT has been revised several times as technology has improved, however the training format described above has remained consistent. The first three versions of the RAPT program were delivered via computer based instruction. In version 1 the materials were presented via a series of top down diagrams of driving scenarios. Version 2 used actual photographs from the driver's perspective in addition to the diagrams. Version 3 presented a sequence of photographs. Version 4 used a low fidelity simulator for the user to drive through training scenarios (Fisher, 2008). Each of these formats of the RAPT program has been evaluated via driving simulator tasks and the use of eye tracker software to monitor visual scanning during the assessment. Fisher, Narayanaa, Pradhan and Pollatsek (2004) administered the RAPT-1 program to 24 learner drivers (who did not hold a licence). Users interacted with RAPT-1 by dragging a yellow oval onto any potential hazards not visible from a drivers' point of view (such as a pedestrian behind a parked truck) and dragged a red circle to areas that should be monitored constantly. Following each scenario, participants were asked two or three questions regarding the prediction of risks and provided with feedback. Following completion of training, participants repeated the scenarios and it was noted that there was an average improvement of 40% in identifying areas to scan continuously and a 70% improvement in hazard anticipation. Further, trained drivers were compared to a demographically similar control group of 24 untrained participants using an evaluation simulator task containing 10 scenarios that matched the RAPT-1 training and six new scenarios. The driving simulator could be considered medium fidelity (similar to Level C EU TRAIN-ALL classification) and consisted of a fully instrumented car and a 150 degree visual display. Simulator driving performance results for this study were reported by Fisher et al. (2006) and indicated that scanning behaviour was superior in trained novices, especially in scenarios that were identical to training. However, the simulated testing drives occurred immediately after training so results may not be reflective of long term effects.

A replication of the Fisher et al. (2004) study using *RAPT-2* showed that differences between trained and untrained drivers persisted 3-5 days after training, although the total sample size was only 24 participants (Pradhan, Fisher, & Pollatsek, 2005). A third study was also conducted with a sample of 24 participants, 12 of whom were trained using *RAPT-3* (Fisher et al., 2006). This time, provisional drivers were used instead of learner drivers because the evaluation of training was conducted using a naturalistic driving test rather than a simulator, thus participants were required to be licensed drivers. As per the findings for the simulator-based evaluation, *RAPT* trained provisional drivers exhibited appropriate scanning behaviour (consistent with training) more often than untrained provisional drivers.

A subsequent study by Fisher (2008) described the fourth version of *RAPT*, which initially used *RAPT-1* to introduce the learner to the concept. This was followed by the *SIMRAPT* training on a high fidelity (similar to Level C EU TRAIN-ALL classification) simulator accompanied by an instructor. As per previous studies, 12 participants completed the *RAPT* training, while a control group of 12 participants completed driver education and simulator drives that were unrelated to hazard perception. Participants were newly licensed drivers aged 16-17 who self-selected into the study and were randomly assigned to the experimental or control group. All participants were evaluated via the monitoring of eye tracking (technology that enables identification of visual areas scanned) during a series of 16 simulated drives. The *RAPT* trained participants were significantly more likely to exhibit appropriate scanning behaviours (consistent with training) than the non-trained participants. Overall, the discrepancy between *RAPT* trained and non-trained participants was again stronger in near transfer scenarios that matched *RAPT* training than far transfer scenarios that were new to both participant groups. The *RAPT* and *SIMRAPT* protocols were used in a more recent study by Carpentier, Wang, Jongen, Hermans and Brijs (2012), which found that training effects persisted two to four weeks following *RAPT* training in novice drivers aged 18-25 years, although skills did deteriorate somewhat. Overall, the findings from the *RAPT* studies suggest that hazard perception skill acquisition is apparent following training. However, the impact of training may be limited as appropriate hazard perception strategy was more often applied to near transfer than far transfer situations. Furthermore, long term follow up and evaluation of subsequent on-road behaviour is noticeably lacking, making inferences regarding potential impact to road safety difficult.

In evaluating a similar hazard perception training program to *RAPT* Samuel et al. (2013) report differences in perception of hazards depending on how visible they are at the point of presentation. Forty eight young novice (licensed) participants were either trained using the Road Aware hazard perception training or a placebo condition (the videos from *RAPT-3* but with no informative feedback). In all cases the trained participants performed better than untrained participants. The difference between groups was significant for both highly visible and partially concealed hazards. The authors note that *RAPT* hazard perception training focusses on training identification of concealed/partially concealed hazards only. The ability to improve hazard perception of both low and high visibility compared to those who completed *RAPT-3* (albeit with no feedback) provides some suggestion that the scope of traditional hazard perception training may be too narrow. There may be potential benefits which are not currently being realised if hazard perception training included more visible as well as partially concealed hazards.

The Forward Concentration and Attention Learning (FOCAL) program developed by Thomas et al. (2011) aims to address the issue of driver distraction by training novice drivers to minimise the time

they glance away from the road during driving. The training task required participants completed simulator tasks which required them to drive and follow a map simultaneously. The learning content was administered via the Attention Maintenance Assessment Program (AMAP), which provided users with a replay of their performance. Feedback was provided to the learner by replaying the simulated scenario and blanking out the visuals for the time periods that they have been looking at the map during their initial drive. This approach was used to illustrate the effect of divided attention on driving, i.e. emphasises that “the driver might as well be driving blind”. As the users advanced through the training the feedback was modified so that the screen only went blank when the user looked away for more than two seconds. Throughout the simulated drives the map was only displayed for a maximum of three seconds and only when requested by the user. Three studies were conducted as part of the investigation, in each case participants were novice drivers who were either on a learners permit and had at least 5 hours of driving experience or on a restricted drivers licence for less than 6 months. In each study, pre-tests were conducted on all participants using the AMAP test, which demonstrated comparable performance amongst all users. The first study indicated that the FOCAL program was associated with a significant reduction in glance duration away from the road during a simulator task. The remaining studies were intended to test the transferability of the FOCAL program to a naturalistic setting. These studies involved the evaluation of eye glance behaviour during a high fidelity simulator or on road driving task with a passive driving instructor (for legal requirements). During these tasks, participants were also required to complete a non-driving task within the car such as finding an object, removing money from a cup holder, or locating an address on a map. Drivers trained with FOCAL glanced away from the road for shorter periods of time than non-trained drivers. These findings represent a positive novel application of simulators to novice driver behaviour, beyond hazard perception. While these findings suggest that the FOCAL program was an effective training tool at modifying off road glance behaviour, the sample sizes were small (15 FOCAL trained participants and 15 placebo trained) and the post-test evaluation was conducted shortly after training so it is uncertain whether training effects will persist over time or translate to naturalistic situations, where the participant is not being watched (Thomas et al., 2011).

The Driver Assessment and Training System (DATS) was intended to develop the higher order cognitive skills of hazard perception, situation awareness and decision making through simulated driving in complex, realistic environments (Fisher et al., 2011). The DATS was developed by Allen and colleagues (Allen, Cook & Rosenthal, 2001; Harmsen, Allen, Rosenthal, Aponso & Markham, 2002; Allen, Rosenthal, Aponso & Park, 2003; Allen, Park, Cook, & Rosenthal, 2004; Park, Allen, Rosenthal & Fiorentino, 2005; Allen, Park, Cook & Fiorentino, 2007; Allen, Park & Cook, 2010; Allen, Park, Terrace & Grant, 2011; Allen, Park, Cook & Fiorentino, 2012) and their research has focused on the effect of fidelity of simulators used to deliver the training. They used two configurations of low fidelity simulators using a steering wheel and floor pedals, and either a single monitor with buttons to look left and right (Allen et al., 2001) or three screens to represent a 135 degree view (Allen et al., 2004). These arrangements were designated as low and medium fidelity respectively by the researchers. The third arrangement consisted of a projector screen display viewed from within a fully instrumented cab, which the researchers described as high fidelity (Park et al., 2005). However, the simulator is more consistent with a medium fidelity simulator (Level C) as described by Lang et al. (2007). The single monitor arrangement was implemented in high school driver education classes for training of students aged 14 to 17 years of age, this included a mix of licensed and unlicensed participants (e.g. Allen et al., 2012). The three monitor and instrumented cab simulator

configurations were available at Department of Motor Vehicle offices. In addition to school based training some participants were recruited from Department of Motor Vehicles offices as they acquired their learners permit. These were more likely to be female and older than high school students, although it was not stated whether age and gender differences were statistically significant (Allen et al., 2007).

All participants self-selected into groups. All three simulator configurations produced improvements in simulator driving performance as a result of simulator use (in each case evaluation occurred on the simulator used for training), however speed and steering errors were less common in the so called medium and high fidelity simulators compared to the low fidelity simulators (Allen et al., 2001; Park et al., 2005; Allen et al., 2012). The authors suggested that lower errors were associated with higher fidelity simulators due to differences in hardware (Park et al., 2005). Despite differences in simulator fidelity, subsequent on-road crash rates were consistent across groups, which suggest that all three configurations were equally efficient at teaching higher order cognitive skills (Allen et al., 2011). However, simulator fidelity may be critical to the transfer of driver training to safe on-road driving. Hazard perception does not occur in isolation and must be accomplished during vehicle operation which may be very distracting to the novice driver with insufficient automation skills (e.g. Vlakveld, 2011).

More recent analyses by Allen et al. (Allen et al., 2007; Allen et al., 2010; Allen et al., 2012) have compared simulator fidelity with crash rates in the first two years of unsupervised driving. The first (Allen et al., 2007), followed 500 novice drivers who had completed simulator learning during the learner phase of their licensing. During simulator training, participants completed six 12 – 15 minute training scenarios in one of three simulator configurations: low – one screen, medium - three screens and high fidelity (as described above). If participants were not considered to have adequate performance during the sixth training session then they completed three additional trials. Overall, 79% of participants successfully completed simulator training, although all participants were included in the crash follow up regardless of simulator training performance. Official accident data was obtained for all participants during their first two years of driving. Regardless of simulator fidelity, accident rates were lower for participants than for the control data. Allen et al. (2010; 2012) followed the same participants, this time including results for 40 months post training. Here, the medium-three screen and high fidelity simulator training resulted in a 75% crash rate reduction compared to the data used as a control. Over the entire follow up period, 15.9% of participants had at least one recorded vehicle crash. Those trained in the lower fidelity one screen simulator also had a lower crash rate than controls, but only marginally. While these results provide some evidence to real world benefits of simulator training there are some limitations which must be considered. All participants were followed from the point of training; this means that the duration of unsupervised licensed driving varied depending on how quickly a participant passed their licence test. To control for this, accidents were analysed on a month by month basis, adjusting for the population size of licensed participant drivers at that time. A further limitation is a lack of control group. The authors instead compare to data reported by other authors in other North American populations of novice drivers. Consequently, there is no matching or controlling of demographics between the experimental and control data. Further, group differences such as age, gender, years between simulator training and licensing, and whether participation was voluntary or part of mandatory education were not controlled for in the earlier publications which make the findings inconclusive.

However, in Allen et al. (2012) there was no significant effect of gender and age at licensure with crash risk.

6.2.3 Europe

The EU TRAINER and TRAIN-ALL projects have made valuable contributions to knowledge about the characteristics and context of computer based and simulator driver training in Europe and throughout the world. However, with the exception of the Netherlands, simulators are not widely used in Europe for driver training (e.g. Hatakka, Keskinen, Baughan, Goldenbeld, Gregersen, Groot, & Winkelbauer, 2003), and fewer of these tools have actually been evaluated (Lang et al., 2007). Descriptions of educational tools used in Europe suggest that computer-based training programs may cover a broad range of training content, including higher levels of the GDE (Lacroix, 2010).

One Swedish evaluation study was conducted using both a computer-based and simulator-based driver training platform, as described by Vlakveld (2005). This study used low fidelity simulators to train hazard perception skills in learner drivers. The simulator configuration consisted of a steering wheel, pedals, gear stick, driver chair and dashboard and a single monitor for the low cost simulator and three monitors offering a wider field of view for the medium cost simulators. The computer-based instruction involved a hazard perception task where users had to click on the hazard, and modules about vehicle operation, management of traffic situations, and driving context and behaviour such as fatigue, social pressure and alcohol, thus multiple levels of the GDE were addressed (Fisher et al., 2011). Three groups of learner drivers were recruited to evaluate the simulators, and participants were assigned to the low and medium cost simulators, or a control group who did not receive simulator training (it is not reported if assignment was random or how many participants represented each group) (Vlakveld, 2005). Soon after training, all participants were evaluated using a high fidelity simulator with motion features (similar to Level E classification of the EU TRAIN-ALL project) on six driving scenarios involving the presentation of hazards or distractions such as a motorist failing to give way, animals walking onto the road, extreme foggy conditions and receiving a text message (Vlakveld, 2005). Findings showed that the learners who were trained in the medium cost simulator were less likely to be distracted in the mobile phone condition, demonstrated by maintenance of correct speed and road position, and more likely to reduce their speed in the foggy driving condition scenario (Fisher et al., 2011). These findings suggest that a narrow field of vision afforded by single monitor configurations may be insufficient for teaching hazard perception skills.

A German study by Weiss et al. (2013) evaluated a computer-based training tool intended to develop learner drivers' hazard perception skills, specifically to teach learners to adopt wider visual scanning behaviour, rather than focusing on the road immediately in front of the car. The program was administered in the form of a series of training videos depicting realistic traffic scenarios with developing hazards. The patterns of hazards were replicated in slight variations to further reinforce skill development. The video would pause at regular intervals and the user would be asked questions about whether they perceived a hazard and if so, how to respond to the hazard and the reasoning. Twenty-five learner drivers with fewer than five hours of driving experience were randomly assigned to the computer-based training group or a control group which received paper-based training materials of similar content. All participants completed a theory exam of road rules prior to training

in their assigned condition. Two days later, participants were evaluated in a high fidelity simulator using an eye tracking device to monitor their visual scanning technique. Prior to data collection a brief training and practice session was completed to ensure capability in operating the simulator. Participants from the computer-based training group demonstrated significantly greater speed and accuracy in detecting hazards compared to participants in the paper based trained control group. All participants reported moderate self-efficacy in their ability to complete the simulator task. However, participants who completed the computer-based training tended to underestimate their ability to complete the task while participants in the control group overestimated their ability, suggesting overconfidence in the control group. Although the sample size was small, the results do suggest that computer-based training may provide advantages over paper-based training, possibly via increased automation of skills and transferability. Further, the paper based training resulted in over confidence, perhaps the lack of validity of training environment resulted in a miss-perception of ability to apply new skills. It could be considered possible that the superior performance in the computer-based training group may indicate a practice effect given that the videos in the training program were similar in appearance to graphics in simulators, however, this effect would likely be minimal as participants had no exposure to training in the simulator itself.

According to Fisher et al. (2011), the United Kingdom tends not to use driving simulators, however hazard perception training via videos are often used (e.g. Crundell, Andrews, van Loon & Chapman, 2010). For instance, McKenna et al. (2006) presented novice drivers with a 20 minute video of a driving scenario containing hazardous situations filmed from the driver's point of view. In the experimental group, this video was supplemented with commentary training, which was supplied by a police driver training program and referred to potentially hazardous events and how to identify them. While in the control condition the video was shown without sound. The participants included 91 licensed drivers with an average age of 19 years and approximately three years driving experience. Following the video session, participants completed three hazard perception tests. The first test video was a scenario focussed on driving speed and participants were required to report whether they would drive faster or slower than the speed demonstrated in the video. The second video demonstrated following distance, and participants were asked to report their perception of a comfortable following distance to a lead vehicle. The third video depicted merging in traffic, and drivers were required to indicate which gaps they would feel comfortable accepting for merging with the traffic. Finally, participants took a video hazard perception test which involved pushing a button whenever a hazard was identified. Participants who had received commentary training were observed to react to hazards more quickly, and to be more cautious in their responses to the tests of driving speed, following distance and traffic merging, suggesting positive effects of hazard perception training.

Chapman et al. (2002) evaluated the effects of hazard perception training and included a follow up evaluation approximately three to six months later. A total of 143 learner drivers were randomly assigned to either the control or training condition. The training program was delivered via a series of videos which utilised both commentary and part task training to improve novice drivers' knowledge of hazards, and teach visual scanning and hazard anticipation skills. Participants completed follow up evaluation consisting of a test drive in a vehicle and a computer based hazard perception test soon after obtaining their open licence (note: no provisional licence in UK), and three and six months later. During testing, eye movements were recorded using a video camera in the driving task and an eye tracking device in the hazard perception test. Approximately 28% of cases

were lost to follow up over the course of the study. Over the three time points novice drivers slightly increased their travel speed and began to follow other vehicles more closely, irrespective of hazard perception training. Participants who had completed training displayed more horizontal visual scanning during the driving task than control participants immediately after training, although this effect was not sustained at the final follow up. In the hazard perception testing again, trained participants performed more horizontal visual scanning than control participants, this time the effect was sustained at follow up. However there were no differences between the groups for duration of visual fixations or vertical scanning patterns. The increased speed and closer following distances exhibited by all drivers over time could be interpreted as increased confidence in driving ability in general, or possibly familiarity with the testing situation. Only horizontal scanning behaviour appeared to be affected by training, and the effects of training seemed to be sustained in the hazard perception test, but not the driving task. This suggests that computer based training may have limited transferability to naturalistic driving, or that other factors such as goals for driving compromise the execution of trained skills.

6.3 Overconfidence

One area where there has been suggestion that simulator training would be beneficial for novice driver training is in reducing overconfidence. Although there are no practical examples of simulator training specifically to reduce overconfidence, there have been some research investigations in this area. As simulators can be used to replay an individual a training event, for instance, to demonstrate problems in driving behaviour, it is hypothesised that the trainee will then be able to recognise their own limitations and overconfidence would reduce as a result. Dogan et al. (2012) tested this hypothesis on licensed drivers with at least 1 year of driving experience. Two groups performed a hazard perception test, with one of the groups receiving feedback but not the other. All participants were asked to evaluate their performance. Consistently, participants reported better than actual performance, regardless of which group they had been in. Demonstrating that receiving feedback does not alter perception of test performance, in fact participants were more likely to doubt the credibility of the test rather than adjust their perception of their own performance.

Rosenbloom & Eldror, (in press) used questionnaires and observed driving behaviour of recently licensed Israeli drivers to compare between those who had received some driving simulator training and those receiving only practical on-road training. Hierarchical regression analysis identified those who had received simulator based training to have less safe self-reported driving intentions than those who had not had simulator training. The authors suggest that those who received simulator training became more confident in their driving abilities. In contrast, the observed driving behaviour (recorded by unobtrusive in-vehicle data loggers) demonstrated those who had received simulator training to brake more often and be less prone to follow preceding vehicles at an unsafe distance. Data was collected within the first year of licensed driving. Those who had undertaken simulator training did so in addition to standard on-road driving lessons. In each case, participants had completed four to six simulator lessons prior to starting their practical in-vehicle training. Social-economic variables were controlled so that there was no difference between those who had completed simulator training and those who had not. These results are somewhat antagonistic making it hard to draw conclusions as to the impact of driving simulator training on overconfidence. Further, although all participants were within one year of passing their practical on-road driving test, their actual on-road exposure was not controlled for. Therefore, it is not possible to know if the

observed difference in driving behaviour was due to the simulator training or differences in driving exposure. Regan, Triggs & Godley (2000a,b) (described in section 6.2.1) also compared confidence perceptions between participants who had received simulator training to those who had not. In this study, participants were shown footage of a near miss and were asked if they believed they would have been able to prevent a crash or not. There was no difference between those who had and had not received training from which the authors conclude that simulator training does not impact driver confidence and does not lead to overconfidence.

6.4 GDE levels addressed by simulator training

While it has been suggested that simulators present training opportunities for addressing all of the identified GDE needs of training (Lacroix, 2010), in practice, research to date has predominantly been focused on the lower level areas of ‘mastery of traffic’ and ‘vehicle manoeuvring’ (Lang et al., 2007).

There is currently less evidence for the use of simulators in training of ‘vehicle manoeuvring’ than ‘mastery of traffic’. There are strong fidelity-related limitations of simulators meaning that in many cases it is easier to train vehicle manoeuvring in a real car (de Winter et al., 2007). In contrast, simulators appear to present an opportunity to ease learning of some ‘mastery of traffic skills’. In many cases simulator training has been used to isolate a particular skill, allowing that skill to be the sole focus of training without distractions of vehicle control (Beanland et al., 2013). Novice drivers have greater difficulty with divided attention driving tasks because the control of the vehicle is not yet automated (Prabhakaran et al., 2013). Simulators allow skills such as hazard perception to be the sole focus of the participant’s attention, therefore facilitating learning of this skill. Using this approach, simulator training can improve many aspects of ‘mastery of traffic’ including: attention maintenance, dual task performance, hazard identification, risk perception, situation awareness, risk management, visual scanning (e.g. Regan et al., 2000b; Isler & Starkey 2011; Fisher et al., 2004; Weiss et al., 2013). However, this targeted approach also results in individual simulator training studies being limited to addressing only the ‘mastery of traffic’ GDE level.

Although less frequent than the lower two GDE levels, there is some research evidence regarding ‘goals for life’. In the above review, two exceptions were identified where ‘goals for life’ were targeted by simulator training. Firstly, during FOCAL training, one aspect addressed managing auxiliary tasks such as map reading. Following completion of training, participants adopted a safer visual glance pattern by spending less time looking away from the road (Thomas et al., 2011). Secondly, Fisher et al. (2011) included training relating to distractions, fatigue, social pressure and alcohol use. Those who completed the training were less likely to be distracted by a mobile phone during a post learning evaluation test. Although, currently there is limited evidence demonstrating the ability of simulators to address goals for life, these two studies suggest there is potential which is worth further investigation. For instance, Hoeschen et al. (2001) suggest that simulators present an opportunity to safely expose novice drivers to risky driving scenarios such as driving while fatigued or under the influence of alcohol, thereby demonstrating the resulting impaired performance. However, the influence of simulator training on the ‘goal for life’ of overconfidence is currently unclear. While there is some evidence that simulator training does not induce overconfidence (Regan et al., 2000b) there is other evidence that simulator training does not mitigate overconfidence (Dogan et al., 2012). There is a danger that if simulator training induces overconfidence, for example, experiencing alcohol impaired driving without negative consequences

may result in overconfidence in novice drivers to handle this simulation in their real driving. More research is needed into the influence of simulator training on overconfidence before risky driving situation training should be considered.

6.5 Summary

The literature discussed above suggests that driving simulators have produced encouraging results in the field of driver training. Procedural skills training for novice car drivers is rare, however findings suggest tentative associations between simulator training performance and practical driving test pass rates (de Winter et al., 2009), as well as a tentative association with reduction in crash risk (Allen et al., 2012). However, the impact on crash risk is also likely to be influenced by the manner in which simulator training is implemented, for example if intensive learning programs are used, which may include a simulator learning component, crash risks are likely to be elevated compared to those learning over a longer time period (Vlakveld, 2004). Research on the training of higher order cognitive skills is extensive, particularly in the area of hazard perception. While strictly speaking the majority of this research has not been carried out on true driving simulators (as identified by Lang et al., 2007), PC-based training is common and has an important role to play in the training of novice drivers, for these reasons this type of training has been included in this report. The majority of higher order cognitive skills studies use computer-based training to deliver hazard perception training via the commonly used methods of part task or commentary training. However, very few studies evaluated their training program beyond an evaluation simulated drive undertaken shortly after training, with the purpose of establishing initial skill acquisition. Notable exceptions are Fisher et al. (2006), who included a practical driving assessment post-test, Carpentier et al. (2012), who retested participants two to four weeks after completing the training program and Chapman et al. (2002) who completed a three to six month follow up. More recent research has begun to explore the pedagogical qualities of hazard perception training programs, for example by comparing the way in which hazards materialise (Samual, Zafian, Borowsky, Romoser & Fisher, 2013). However, there is still limited evidence as to which elements of hazard perception training are the most effective for novice drivers, and whether hazard perception training produces long term benefits to the development of hazard perception skills in novice drivers.

7 Role and effectiveness of simulators for novice driver assessment

Both theoretical and practical driving tests are used in most countries to determine whether the novice driver has achieved the training requirements to obtain a licence (OECD, 2006). The point within the licensing process where assessment is implemented varies between jurisdictions. Theoretical and practical tests may be administered as a requirement to progress to a learner licence and/or a provisional driver's licence. Commonly the theoretical and practical assessments are not completed during the same assessment setting (Bates et al., 2013).

7.1 Practical driving assessment

The practical driving assessment is especially critical as it serves the purpose of evaluating the learner driver's competence in operating a vehicle in traffic, with the aim of differentiating between safe and unsafe drivers (European Commission, 2007). This assessment is completed on-road. No examples were found within the literature of a novice driver practical driving assessment being conducted solely in a simulator. However, one example was identified for truck driver assessment, in Ecuador, replacing an assessment which had previously been conducted on a closed (no traffic) circuit (Allen, Woon, Park & Grant, 2010). The assessment simulator is made up of a vehicle seat, steering wheel and pedals in front of a 42 inch flat panel display. The setup is similar to level C simulator classification from the EU TRAIN-ALL project. The simulated testing scenarios depict the look and feel of driving in the capital city of Ecuador (Guayaquil). There are four components of the driving assessment (1) Orientation drive, used to familiarise participants with the simulator, (2) Rural drive, 8 minutes including high speeds, required speed reduction, left turn into oncoming traffic and an overtaking task, (3) Suburban drive, 5 minutes at slow vehicle speeds with narrow streets and pedestrians, (4) Metro drive, 5 minutes with many pedestrians and high traffic volume, includes merging and right turn intersections. The simulator assessment provides examiners with performance scores including major (accident and traffic offences) and minor errors (e.g. crossing centre lines, fail to use turn indicator etc). Examiners interpret the performance scores to determine if a licence should be granted. This novel approach provides new insight into the application of simulators for driver assessment, however at the time of publishing Allen et al. (2010) note that only four people had undergone assessment (2 passed) so it was too early to determine road safety implications for simulator assessment and it is not stated if simulators are now explicitly used for assessment or if closed circuit assessment is still possible. Further, this application is for the assessment of truck drivers who would already be experienced car drivers. Therefore, it is not possible to infer results to the assessment of novice drivers.

Practical driving tests have several weaknesses which simulator assessment may have potential to address. In on-road driving tests, the novice drivers under examination are unlikely to be exposed to all required traffic situations and variation in traffic routes that they will be expected to successfully negotiate once qualified (OECD, 2006). Additional disadvantages of the on-road practical driving assessment reported by Kappé, de Penning & Marsman (2010) include the examiner's inability to control the traffic situations encountered during the testing session, the potential for student performance to be influenced by extraneous factors, and the role of the assessor in interpreting the driver's performance, such that bias based on the students' age, sex or other personal characteristics may influence the test outcome. The Organisation for Economic Cooperation and Development (OECD), (2006) notes that the practical driving assessments may be unreliable at assessing learner

driver's ability to drive safely without supervision, in doing so it quotes a test-retest reliability of 64% based on research conducted in Great Britain (Baughan & Simpson, 1999). This finding suggests that if novices were required to complete a practical driving test twice, 36% would receive a different outcome on their second sitting. Furthermore, it is well documented that newly licensed drivers are at higher crash risk than all other groups of drivers (Lewis-Evans, 2010; Mayhew, Simpson, & Pak, 2003) and evidence suggests that there is little relationship between on-road assessment scores and subsequent crash risk (Senserrick & Haworth, 2005). Such results indicate that current practical assessments are not adequately determining subsequent safe driving performance.

To date, simulators are not used to assess practical driving skills. However, the Netherlands who are at the forefront of simulator training, are also leading the development of simulation for driver assessment. Kappé, de Penning, Marsman & Roelofs, (2009) state that "tasks that can be trained well can also be assessed well" in simulators (p. 185) and go on to note that the specific simulator features required for accurate assessment will depend on the skills to be assessed. For instance, it is likely that operational skills would only be assessable within a fully instrumented cab, whereas assessment of visual scanning skills may require at least a 180 degree visual view, while assessment of traffic negotiation would only be feasible if scripted interactions with other road users are programmed into the simulator. Each of these assessment examples would be difficult even with the modern high fidelity simulators, as high end hardware and a full range of scenarios to all possible traffic encounters would be required. Despite the difficulties, an assessment module is currently being developed to assess practical driving skills. Development is being informed by data collected on student performance on trial simulator assessments, and on-going research of instructor assessment of learner performance to incorporate their decision making processes into a simulator program to assess driver skills Kappé et al. (2009).

While it appears unlikely that simulator assessment will replace practical driving assessment of novice drivers in the near future, driving simulators may have potential applications for the assessment of isolated procedural skills, which, although integral to driving are rarely encountered during practical driving assessments. For example, driving under extreme weather conditions or responses to potentially dangerous situations are events which would not routinely be encountered during a practical driving assessment but could be programmed into a simulator assessment.

Although such an isolated procedural skill assessment is not yet available, simulator research comparing novice and experienced drivers shows that such skills are measurable and heightened in the experienced driver (Damm, Nachtergalele, Meskali & Berthelon, 2011). In that study, participants received brief training on how to operate the simulator prior to completing two drives in which a series of hazardous scenarios occurred in counterbalanced order. Example situations included a vehicle suddenly leaving a parking space, being over taken, and a vehicle turning across the driver's path. The performance of newly licensed drivers was compared with experienced drivers. The experienced group ($n=12$) had held their licence for at least 3 years and had driven 50,000km or more, while the novice drivers consisted of 12 participants who received their open licence less than one month ago (note: this is a United Kingdom study where there is no provisional licence) after 20 hours of professional instruction, and a second group of novice drivers who had completed 3000km supervised driving post licence, in addition to professional instruction prior to licensing. Participants were all male and recruited from a driving school. The driving tasks were carried out in a medium fidelity (similar to Level C EU TRAIN-ALL classification) simulator which

consisted of a fully instrumented driving seat and a screen which presented a 150 degree view of the driving scenario. All groups were found to respond similarly to the scenarios in terms of reaction time and speed, however there were subtle differences in performance related to road position as the two groups of novice drivers were more cautious in some situations than experienced drivers. The experienced drivers were more effective in their evasive manoeuvres, followed by the novice drivers with 3000km supervised on-road experience. This type of simulated hazard test appears to be sensitive to differences between experienced and novice drivers; however, during testing eight crashes occurred. Two crashes occurred in the experienced group, two in the novices with extended supervision and four in the novice group without extended supervision. Before such a test could be practically applied to driver assessment, it may be desirable to ensure that it could be completed by experienced drivers without crashing, thus demonstrating sensitivity to driving experience.

7.2 Hazard perception assessment

The most advanced area of simulator training for novice drivers is that of higher order cognitive skills training (discussed in section 6.2). Similarly, the most advanced area for simulator assessment of novice drivers is that of the higher order cognitive skill hazard perception. Hazard perception skills are vital to safe driving (Lidestam et al., 2010) and form a standalone component of assessment in many jurisdictions prior to progression to less restrictive licences (OECD, 2006). Computer-based tests are beneficial for the assessment of hazard perception due to the lack of potential risk to novice drivers and examiners, and the ability to control the presentation of hazards which is not possible in practical driving assessments (Wetton, Hill & Horswill, 2011). Prior to the introduction of a hazard perception test (HPT) to jurisdictional licensing requirements, it is common for development and validation research to be completed. The literature surrounding the development and validation of HPTs is considered in Australia, the United States of America and Europe in sections 7.2.1 to 7.2.3.

7.2.1 Australia

The Victorian HPT was originally implemented in 1996 as a component of provisional licence assessment along with a theory and practical driving test (Catchpole & Leadbeatter, 2000). Apart from Western Australia, Victoria is the only jurisdiction within Australia that requires the passing of a HPT prior to obtaining a provisional licence. The original version of the Victorian HPT was found to possess low re-test reliability. However, HPT performance was found to predict fatal and serious injury crashes, suggesting that although test results were not consistent, the underlying concept was related to safe driving. The test was later upgraded in an attempt to improve the reliability of the instrument. This included a revision of the instructions to simplify the test for users with limited English language proficiency, as well as a detailed practice session to train users to interact with the HPT interface.

The format of each practice hazard scenario involves responding to the hazard via touching the screen, and participants are asked to select an appropriate action such as slow down, overtake, turn, or move off. Participants also received feedback indicating their action and whether it was correct. The instruction and practice format was trialled with 10 users and revised to make the session timing user-controlled rather than automated. The number of possible hazard scenarios was also increased from 12 to 150. The new scenarios were informed by Victorian statistical data on car crashes reported to police where the driver was not intoxicated. Focus was placed on the crash scenarios most commonly experienced during the first year of unsupervised driving, those which highlight skill

deficits and those occurring in frequently experienced driving scenarios. The most common crash scenarios were used to model 49 traffic scenarios; several variations of each were developed to form a total of 150 potential simulator scenarios (Catchpole & Leadbeatter, 2000). Of the 150 potential scenarios, 110 were later filmed in 20-30 second segments using a camera within a vehicle to depict the driver's view of the road (Catchpole, Pongdon & Leadbeatter, 2001). All of the filmed scenarios and the scenarios from the original HPT were used for pilot testing. The pilot HPT was administered to a total of 405 learner, provisional and expert drivers, 363 of which provided useable responses. Items were analysed via Rasch modelling (a statistical technique commonly used to investigate the relationship between ability and test difficulty) to identify which scenarios received infrequent correct responses. These items were either corrected if testing parameters were considered to be too stringent or deleted if such modification was not possible. This resulted in a pool of 90 scenarios. Males were found to achieve higher scores on the HPT than females, and this finding was statistically significant. Expert drivers achieved greater scores than provisional drivers, who obtained higher scores than learners, although these findings were not statistically significant. The final version of the HPT included 30 scenarios of approximately 15 seconds each. These scenarios either required a response from the user, or no response due to a lack of opportunity to safely take action. As a result of this revision, the test/retest reliability of the Victorian HPT has been increased from .27 to .68 (higher values representing better reliability, with 1 indicating perfect reliability).

Wetton et al. (2011) describe the development of the hazard perception test for the Queensland licensing system by Horswill and co-authors. In Queensland, drivers are required to pass a hazard perception test to progress from a provisional to open licence. According to Wetton et al. (2011), a hazard perception test should present realistic driving scenarios where hazardous situations are clearly identifiable. Furthermore, the purpose of the test should be a specific measure of hazard perception skills only, such that all differences between examinees reflect variation in hazard perception skills and no other influencing factor. Lastly, the test should be able to accurately classify appropriate and inappropriate responses to prevent cheating, for example, by repeated pushing of a button. Similar to the Victorian HPT, the Queensland HPT development process involved the identification of common crash scenarios experienced by novice drivers. In this case, focus was on crashes occurring as a result of inadequate visual scanning, these included crashes into another car travelling in the same or opposite direction, and crashes into pedestrians, cyclists and motorcyclists. Filming then commenced with video being taken from within a vehicle cab to provide a driver's perspective of potentially hazardous scenarios with other road users in a variety of driving contexts. The video footage was evaluated by experts to identify scenarios where unambiguous hazards were safely evaded by the driver, and which were proceeded and followed by uninhibited driving. This was to ensure that the hazard could be accurately perceived by test takers. A total of 91 scenes fulfilled these criteria. A trial HPT was constructed with 15 driving scenarios preceded by a simple video that instructed users to pretend they were driving the car, and to identify situations where they would be required to slow down or change course to avoid a crash. Participants responded to hazards by clicking on the other road users likely to be hit in a crash as soon as they recognised the need to intervene. To ensure that the test instructions were comprehensible to users with limited language skills, the test was administered to a sample of 18 licensed drivers from a non-English speaking background with English language proficiency comparable to a 10 year old native speaker. Participants were given the option to replay the video, and reaction time, mouse skills and language proficiency were also measured to control for these variables. Fifteen participants reported that

they understood the video, and were able to correctly respond to 92% of hazardous situations. The remaining participants who did not understand the video indicated a very low level of English language proficiency. A second study evaluated the 91 hazard scenarios using a sample of 94 learners and 56 experienced drivers. The learner drivers indicated an average age of 18 years (range 16-44 years) and had driven an average of 3,439km (range 0-30,000). Experienced drivers reported an average age of 47 years (range 40-72 years), and had driven an average of 19,671km (range 250-16,458). Experienced drivers had held an open licence for a minimum of 15 years, while learner drivers had held their learner licence an average of 4.2 months. Participants were recruited from Brisbane, Toowoomba and surrounding areas, the majority owned a computer (96%) and were familiar with operating a computer mouse (95%). Learner drivers displayed significantly faster reaction times and better mouse skills compared to experienced drivers, which is likely to reflect age differences in the two samples. Despite greater computer proficiency, learner drivers were significantly slower at responding to hazards compared to the experienced drivers. Compared to experienced drivers, learner drivers were also more likely to fail to respond to hazards. HPT scores were not related to computer or mouse experience, education level, income, or gender. From this pool of 91 items, 60 items with superior discriminant validity were selected to represent the different crash types, which were divided into four different hazard perception tests currently used for licensing in Queensland, Australia (Wetton et al., 2011). Such detailed development provides the greatest potential that HPT will have an impact on road safety. By following the development procedures outlined above, both the Victorian and Queensland HPTs specifically target assessment of skills known to be necessary to avoid the crashes most common to novice drivers. However, it is important to note that HPTs are not expected to be effective in isolation. Rather, they should form part of a wider driver training/education program. The effectiveness of a HPT will likely be influenced by its position within a GDL. As such, it is difficult to make comparisons between jurisdictions which position the HPT at different points within a licensing system (i.e. for comparisons with the UK). In addition, the lack of long term evaluation means that impact on road safety is inferred and may not be absolute.

New South Wales drivers are required to pass an HPT comparable to those described above for Queensland and Victoria in order to progress from a provisional licence to an open licence (Senserrick, 2007). The large scale DRIVE study collected data on 20,822 novice drivers aged under 25 years in New South Wales (Boufous et al., 2011). In the DRIVE study, scores on the HPT were compared with police recorded crashes for up to one year, controlling for risk taking behaviour, age, gender, socioeconomic status, location and driving experience. Overall, 85% of participants passed the HPT on their first attempt, while 12.7% passed on the second attempt, and the rest required three or more attempts to pass. Pass rates decreased with older age, increased remoteness and decreased socioeconomic status. Logistic regression analysis revealed that failing the hazard perception test twice or more almost doubled the risk of being involved in a crash (Relative Risk: 1.83), and the risk was even higher for males (Relative Risk: 2.5) and residents of rural or remote locations (Relative Risk: 5.53) who had failed the HPT at least twice.

7.2.2 United States of America

Scialfa's, (2011) HPT was developed for use with a North American population, and both hazard and hazard-free video clips were included for comparison. A total of 95 driving scenes lasting from 10 seconds to just over one minute were filmed within a vehicle cab to provide a driver's perspective.

However, two thirds of the scenes involved the driver taking evasive action to avoid a hazard, while one third of the scenes did not involve a hazard and were included for comparison. Participants were aged approximately 21 years or less, 83% were experienced with at least 2 years unsupervised driving experience, while 17% indicated less than 6 months of driving experience and were classed as novice drivers. The scenes were presented on a touch screen computer approximately 50 cm away from the participant, who was required to touch the hazard onscreen when an evasive action was deemed necessary. Novice drivers demonstrated significantly slower reaction times than experienced drivers, at 3.16 seconds and 2.76 seconds respectively. Hazard miss rates were 8.62% and 5.18% for novice and experienced drivers respectively, while comparable rates for false alarms were 3.62% and 4.55%, with experienced drivers demonstrating more false alarms. However, a logistic regression failed to accurately predict misses and false alarms for novice drivers, possibly due to the small number of novice drivers (n=29) included in the study. Results suggest that HPTs are sensitive to differences between novice and experience drivers, indicating that they are likely a good tool to assess when a novice has obtained hazard perception skills. As at 2008, hazard perception testing was not an explicit requirement for licensing for many jurisdictions within the United States of America (NHTSA, 2008).

7.2.3 Europe

Great Britain is considered to have one of the most stringent driving test protocols of any European country (House of Commons, 2007).¹ Drivers in Great Britain have been required to pass a computer-based HPT as a component of a theory test during the learners' licence phase since 2002 (Wells & Baughan, 2003). According to Grayson and Sexton, (2002) the HPT used in Britain was developed and piloted by the National Foundation for Education Research using a similar protocol to HPTs developed in Australia. The HPT used in the United Kingdom was refined for the purpose of licence testing and the final version consisted of two alternate forms (A and B) with 27 items each. These two forms of the test were each trialled on 150 of the following three groups: learner drivers, novice drivers on an open licence with a maximum of two years driving experience (note: this is a United Kingdom study where there is no provisional licence), and experienced drivers with a minimum of 10 years' experience. It was found that 16 scenarios distinguished between all three groups of drivers, while an additional 22 distinguished between experienced and less experienced drivers only. These 38 items were retained for the final version of the HPT which possessed a reliability of 0.81 for form A and 0.84 for form B (Grayson & Sexton, 2002).

Findings from the Cohort Study, which followed the experience of learning to drive from 1988 to 2005, suggested that the introduction of the UK HPT in Great Britain reduced crash risk (Wells, Tong, Sexton, Grayson & Jones, 2008). In the UK, once the practical driving assessment has been passed novices receive an open licence; there is no provisional licence stage. The main findings were (1) learner drivers who had passed the HPT were more likely to report readiness for undertaking their practical test and were more likely to pass their driving test on their first attempt (53%) compared to learners who had not completed a hazard perception test (39%), (2) Passing of a HPT and HPT score had a small effect on crash risk (in the first year of unsupervised driving) when demographic and

¹ The terms 'Great Britain' and 'United Kingdom' are often used interchangeably in the literature. A distinction is made in this section to denote that the Hazard Perception test referred to here is used throughout the UK (England, Wales, Scotland and Northern Ireland) but that the evaluations related to it used samples drawn specifically from Great Britain (i.e., no participants from Northern Ireland were used in the evaluations).

driving related variables were controlled for. In relation to crash risk, passing the HPT was associated with a reduction in crash risk of 0.3% compared to drivers who had not passed the HPT. Higher scores on the HPT were associated with a subsequent crash risk of 0.9% lower compared to drivers who received low scores on the HPT. In this analysis, low speed minor crashes common to novice drivers were removed. These results suggest that the introduction of the HPT has had a positive impact on road safety in the Great Britain, however, it is unclear if results will be transferable to jurisdictions with a GDL.

While it appears that no other European jurisdiction incorporates a separate test explicitly for measuring hazard perception, Malone & Brunken, (2013) state that a portion of the computer-based theoretical driving test in Germany is devoted to testing hazard perception skills. They conducted two separate studies comparing the effects of photo and video presentations of hazards in HPT, and changes in video-based HPT performance over time for drivers attending driving schools. In the first study, 63 expert drivers (minimum 2 years independent driving experience) and 57 novice drivers (learner drivers with no unsupervised driving experience) were randomly assigned to either the photo or video condition to complete a 22 item HPT. Neither participant experience level or test presentation affected test scores. However, there was an interaction between experience and test presentation, such that experts outperformed novices in the photo condition, while both groups performed similarly in the video condition.

In the second study, 50 learner drivers and 50 experienced drivers completed three HPTs over a period of 9 to 12 months during which learner drivers progressed towards preparing for their practical driving test. Learner drivers were found to improve their HPT scores from time 1 to time 2, and time 2 to time 3. Malone & Brunken's, (2013) research showed that video-based HPTs were a useful assessment aid for monitoring learner drivers' performance. Although the test developed in the study did not reliably distinguish between experienced and inexperienced drivers. It should be noted that the theoretical test in Germany is not meant to assess learner drivers' readiness for unsupervised driving. However, if such a test were to be used as an assessment, validation would be important. A valid test of hazard perception skills must be able to discriminate between experienced and inexperienced drivers (e.g. OECD, 2006; Wetton et al., 2011).

7.3 GDE levels addressed by simulator assessment

The only GDE level currently being addressed by simulator assessment of novice drivers is 'mastery of traffic', although there is evidence from truck driver assessment that simulator assessment can also address the GDE level 'vehicle manoeuvring'. The practical driving assessment is used to evaluate learner driver's competence in operating a vehicle in traffic, and ultimately differentiating between safe and unsafe drivers (European Commission, 2007). Under practical on-road circumstances, driving examiners should have opportunity to assess novice drivers against the range of GDE levels. However, one disadvantage of practical driving assessment is the examiners inability to control the traffic situations encountered (Kappé et al., 2010). Consequently, some examinees may not be exposed to situations which allow them to demonstrate skills relating to each GDE level. Simulators may have potential to address this issue, as hypothetically, it should be possible for simulator assessment to be applied to any area of training, provided that the simulator is designed to address the assessment needs, e.g. traffic negotiation assessment requires a simulator with traffic programming capabilities (Kappé et al., 2009). However, there is currently no evidence to suggest that simulators are able to be used as a component of the novice driver practical driving assessment.

There is strong evidence that basic simulators can be successfully used to assess the 'mastery of traffic' skill of hazard perception (e.g. Catchpole & Leadbeatter, 2000; Wetton et al., 2011; Grayson & Sexton, 2002). It is common for a PC-based simulator assessment to be required as part of licensing independently from the practical driving assessment (Bates et al., 2013). These simulator assessments focus on the specific skill of hazard perception and consequently only address the GDE level of 'mastery of traffic'. No current evidence was identified for the use of simulator assessment to address any other GDE level in novice drivers. Research development into simulator training and assessment are likely to maintain a strong relationship. Currently, there is most evidence for the training and assessment of 'mastery of traffic' skills. If strong evidence emerges demonstrating ability to train other GDL levels it is likely that assessment development will follow, because skills which can be taught in simulators should also be assessable in simulators (Kappé et al., 2009).

7.4 Summary

The literature discussed above demonstrates the current limited use of driving simulators as assessment tools. In particular, there has been little application of driving simulators to procedural skill assessment. Although, evidence is developing that suggests simulators of the future may have a role to play in novice driver assessment. The controlled nature of a simulator is an attractive option for assessment as it means that all examinees can be tested against the same criteria, which should result in a high reliability test. In particular, benefits may be realised for the manipulation of uncommon events (OECD, 2006). There is little evidence that exists for using simulators to test procedural skills, although, in theory, skills which can be trained in a simulator could also be tested in a simulator (Kappé et al., 2009). The first steps in research to demonstrate the use of simulators for assessment are being taken, with evidence that simulator assessments can accurately distinguish between experienced and novice drivers (Damm et al., 2011). Further research and development is now necessary to refine simulator assessment so that the accurate separation of novice drivers with adequate skill from those requiring further training is possible. In contrast, research, development and subsequent validation has already been conducted for PC-based HPT. These tests form a legal component of licensing for many jurisdictions. While under a tighter simulator definition, PC based HPTs may not be seen as a form of simulator assessment, under the definition of the current report they are accepted. Hazard perception is a good choice of skill to assess using a simulator because the simulator allows the controlled presentation of hazards which is not possible during a practical driving assessment (Wetton et al., 2011). The development of HPT has been well invested in and consequently the tests produced are highly repeatable and are specifically targeted at assessing the skills required to avoid the most common form of novice driver crashes (excluding low speed minor crashes, e.g. Catchpole & Leadbeatter, 2000; Wetton et al., 2011; Grayson & Sexton, 2002). HPTs have not only been demonstrated to be sensitive at identifying those who require further skill development, but have also had practical impact on reducing crash risk (Boufous et al., 2011; Wells et al., 2008). However, there is no clear consensus as to when HPTs should be administered, with some jurisdictions favouring the learner stage and others the provisional stage.

There is still limited evidence as to which skills, beyond hazard perception, would be best suited to assessment via driving simulator. It is also not clear how such testing would be practically implemented into a licensing system. However, simulators for testing specific skills, in combination with a practical driving assessment may have potential for application in novice driver assessment.

8 Transfer-of-training case study

The final component of the current report is a case study of an on-going Canadian investigation, “Transfer-of-Training” (ToT), into the use of driving simulators for novice driver training. This work is one of the first to empirically investigate the long term and practical implications of using driving simulators for novice driver training using a naturalistic design. This is the first study in which learner driver participants are allowed to substitute mandatory on-road instruction for simulator based instruction. Consequently, the simulator is being used instead of, rather than in addition to “training as normal”. In this case, simulator learning is implemented at the learner licence phase. Although this program of research is not yet complete, its innovative approach was considered directly relevant for the current report, and therefore warranted inclusion. The below overview and preliminary results have been verified by Dr Pierro Hirsch, the lead investigator of this project.

8.1 Project methodological overview

The ToT pilot study was initiated in 2010 to use a “real world” protocol to examine the effectiveness of substituting hours of simulator-based driving training for hours of on-road driver training.

8.1.1 Context

In Quebec, learner drivers are required to complete the driver program administered by the Quebec Government Insurance Board (SAAQ). This includes a set curriculum of 24 hours of class room theory and 15 hours of on-road lessons, completed in a minimum 12-month period. The development of this curriculum was grounded in research evidence and is designed to address each aspect of the GDE (SAAQ, 2010). Learners participating in the ToT project are allowed to substitute one hour of on-road instruction for one hour of driving simulator instruction, for up to 6 hours of the mandatory 15-hour on-road lesson requirement.

8.1.2 Participants

All driving schools in Quebec were invited to participate, currently three have accepted. Learner drivers attending each school were free to self-select to undertake simulator training, participants receive no financial incentive for participating in the study.

8.1.3 Instructor training

The simulator is a novel teaching environment for the driver trainers. To ensure the driver trainers are able to teach in the driving simulator, a three-day train-the-trainer course has been delivered to all driving instructors involved in the project, an instructor’s guide has been made available and voluntary annual workshops are being offered.

8.1.4 Driving simulator scenarios

All training is being delivered using set scenarios in a VS500M driving simulator. A rigorous process was undertaken to develop the simulator scenarios. The decision was taken to focus on vision skill as the primary training area of concern. Vision skill may be considered a type of situation awareness training, whereby the trained skill involves knowing where and when to look, who and what to look for and how to interpret the information correctly. Each scenario follows a set pattern of progression from simple through to complex tasks. The simulator allows for performance to be replayed to the trainee from both the driver perspective and an overhead view. The scenarios represent a range of learning outcomes, including, how to check mirrors and blind spots, driving in different environments and climate conditions and hazard perception training.

In total, 6 hours of driving simulator learning scenarios are available. These are organised according to the SAAQ novice driver curriculum (SAAQ 2010). Each one-hour simulator session contains several 5 – 10 minute training scenarios. No prescribed number of scenarios per hour has been stipulated. Each simulated scenario is preceded by a PowerPoint slide detailing the learning content for each scenario. The 8-minute (average) long scenario is then completed. In many cases this is then followed by objective driver performance feedback.

8.1.5 Measures

The final results of the ToT study are due in December 2015. They will address two main questions:

1. Compared with on-road instruction, do novice adolescents learn driving skills in a driving simulator with equal or greater efficiency?
2. Does driving simulator-based training improve adolescent driver safety?

To address these questions learner driver participants will be monitored for one to three years, with the primary outcome measures being:

- Performance on the practical driving test, e.g. number of attempts required to pass
- Traffic offences
- Police-reported crashes, i.e. frequency, type and severity

Secondary outcomes include:

- Subjective opinions of learners as to the simulator learning experience
- Subjective opinions of learners trained on the driving simulator
- Interactions between individual characteristics and primary outcomes (e.g. Does simulator training moderate risk-taking tendencies measured by first questionnaire and manifested by first year(s) of driving record data?

8.2 Preliminary findings

As the study is on-going, main results are not yet available. To date, one cohort of novice driver adolescents has completed their driving training. Preliminary, secondary outcome findings relating to initial perceptions of the simulator training from this cohort have been presented at the 2013 Canadian Multidisciplinary Road Safety Conference (Hirsch, 2013). Here, the results most relevant to the current report have been summarised.

8.2.1 Learner driver participants

So far, 159 learner drivers (mean age 16.45 years), 51% male, have completed at least one hour of training in the driving simulator and graduated from the driving school. The learners completed three questionnaires, at three different time points during their 15 hours of training.

- Questionnaire one: completed at signing up to the project. This questionnaire measured computer use, past traffic experience (motorised and non-motorised vehicles), risk perceptions and lifestyle.
- Questionnaire two: completed after the first driving simulator lesson. This questionnaire evaluated the learning experience.

- Questionnaire three: completed after the final on-road evaluation at the end of the mandatory twelve-month driving school program. At this point the learners had completed both simulator and on-road lessons and covered the complete SAAQ curriculum.

Simulator exposure

The way in which the simulator was incorporated into the training program varied between the three participating driving schools. The first school to participate developed methods for integrating the simulator training, and did so in a way that most suited its clientele, as a result the majority of participants completed at least 3 hours simulator training. The second school to join the project worked in conjunction with the first to set up its simulator training, which is consequently similar. The final school restricted access to the driving simulator to one hour per student. Despite variations in simulator exposure there was no statistically significant association between the number of simulator training hours and questionnaire responses.

Perceptions of initial simulator use

Two sets of items were investigated following the first driving simulator lesson: (1) psychological or emotional reactions to simulator learning, (2) opinions of the session structure, scenarios and potential benefits to simulator learning. In general, participants found the simulator learning enjoyable and stimulating, although not entirely easy or relaxing. In regards to the simulator session itself, participants were positive about the session and saw benefits in simulator-based learning. Questionnaire three also contained the questions of (1) Learning to drive on the simulator. Overall appreciation for using a simulator to learn to drive improved from questionnaire two to questionnaire three. In particular, appreciation for ease of learning and relaxed learning increased. As a comparison, participants were also asked to rate their experience of on-road practical driver training. Participants perceived the simulator learning to be easier, more relaxed and slightly more enjoyable.

Finally, questionnaire three listed 15 skills of driving and asked participants to retrospectively consider the efficiency of learning each skill in a one-hour on-road lesson compared with a one-hour simulator lesson. The simulator performed most favourably for: understanding the mirrors and blind spots, driving in city traffic, risk perception, expressway merging and exiting and visual exploration. In contrast, parking was considered more efficient to learn on real roads and response was mixed as to whether speed control was more efficiently learnt in the simulator or on-road.

8.2.2 Driving teachers

The perceptions of the driving teachers were also investigated by questionnaire. Nineteen driving teachers have evaluated their students driving competency as a result of simulator training. The questionnaire was completed following the on-road evaluation conducted at the 15th (final) hour of the mandatory driving course. Evaluation questionnaires were completed in relation to 114 trainees. Of the 114 trainees, the driving trainers predicted that 87.3% would pass the Quebec government road exam on the first attempt. These results do not specifically relate to the simulator.

8.3 Conclusion from results so far

Overall, students found the simulator to be an easier and more relaxing learning environment than on-road driving lessons. These feelings appear to increase over the first year of learning to drive.

It should be noted that the simulator was a very controlled learning environment with a highly structured lesson progression. It is not possible to achieve the same level of controlled structure during on-road training. In addition, during on-road lessons, a teacher's attention is necessarily directed at reducing risk for the learner and all other road users in the immediate vicinity. In contrast, in a simulator the teacher can focus 100% of his or her attention on teaching the skills required by the learner driver to control their own driving risk in the real world. In this way, a driving simulator acts as a bridge between the theory of driving and real-world driving exposure to uncontrolled situations. This is achieved by allowing the learner to be guided by the teacher through a series of planned driving exercises, designed to help the learner understand and practice behaviours that systematically reduce their risk of crashing. It is arguably safer and more efficient to learn and practice these crash prevention behaviours without actually exposing oneself to actual crash risk.

8.3.1 Limitations

As this is the first empirical study to investigate the use of driving simulators for novice driver training in a naturalistic protocol, it is partly exploratory in nature. The best practice methods for implementing simulator-based driver training are not yet known. The individual participating schools have implemented simulator training into their curriculum in a manner best suited to them. The applied nature of this protocol results in many uncontrolled variables which may potentially influence how the simulator is used. However, it should also be noted that on-road driving instruction is subject to these same limitations.

Learner drivers were free to self-select into simulator learning. In particular, this is likely to have an impact on self-report measures as those with favourable attitudes towards simulator learning may be more likely to have volunteered to participate, thus causing bias in the questionnaire sample. However, the objective measures of crashes, offences and driving test pass rates which will later be collected will enable a fuller picture of the effectiveness of simulator training.

9 Overall conclusion

Interest in the use of driving simulators for novice driver training and assessment has been growing, which is reflected in the increasing body of literature on this topic. However, when evaluating the effectiveness of simulators as a road safety intervention, it is difficult to produce an overarching consensus. In part this is due to “significant” results bias within published literature, meaning that studies demonstrating a significant result are more likely to be accepted for publication than those reporting not significant differences (Easterbrook, Gopalan, Berlin & Matthews, 1991). A further limitation in interpreting the literature is that simulators as technology are an area subject to great individual differences. This means that while training or assessing a particular skill may be successful using one simulator configuration, it may not be successful in a different simulator. The underlying mechanisms causing these differences are not understood (Ouimet et al., 2011) and to date, little attempt has been made to compare between simulated training techniques to understand these differences (Samual et al., 2013). The simulator itself is a tool, as such the outcomes of training will be as much (if not more) influenced by the processes and goals of the education program as a whole as they will be by the physical simulator used. Currently, there is a lack of research controlling for educational aims and curriculum and only altering point of implementation (simulator vs on-road) without such a controlled investigation it is not possible to separate the influence of the education material from the influence of the delivery method. It has been proposed that the ideal novice driver training program must address all levels of the GDE (Hatakka et al., 2002). Currently, simulator training and assessment appears most proficient at addressing the lower GDE level of ‘mastery of traffic’ although, some evidence is also starting to emerge for the benefits of training ‘goals for life’. The focus of simulator training and assessment research towards this one level suggests that an exclusively simulator based training program is a long way off.

The most important consideration when inferring results from a particular simulator training or assessment tool to real world context is the ecological/relative validity of the simulator. That is, one must consider the degree to which driving behaviour observed in the simulator is representative of driving behaviour on real roads. A further consideration is that of simulator fidelity; the extent to which the simulator behaves in a real world manner. It is clear within the novice driver simulator literature that it is possible to have a low fidelity simulator with high validity. Repeatedly, it has been demonstrated that hazard perception can be trained and assessed with low fidelity simulation (often as simple as button pressing in response to a visual PC task) resulting in a corresponding real world behaviour change, and subsequent reduction in crash risk (Boufous et al., 2011; Wells et al., 2008). However, although this is the case for hazard perception, there is insufficient evidence to determine if low fidelity simulation will have similar success with other driving skills. In particular, high fidelity is likely to be important if training or assessing procedural skills (Andersen, 2011). Evaluating the required simulator fidelity and validity necessary to successfully achieve novice driver training and assessment is practically impossible due to inconsistency in describing simulators within the literature. There is no standardised taxonomy by which simulators are classified; an EU classification has been developed (Lang et al., 2007) but it is not widely used. While one researcher may describe their simulator as high fidelity, another may describe the same simulator as medium fidelity. Without a definitive way to compare between simulator studies it is not possible to speculate on which aspects of simulators are necessary for effective novice driver training and assessment.

One influencing factor relative to the use of driving simulators for novice driver training and assessment is the lack of actual risk or danger. This distinct difference from on-road driving presents both opportunity and limitation. The lack of risk may mean that simulator users do not respond to the training/assessment as seriously as they would do if they were driving on real roads (Ranney, 2011). Further, due to both lack of risk and lack of journey purpose it is hard to apply simulator-based training/assessment to the higher levels of the GDE matrix. Conversely, the lack of risk presents an opportunity to remove the distracting component of vehicle control allowing the novice to focus on the specific skill of interest. Completely novice drivers lack automation of vehicle handling because this skill develops with experience. Consequently, new novice drivers have to apply a comparatively larger amount of effort to handle the vehicle than more experienced novice drivers, thereby reducing their capacity for learning a new skill, such as hazard perception (Vlakveld, 2011). When the risk is removed, novice drivers are free to focus on training of the new skill. This approach has been successfully applied to the GDE level of 'mastery of traffic'.

It is important that a trainee invests emotionally and psychologically in the simulator training, and believes it to be applicable to real driving. There is some concern that using simulators as training tools may result in overconfidence, in part due to a lack of real risk. However, while overconfidence following simulator training has been observed by some (Rosenbloom & Eldror, in press) it has not by others (Regan et al., 2000b). If real world driving skills are improved by simulator training, any practical road safety benefit would be diluted if the training also results in overconfidence. The inconsistency within the published literature leaves it difficult to determine the relationship between simulator training and overconfidence. It is possible that inconsistencies are occurring as an artefact of particular simulator set up, including both physical set up and the type/goal of the associated training, or study design, and further research is necessary before firm conclusions can be drawn. Such inconsistencies also highlight the importance of the education context in which simulator training is applied.

It appears that those predisposed to simulator based training (i.e. self-selecting to undertake simulator training), the experience of training in a simulator can be subjectively positive both for trainee and trainer (Hirsch, 2013). Further, the retrospective positive subjective experience of trainees towards simulator training has been found to increase with increased practical driving experience. This change is most likely a result of novice drivers gaining a better understanding of what is required of learning to drive. Although, it is not known if this feeling is unique to simulator training, it nonetheless demonstrates that simulator training is generally well perceived by those experiencing it. However, retrospective subjective rating is also influenced by memory, as when asked subjectively to evaluate something, the accuracy of response is related to ability to recall. Furthermore, it is possible that any developed negative perceptions of on-road learning may influence the way prior simulator training is perceived.

The only jurisdiction identified, where simulators are being widely used for novice driver training, other than hazard perception training, is the Netherlands. Here, first stage learner drivers are expected to undergo training using a medium fidelity simulator. This training is administered according to a standardised curriculum (across 18 sessions of 20 minutes each), with clearly stated learning goals for each component (Kappé, 2005). Emphasis is placed on higher order cognitive skills while basic procedural skills are taught during practical driving lessons (Fisher et al., 2011). Simulator training in this manner results in novice driver skill acquisition, but the longer term effect on on-road

driving behaviour, as measured by crashes and traffic offences are currently unknown (de Winter et al., 2009). The mainstream introduction of simulators for training in the Netherlands is relatively recent and therefore, the long term impact is not yet known. It is likely that with time, more research will evaluate this simulator program. As information becomes available this will assist other jurisdictions in deciding if they wish to adopt a similar strategy.

Although, there are currently no practical examples of driving simulators being used as a component of practical driving assessment for novice car drivers, this is an area with potential. In particular, it would be possible to address some of the current limitations of on-road practical driving assessments. For instance, simulation would create a standardised experience for all examinees, with controlled environmental conditions and removal of the potential for examiner bias which may occur in practical driving assessment (Kappé et al., 2010). It would also be possible to assess response to situations not routinely experienced during practical driver training and assessment (Damm et al., 2011). While a combined approach to using a simulator in conjunction with a practical driving assessment has potential benefits, there is no evidence in the literature at this point in time that driving simulator assessment should replace practical driving assessment for novice drivers. In contrast, these potential advantages are already been realised by the inclusion of an HPT as part of the licensing process. In jurisdictions where computer based HPTs are mandatory all examinees experience the same testing conditions, which may include driving situations they do not routinely face. This may explain research evidence that shows those residing in rural areas less likely to pass their HPT than those in urban areas (Boufous et al., 2011); possibly the tests are presenting situations which may not, or rarely, have been experienced. Additionally, a standardised scoring system is used therefore test outcome is not influenced by the examiner. The HPTs are currently conducted in low fidelity simulators (often PC based). Lower fidelity simulators are attractive as they are less costly and less likely to invoke simulator sickness than high fidelity simulators (Fisher et al., 2011). The little evidence which currently exists suggests that the fidelity of a simulator used for hazard perception training has no impact on subsequent on-road crash risk (Allen et al., 2001, Park 2005; Allen et al., 2012). However, because few studies have investigated the impact of simulator fidelity on hazard perception training and assessment, it is not possible to conclusively determine whether higher fidelity simulators for hazard perception training and assessment would provide added benefit or not.

While the increase in literature in this area is improving the knowledge base regarding simulators for novice driver training and assessment, such results are not always practically applied. It has been reported that many simulators and associated training, which are being used for training are often independently constructed and have not been validated (Lang et al., 2007). As such, there may be many simulator training programs in existence which are not represented within scientific literature. In cases where evaluation has occurred there is a tendency to focus on proving the less robust outcome of skill acquisition rather than stronger outcomes such as crash risk. Notable exceptions are the longitudinal follow up by Allen and co-authors, where training in a medium or high fidelity simulator was associated with lower crash rates than control data from novice drivers with no simulator exposure (Allen et al., 2010; 2012). Additionally, two investigations into HPT assessment reported reduced relative risk of a crash (Boufous et al., 2011; Wells et al., 2008). Research priorities in this domain should include long term evaluation to determine the impact of simulator based training/assessment on crash risk and traffic offences. Currently this is noticeably lacking and should be a strong consideration for any road safety intervention. Recently, such a large scale study has

started (ToT; Hirsch, 2013), and hopefully more will follow in the future. Furthermore, there is a lack of cost benefit analysis to determine the implications for simulator training beyond what is achieved by “training as normal” and no consensus on how much on-road training/experience can be substituted for simulation without detrimental effects (also a consideration ToT).

In conclusion, while there is some evidence that simulators are beneficial for training and assessment of some novice drivers, under some circumstances, there is insufficient evidence for policy makers to make clear judgements regarding potential inclusion of simulators to existing suites of training and assessment tools. To address this gap in the knowledge base future research priorities should include:

- Long term evaluations to determine the impact of simulator training/assessment on crash risk and traffic offences;
- Cost benefit analysis;
- Improving understanding of the underlying mechanisms of training in simulators compared with practical driving;
- Standardising the classification of simulators to facilitate transferability of research findings;
- Controlled robust comparison between training programs using different types of simulators to train the same skill;
- Improving the ecological validity of driving simulators, combining skills from novice driver training experts and simulator development/engineering expertise; and
- Widening the scope of simulator training/assessment to address a greater range of GDE levels and considering where the simulator training fits within an education program as a whole.

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