

# **Driver Training and Driving Performance**

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## **Dedication**

This thesis is dedicated to the drivers of tomorrow, namely Caitlin (4years), Holly (4 years), Gareth (3 years), Jasmine (2 years), Elijah (2 years), Emma (2 years), Byron (6 months), and William (1 month).



## **Abstract**

Inertial forces experienced during driving can perturb a driver's posture, which may in turn diminish a driver's perceptual sensitivity and corresponding control actions. The general purpose of this study was to investigate the effects of a specific driver-training program taught by Holden Performance Driving Centre (Norwell, Queensland) on driver skill and driving performance as revealed by vehicle motion and postural stability during a range of common driving manoeuvres; emergency braking, cornering, and evasive lane change and return. Three driving experiments were conducted on a closed-circuit track, from which vehicle and driver kinematic data was collected using a variety of instruments. After an initial test-sessions, trainee drivers participated in a driver-training program based upon the development of perceptual-motor skills through enhanced driver's postural stability as well as instruction in vehicle control strategies that were not primarily reliant upon safety technology, such as an antilock brake system (ABS). A second test-session followed training. For all three experiments, statistical analyses were conducted between cohorts of trainee and control drivers' first and second test-sessions. For the turning manoeuvres, data from a cohort of driver-training instructors was analysed against the post-test sessions from trainee and control drivers.

In the first experiment, a group of trainee ( $n = 26$ ) and control ( $n = 13$ ) drivers were assessed during an emergency braking manoeuvre initiated from 80 and 100 km/hr in a vehicle fitted with ABS. Results indicated the post-test trainees had a significantly smoother brake profile with enhanced postural stability during deceleration compared with the control group. The trained drivers were also less reliant on the ABS, stopped within one car length, and had significantly lower mean deceleration compared with

stops assisted by good quality ABS. Results also confirmed that trained drivers were able to more effectively stabilise their upper body than were untrained drivers. Qualitative analysis of handgrip pressure data suggested that the majority of trained drivers had a more relaxed grip on the steering wheel compared with the controls.

In the second experiment, a group of trainee ( $n = 21$ ), control ( $n = 12$ ), and training instructors ( $n = 13$ ) drivers were assessed during two test-sessions for a corner manoeuvre (radius 30 m). Trainees exhibited enhanced postural stability and reduced the magnitude and onset of peak vehicle lateral accelerations following training. Prior to training, drivers who were more posturally unstable tended to demonstrate higher lateral vehicle accelerations and drivers with the biggest improvements in postural stability following training tended to have the greatest reductions in lateral accelerations of the vehicle. Training led to changes in postural stability that was associated with reduced lateral accelerations during cornering. None of these beneficial changes were evident from control drivers although they had experienced the manoeuvre during the two separate test-sessions. By comparison, the instructor drivers demonstrated better vehicle kinematics and postural stability that could be attributed to the deliberate practice required prior to instructing the training program.

In the final experiment, a group of trainee ( $n = 26$ ), control ( $n = 15$ ), and instructor ( $n = 13$ ) drivers were assessed during an evasive lane change and return manoeuvre. Travelling at 60 km/hr, drivers were required to swerve around an obstacle blocking either a left and right lane and recover back to their initial lane within a distance of 32 m. Following training, the trainee group minimally applied the brake, significantly reduced the lateral acceleration during the recovery phase, reduced the difference

between driver and vehicle accelerations during the recovery and exit phases, and in general, improved the coupling between the driver and vehicle. Trainees also reduced handgrip pressure on the steering wheel as they braced their leg against the door and console of the vehicle. In contrast, controls who applied the brake upon entry, travelled the slowest, and consequently had the most time to control the vehicle demonstrated the highest level of lateral accelerations and did not brace but rather applied large handgrip pressure on the steering wheel. The instructor group, who demonstrated low levels of lateral acceleration and greater levels of bracing, had the strongest coupling between vehicle and driver accelerations.

Based on the results of the experiments within this study, it was concluded that (i) prior to training, drivers who were more posturally unstable tended to experience greater vehicle accelerations, (ii) postural stability was enhanced following training, (iii) postural stability was established and maintained by using a lower-leg brace technique rather than the pre-training strategy of increased handgrip on the steering wheel, and (iv) trained drivers reduced the magnitude of vehicle acceleration by changes in vehicle control strategies, such as, timing changes in steering to coincide with minimal velocity and adopting a braking technique that did not rely upon ABS technology. Overall, these findings suggest that driver-training programs based upon the development of perceptual-motor skills through enhanced postural stability demonstrate positive effects on vehicle motion. An application for this study is to inform and guide advanced curriculum development in driver-training programs. When combined with other important factors, such as practicing the lessons learnt during training and driving with appropriate attitudes towards safety, driver-training programs could better contribute to overall safer driving.



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## **Statement of Originality**

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Andrew Petersen  
26 September 2007



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## **Thesis organisation**

Chapter 1 provides a brief introduction to safe driving and driver-training, and introduces the general and specific purposes of the experimental studies.

Chapter 2 reviews the pertinent literature in order to provide the background from which this research is based. This chapter reviews three interrelated areas within the literature: (i) the issues associated with driving and driving manoeuvres, (ii) the elements of driving, such the various theories of driving, physics of driving and a driver's posture during driving, and (iii) driver-training and the subsequent effects from driver-training.

Chapter 3 details the general methodology that is common to all three experiments described in Chapters 4, 5, and 6.

Chapter 4 describes an experiment that evaluates the effects of training on an emergency brake manoeuvre.

Chapter 5 describes an experiment that evaluates the effects of training on a cornering manoeuvre.

Chapter 6 describes an experiment that evaluates the effects of training on an evasive lane change and return manoeuvre.

Chapter 7 presents a summary and synthesis of the results from the three experiments presented in chapters 4, 5, and 6, and draws conclusions in regards to driver training based upon the objectives stated in chapter 1. Recommendations for future research into driver-training and final conclusions are made.

## **Publications**

The publications listed below are related to the research conducted as part of this thesis. The following journal articles have been published, accepted for publication, or submitted for publication.

Petersen, A.J. and Barrett, R.S. (under review). Driver-training improves vehicle dynamics and postural stability during an evasive lane change and return manoeuvre.

Petersen, A.J., Barrett, R.S., and Morrison, S. (2008). Enhanced postural stability following driver-training is associated with positive effects on vehicle kinematics during cornering. *Human Factors, In Press*.

Petersen, A.J., Barrett, R.S., and Morrison, S. (2006). Driver-training and emergency brake performance in cars with antilock braking systems. *Safety Science*, 44 (10), 905-917.

The following conference articles have been presented or scheduled to be presented.

Petersen, A.J., Barrett, R.S., and Morrison, S. (2007). *Enhanced postural stability after driver training is associated with improved vehicle kinematics during cornering*.

Paper presented at the 43<sup>rd</sup> Conference of the Human Factors and Ergonomics Society Australia, 26-28 November, Perth, Australia.

Petersen, A.J., Treffner, P., and Barrett, R.S. (2003). *Mobile phones and driving: Degradation of affordance perception, anticipation, and coordination?* Poster presented at the Twelfth International Conference on Perception and Action, 13-18 July, Gold Coast, Australia.

Petersen, A.J., Treffner, P., and Barrett, R.S. (2003). *What forms the basis of skilful and safe driving?* Poster presented at Sensorimotor Coordination Conference, 10-12 July, Fraser Island, Australia.

Treffner, P., Petersen, A.J., and Barrett, R.S. (2003). *Speaking on a hands-free mobile phone while driving degrades perception of affordances.* Paper presented at the Vision in Vehicles 10 Conference, 6-10 September, Granada, Spain.

Petersen, A.J., Treffner, P., and Barrett, R.S. (2002). *Dynamics, stability, and control: Driving the ideas home.* Paper presented at the 4th Australian Biomechanics Conference, 28-30 November, Melbourne, Australia.

Treffner, P., Barrett, R.S., Petersen, A.J., and White, R. (2002). *Active stabilisation and perceptual sensitivity in safe driving.* Paper presented at the Travelsafe Australian College of Road Safety Conference, 21-23 July, Brisbane, Australia.

Barrett, R.S., Treffner, P., and Petersen A.J. (2001). *Driving performance and skill: Field investigation using an instrumented vehicle.* Paper presented at the Vision in Vehicles 9 Conference, 19-22 August, Brisbane, Australia.

Treffner, P., Barrett, R.S., Walker, G., and Petersen, A.J. (2001). *Information and active stabilisation in skilled driving.* Paper presented at the Sixth Biennial Motor Control & Human Skill Research Workshop, 6-9 December, Fremantle, Australia.





# Chapter 1

## Introduction

“One thing that seems to unite all human beings  
regardless of age, gender, religion,  
economics status, or ethnic background  
is that, deep down inside,  
we ALL believe we are above average drivers.”

(Anon)



# **1.0 INTRODUCTION**

## **1.1. Background**

During the past fifty years, the number of people worldwide who drive has rapidly grown. In a country, such as Australia, most people between the ages of 18 and 70 years are regular drivers. In general, people drive a vehicle because it affords them freedom to travel when and where they want. Some people would say driving is a fun and enjoyable experience. For many people, driving a vehicle involves little more than sitting in the vehicle, starting the engine, selecting first gear (or “Drive”), and driving off; much of which is performed without conscious consideration. In general, motorists do not think of driving to be a particularly challenging task. In fact, many drivers believe they have above average driving skills (de Joy, 1989; McCormick, Walkey, & Green, 1986; Waylen, Horswill, Alexander, & McKenna, 2004; Williams, 2003b; Williams, Paek, & Lund, 1995). Yet, the high rates of traffic violations and/or involvement in a motor vehicle crash, either involving another vehicle or as a solo event, such as colliding into a tree, are not consistent with such a notion (A.T.S.B., 2006). As driving a vehicle is recognised as a complex and demanding perceptual-motor task (Gibson & Crooks, 1938; Schiff & Arnone, 1995), many driver-training programs include instruction within the curriculum for a variety of skills necessary to safely operate a vehicle.

Developing successful models of driver-training programs is a vexatious issue because unsafe driving is potentially caused by multiple factors. Unsafe driving can occur due to factors related to the driver, vehicle, or road environment, although in general, it is considered to be the driver who is predominately responsible (Brown, 1986; Groeger, 1989, 1990). Medical and psychological characteristics of a driver, traffic rule

knowledge, driving skills, and driving performance were initially used to differentiate crashless drivers (consider as safe drivers) from drivers who had preventable crashes (Malfetti & Fine, 1962). In regards to young novice drivers, specific issues include the initial learning curve to control a vehicle (Lam, 2003), factors associated with adolescent development (Keating, 2007), and a general lack of driving experience especially towards perceiving driving risks (Mayhew, 2003; Stevenson, 2005; Williams, 2003a). In regards to experienced drivers, some broad factors associated with unsafe driving include a driver's age and gender (Hakamies-Blomqvist & Peters, 2000; Turner & McClure, 2003), errors of judgement (Reason, Manstead, Stradling, Baxter, & Campbell, 1990), over-confidence (Groeger, 2001a), being under the influence of alcohol and / or drugs (pharmaceutical or recreational) (Drummer, et al., 2004; Kelly, Darke, & Ross, 2004), distractions such as conversing upon a mobile phone and / or lapses of concentration (McEvoy, Stevenson, & Woodward, 2006), and attitudes motivated by factors other than safety, such as reacting to stress, being in a hurry or sensation seeking (Jonah, 1997; Musselwhite, 2006; Parker, Reason, Manstead, & Stradling, 1995).

Driver-training typically occurs during the learning phase of driving, and to a lesser extent, after a driver has their licence in order to modify or improve established driving skills. The effectiveness of "learn-to-drive" training programs has been extensively investigated with evaluations typically having non-conclusive results (Williams, 2006). Part of the reason for non-conclusive results is considered to be due to a lack of a statistical evidence for a reduction in the rate of traffic violations and crashes after training completion (Engström, Gregersen, Hernetkoski, Keskinen, & Nyberg, 2003; Katila, Keskinen, Hatakka, & Laapotti, 2004; Lund, Williams, & Zador, 1986; Potvin, Champagne, & Laberge-Nadeau, 1988). However, some criticisms have been made

about the use of traffic violation and crash statistics for determining the effectiveness of a program. This is because confounding factors not related to training can distort the statistics of traffic violations and / or crashes, such as, events not reported or incorrectly reported (Arai, Nishimoto, Ezaka, & Yoshimoto, 2001; Cryer, et al., 2001; Hauer, 2006; Rosman & Knuiman, 1994; Shinar, Treat, & McDonald, 1983).

In contrast to the extensively investigated “learn-to-drive” training programs, little is known about the post-licence driver-training programs suitable for experienced drivers. Presumably, trainees in post-licence programs differ from learner drivers as they have progressed beyond initial learning difficulties and have gained some driving experience. Nevertheless, some review articles of post-licence training program research that retrospectively analysed traffic violation and / or crash statistics claim these training programs are also ineffective (Ker, et al., 2005; Lund & Williams, 1985; Stuckman-Johnson, Lund, Williams, & Osbourne, 1989). However, a major limitation in some reviews articles is the inclusion of numerous training programs for drivers who require special consideration, such as, elderly drivers and problem drivers (e.g., persistent drink drivers). This limitation is noticeable within the three cited review articles (Ker, et al., 2005; Lund & Williams, 1985; Stuckman-Johnson, et al., 1989). The conclusion that post-licence training is ineffective may not apply to many modern post-licence programs suitable for ordinary experienced drivers.

Recent research has shown driver-training can elicit positive effects as measured by either crash statistics or driving skill performance. The results from a French study that analysed the effects of a localised training program specifically aimed at reducing crash rates revealed that fewer young drivers after training were involved in a crash compared to untrained young driver living in neighbouring areas (Carcaillon & Salmi, 2005). In a

study into workplace crashes, a reduction in crash rates was noted from experienced commercial drivers who participated in either a training program, group discussion, or were offered financial incentives compared to a group of drivers who participated in a safety campaign or the control group drivers (Gregersen, Brehmer, & Morén, 1996). Research into training has also repeatedly demonstrated that a driver's skill at scanning for visual information improves following driver-training that utilises a computer simulator (Chapman, Underwood, & Roberts, 2002; Dorn & Barker, 2005; Fisher, Pollatsek, & Pradhan, 2006).

Another aspect of driving skills is the manner in which a driver operates a vehicle's controls, which has also been shown to benefit from training. For example, an identified problem after the introduction of anti-lock braking systems was that rate of crashes during an emergency increased rather than the expected decrease (Farmer, Lund, Trempel, & Braver, 1997). While a driver's over-confidence in the new technology was partly to blame, researchers have revealed that drivers often did not properly apply anti-lock brakes in an emergency situation until after completion of an ABS training program (Mollenhauer, Dingus, Carney, Hankey, & Jahns, 1997).

In a study by Safren, Cohen, and Schlesinger (1970), experienced drivers tended to exhibit smoother (i.e., less varied or jerky) accelerations during driving compared to inexperienced drivers. Safren, et al., (1970) discussed that smoother accelerations are a good indicator of high level skills and overall driving performance, which can potentially contribute to safer travel. A more recent investigation found similar results in a comparison between two cohorts of experienced drivers who were either (i) trained prior to the study in particular driving skills or (ii) had received no post-licence training (Treffner, Barrett, & Petersen, 2002). The trained experienced drivers exhibited lower

accelerations during cornering, lane change and return, and braking manoeuvres compared to untrained experienced drivers. This was despite each group travelling at experimentally controlled velocities. However, a question that formed from this research was whether an untrained experienced driver can improve driver skills and driving performance following participation in a driver-training program.

Driving a vehicle is an activity that occurs in an inertial environment by virtue that gravito-inertial forces are generated as a vehicle accelerates. At present, few researchers have considered the implications of vehicle accelerations and the creation of an in-vehicle environment suitable for a driver to operate a vehicle. For example, little is known about how a driver's whole body posture is challenged or how a driver accommodates inertial forces during a driving manoeuvre, such as cornering, or more demanding situations, such as an evasive lane change and return manoeuvre or an emergency brake manoeuvre. It is known from research into sporting activities, such as shooting, simulated down-hill skiing, and archery, that improved activity performances can be achieved after a person stabilises their posture (Era, Kontinen, Mehto, Saarela, & Lyytinen, 1996; Hong & Newell, 2006; Stuart & Atha, 1990). However, similar research has not been conducted in regards to safe driving. Hence, advancing our knowledge into driving activities is of interest as postural stability may be advantageous for driving performance by (i) increasing a driver's ability to detect relevant information and perception of situations and (ii) enhancing a person's ability to safely operate a vehicle (Paloski, et al., 2006; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000; Treffner, et al., 2002).

A lack of postural stability is emerging as an important area of research in relation to both safe driving and driver-training programs (Treffner, et al., 2002; Watson, 2003).

Postural stability is about controlling a body's spatial position with the intention to achieve a stable orientation within its environment (Stoffregen, et al, 2000). From Zikovitz and Harris' (1999) investigation into corner driving, it is known that drivers tend to tilt their heads into the turn. Zikovitz and Harris (1999) discussed that drivers align their head with the direction of balance, which is in the opposite direction to the gravito-inertial force. In regards to whole body posture, Treffner, et al., (2002) revealed that the untrained experienced drivers' postures were unstable, that is, their postural motion was not coupled (i.e., matched) with the vehicle's motion. In addition, many untrained drivers tended to increase handgrip pressure onto the steering wheel in an attempt to use it as a postural anchor point, which was found to be ineffective as well as being strongly discouraged because of the potential to oversteer a vehicle in an emergency (Gardner, 1998). In contrast, trained experienced drivers demonstrated stable postures that resulted from their use of a leg-bracing technique taught during training, which permitted drivers to also have more relaxed handgrip.

In summary, the development of successful models of driver-training programs has been a vexatious issue because unsafe driving is potentially caused by multiple factors (McKnight & McKnight, 1999). Many training programs have been investigated; however, most of these were "learn-to-drive" programs and typically found non-conclusive results partly because of a lack of statistical evidence for a reduction in rates of traffic violations or crashes (Engström, et al., 2003; Katila, et al., 2004; Williams, 2006). In contrast, few post-licence driver-training programs have been investigated. Some past reviews of literature have concluded that post-licence driver-training is ineffective, but these results are negatively biased due to the inclusion of special training programs for elderly drivers and problem drivers, such as persistent drink-drivers (Ker, et al., 2005; Lund & Williams, 1985; Stuckman-Johnson, et al.,

1989). More recent research has revealed that some driver-training programs can elicit positive effects as measured by reduced crash statistics or improved driving skill performance (Carcaillon & Salmi, 2005; Dorn & Barker, 2005; Gregersen, et al., 1996; Mollenhauer, et al., 1997). From these studies, research into a driving-training program that considers the vehicle as an inertial environment as well as the problems and benefits of a driver maintaining a stable posture appears to show potential for safer driving (Treffner, et al., 2002). It is suggested that by controlling the acceleration of a vehicle and establishing a stable driver's posture can increase a driver's ability to detect relevant information, perceive safe driving situations and enhance their ability to safely operate a vehicle (Treffner, et al., 2002; Watson, 2003). However, it is uncertain from this study whether ordinary experienced drivers can be trained to achieve these positive outcomes, and with other safe driving initiatives, become safer drivers.

## **1.2. Statement of the problem**

Annually in Australia, approximately 100,000 drivers and passengers are injured, including around 12,000 serious injuries or fatalities (A.T.S.B., 2003b, 2004, 2005, 2006). Many countries with an established driving history, such as Australia, have decreased their rates of fatalities over the past two decades (Evans, 2003) but increased the rate of serious injuries as measured per (i) 100000 people, (ii) 10000 registered vehicles, or (iii) 100 million kilometres travelled (A.T.S.B., 2003a). In addition, crashes during driving and subsequent injuries are a global phenomenon (O'Neill & Mohan, 2002; Richter, Friedman, Berman, & Rivkind, 2005; Sleet & Branche, 2004; W.H.O., 2004). An emerging problem is that fatality and injury rates are expected to increase in developing countries (e.g., China and India) as their driver populations increase (Kopits & Cropper, 2005; Roberts, Mohan, & Abbasi, 2002).

Driver-training has been extensively used in many countries as a counter-measure to the rates of traffic violations and / or crashes. Numerous research studies have identified that some of the factors linked to violations and crashes can be effectively trained, for example, visual scanning of hazardous situations (Chapman, et al., 2002; Dorn & Barker, 2005; Fisher, et al., 2006) and correct ABS usage (Mollenhauer, et al., 1997). However, little is known about the effectiveness of driver-training in regards to a driver performing and maintaining optimal vehicle motion as well as establishing postural stability during various driving manoeuvres that may confront drivers.

Furthermore, with the implementation of a graduated drivers licence systems within many countries, some experts have identified a need to improve training programs by integrating scientific knowledge and evidence into their design (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002; Watson, 2003; Williams, 2006). This is in response to the development of many training programs that generally progressed from traditional and intuitive ideas, such as the views and opinions of driving experts (Mayhew & Simpson, 2002; Williams, 2006).

### **1.3. Purpose of the study**

The general purpose of this study was:

To investigate the effects of a specific driver-training program  
on vehicle motion and postural stability during  
a range of common driving manoeuvres

This research was intended to provide new information that can contribute to the evidence-base for the development of the perceptual-motor skills components within driver-training programs.

The specific purposes of the experiments comprising this study were to:

- (i) To determine the effects of driver-training on vehicle motion;
- (ii) To determine the effects of driver-training on a driver's postural stability;
- (iii) To examine the relation between postural stability and vehicle motion,

in a range of driving manoeuvres. Vehicle motion (displacement, velocity, and acceleration) was quantified using global position system data and 3-D accelerometry. Postural stability was quantified in the latitudinal and longitudinal directions according to the difference between peak driver and vehicle accelerations. The specific manoeuvres under investigation were (i) cornering, (ii) evasive lane change and return, and (iii) emergency braking. Each was selected because of the different inherent challenges to the vehicle's dynamics and consequently a driver's posture.



#### **1.4. Significance of the study**

Improvements to driver-training programs have the potential to result in safer drivers, which could subsequently reduce the rates of traffic violations and vehicle crashes as well as the considerable social and financial costs. Driver-training is highly regarded within many communities although some drivers after training may still be involved in traffic violations and / or crashes. Support for driver-training is further evident with the implementation in Australia of a graduated driver's licence systems that encourages learner drivers to participate in driver-training (Senserrick, 2007). This has led some experts to identify a need to improve training programs by integrating scientific knowledge and evidence into their design of training curriculum (Watson, 2003; Williams, 2006).

The literature in general has suggested that some driver-training programs did not result in safer drivers (Williams, 2006). In contrast, recent research has indicated that some specific skills for driving can be enhanced following training, which could potentially lead to over-all safer driving (Carcaillon & Salmi, 2005; Gregersen, et al., 1996; Treffner, et al., 2002). Visual scanning has been found to enhance a driver's ability to detect and perceive risks and hazards (Chapman, et al., 2002; Dorn & Barker, 2005; Fisher, et al., 2006). However, it is also known that when a driver's posture is unstable due to the perturbing effects of a vehicle's motion, the ability to scan for visual information and perceive risky situations is diminished. Currently, there is little information that specifically applies to vehicle motion and postural stability. It is foreseen that this research will provide new insights into a driver's performance at controlling the motion of a vehicle along with their postural stability.





## Chapter 2

# Literature Review

“It takes 8460 bolts to assemble an automobile,  
and one nut to scatter it all over the road.”

(Anon)



## **2.0 LITERATURE REVIEW**

This review has four sections. The first two sections provide an overview of the general problems and risk factors associated with driving. This is the focus for much of the road-safety literature. The third section reviews vehicle driving theories and models, physics of driving, and vehicle motion during two common driving manoeuvres (turning and braking) as well as stability of a driver's whole body posture. The fourth section reviews some of the driver-training (and education) literature, theories, and models of driver-training along with outcomes of such programs in terms of crash statistics and driving skill / performance. In this section, the driver-training program delivered by the project's industry partner is briefly described.

### **2.1. Crash statistics**

Problems associated with driving are common in the general community. Such is the extent and range of problems that drivers of various ages and experience levels are involved rather than being isolated to a single group, such as, learner drivers. Almost daily, the mass media reports sensational road traffic crashes, typically those incidents with serious consequences. Many others, of course, go unreported by the media.

Crashes during driving and subsequent injuries are a global phenomenon (O'Neill & Mohan, 2002; Richter, et al., 2005; Sleet & Branche, 2004; W.H.O., 2004). Annually in Australia, approximately 100000 drivers and passengers are injured, including around 12000 serious injuries or fatalities (A.T.S.B., 2003b, 2004, 2005, 2006). When pedestrians, motorbike riders, and other road users are included, the incidents of serious injury or death double (A.T.S.B., 2006). The World Health Organisation (W.H.O.) estimated that globally each year 1.2 million people died in road crashes and up to

50 million were injured (W.H.O., 2004). These statistics are considered by W.H.O. as the tip of a larger unmeasured problem. Furthermore, these figures are projected to increase by approximately 65% over the next 20 years unless there are new and effective commitments to vehicle crash prevention (W.H.O., 2004).

Many countries with an established driving history, such as Australia, have decreased their rates of fatalities over the past two decades (Evans, 2003) but increased the rate of serious injuries as measured per (i) 100000 people, (ii) 10000 registered vehicles, or (iii) 100 million kilometres travelled (A.T.S.B., 2003a). In contrast, developing countries (e.g., China and India) are expected to increase both fatality and injury rates as their driver populations increase (Kopits & Cropper, 2005; Roberts, et al., 2002). While fatality rates differ around the world, it appears that there is a consistent upward trend in the number of injuries related to vehicle crashes. It is suggested that such injuries may soon become the third-highest cause of morbidity worldwide (Richter, et al., 2005). These statistics underscore the fact that driving a vehicle is not necessarily a safe activity.

In regards to the statistics of unsafe driving, it is prudent to consider that there are significant methodological issues associated with these measures (Hirst, Mountain, & Maher, 2004). The primary measures of unsafe driving are the rates of traffic violations, crashes, and related deaths and injuries. Police incident reports, hospital admissions, traffic violation registers, and insurance records all provide data for injuries and crash statistics. Amongst these statistics, however, there are many crashes and injuries not reported or incorrectly reported (Cryer, et al., 2001; Hauer, 2006; Rosman & Knuiman, 1994; Shinar, et al., 1983). Hauer (2006) suggests that 20% serious injuries, 60% property damage, 75% slight injuries, and 90% scrapes and bruises

sustained in a crash are not reported. It is also worth noting that many instances of unsafe driving result in near-misses, which are seldom accounted for in the statistics (Arai, et al., 2001; Harrison, 2004).

A number of confounding factors can distort the interpretation of statistics for unsafe driving. These include comparing rates of crashes to different (i) distances travelled, (ii) frequency of trips, and (iii) types of driving situation encountered. Furthermore, the distinction between active (i.e., I crash) and passive (i.e., I am crashed into) incidents, severity of crash, susceptibility to being injured, and vehicle safety features can also skew such injury risk statistics (af Wåhlberg, 2003; Elvik, 2002; Hakamies-Blomqvist, 1998). Hauer (2006) recommended that care is required when making interpretations about the causes of an unsafe driving incident from injury and crash statistics.

Given the number of drivers on the roads, research indicates that vehicle crashes are relatively rare but that unsafe driving is not (Berg, 2006; Jonah, 1997; Leonard, Hill, & Overdorff, 2005). There are few consistent views about the relative importance of the various factors that lead to such high level of unsafe driving. It is generally accepted that consideration must be given to the fact that driving is a complex process rather than a simple stationary “person-machine” activity (Herbert, 1963). Moreover, the relation between the driver, vehicle, and environment is complicated by the dynamic elements of vehicle travel (Gibson & Crooks, 1938; Schiff & Arnone, 1995; Treffner, et al., 2002). As such, unsafe driving may arise from complex and varying interactions between the driver, vehicle, and environment. However, one consistent proposal in the literature is that unsafe driving is principally attributable to the driver, whether it be an unintentional driver error (Brown, 1986; Groeger, 1989, 1990) or deliberate and risky driving (Blockey & Hartley, 1995; Jonah, 1997; Parker, Reason, et al., 1995).

## **2.2. Risk factors for unsafe driving**

A traditional approach to understanding unsafe driving has been to describe the individuals involved in crash incidents. Research into characteristics of unsafe drivers often uses retrospective epidemiological methodologies. Although the use of such methodological approaches have known limitations, researchers depend upon statistical databases of crashes or traffic violation records to identify specific factors such as age, gender, experience level as well as general factors such as socioeconomic backgrounds, locations of unsafe driving events, and type of vehicle driven. In addition, temporary factors can compound these aforementioned risk factors, such as fatigue (Philip, et al., 2003; Sagberg, 1999), drugs and alcohol (Drummer, et al., 2004; Kelly, et al., 2004), travelling at night (Anderson & Holliday, 1995; Lin & Fearn, 2003), travelling on a public holiday (Farmer & Williams, 2005), and driving in foreign countries (Dobson, Smith, McFadden, Walker, & Hollingworth, 2004; Leviakangs, 1998). Importantly, risks associated with unsafe driving are multifactorial, that is, there is seldom a single factor that precedes unsafe driving (Hakamies-Blomqvist, 2006; Hemenway & Solnick, 1993; McKnight & McKnight, 1999).

### ***2.2.1. Age and gender***

Age is one of the most cited risk factor related to unsafe driving. Research has reasonably concluded that young drivers (i.e., 18 to 25 years old) are more likely to engage in unsafe driving leading to crashes (McCartt, Shabanova, & Leaf, 2003; Ryan, Legge, & Rosman, 1998; Turner & McClure, 2003). Some suggested reasons why young drivers are at such high risk include (i) initially learning to drive (Lam, 2003), (ii) being at an age that coincides with the legal drinking age in Australia (Ferrante, Rosman, & Marom, 2001; Rosman, Ferrante, & Marom, 2001), (iii) attaining

independence from parents and gaining mobility (Simons-Morton & Ouimet, 2006), (iv) adolescent development (Keating, 2007), and (v) driving vehicles that rank low in crash protection or may increase crash risk (Williams, Leaf, Simons-Morton, & Hartos, 2006).

Elderly drivers (typically considered as drivers over 65 years) are also identified as a high risk group (Carr, 2000; Tavris, Kuhn, & Layde, 2001; Zhang, Fraser, Lindsay, Clarke, & Mao, 1998). A possible explanation may be older age has an association with a natural increase in health related problems, such as visual impairment (Wood, 2000, 2002a, 2002b). This does not mean that elderly drivers can not drive as some driving skills, such as appropriate speed selection, are well preserved in healthy elderly drivers (Carr, Jackson, Madden, & Cohen, 1992). Recent research has questioned the apparent link between elderly drivers and increased risk during driving (Hakamies-Blomqvist, 1998; Hakamies-Blomqvist, Wiklund, & Henriksson, 2005; Langford, Methorst, & Hakamies-Blomqvist, 2006). Such studies indicate a reduction in elderly driver's crash involvement in comparison to the general driving population during the last two decades. But when a crash does occur, it tends to cause a serious injury or fatality for an elderly driver that would otherwise be less serious to a younger driver. The result is an elderly driver's crash is more likely to be reportable because of a high risk for an injury, thereby giving the appearance of increased crash rates. Based upon research by Ryan, et al., (1998), Figure 2.1 and Figure 2.2 illustrate the changing risk levels associated with different age groups by gender and per 100 million kilometres driven.

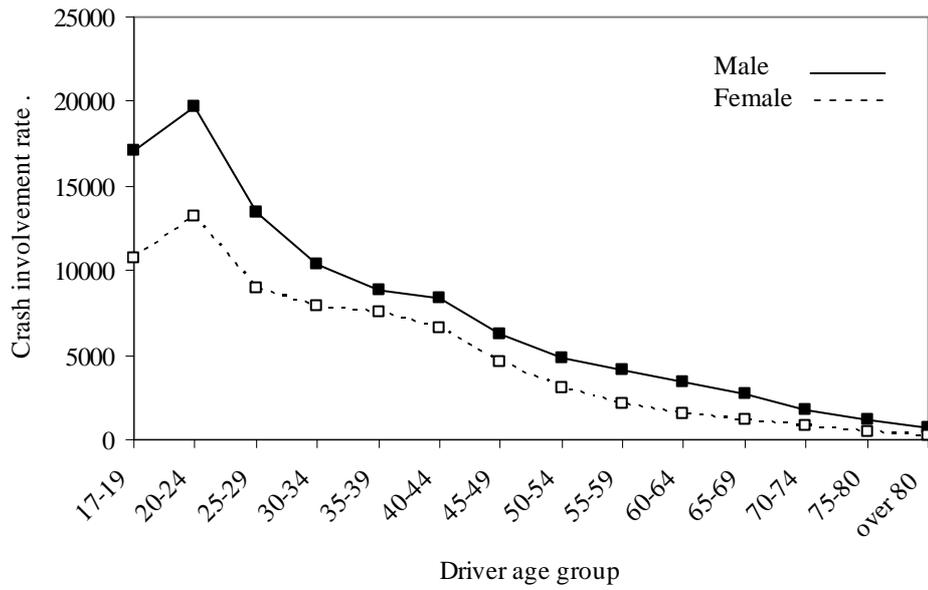


Figure 2.1 Involvement of drivers in a crash by age and gender in Western Australia (1989-1992).

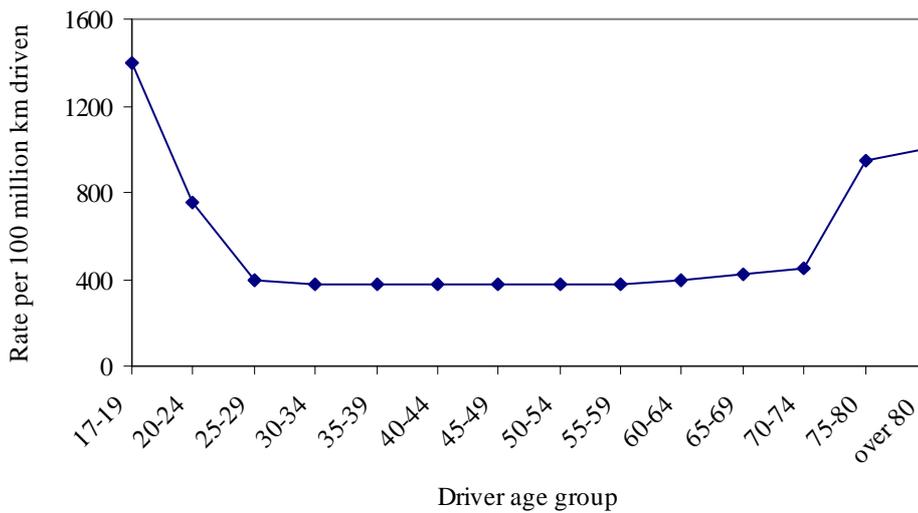


Figure 2.2 Involvement of drivers in a crash by age per 100 million kilometres driven. Western Australia 1989-1992.

Gender is an equally well-cited risk factor for unsafe driving. Both male and female drivers are known to drive while unlicensed, break licence restriction rules, and not always wear their seat-belt (Harre, Field, & Kirkwood, 1996). Female drivers tend to be more involved in dangerous driving errors (Blockey & Hartley, 1995), have crashes on a slippery road (Laapotti & Keskinen, 1998), and an occupant sustaining an injury when a crash does occur (Massie, Campbell, & Williams, 1995). Male drivers, especially when young and / or newly licensed, are overrepresented in vehicle crashes statistics (Figure 2.1). Compared to female drivers, male drivers tend to be involved in dangerous traffic violations (Blockey & Hartley, 1995), have more single vehicle crashes (Laapotti & Keskinen, 1998; Monarrez-Espino, Hasselberg, & Laflamme, 2006; Turner & McClure, 2003), and in general, have crashes that result in fatality (Massie, et al., 1995). In addition, male drivers tend to exhibit higher acceleration levels during travel (Ericsson, 2000), follow too closely to a lead vehicle (Boyce & Geller, 2002), drive after drinking, and excessively speed (Harre, et al., 1996). According to Turner and McClure (2003), Queensland male drivers, regardless of age, are more likely to be aggressive drivers, seek thrills while driving, and be accepting of such aberrant behaviours compared to female drivers. In a study of Turkish drivers, the male driver's aggression was associated with a "macho" personality, while in contrast, female drivers were more likely to demonstrate safety related driving-skills (Ozkan & Lajunen, 2006).

### ***2.2.2. Driving experience***

Driving experience, which is considered as the duration and participation of different driving situations, is considered a key factor for safe driving. This is especially the case for new drivers, for whom, having little driving experience often coincides with being a young driver and, as such, are considered interrelated issues (Lam, 2003; McCartt, et al., 2003). Over a two year period, Mayhew, Simpson, and Pak (2003) examined the

driving history of supervised learner and unsupervised novice drivers (Figure 2.3). They revealed that many crashes occurred during the initial period of solo driving for novice drivers and declined throughout the first two years of solo driving. Mayhew, et al. (2003) suggested that such a reduction was related to drivers gaining experience. McKnight and McKnight (2003) found similar results from their study and suggested that increased experience more so than increased age was related to a reduction in the likelihood of a crash.

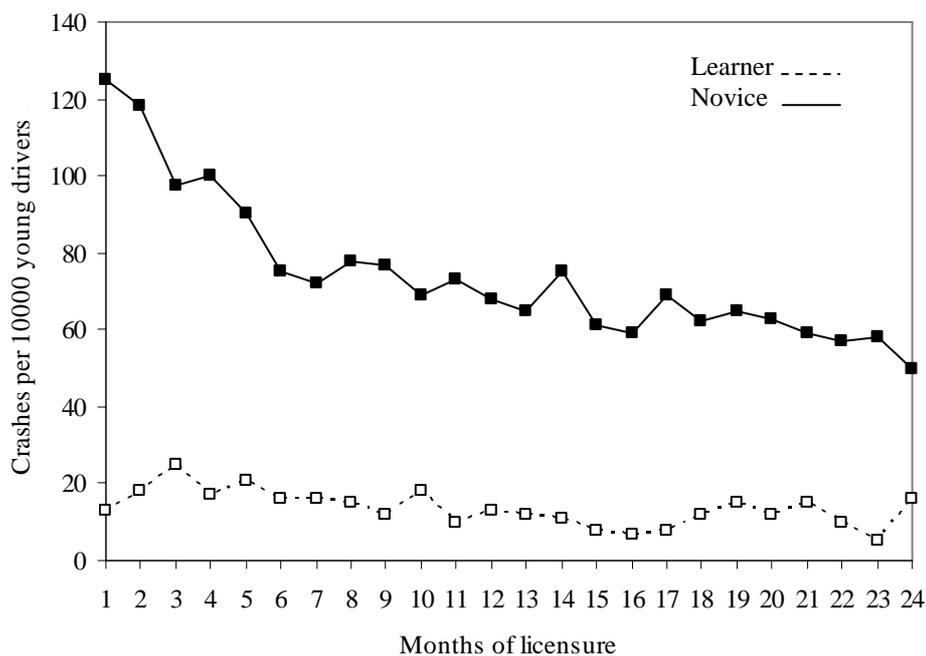


Figure 2.3 Crash rates by Canadian licence category and months of licensure.

### 2.2.3. Attitudes and behaviours

Some researchers suggest that attitudinal and behavioural factors are of paramount importance to understanding the prevalence of unsafe driving (Evans, 1996; Gregersen & Berg, 1994). One identified reason is negative attitudes and inappropriate behaviours are associated with both unintentional and/or deliberate unsafe driving (Blockey & Hartley, 1995; Parker, West, Stradling, & Manstead, 1995; Reason, et al., 1990). Research into risky (Harre, Brandt, & Dawe, 2000), careless (McKnight &

McKnight, 2003), sensation seeking (Jonah, 1997), and general aberrant driving (Aberg & Rimmo, 1998) reflects similar sentiment about drivers who think that unsafe driving is allowable. For example, research that employed a driver behaviour questionnaire demonstrated that drivers tended to engage in unsafe driving (e.g., drink driving, speeding, close following, and / or dangerous overtaking) if a driver thought that the consequences would not increase the risks, such as, being caught by police, losing their licence, being banned from driving, and / or putting lives at danger (Parker, West, et al., 1995). According to Fuller (1991), drivers tend to speed because the immediate rewards of reduced travel time out-weighed any negative consequences they can experience. In addition, it was recently discussed that young risky drivers displayed risky behaviours during other activities during mid-childhood (Vassallo, et al., 2007).

A beneficial reason why attitudinal and behavioural factors are considered important is that some past success in overall road safety is evident after drivers adopted positive attitudes and behaviours towards (i) drink driving (Connor, Norton, Ameratunga, & Jackson, 2004; Ditter, et al., 2005) and (ii) wearing of seat belts (Shinar, Schechtman, & Compton, 1999, 2001). However, recent research into seat belt usage illustrates that improvements may be associated with external factors (e.g., specific laws of an area) rather than a permanent change in a driver's attitudes and behaviour (Curtis, Rodi, & Sepulveda, 2007). This is illustrated by a higher rate of usually law-abiding drivers who do not wear a seat belt when not compulsory by local laws (Campbell, 1988; Glassbrenner, Carra, & Nichols, 2004; Houston & Richardson, 2005). Suggestions are made that attitudinal and behavioural changes need to influence the driver's motivation (Goldenbeld, Levelt, & Heidstra, 2000; Musselwhite, 2006; Naatanen & Summala, 1974) with Watson (2003) suggesting that research is required to determine the effects

of enhanced motivations in respect to changing a driver's poor attitudes and behaviours in relation to safe driving.

#### ***2.2.4. Over-confidence***

A specific case of an attitudinal problem is over-confidence or the belief in one's own superior driving performance. Researchers have repeatedly shown that some drivers have an unrealistic opinion regarding their capability to safely control a vehicle (de Joy, 1989; McCormick, et al., 1986; McKenna, 1993; Svenson, 1978; Waylen, et al., 2004; Williams, et al., 1995; Williams & Shabanova, 2003). This is compounded by suggestion that over-confidence is rife throughout the driving community and not just confined to young drivers as is often considered (Gregersen, 1996; Groeger, 2001a). A commonly seen example is the large number of drivers of different ages and experience levels who travel too fast for the driving conditions although speed is a well known crash risk factor (Aarts & van Schagen, 2006; Boufous & Williamson, 2006; Holland & Conner, 1996; Williams, Kyrychenko, & Retting, 2006). The reality that tends to be ignored by over-confident drivers is that driving at fast speeds may leave a driver with little chance of avoiding a collision, for example, in the event of an obstacle unexpectedly blocking their path (Svenson, 1978). Another powerful example is the group of drink-drivers who have not had a crash after drinking tend to be over-confident in their abilities and continue to drive while intoxicated (Ferrante, et al., 2001; Job, 1990). Not having a crash is almost an endorsement for some drivers to claim to be superior in their driving abilities (Groeger & Grande, 1996). Ultimately, individuals with a falsely inflated opinion of their driving skills demonstrate an altered perception of safe driving possibilities (Matthews & Moran, 1986).

### ***2.2.5. Attention and distraction***

Safe travel in a vehicle requires that a driver be attentive to the traffic and their environment. Sometimes drivers simply do not fully attend to driving, such as when they are distracted (McEvoy, et al., 2006). Typical distractions during driving are talking on a mobile phone (Hancock, Lesch, & Simmons, 2003), eating and drinking (Stutts, et al., 2005), engaging an entertainment system for music or movies (Brodsky, 2001; Stevens & Minton, 2001), and conversations with passengers (Preusser, Ferguson, & Williams, 1998). When a driver is distracted, there is an increased likelihood of engaging in unsafe driving, such as red-light running (Porter & Berry, 2001), unnecessarily over-taking of a lead vehicle (Bar-Gera & Shinar, 2005), close following of a lead vehicle (Rajalin, Hassel, & Summala, 1997; Summala, Lamble, & Laakso, 1998), and sudden application of the brake (Evans & Gerrish, 1996). These examples highlight an associated problem when distracted, which is a driver's failure to detect or perceive hazards and / or develop situational awareness (Endsley, 1995; McKnight & McKnight, 1999, 2003).

### ***2.2.6. Licensure***

The manner in which a person attains a licence differs throughout the world, especially in regards to the time to earn a full licence. The importance of time and experience in regards to licensing was underestimated for sometime, especially in America. Only a decade ago, gaining a licence in fourteen out of fifty American states required no learner's permit (Williams, Weinberg, Fields, & Ferguson, 1996). This meant that no prerequisite minimal learning period or experience was required by a predominately young driver population. While other states did issue learner's permits, full licences were granted after just 90 days in eleven of those states. To compound the problem in

some areas of America, drivers who attended formal driver education / training programs were rewarded with a reduced learner permit period (Lund & Williams, 1985; Vernick, et al., 1999). Calls have been made for the American regulators to eliminate the early licensure rewards as it is counter-productive in that it does not provide the necessary time to experience various driving situations (Brown, Gains, Greydanus, & Schonberg, 1997; Vernick, et al., 1999).

Recognition of these licensure problems has led to the introduction of a graduated driver licence (GDL) scheme in America and other countries (Begg & Stephenson, 2003; Hedlund, Shults, & Compton, 2003; Senserrick, 2007; Waller, 2003). This GDL scheme requires that a driver engages in driver-training, gain a minimum duration of driving, and most importantly, a set of driving situations that a driver must participate in during the learning phase of licensure (Hedlund & Compton, 2004, 2005; Hedlund, Shults, & Compton, 2006; McKnight & Peck, 2003; Senserrick, 2007; Waller, 2003). Also, restrictions during the learning and provisional licence periods are suggested (Lin & Fearn, 2003), which include (depending upon licensure region) limits on the number of passengers, permissible hours to drive, a zero blood-alcohol reading, restrictions imposed on mobile phone usage, and restrictions on the type of vehicles that can be driven, such as high-powered and high performance vehicles.

The GDL scheme has similarities to existing Australian licence systems. In Queensland at the time of testing, drivers progressed through three licence stages, which were (i) learner licence for six months, (ii) provisional licences for up to three years before finally progressing to (iii) a full licence (*Queensland Driver Licence*, 2006). The recent changes for learner drivers requires they now hold a learner's licence for twelve months before progressing to the first level of provisional licence (P1). Progression to the

second provisional level (P2) occurs after one year of holding a P1 licence and the successful passing of a hazard perception test. Full licence is available after two to three years of driving on provisional licences (P1 and P2), depending upon age when licences are issued. Another difference between the pre-GDL and GDL scheme is that the GDL scheme stipulates a selection of driving situations to be experienced (e.g., night-time driving). In a study by Harrison (2004) prior to licensure changes, an analysis of Victorian young drivers revealed that their self-reported driving experiences was predominately gained during daytime and in fair weather. New drivers are now required to gain general driving experience, which includes a minimum 10 hours of night-time driving, as evident by the new log-book requirement for 100 hours during the one year learning phases (*Queensland Learner Driver Handbook, 2007*). However, there exists an allowance for a driver to log three hours of driving from every one hour of formal driving lesson with an accredited driving instructor, up to 30 hours (i.e., 10 × 1 hour lesson) (*Queensland Learner Driver Handbook, 2007*). This seems to be at odds with the previous evidence from America that reduced time and experience during learning was detrimental to overall safe driving.

### ***2.2.7. Generic driving skills***

The manner in which a driver operates a vehicle understandably determines the motion of a vehicle, for better or worse. As such, drivers need to be competent in driving skills. Such skills are necessary before travel begins as a driver needs to initially adjust the seat and steering wheel positions to best accommodate their own body's anthropometrics. Once in motion, a driver needs to be skilful in detecting relevant information and perceiving the state of a driving environment. These are followed by skills for vehicle operation that involve the timing and application techniques of a vehicle's main

controls, which are the steering wheel and two or three pedals (i.e. accelerator and brake, plus in a manually geared vehicle, clutch).

The use of vision during driving is understandably an essential skill for safe driving. A driver needs to be skilful at viewing a path of safe travel as well as distinguishing between safe and hazardous traffic situations. In this regards, much research has considered a driver's ability to view their driving environment. For example, Land and colleagues' investigations into where a driver looks during cornering indicated that drivers essentially focused on a point that was tangential to the curve (Land & Horwood, 1995; Land & Lee, 1994; Land & Tatler, 2001). In addition, a driver's useful field of vision, ability to scan a driving environment, and patterns of eye movements have been shown to differ between new and experienced drivers (Crundall, Underwood, & Chapman, 1999; Falkmer & Gregersen, 2005). Better drivers in general displayed extended field of vision and tended to not fixate on an object within their view. Some of the problems with vision during driving include (i) the glare from an oncoming vehicle's headlights (Anderson & Holliday, 1995; Rice, Peek-Asa, & Kraus, 2003), (ii) age-related degeneration in eye sight (Wood, 2002a, 2002b) as well as (iii) community wide ophthalmology problems, such as poor visual acuity (Owsley & McGwin, 1999).

Research into steering control has often quantified steering wheel rotations by a driver as measure of driving skills (Blaauw, 1982; Donges, 1978; Macdonald & Hoffman, 1980; McLean & Hoffman, 1971; McRuer, Allen, Weir, & Klein, 1977; Weir & McRuer, 1970). By measuring the number of rotations (i.e., rotate and reverse) and the amplitude of a rotation in relation to trajectory changes, researchers revealed that new drivers younger than 25 years, typically linked several smaller rotations of the steering

wheel to navigate a corner. However, such results contrast other suggestions that a single steering wheel action is more desirable when navigating a corner (Gardner, 1998; Home Office, 1961).

The application of pedals is fundamental for control of speed, braking and, in some vehicles, changing gears without stalling a vehicle's engine. Research focus has recently investigated the application of an antilock braking system (ABS). Although designed as a safety feature, statistics indicate that crashes continue to occur in vehicles fitted with ABS (Broughton & Baughan, 2002; Delaney & Newstead, 2004; Evans & Gerrish, 1996; Farmer, 2001; Williams & Wells, 1994). Part of the apparent problem was noted as improper application of ABS whereby a driver pumped the brake in ABS equipped vehicles as if suddenly stopping a non-ABS vehicle, which would be appropriate for those vehicles. Mollenhauer, Dingus, Carney, Hankey, and Jahns (1997) showed that basic training, such as a four-page booklet, resulted in the majority of new drivers properly applying the ABS compared to untrained controls who continued to pump the brake pedal. However, a point of discussion is how effective such training is for experienced drivers who have a particular habit of brake application. The authors express concern that some drivers may revert to established habits rather than newly formed techniques during an emergency situation.

Another aspect of pedal control is a driver's reaction times for pedal depression. Sohn and Stepleman (1998) and Young and Stanton (2007) each published a review of literature on braking reaction times and similarly concluded that reaction time for brake application is affected by (i) awareness of need to brake, (ii) distance away from object to avoid, and (iii) the perceived consequence for not stopping before object. Green (2000) and Warshawsky-Livne and Shinar (2002) investigated the issues related to

driver awareness and expectations for the need to stop. Green (2000) revealed that the reaction time differences between expected and unexpected situations were respectively 1.25 s and 1.50 s. Using data from Warshawsky-Livne and Shinar's (2002) study, even short time periods can be problematic considering that a vehicle travelling at 90 km/hr might travel 6.25 m extra in distance during 0.25 s. This equates to approximately one vehicle length extra in distance.

### ***2.2.8. Vehicle acceleration***

An area of increasing research and of particular interest in this thesis is a driver's skill for controlling a vehicle's acceleration and associated inertial forces. Acceleration occurs when a driver changes a vehicle's direction and / or speed during travel. Hindle (1967) demonstrated that as a driver controlled steering outputs more smoothly (i.e., less jerky) during a turn, the maximum lateral acceleration was reduced. This is advantageous as excessive lateral accelerations during a turning can potentially lead to an inability to steer an intended course, cause loss of vehicle control, and if sufficiently large in magnitude, a vehicle roll-over crash (Clarke, Ward, & Truman, 2005; Laapotti & Keskinen, 1998). However, it is also known that some drivers, namely those with a history of crashes, tend to ignore acceleration as a risk factor. Such drivers tend to drive fast around a corner regardless of radius while steering in a manner that increases lateral accelerations (Lajunen, Karola, & Summala, 1997).

Some researchers have investigated a driver's acceleration profile. Robertson, Winnett, and Herrod (1992) hypothesised that higher magnitude of accelerations measured at the driver were related with greater risk of crashes. Results showed that large differences in acceleration existed between the study's ten drivers while an individual's within-driver variability was relatively small. Robertson, et al., (1992) suggested that by identifying

drivers with high magnitudes of accelerations, a potential existed to train such drivers to adjust their vehicle control in order to reduce accelerations.

During previous work by our group, the longitudinal and lateral accelerations of a vehicle and drivers were studied (Treffner, et al., 2002; Treffner, Barrett, Petersen, & White, 2002). Driving manoeuvres, such as, cornering, braking, and evasive lane change, were assessed in the study; with the results consistently showing that previously trained experienced drivers exhibited lower peak and mean accelerations compared to experienced but untrained drivers. It was suggested that the trained drivers accelerated less due to their better-coordinated steering and speed controls. As such, the untrained experienced driver's higher magnitudes of accelerations may therefore be due to their less smoothly coordinated steering and speed control.

### **2.3. Elements of driving**

This section reviews the literature pertaining to a vehicle's motion, forces that exist during travel, and the effects of both on the vehicle and the driver. Definitions of key concepts regarding driving physics, vehicle handling, and vehicle dynamics are detailed and discussed. This section also reviews the literature regarding postural stability.

#### ***2.3.1. Theories and models of vehicle driving***

The selection of a theory to apply to an investigation needs to be acknowledged as each particular theory has unique assumptions that will influence the interpretation and discussion of experimental results (Burgess-Limerick, Abernethy, & Limerick, 1994). In regards to safe driving, a variety of theories and models for driving have underpinned an equally wide range of research. The most prevalent of these are driving models

based upon psychological theories. A common theme for such models is the attitudes and behaviours of a driver. These models have drawn attention to problems associated with aberrant behaviours and attitudes, such as deliberate risk taking (Harre, 2000; Jonah, 1986). An important basis for many behavioural and attitudinal models are the complimentary theories of “Reasoned Action” (Fishbein & Ajzen, 1975) and “Planned Behaviour” (Ajzen, 1985, 1991), which (in brief) proposed that a person’s behaviour can be predicted by their attitudes, their beliefs in how others will view their performance (i.e., social norms), and their own perceived behavioural control. These theories were successfully applied during research into a driving errors and traffic violations that may have been unintentional and / or deliberate (Blockey & Hartley, 1995; Parker, Manstead, Stradling, & Reason, 1992; Reason, et al., 1990). Another important basis for models is the risk homeostasis theory (Wilde, 1982; Wilde, Robertson, & Pless, 2002), which proposes that risks taken by a driver increase when their perception for negative consequences decreases. For example, the introduction of ABS led to drivers travelling closer to a lead vehicle and at faster speeds until their perceived level of risk was the same as before (Sagberg, Fosser, & Sætermo, 1997). Such a model can guide investigations into the problem of driver overconfidence that sometimes follows accumulation of driving experience and / or participation in driver-training (e.g., Gregersen, 1996; Groeger, 2001a)

Another perspective from which to model driving a vehicle is to consider it as a perceptual-motor activity in line with theories of perception and / or movement (Cohen & Studach, 1977; Gibson, 1954/1994, 1979; Hildreth, Beusmans, Boer, & Royden, 2000; Lewin, 1982; Reed, 1982; Treffner, et al., 2002; Turvey, Carello, & Kim, 1990). Two theoretical paradigms provide guidance for such research, which are (i) the motor-program or schema approach and (ii) the ecological approach. The

motor-program approach includes theories based upon models stemming from mechanistic or computational concepts whereby a person's motion is functionally defined in terms of a machine and their world is perceptually inferred. In general, a person moves about a space via an ordered program of interpreting and processing sensory inputs (e.g., vision) compared against a mental model that is stored in the brain and peripheral nervous system from which action commands are sent to the limbs (Schmidt & Lee, 2005).

The ecological approach that contrast the motor-program approach was proposed by James Gibson (1966; 1979). At the basis of the ecological approach is the idea that actions are coupled to the environment via information that is specific to a task, which in turn constrains a person's actions via their perception for the possibilities to conduct a task. In regards to driving, relevant information needs to first be detected by drivers. Gibson (1966; 1979) asserted that such information is actively detected rather than passively received, which is a central assumption of the ecological perspective. For example, visual information is well accepted as vital for driving and when travelling, a driver can detect a vehicle's motion via a flow of optical images. Other relevant sources of information utilised during driving include auditory (e.g., screeching tyres) and vestibular (e.g., inertial forces). It is the inertial forces that a driver feels / detects as a vehicle accelerates. Importantly, separate sources of information may not be individually detected but rather detected as a combined form that is the global array of information (Stoffregen & Bardy, 2001). These authors suggest that a global array of information provides greater insight to a situation, and thereby enhances a driver's perception of a situation.

Another major assumption of the ecological approach is that a driver can directly perceive a driving situation due to the mutual relationship that exists between a driver and their environment. This concept is known as direct perception (Michaels & Carello, 1981). Such an assumption contrasted the then more common theories of indirect perception, which assumed a driver perceived the world separately from their body by matching or inferring sensory information about driving with a mental representation (Jordan & Wolpert, 1999; Kawato, 1999; Rock, 1997; Wolpert, 1997). Ecological models of visual perception have provided significant insight into how a driver controls a vehicle in regards to their environment, especially other vehicles. From this (and other perceptual information), a driver can perceive (i) a path that is clear of obstacles (Schiff & Arnone, 1995; Warren, 1998b), (ii) the motion of their own and others' vehicles (Fajen & Kim, 2002; Fajen & Warren, 2000; Warren, 1998a), and (iii) their rate of approach to an object, which is often referred to as "tau" (Lee, 1974; Schöner, 1994; Yilmaz & Warren, 1995). David Lee's theory of tau, which is the time-to-contact with an object (Lee, 1976) is well established and thoroughly investigated by others (Bardy & Warren, 1997; Fajen, 2001; Kim, Turvey, & Carello, 1993; Schöner, 1994; Yilmaz & Warren, 1995). Lee theorised that people can perceive the time to contact by detecting the rate of expansion of an upcoming object.

The ecological perspective also assumes that the environment and its information are not perceived; rather the action possibilities that exist for a person in regards to that environment are perceived. These possibilities to act are termed "affordances" (Chemero, 2003; Gibson, 2000; Scarantino, 2003; Stoffregen, 2000, 2003). It is a person's perception of affordances that constrain their actions (Ricchio & Stoffregen, 1988; Turvey, 1992). For example, a driver detects upcoming roadwork and perceives a

possible path at slow speeds, which in turn constrains the driver's actions relating to vehicle control.

Furthermore, as a driver travels through the environment, the motion of travel reveals further information, which in turn constrains their perception for possible travel continuation, and so on. This circular process is a well-known model termed the "perception-action cycle" (Kugler & Turvey, 1988; Schöner, Dijkstra, & Jeka, 1998; Turvey, et al., 1990) and represents the combined approaches from the theories of perception (Gibson, 1966, 1979) and the theories of action systems (Reed, 1982, 1986; Reed & Bril, 1996). This model considers that such coupling between perception and action permits a driver to adjust their vehicle control to best suit a changing environment, which is continuously changing during travel (Schöner, et al., 1998).

A close companion to the ecological approach is the dynamical system perspective to movement coordination, which considers the evolution of non-linear spatiotemporal relations that exist between a person, their environment, and the possibility for an activity (Schöner, 1990, 2002; Schöner, et al., 1998; Schöner & Kelso, 1988a, 1988b). It also emphasises the identification of observation of macroscopic variables in order to characterise movement (Scholz, 1990). Such a perspective presents a person's movements as coordinated structures comprising many degrees-of-freedom that are constrained by a particular task (Saltzman & Kelso, 1987).

### ***2.3.2. Physics of driving***

To describe vehicle motion, a frame of reference needs to first be established so that unambiguous vehicle positions (i.e., coordinates) can be specified. There are two frames of reference generally used, which are (i) the inertial frame (a reference frame

that is not accelerating, e.g., the Earth) and (ii) the non-inertial frame (a reference frame that rotates or accelerates, e.g., a moving vehicle). Vehicle motion is typically referenced in relation to the road with distance and speed (i.e., changes for distance in respect to time), which represents the most commonly used kinematic variables. Other variables include velocity, which is the rate of change of displacement in relation to time and acceleration, which is the rate of change of velocity in relation to time. In respect to rotational motion of a vehicle, roll, pitch, and yaw are respective measures of rotation about the longitudinal, lateral, and vertical axes. These three variables are beyond the scope of this thesis and will not be discussed further.

When a vehicle is travelling in a straight line at a constant velocity, no acceleration is present. Change a vehicle's speed, such as an increase (e.g., start of travel) or decrease (e.g., brake to stop), and longitudinal accelerations occur. Change a vehicle's direction, for example, steering a curved path around a turn and lateral accelerations occur. Lateral acceleration is a linear acceleration directed towards the centre of rotation and is proportional to a vehicle's tangential velocity (squared value) and inversely related to radius of turn.

A driver's choice of speed during a turning manoeuvre has been thoroughly researched. Using a driver simulator study, van Winsum (1996) suggested that drivers chose a speed so that a vehicle remained at a constant distance from the inside edge of a road. However, a later simulator study suggested that lateral acceleration may be important in speed choice but could be overlooked due to the difficulty in simulating lateral accelerations (Reymond, Kemeny, Droulez, & Berthoz, 2001). A consistent finding from field studies is that a driver's choice of speed is related to (i) the radius of the corner (Kanellaidis, Golias, & Efstathiadis, 1990; Kojima & Nagai, 1997) and

(ii) inversely related to the lateral acceleration experienced by the driver (McLean, 1981; Ritchie, McCoy, & Welde, 1968). Ritchie, et al., (1968) suggested that travel becomes faster when a turn is wider (or flatter) with an increase in turning radius and less lateral acceleration was experienced. In contrast, slower speeds occurred during tighter turn where a small increase in speed resulted in a large increase in lateral acceleration (Figure 2.4).

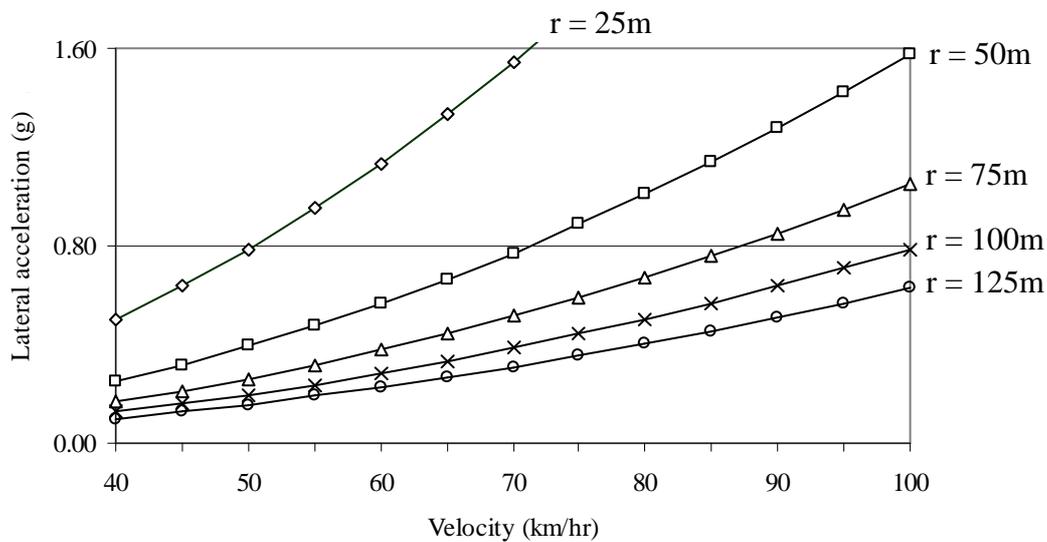


Figure 2.4 Effects of velocity and turning radius (r) on lateral accelerations.

Vehicle kinetics, by comparison, considers the effects of motion on a vehicle and its occupants (e.g., a driver). Forces are generated during travel that will affect a vehicle's motion, and as a consequence, a driver's ability to operate a vehicle. During travel, the primary forces are mechanically exerted by a vehicle's engine and brakes that work to change a vehicle's position, that is, accelerate / decelerate a vehicle. According to Newton's second law of motion, such a force is proportional to a vehicle's mass and its acceleration. Therefore, it stands to reason that a larger force is required to accelerate a more massive vehicle, which will accelerate in line with the applied force. Once in motion, a vehicle acquires momentum, which is proportional to a vehicle mass and

velocity. Momentum of a vehicle will keep the vehicle moving at a constant velocity unless acted on by an external force. In addition, inertia, which is a property of an object, will resist changes in motion, whether at rest or moving. The inertia of a moving vehicle is responsible for changes in load distribution across the four wheels of the vehicle. During braking, vehicle load is distributed onto the front tyres. While in a turn, more vehicle load is distributed onto the side opposite of the turn.

In regards to a vehicle turning, the literature describes two lateral forces that are oppositely directed. The first, centripetal force, is directed towards the centre of rotation and holds a vehicle on its curved trajectory. Assuming a constant mass for a vehicle, centripetal force is (i) proportional to a vehicle's tangential velocity (squared value) and (ii) inversely related to radius of turn.

The second lateral force is centrifugal force, which is directed outward from the centre of rotation. Centrifugal force is a common term used to explain the phenomenon of unsecured objects in a vehicle moving away from the corner's centre during a turn. Hence, the term means "centre-fleeing" force. However, a centrifugal force is typically considered to not be a true force but rather a pseudo-force (i.e., fictitious). According to classical physics, the reasons centrifugal forces are considered fictitious are (i) they do not arise from a physical action but rather from the acceleration of a reference frame, e.g., a vehicle and (ii) they do not have a true equal and opposite force (Karnopp, 2004).

Another essential force during driving is the frictional force between two contacting surfaces that resists potential sliding motion. The main frictional contacts of interest in this thesis are (i) between the vehicle's tyres and the road and (ii) between a driver and their seat-back. The magnitude of frictional forces required to produce motion is

dependent upon (i) the force that is normal to the contact surfaces and (ii) the coefficient of friction particular to the contacting surfaces, which changes depending upon whether the contact is static or dynamic in motion, as coefficients for surfaces at rest are typically greater than for surfaces that are already sliding (*CRC Handbook of Chemistry and Physics*, 2006). For example, the normal force for a vehicle sitting on a road is gravity and the coefficients of friction for two driving environments are:

Rubber on Asphalt (dry):  $\mu = 0.5 - 0.8$ , and

Rubber on Asphalt (wet):  $\mu = 0.25 - 0.75$ .

In consideration of the research vehicle used in this thesis, its mass and gravity would generate a normal force of approximately 16000 N and the frictional forces could resist between 12800 N in dry conditions, but only 4000 N in wet conditions. This highlights the fact that the same section of road can have drastically different frictional characteristics when surfaces are lubricated by an agent such as water. The consequences of exceeding frictional resistance can have dire consequences such as longer stopping distance and / or skidding (Figure 2.5).

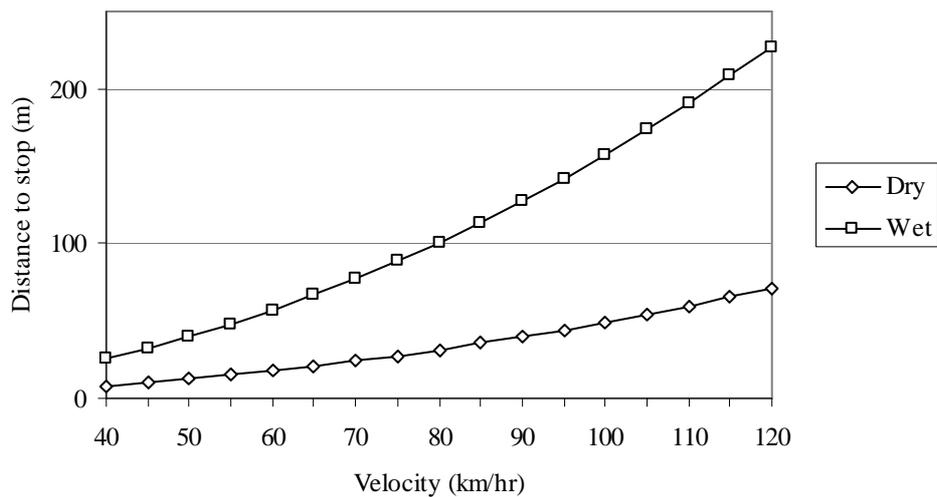


Figure 2.5 The effects of road surface conditions on distance to stop.

### ***2.3.3. Posture and driving***

The road safety literature related to a driver's posture has generally focused upon ergonomic considerations of driver comfort, vibration attenuation, and instrument / control locations. Researchers have revealed that appropriate vehicle interior set-up to accommodate a driver's anthropometrics is critical for safe driving. For example, researchers demonstrated that a driver's anthropometric characteristics, such as leg and arm reach distances, determined an optimal distance for a driver's seat from the steering wheel (McFadden, Powers, Brown, & Walker, 2000; Reed, Manary, Flanagan, & Schneider, 2000). Gardner (1998) recommends that correctly positioning a driver's seat is essential for effective arm and leg actions by a driver. A driver's ability to effectively interact with a vehicle's controls is related to the seat position and a driver's leg and arm length (Gardner, 1998; McFadden, et al., 2000). In a study by Scott, Candler, and Li (1996), the time to apply the brake pedal, and subsequently, the distance to stop improves when a driver adjusts a vehicle seat in respects to their height, that is, taller drivers sit further away from the pedals. Other groups of studies have considered a driver's posture and comfort during travel (Andreoni, Santambrogio, Rabuffetti, & Pedotti, 2002; Coelho & Dahlman, 1999; Harrison, Harrison, Croft, Harrison, & Troyanovich, 2000; Kolich, 2003; Park, Kim, Kim, & Lee, 2000; Reed, et al., 2000) and vibration attenuation (Boileau & Rakheja, 1998; Rakheja, Stihara, & Boileau, 2002) afforded by a driver's seat. Although many studies are conducted using a static models of driving, several research groups discuss the importance of a driver resisting the destabilising effects associated with lateral accelerations in regards to the stability of a driver's base of support (Andreoni, et al., 2002; Coelho & Dahlman, 1999; Harrison, et al., 2000). In addition, Coelho and Dahlman (1999) noted that drivers tended to respond to lateral acceleration by either gripping the steering wheel or leaning away from the turn.

Little is published about a driver's posture during safe driving when exposed to vehicle dynamics. It is known that a driver's posture will be perturbed when exposed to inertial forces unless there is some form of restraint. Some researchers have investigated a seat's design, especially the side supports at the base (i.e., seat bolsters) as a way to restrain movement due to perturbation (Coelho & Dahlman, 1999; Harrison, et al., 2000). For example, Harrison, et al., (2000) proposed that a driver's seat should be fitted with arm rests to increase resistance to postural perturbations. In contrast, Zikovitz and Harris (1999) considered head movements during cornering and revealed that a driver's head tended to tilt in towards the centre of a turn in response to perturbations associated with lateral accelerations as a vehicle travels around a corner. These authors discuss that drivers align their head with the direction of balance, which is parallel in the opposite direction to the gravito-inertial force (Riccio, Martin, & Stoffregen, 1992). Unfortunately, Zikovitz and Harris' (1999) study did not formally address a driver's overall posture. Instead, the authors provided an informal insight into a driver's overall posture by noting that "a driver sitting down and holding onto a steering wheel is fairly stabilised against the tendency to tilt passively out of the corner like their passengers" (Zikovitz & Harris, 1999, pp 745). Similar comments were noted in the driving posture research conducted by Coelho and Dahlman (1999).

Postural stability is about controlling a body's spatial position with the intention to achieve a stable orientation with its environment. A stable posture provides a sturdy foundation that will support all movements required for an activity, such as, driving. Importantly, postural stability should not be consider in isolation but rather the evaluation of postural control should be considered in regards to consequences for other actions (Stoffregen & Riccio, 1988). For example, well functioning postural control is essential for the development of prospective stability control as an anticipatory action.

However, using the steering wheel for stabilisation is regarded as inappropriate and not effective as demonstrated by those drivers who used such a technique in the study by Treffner, et al., (2002). Gardner (1998) recommends an alternative leg brace technique for resisting perturbations, which required the leg to be pushed against the adjacent surface. In regards to the recommended leg brace technique, Treffner, et al. (2002) revealed that a driver's postural stability was enhanced when leg bracing was employed compared to drivers who gripped onto the steering wheel.

In recent times, the models of postural stability during various perceptual-motor activities have been incorporated into ecological models of movement. Suggestions are made that a driver's perception of a driving situation is influenced by the stability of their posture (Gardner, 1998; Riccio, 1995). An accelerating vehicle generates an inertial force that can perturb a driver's posture and as such can change a driver's head orientation, which alters their relation with spatial reference frames, such as the horizon (visual information) and gravity (vestibular information). Research has considered such implications in regards to pilots during flight, where it has been revealed that destabilised pilots tended to align their head with the horizon if their orientation changed (Patterson, Cacioppo, Gallimore, Hinman, & Nalepka, 1997; Smith, Cacioppo, & Hinman, 1997). Furthermore, recent research conducted by Wallis, Chatziastros, Tresilian, and Tomasevic, (in press) suggests that the tilting of a driver's body due to inertial forces and the subsequent need to counterbalance this tilt may constitute a source of information used by drivers to control a vehicle. Macuga, Beall, Kelly, Smith, and Loomis (2007) and Wallis, et al., (in press) suggested that drivers could use inertial information to guide steering when vision was temporarily limited.

## **2.4. Driver-training**

This section reviews the literature pertaining to driver-training, and to a lesser extent, driver-education. Theories and models of training programs as well as the development of such programs are discussed. This section also reviews the literature regarding the outcome of driver-training. Finally, a description of the driver-training program used in this study is presented.

### ***2.4.1. Theories and models of driver-training***

Driving a vehicle is recognised as a complex and demanding perceptual-motor task. To assist a driver, education and training programs are available in most communities (Mayhew, Simpson, Williams, & Ferguson, 1998). Driver-education and training programs offer an attractive possibilities for better driving and road safety (Mayhew, et al., 1998). In general, programs offer instruction for a combination of physical, perceptual, and social skills required to safely drive a vehicle (Williams, 2006). Table 2.1 provides a summary of selected research into driver-training programs illustrating some of the various skills and attributes taught to drivers.

Driving programs reported in the literature are generally described as “driver-education” and “driver-training”. A problem within the literature is that no stringent definition exists, and as a consequence, some authors assume colloquial meanings for these terms as if they are interchangeable. Furthermore, many commercial operators prefer to promote a “driver-education / -training” program that combines both theoretical and behind-the-wheel practical elements, which tends to add to the confusion within both the general community as well as the scientific community. The following definitions are employed to distinguish between the two terms within this thesis. Driver-education

is predominately taught in a class room settings, typically to high-school students, as part of the pre-licence stage of driving (Bell, Young, Salzberg, & West, 1991; Engström, et al., 2003; McKnight, 1984; Senserrick, 2007). Lessons tend to cover theoretical aspects of learning to drive, such as road rules, the importance of appropriate attitudes and behaviours along with the negative impact of drugs, alcohol, fatigue, and distractions (Harre & Field, 1998; Lesch & Hancock, 2004; McKenna, 2004; Robinson, 2002). Education programs can be delivered to large groups by few facilitators or school teachers and are hence cheap to administer.

In comparison, driver-training typically involves practical application of knowledge and skills via the use of an on-road vehicle or vehicle simulator. Some training programs instruct drivers to increase their field of visual scanning (Chapman, et al., 2002), steer and position a vehicle within a lane (Smiley, Reid, & Fraser, 1980), perceive hazards (McKenna, Horswill, & Alexander, 2006), adapt behaviour for fuel efficiency (af Wåhlberg & Melin, in press), and the proper application of ABS (Mollenhauer, et al., 1997). Training programs are popular because of the hands on experience gained by drivers (Leonard, et al., 2005). While driver-education as defined above is clearly important, the following section of this review will mainly focus on the literature relating to driver-training.

Table 2.1 Selection of research into driver-training programs

Authors	Training program details	Summary of main findings
Carcaillion, et.al., (2005)	Young drivers (N ~ 500) The program "Atout-Route" modifies attitudes towards and behaviours related to the risk of alcohol, drugs, and fatigue while driving.	A greater decrease in the number of collisions and fatalities involving drivers 25 year old & younger was recorded in study area compared to surrounding untrained districts.
Carstensen (2002)	Novice drivers (N ~ 2000) Comparison between new & old program offered in Denmark. Part of the content was the subject of defensive driving and/or hazard perception.	Drivers trained in the new education program, had a lower crash risk than those who trained in old program. Reduction was mainly concentrated in the 1st year of driving for multiple-vehicle & manoeuvring crash, while single-vehicle crashes did not change.
Chapman, et.al., (2002)	Novice drivers (N = 103) 3 tests in 1 <sup>st</sup> year driving Training informs about their typical patterns of visual search and stresses the need for scanning multiple locations.	Intervention produced notable changes in the drivers' search patterns in real and simulated driving. Not all changes were still detectable at a final phase of testing three to six months after the intervention.
Dorn, et.al., (2005)	Trained (N = 54) Untrained (N = 56) Training based upon 'Roadcraft: The Police Drivers Handbook' involving 3-5 weeks of classroom-based and in-vehicle instruction with an emphasise on observation and focuses on road cues to potential hazards.	In a simulated driving task, trained drivers were less likely to cross the central division of the road at unsafe locations during the overtaking task and reduced their speed on approach to pedestrians at the roadside in the following task to a greater extent as well as adopting a more central lane position.
Dreyer, et.al., (1979)	Pre-licence driver Traditional training (N = 918) Driving centre (N = 1139) Traditional - driving was given on the street in a normal traffic environment. Driving centre - driving in an off-street, multiple-car driving centre plus several hours of additional driving time conducting driving and parking manoeuvres. The centre is supervised by an instructor in a 6 meter high control tower, with as many as 16 students (each in own vehicle) There is one-way radio communication between the trainee and the instructor, who directs and gives immediate feedback to the learner.	Driving skill not different between groups Fewer crashes by driving centre trainees compared with traditional training. Reduction in crashes may be caused by a type of Hawthorne effect that is, a motivational effect caused by the special treatment given at driving centre.

Goldenbeld, et.al., (2004)	<p>Moped bike training program  Trained (N = 25)  Untrained (N = 21)  Training was 16 hrs - 4 weeks  4 hrs = vehicle handling on closed circuit track  8 hrs = traffic situations - riding on roads  3 hrs = traffic comprehension  1 hr = exam preparation training</p>	<p>Two weeks after the practical training  Trainees consistently performed better than the group of non-trainees on three vehicle control tests and a riding in traffic test.  Results show that practical training can increase cognitive understanding of traffic situations.  One year after training, trained and non-trained subjects were similar in skill level. Improved skill of riding in traffic could not be sustained with time.</p>
Gregersen, et.al., (1996)	<p>5 programs compared  Driver training (N = 936)  i.e., manoeuvring, skid-training, "commentary driving" - see (Gregersen, 1994)  Safety campaign (N = 915)  meetings, videos, pamphlets  Group discussion (N = 917)  Small group discuss safety  Financial bonus (N = 900)  non-crash bonus  Control (N = 988)</p>	<p>Reductions in crash risk for driver training, discussions and bonus groups.  Training and the group discussions had the largest reduction.  Training aim was not primarily to increase the drivers' skill in manoeuvring the vehicle, but to create insight about risks in traffic and about the drivers' own limitations.</p>
Katila, et.al., (1996)	<p>Skid training (N = 382)  Anticipating skills  -recognize risky situations  -avoid dangerous situations  -meaning of tyre grip  -detect the changes in tyre grip  -adjust speed for conditions  -adjust speed for braking distance  -avoid mistakes on a slippery road that may lead to loss of control of the car.</p> <p>Manoeuvring skills  -correct a sideways skid  -avoid accelerating or braking in a curve  -correct clutch &amp; steering usage in a sideways skid  correct a sideways skid caused by driving too fast  -steer clear of an obstacle when the braking distance is too short  -maintain tyre grip with the correct driving technique in different situations and at different speeds  -know what to do on a slippery road during loss of vehicle control</p>	<p>The results of mailed out questionnaires showed that students on skid training courses fail to grasp the idea of the courses, i.e. that safe driving in slippery road conditions is based on being able to avoid a skid rather than being able to correct a skid.  The instructors rated anticipating skills as more important than manoeuvring skills.</p>

Katila, et.al., (2004)	Compare changed skid training New training (N = 14298) Old training (N = 15177) Finland 1990 - a two-phase driver training system Skid-training in second phase Encourage drivers to anticipate the behaviour of others and to foresee risks. Vehicle handling skills should be learned thoroughly but emergency manoeuvring skills in slippery road conditions, for example, were considered to be of secondary importance.	The results indicate that the renewal of the Finnish driver training system was at least partly successful. The rate of slippery road crashes was similar in both the curriculum groups. However, more drivers from the new training had crashes than from old training. When the increase in exposure was controlled, no significant difference in crashes was found. It seems to be an oversimplification to say that increased confidence in skills will inevitably lead to more crashes.
Molina, et.al., (2007)	Young drivers (N = 263) 2 phase training Simulator track experience 20 mins on-road feedback Group discussion	Significant positive change for the 'Skills for Careful Driving' scale. Subjects assessed that after nine months their "Skills for Careful Driving" were still better than before the safety training course.
Mollenhauer, et.al., (1997)	Young driver (N = 26) Training - Antilock Brakes-ABS 5 min to read pamphlet -what is ABS -correct ABS application -feel of ABS when activated -benefits of using ABS -types of manoeuvres that are possible under extreme braking conditions	Results indicated that trainees Stopped in shorter straight line distances. More often used the correct brake activation technique. However, the stopping distance benefits were not realized in the curved and surprise braking events. Results suggest that the transfer of verbal knowledge may have value as a means for solving the apparent problem of improper ABS usage.
Potvin, et.al., (1988)	Quebec new licence drivers (N = all - Jan 1980 - Aug 1984) Training program 30 hrs in-class lessons 8-10 hrs vehicle control	Increase risk of crash with no injury. Increase risk of crash with injury.
Smiley, et.al., (1980)	Novice driver (N = 12) 3 week education program No specific details provided	Initially trainees controlled lateral position, but after 2-3 days began to control heading angle, which influenced lateral position.

In general, drivers are more likely to participate in a training program for two reasons. The most common reason is as part of the initial learning phase of driving with "learn-to-drive" programs typically teaching the basics of driving (Forsyth, 1993; Williams, et al., 1996). By far, the bulk of the literature deals with such programs because of (i) the large number of participants at this stage and (ii) the problems associated with learner drivers. In addition, a smaller number of drivers elect to

undertake a driver-training program after receiving a licence. In the literature, post-licence programs have been termed “advanced-driving”, “defensive-driving” or “driver-improvement”. According to Gardner (1998), post-licence programs offer the attraction of modifying and improving established driving skills and driving performance. Post-licence programs are of particular relevance towards the content of this thesis for two reasons. First, drivers who participate in post-licence programs are considered experienced drivers, and therefore, many of the problems that affect learner driver programs may not exist. Second, much less research is published in this area and hence the effectiveness of such programs is uncertain.

It appears from some literature review articles that post-licence driver-training programs are generally ineffective. However, many reviews generally have too wide a scope and include programs focussed on drivers whose training requires special consideration, such as (i) elderly driver (Bedard, Isherwood, Moore, Gibbons, & Lindstrom, 2004; Simoes, 2003) and (ii) problem driver, such as persistent drink drivers (Masten & Peck, 2004). For example, the literature reviews by Ker, et al., (2003; 2005), Stuckman-Johnson, Lund, Williams, and Osbourne (1989), and Lund and Williams, (1985) included far more problem-driver remedial-programs as examples of post-licence training compared to programs suitable for ordinary experienced drivers (Table 2.2). Not surprisingly, such reviews tended to find a negative training effect, which was potentially due to the difficulty dealing with drivers who require special consideration rather than any post-licence training program per se. If these were excluded, the few remaining post-licence programs provide some evidence that training may be positively effective. Therefore, such reviews are problematic, biased, and controversial, especially as the discussions and conclusions are generalised to general post-licence programs.

Table 2.2 Summary of published literature reviews of post-licence driver-training

Authors	Description of review articles	Summary of review findings
(Ker, et al., 2005)	<p>Criteria - randomised controlled trials comparing post licence driver education with group, correspondence one-on-one training or no training.</p> <p>1300 published and unpublished studies identified, 87 were potentially relevant, 24 met the inclusion criteria.</p> <p>4 investigated the effectiveness of advanced driver training, 20 studied problem driver training, 1 only was conducted outside the USA.</p>	<p>No evidence was provided that driver training programs were effective in preventing road traffic injuries or crashes.</p> <p>A small reduction in the occurrence of traffic violations was noted.</p> <p>The authors claimed this may be due to publication or other selection biases, or else to bias in the included trials.</p>
(Lund & Williams, 1985)	<p>Defensive Driving Courses ( National Safety Council, 1965) 8 hr training usually spread over 4 sessions that emphasises specific actions drivers can take to reduce the chance of a crash.</p> <p>17 studies that occasionally included other training courses for comparison were identified.</p> <p>5 tests strong method design, 5 five weak method design, 7 inadequately designed.</p> <p>5 studied adult drivers, 9 studied problem drivers, 3 studied learner drivers.</p>	<p>The more positive effects of DDC were found in the methodologically weaker studies, and strong studies usually found no significant effects of DDC for crashes.</p> <p>A small reduction for traffic violations was noted.</p>
(Stuckman-Johnson, et al., 1989)	<p>100 publications dealing with aspects of driver improvement.</p> <p>65 studies were identified that evaluated the effectiveness of one or more driver improvement activities.</p> <p>19 studies evaluating 59 different driver improvement activities were identified as providing strong method design.</p> <p>5 studied adult drivers, 52 studied problem drivers, 2 studied learner drivers.</p>	<p>Crash reductions were not demonstrated. More than 25% of the comparisons showed increased numbers of crashes.</p> <p>A small reduction for traffic violations was noted.</p> <p>The success of programs in reducing new violations does not imply similar success in reducing new crashes.</p>

#### ***2.4.2. Development of driver-training***

The development of training program models have generally progressed from traditional and intuitive ideas, such as the views and opinions of driving experts (Mayhew & Simpson, 2002; Williams, 2006). For example, one early program (circa 1935) that was based upon observations and intuitive ideas about driving was the British Police Driving School program. With a companion book “Roadcraft: The Police Driver’s Handbook” (Home Office, 1961), this program became influential and led to the establishment of training programs within many communities worldwide. More recently, there have been calls for driver-training to be based upon theories and empirical evidence (Hatakka, et al., 2002; Watson, 2003; Williams, 2006). Sports-training also developed from similar observations and intuitive ideas of experts, which was a well recognised problem in sports-training literature and subsequently led to research and theoretical input being considered a crucial part of sports-training program development (Williams & Hodges, 2005).

Researchers, such as Watson (2003), have recently proposed a selection of research priorities for future development of driver training models. The first group of priorities is towards promoting skill development and gaining experience for detection, perception, and anticipation of risks and hazards during driving, which are areas under current consideration by others (McKenna, et al., 2006; Senserrick, 2006; Williams, 2006). A second priority suggested by Watson (2003) is into skill development for postural stability of a driver because of its role in enhancing a driver’s detection, perception, and anticipation of risks and hazards.

Many recent models have focused their attention upon the roles that attitudes and behaviour play in safe driving. Such models consider inappropriate attitudes and

behaviour as a principal cause of crashes. For example, a model that has gained support depicts driver-training as a four-level hierarchy of psychological and social motivators (Hatakka, et al., 2002). According to this model, the most important role of driver-training is to develop a driver's skills for self-control as these impact upon their goals and intentions for driving (second top level of the model), which influences the lower levels of mastery of a driving environment, and ultimately, a driver's vehicle control ability and driving performance (lowest level).

Traditional forms of training programs are generally considered to have ineffective instruction methods (Williams, 2006). Typically, the type of training being criticised was short in duration, focused solely on vehicle operation skills, and used scare tactics to invoke safe driving (Williams, 2006). In some circumstances, vehicle operation skill training was little more than a demonstration of particular driving manoeuvres that a student driver copied. As such, researchers have proposed that models of driver-training programs should embrace modern pedagogical ideas (Hatakka, et al., 2002; Mayhew & Simpson, 2002; Watson, 2003; Williams, 2006). One proposed model advocates that during training a driver should gain awareness of the limits of their driving skills rather than simply learning actions that form a skill (Gregersen, 1996). Gregersen uses the term "insight training" and promotes it as a model for a driver to gain a more realistic understanding (i.e., "insight") into their capabilities. Another model is "commentary training", whereby a driver articulated to an instructor the various situations and their driving actions as they occur (Gregersen, 1994). It is suggested that without such feedback, training can lead to over-confidence and potentially put the driver at an increased risk of crashing (Gregersen, 1996).

Driver-training models that include parents have undergone resurgence in recent time. Although parents have been involved in driver-training for a long time, the recently proposed models have sought to formalise their role. In Australia, attendance at a formal driver-training program was not compulsory and permitted many parents to teach driving (Cambridge, 2002). In other countries, training by parents is more common compared to formal courses (Berg, Gregersen, & Laflamme, 2004). However, research has unveiled two areas of concern in regards to parental involvement during training. One major concern is that parents are not necessarily effective trainers, especially as some are prone to suffer from stress and anxiety that can be imparted to a trainee (Simons-Morton & Ouimet, 2006). A model by Gregersen, Nyberg, and Berg (2003) proposes that parents as lay-instructors need to be trained beforehand. Other models extend this by recommending that parents be systematically integrated into formal training programs (Gregersen, 1994; Hedlund, et al., 2003; Williams, 2006). A complementary model presents parents in a role of making training more effective through their involvement during the practice phase (Simons-Morton & Ouimet, 2006).

The second area of concern is that parents act as role models for new drivers regardless of assuming the role of a driver-trainer. Of primary concern is that parents may unintentionally impart their own poor driving habits onto a trainee driver. Parents with a history of unsafe driving habits are more likely to have children with a higher risk of crashing in the first year of driving (Ferguson, Williams, Chapline, Reinfurt, & De Leonardis, 2001; Wilson, Meckle, Wiggins, & Cooper, 2006). In addition, a study by Bianchi and Summala (2004) suggests that children may inherit a genetic disposition to adopting their parent's driving habits. This unintentional transfer of driving habits onto children may become enforced as parents train their children to drive.

Training models that incorporate deliberate practice of skills learned during training are emerging as an important. While such concepts are firmly embedded in sports-training (Ericsson, Krampe, & Tesch-Romer, 1993; Smethurst & Carson, 2001; Starkes & Ericsson, 2003; Williams & Hodges, 2005), few models of this type have been proposed in regards to driving-training. This may be because models have typically suggested that accruing hours of experience after training was the important step, such as, experience wet weather braking (Mollenhauer, et al., 1997; Williams & Wells, 1994). However, experience and practice are different concepts. According to Duncan, Williams, and Brown (1991), experience need not lead to expertise. Two fundamental advantages for modelling driver-training with practice are (i) the additional benefits for a driver to deliberately re-enacts aspects of the training that strengthens lessons learned (Groeger, 2001b) and (ii) feedback derived during practice provides information about driving performance (Duncan, et al., 1991). Furthermore, longer periods of practice rather than longer periods of training are suggested as more beneficial (Hall & West, 1996). However, training plus practice models may be weakened because the duration of driving practice is sometimes limited by the availability of a fully licensed driver, typically a parents, to act as supervisors (Berg, Eliasson, Palmkvist, & Gregersen, 1999).

#### ***2.4.3. Driver-training and crash and traffic violation outcomes***

The effectiveness of driver-training in regards to rates of crashes and offences involving trained drivers is a prominent research consideration. A focus on outcome measures is not surprising, given that people wish to establish whether an expenditure of time and funds on driver-training is warranted (Watson, 2003). In general, driver-training programs are purported to prevent traffic violations and crashes, or at least reduce the risk of involvement. However, driver-training has been described as ineffective for the

reduction of violations or crashes. Another issue was highlighted in a commentary to a recent review by Mayhew and Simpson (2002), which was that historical research rather than recent studies was used as the basis for deducing that training programs were ineffective (Robinson, 2002). For example, the historical “DeKalb County” driver-training study (DeKalb County, Georgia, 1978-1981) is often used as an example of a large-scale training program (i.e., more than 16000 high school participants) that did not result in dramatic reductions in unsafe driving. It was reported that drivers in an enhanced training group continued to violate traffic laws and crash at similar rates to the untrained group (Lund, et al., 1986). In re-examining the original data, Lund, et al., (1986) concluded that participation in such a training program was not beneficial because there were no statistically significant net reduction in incident rates. However, these researchers seemed to ignore their other finding, which was that training led to early licensure. Possibly, a more appropriate conclusion might have been that early licensure rather than a training program contributed to the continued incidents of violations and crashes. Their conclusions were somewhat surprising considering other researchers, such as O’Farrell (1983), had already published a concise summary of the positive outcomes from the study. But as O’Farrell states “the one point that was exploited by the media and training program adversaries was an observation that training programs did not increase or decrease the mean accident experience of any the groups ” (O’Farrell, 1983, pp 9).

In contrast, more recent studies have found that training can be effective. In a study by Gregersen, Brehmer, and Morén (1996), drivers within a large company were encouraged to drive safely by either using (i) a driver-training program, (ii) a safety campaign, (iii) group discussion, or (iv) financial incentive to crash safe driving. A fifth group received no interventions and acted as the control group. Results indicated that

the driver-training, discussions, and incentives reduced their rates of crashes and was beneficial for safer driving. A French study by Carcaillon and Salmi (2005) investigated the effectiveness of a crash reduction program aimed at drivers under 25 year old and utilised local database of crash rate incidents. The researchers reported the program a success, although the measured reduced rate of crashes did not achieve statistical significance. The researchers concluded that lack of significance was due to measuring the potential effects too early after the program was implemented. This lack of statistical significance is a point of interest in an article by Hauer's (2006), who suggests that some training evaluations with inconclusive evidence may actually have non-significant beneficial outcomes.

#### ***2.4.4. Driver-training and driving performance outcomes***

Another approach to determining the effectiveness of a training program is to measure the changes in driver skills and driving performance. Driving requires a level of skill proficiency in order to safely operate a vehicle. However, because of the dominance placed upon attitudes and behaviours in unsafe driving, such research has traditionally been criticised as too simplistic and not reflective of all the factors that lead to a crash. While such comments may be warranted, driving skills are still a major part of safe driving. It is from this view that studies into driving skills are considered an important contribution to overall driving performance.

The training of vision, arguably the most important driving skill, has received renewed attention. For example, it has been shown that a novice driver can improve their visual scanning of the environment (Chapman, et al., 2002; Underwood, Chapman, Bowden, & Crundall, 2002). Such programs have used computer simulators and video of traffic scenarios during training. The ability to control a vehicle has also been a focus of

research. For example, antilock brake systems have been found to not reduce rates of crashes. However, research has found that it was not the system that failed but rather drivers did not know how to use the system. One study investigated the effects of training drivers to properly apply these brakes (Mollenhauer, et al., 1997). Although they utilised a booklet as the basis of training, positive results were found.

The assessment of training has also considered a driver's retention of taught techniques. A prospective study considered training for a different mode of transport: the moped, which is a small low-power motorbike (Goldenbeld, et al., 2004). While the vehicle was different, the study had several good take home messages that were relevant for driver-training. This investigation into moped riding revealed that training did indeed improve a person's ability to ride after training. However, after almost one year, riders who had trained were no different compared to riders who received no training. Many reasons were suggested for the lack of sustained benefits over the long term, including the fact that once a driver leaves training it was up to the individual to maintain any benefits gained from a program.

#### ***2.4.5. Driver-training at Holden Performance Driving Centre***

A specific post-licence driver-training programs that is employed in this research is offered at the Holden Performance Driving Centre (HPDC) at Norwell in South-East Queensland. This program is a combination of education and in-vehicle training with a take-home companion book: "Drive to Survive" (Gardner, 1998). Throughout the duration of training, factors associated with attitudes and behaviour are discussed, both formally in the classroom and informally during instructional driving (Gardner, 1998). In regards to in-vehicle training, instructors teach a driving technique that combines skills for (i) enhanced perception of normal and hazardous driving situations,

(ii) avoidance of hazardous situations, and (iii) handling of a hazardous situation if it was unavoidable. Such a training approach is supported by suggestions made by McKnight (1984). A unique aspect of this driving technique is a focus upon maintaining postural stability when perturbed by inertial forces. The technique advocates the use of the driver's legs to brace against an adjacent surface as a way to resist perturbations and thereby achieve stability. A rationale for this is that a driver who is posturally stable via the lower body does not need to resist perturbing forces by tightening their handgrip on the steering wheel. A detailed description of this program is presented later in the methods chapter.

## **2.5. Conclusion**

This literature review considers vehicle driving, the training of drivers, and many of the scientific theories behind some of the concepts. From the literature, the problems and risk factors associated with driving are identified as multi-factorial in nature, encompassing psychology attributes as well as perceptual-motor skills. Numerous studies conducted into understanding many of the factors associated with unsafe driving are aimed at potentially being incorporated into future driver-training programs. In general, many studies indicate that training does not result in a statistical improvement when compared to untrained drivers. However, criticisms exist regarding the use of third-party databases of crash statistics, as they are not considered to be complete and thorough representations of all the unsafe driving events on the roads. More recent research into the effects of training has revealed benefits for selected skills that can potentially lead to improving a driver's ability to safely control a vehicle, for example, stabilising a driver's posture during accelerative driving situations.





# Chapter 3

## Methods

“Any man who can drive safely while kissing  
a pretty girl is simply not giving the kiss  
the attention it deserves.”

(Albert Einstein)



## **3.0 METHODS**

This chapter describes the study design and methodology common to the three experiments reported in this thesis. Details specific to the individual studies are presented in the relevant experimental chapter. All experiments were conducted in accordance with Australia's National Health & Medical Research Council guidelines for ethical conduct in research that involved human participants (NHMRC, 1999) with approval from the Griffith University Human Research Ethics Committee (PES/03/00/HREC).

### **3.1. Experimental design**

The goal of these experiments was to investigate changes in driver and vehicle performances as a result of driver-training. Three different driving manoeuvres, each comprising a separate field study, were investigated: (i) cornering, (ii) evasive lane change and return, and (iii) emergency braking. Each study was designed as a prospective randomised-control test with three cohorts of drivers. A trainee group received driver-training; while an age and driving experience matched control group did not attend training. An instructor driver group was also tested. The dependent measures were driver actions over the vehicle control, the resultant vehicle motion and the driver's postural stability.

### **3.2. Participants and recruitment**

Participants in the present study were volunteers recruited from the general population within Queensland, Australia. Each held a valid Australian provisional or full licence as defined in Table 3.1, which has been redefined since testing (Table 3.2). Drivers were excluded if they had a learner's permit or overseas issued licence, court imposed licence

restriction, medical condition noted on their licence or had previously attended a Holden Performance Driving Centre (HPDC) or comparable course. In addition, HPDC staff with at least six months instructor experience were eligible to volunteer.

Table 3.1 Definition of driving licences at time of testing (2005-2006).

Group	License class	Age and minimum driving experience
Learner (Not tested)	Learner permit	16 ½ yrs and older requires 6 months
Provisional	Provisional licence	17 - 23 yrs old requires 36 months 23- 24 yrs old requires 24 months > 24 yrs old requires 12 months
Experienced	Full licence	
Instructor	Full licence	> 6 months instructor experience

Table 3.2 Definition of driving licences from July 2007.

Group	License class	Age and minimum driving experience
Learner (Not tested)	Learner permit	16 yrs and older requires 12 months
Provisional	Provisional licence 1 (P1 licence)	> 17 old requires 12 months
	Provisional licence 2 (P2 licence)	18 - 24 yrs old requires 24 months > 25 yrs old requires 12 months
Experienced	Full licence	
Instructor	Full licence	> 6 months instructor experience

This information is based upon local state licence regulations. Other Australian states may slightly differ. Information source (June 2007).  
[http://www.transport.qld.gov.au/Home/Licensing/Driver\\_licence/](http://www.transport.qld.gov.au/Home/Licensing/Driver_licence/)

Participant recruitment was conducted over a nine month period (except for HPDC staff) in one of two ways. First, recruitment was in response to posters placed on public noticeboards (principally in suburban shopping centres and on university campuses) and interest created by word of mouth. Second, participants were recruited via HPDC. All drivers who enquired at HPDC about training during the experimental period were told about this research. Interested drivers were contacted later by the researcher. To limit differences between volunteers, the researcher interviewed all potential recruits. The interview elicited information about driving behaviour and attitudes. The interview questions were based on previously validated questions and scoring protocols developed by Reason, Manstead, Stradling, Baxter, and Campbell (1990). Volunteers with high scores, indicating extreme aberrant behaviour or attitudes, were excluded. Volunteers who made the criteria for inclusion in this study were placed into groups according to the above recruitment methods. The first group (public recruitment) consisted of forty-two volunteers, while the second (HPDC recruitment) had thirty-five volunteers. In addition, all thirteen HPDC staff who volunteered were recruited.

The first cohort, trainee drivers, comprised thirty participants. Ten and twenty participants were respectively selected from the first and second groups. All selection was randomised using a random number generator available on the internet ([www.randomizer.org](http://www.randomizer.org)). Each of the ten volunteers from the first group was allocated a free training place. This was done to limit differences between HPDC recruited volunteers who had previously considered driver training and the publicly recruited volunteers who had not. Five participants who dropped out of the experiments for personal reasons were replaced. The second cohort, control drivers, comprised fifteen participants from the first group. Control participants were matched to the trainee group for age and driving experience. As there were twice as many trainees as controls,

matching was conducted in relation to pairs of trainees of similar age and driving experience. None of the second group joined the control group as sufficient time was not available to conduct experiments before commencement of their scheduled course. The third cohort, instructor drivers, comprised thirteen participants. Not all participants completed the experiments. Reasons for non-completion included wet weather and technical problems.

### 3.3. Manoeuvres and test sessions

Three experimental manoeuvres, each with two conditions, were randomly presented to participants during a single test session. The experiments and conditions were (i) cornering from clockwise and anticlockwise directions, (ii) emergency braking initiated from 80 km/hr and 100 km/hr, and (iii) obstacle avoidance approaching from right and left lanes, which totalled six manoeuvres. All manoeuvres were conducted with no other vehicles on the track. A series of highly visible traffic markers were positioned for the cornering and obstacle avoidance manoeuvres. The set-up of markers is described in each experimental chapter as are the specific manoeuvre protocols. Trainee and control drivers participated in two test-sessions (pre- and post-test), while the instructor drivers participated in one test-session (Figure 3.1).

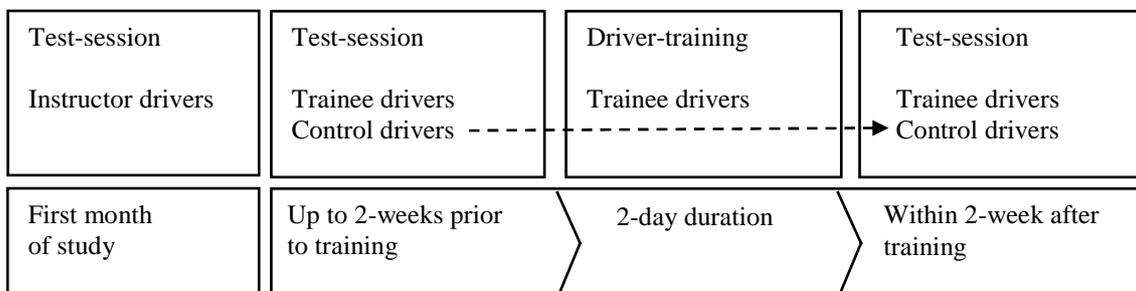


Figure 3.1 Schematic showing timeline for testing and training.

All six manoeuvres were conducted during a test session that took no longer than 90 minutes to complete. This time included initial participant briefing, driver specific instrumentation set-up, warm-up laps, repeating each driving manoeuvre six times and rest breaks between manoeuvres. Before driving any of the six manoeuvres, the specific manoeuvre protocols were discussed between the researcher, the participant, and a HPDC instructor. The instructor travelled in the front passenger seat as an observer and for reasons of safety. Sometimes lack of track availability, pending wet weather, or fading daylight limited driving time during a test session. In these circumstances, manoeuvres were initially repeated three times, and if possible, additional performed were performed at the end of the test session. These replacement trials were additional trials performed to replace earlier trials with suspected data problems.

### **3.4. Training program**

An existing HPDC driver-training program was used for these experiments. This training is suitable for post-licence drivers who have a sound knowledge of basic vehicle operations, which is distinctly different from a learn-to-drive training program. The training program was scheduled two to three times each month throughout the project duration. Conducted over two consecutive days, the program instruction included group discussions in a seminar room, watching driving demonstrations by the instructor and in-vehicle driving by the trainee with an instructor sitting adjacent. There was one HPDC instructor per two students during the in-vehicle manoeuvres. Each trainee had equal time to drive the vehicle during training. Presented in Table 3.3 are some of the topics taught during driver-training at HPDC. Outline within Table 3.4 and Table 3.5 is an approximate time schedule used during the two days of training.

Table 3.3 Description of topics taught during driver training at HPDC.

Topics	Description
Vehicle set-up	<p>Outside vehicle</p> <p>Ensure tyres are inflated, path of travel is clear &amp; windows clean</p> <p>Inside vehicle</p> <p>Seat and steering wheel position</p> <p>Distance of seat is measured between feet against firewall and bottom at rear of seat</p> <p>Distance of steering wheel is measured between shoulders against seat backrest and wrists on top of steering wheel</p> <p>Height of steering wheel is low without obscuring dashboard</p> <p>Mirrors</p> <p>Rear mirror to look directly behind</p> <p>Left and right side mirrors are horizontally angled until the vehicle's side is just viewable</p>
Visual scanning	<p>Look between the destination of travel and the vehicle</p> <p>Locate other moving objects, e.g., traffic and pedestrians</p> <p>Look for existing and potential hazardous situations</p>
Pedal control	<p>Position right foot with heel on the floor between the accelerator and brake pedal</p> <p>Swivelling at the heel to change between pedals</p> <p>Use graduated pedal depression</p>
Steering wheel control	<p>Use a relaxed grip</p> <p>Hand position at horizontal mid-line in straight line travel</p> <p>Position hand at top of wheel prior to wheel rotation</p> <p>Rotate wheel by first pulling wheel down, then push up if more rotation required</p> <p>Do not cross arms over face of steering wheel</p>
Bracing against	Sit with bottom at rear of seat
Door	Abduct the leg to the door with the heel still grounded
Console	Abduct the leg to the console with the heel still grounded
Footrest	Extend left leg forward onto the firewall (or footrest if available)

Table 3.4 Outline of Day 1 schedule used during driver training at HPDC.

Day 1	
Time	Description of training manoeuvre
0830 – 0900	Group seminar Awareness towards driving physics, driving attitudes & behaviour, driving environment, hazard detection & risk perception, driving technique, driving posture and vehicle control & dynamics
0900 – 0915	Safety-check of vehicle – outside and inside Continued discussion on mental awareness towards driving, driving attitudes & behaviour before entering vehicle. Once inside vehicle, summary of group discussion reinforcing the basic technique, seating position & headrest, adjusting mirrors, familiarisation with vehicle controls, use of steering wheel, scanning of environment & use of indicators
0915 – 1030	Clockwise manoeuvres with two trainees and instructor as alternate drivers Instructor demonstration includes visual scanning, steering and pedal control and vehicle dynamics, leg bracing and postural stability. Also demonstrates how to avoid locking wheels and skidding by increasing awareness, known as “switching on” and regulating brake pressure, known as “brush & bury” Trainees drive with the instructor. Trainees discuss their current driving style, implement the driving technique, recognition of individual learning, attitude and behaviour limitations Skidpan driving occurs during this time for training in the braking technique on a wet road, and correct steering control in order to prevent oversteer and understeer
1030 – 1100	Morning tea rest break
1100 – 1300	Clockwise circuit driving continues
1300 – 1315	Demonstration of minimum distance between two vehicles travelling at 100 km/hr when the lead vehicle suddenly brakes to a stop
1315 - 1400 <sup>+</sup>	Lunch rest break and informal discussions

Table 3.5 Outline of Day 2 schedule used during driver training at HPDC.

Day 2	
Time	Description of training manoeuvres
0830 – 0900	Group seminar mental awareness towards driving, driving attitudes & behaviour, driving environment & hazard detection, driving technique, driving posture, and vehicle control & dynamics, especially oversteer & understeer Safety-check of vehicle – outside and inside
0900 – 1030	Anti-clockwise manoeuvres with two trainees and instructor as alternate drivers
1030 – 1100	morning tea rest break
1100 – 1330	Anti-clockwise circuit driving continues
1330 - 1400 <sup>+</sup>	lunch rest break, informal discussions, and course summary

### **3.5. Holden Performance Driving Centre training facility**

Experiments were conducted at the HPDC facilities, which is located between Brisbane and the Gold Coast. The HPDC facilities included a 1.25 km purpose built closed-circuit track, i.e., closed off to general traffic (Figure 3.2). The track was 10 m wide, which was equivalent to a typical two-lane road, but did not have any dividing lane markings. The circuit was free of visual obstructions and regularly maintained to a high standard of road surface. Large areas of flat vacant land surrounded the circuit and afforded safe vehicle run-off space in case of emergency, which is important because drivers will not always be successful in controlling the vehicle during a training manoeuvre. For the current experiments, all testing was conducted on a dry track.



Figure 3.2 Holden Performance Driving Centre training facility.

### **3.6. Vehicle and research equipment**

#### ***3.6.1. Vehicle***

All experiments were conducted in a right-hand drive passenger sedan (Commodore, Holden) that had automatic transmission with power steering (Figure 3.3). An anti-lock braking system (ABS) was engaged during all experiments. The vehicle was regularly

serviced and the tyre pressure was standardised to 250 kPa. Drivers could adjust the seat position forward, backward, tilt up or down plus incline or reclined the backrest to accommodate different driver anthropometrics. Trainees after training and instructor drivers positioned their wrist on top of the steering wheel to guide the positioning of the seat. In addition, the steering wheel was adjustable up, down, towards or away from the driver. Seat belts were used by driver and vehicle occupants during driving at all times. The radio was turned off during experiments.



Figure 3.3 Research vehicle: Holden Commodore sedan.

### ***3.6.2. In-vehicle data acquisition system***

An in-vehicle data acquisition (DAQ) system consisted of a series of data acquisition units and modules, electronic instruments, and a laptop computer (Figure 3.4a). A data acquisition unit (DAQBook 200, IOtech) with a data acquisition card (DAQBoard 200A, IOtech) was the core of the system. Two data acquisition modules; a 8 channel strain gauge module (SGM) (DBK43A, IOtech) and a 16 channel voltage input module (VIM) (DBK80, IOtech) were connected into the DAQ book, which was connected to a laptop computer (Latitude CPt, Dell) (Figure 3.4b). The SGM and VIM had programmable gain input amplifiers, performing analogue to digital conversion, signal conditioning and signal expansion. The instruments comprising the data collection system included a

global positioning system (GPS, 10 and a range of analogue (ANA, 100 Hz) devices. The instruments were arranged such that the GPS was connected to a laptop via the serial port, while ANA instruments were connected to either a SGM or VIM modules. The complete DAQ system was located behind the driver's seat, while the laptop was held by an in-vehicle researcher. The DAQ system was powered from the vehicle's mobile phone power outlet via an extension lead that ran along the side of the centre console to the back of the vehicle. All instrument cables were shielded against electronic interference from the vehicle and other electronic instruments.

At the beginning of each test session, all instruments were connected to their allocated input socket. To ensure correct connections at each test session, the cables and respective sockets were colour coded. The SGM had eight plug-in input sockets accessible from outside the module. The VIM had sixteen analog inputs, which were presented as rows of screw-down connector blocks embedded on an electronics board located within the VIM housing. To permit instruments to be easily connected to the VIM, short extension leads with a plug-in input socket (accessible from outside the module) were hardwired into these connector blocks. Extra care was taken to minimise crosstalk between instruments, which was controlled by shielding adjacent cables and ensuring that no exposed wires (required for insertion into screw-down connectors) touched another exposed wire.

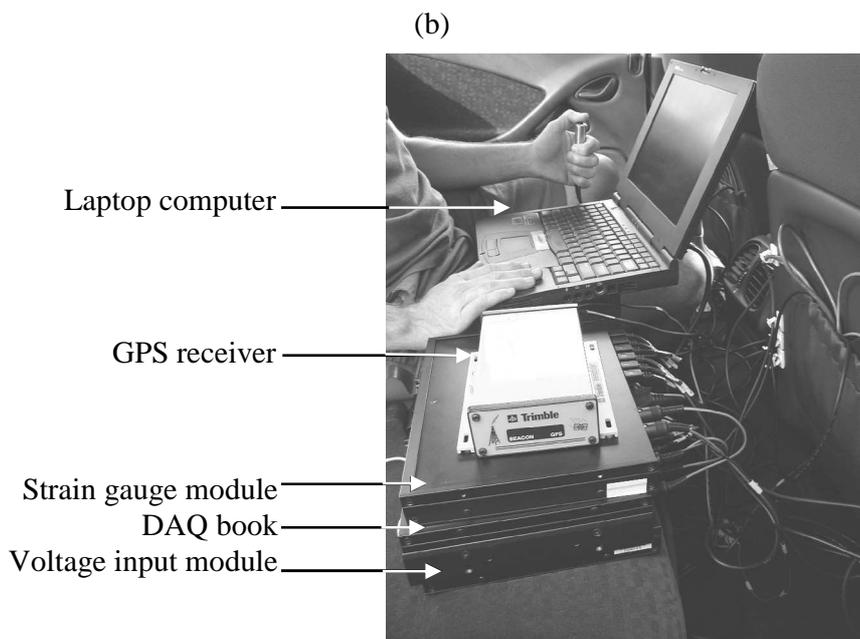
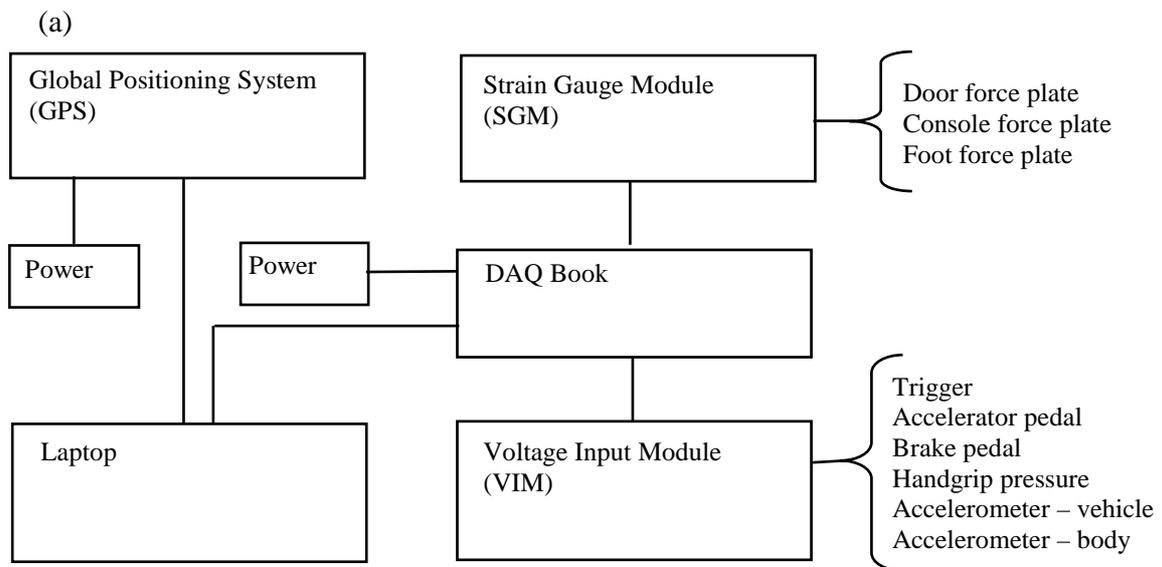


Figure 3.4 Data acquisition system: (a) schematic, (b) instrumentation (resting on seat only for illustrative purposes).

### 3.6.3. Global positioning system

A portable GPS instrument (DSM 212H, Trimble) was used to locate the position and measure velocity of the vehicle. The dome-shaped GPS antenna was magnetically attached to the middle of the vehicle's metal roof (Figure 3.5a). The receiver box was

located inside the vehicle (Figure 3.5b) and connected to the antenna via an insulated cable lead. A 12 volt battery (Bosch, Melbourne) that powered the GPS was securely located in the footwell behind the front passenger seat was.

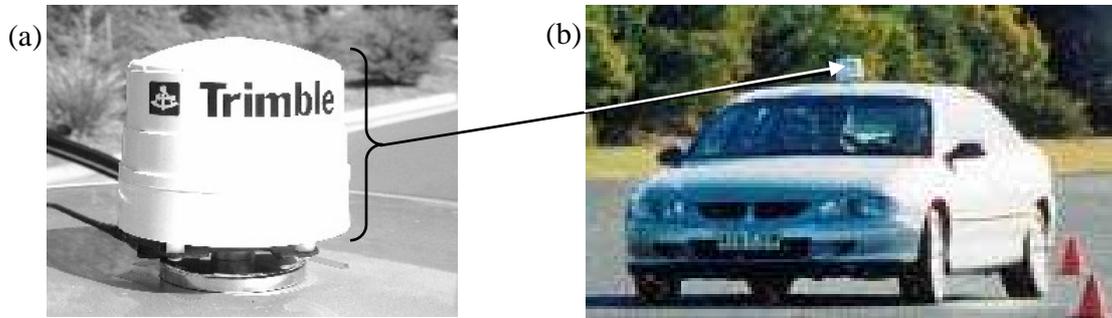


Figure 3.5 The GPS set-up: (a) antenna, (b) antenna positioned on the vehicle's roof.

GPS technology employs a network of satellites located in a stable orbit above the earth. By detecting at least four satellites, the GPS receiver is able to determine the antenna's position by triangulation between a receiver, the satellites, and a permanent reference GPS ground station located at the nearby Port of Brisbane. Whenever fewer satellites are detected, positions suffer degraded accuracy. This GPS instrument was operated in differential global positioning system (DGPS) mode in order to compensate for common mode noise.

Data was sampled at 10 Hz, which for a vehicle travelling at 60 km/hr (16.67 m/sec) provided position measurements at intervals of approximately 167 mm or 1/30<sup>th</sup> of the vehicle's length. Measurements from the GPS were in the form of string codes, which were standardised by the National Maritime Electronics Association (NMEA). Twenty-six NMEA code options were available for output, but only three were selected:

- (i) Position data provided latitude and longitude information,
- (ii) Velocity data, and
- (iii) Confirmation of satellites activity and accuracy of position data.

Remaining NMEA codes were manually turned off via the proprietary software. Another aspect of the software permitted operation modes to be set, with the choices being “land”, “sea”, and “air”. The ‘land’ option was intended for slow speeds, less than 10 km/hr, e.g., a person walking. The ‘sea’ option suited travel speeds expected from a boat, i.e., 6 - 20 knots (approximately 10 km/hr and 40 km/hr), while ‘air’ was used for faster travel applications (greater than 40 km/hr). Experiments in this study required the vehicle to travel between 40 km/hr and 100 km/hr. The ‘air’ operation mode was selected.

The GPS instrument used in this study was rated to measure latitude and longitude coordinates with sub-metre accuracy, i.e.,  $< \pm 1$  m ( $2 \times 2$  m area) and velocity with an accuracy of  $\pm 0.16$  km/hr. However, coordinates for a stationary location slightly shifted within this area between GPS activations. To compensate, GPS coordinates from three permanent trackside landmarks located in different corners of HPDC were collected at the beginning of test sessions. Each landmark position was compared to the known location of the respective landmark, which allowed an offset measurement to be calculated. As the offsets from the three landmarks occurred in a similar direction and at a similar distance, a mean offset was subsequently calculated. This mean offset became a compensation factor for that test session, which was applied during data processing to all GPS coordinates (up to 48 sets). However, examination of the data revealed that the positions in relation to the edge of the circuit or between repeats from a driver in a session (as previously measured in earlier studies) were still not reliable. Position data were therefore not analysed for location measures, although the GPS data was still suitable for measuring travel distances.

#### ***3.6.4. Force plates***

Three custom-built force plates located on three sides of the driver's footwell were used to measure the forces of leg brace application. A door-mounted force plate was configured with a 35 kg low profile single-point load cell (Scale Components) centrally located behind a metal faceplate (310 mm wide  $\times$  260 mm high  $\times$  2 mm thick) (Figure 3.6a). The force plate was vertically mounted onto a rigid surface provided by a custom-built H-shaped metal bracket bolted onto the door's substructure. The plate faceplate was 330 mm to the right of the seat centreline. A driver could contact the doorplate by right leg abduction regardless of the seat's height, tilt angle, and driver's proximity from the steering wheel.

On the opposite side of the footwell, a force plate configured with a 35 kg low profile single-point load cell (Scale Components) was located on the centre console and measured 215 mm wide  $\times$  230 mm high  $\times$  2 mm thick; which allowed the driver's seat to move forward unimpeded (Figure 3.6a). The interior panel that forms the centre console was cut away to reveal the underlying metal, which was used to screw-fix the force plate's bracket. The console faceplate was 210 mm to the left of the seat centreline. Contact could be made by abducting the left leg regardless of the seat's height, tilt angle, and proximity from the steering wheel.

The third was the footrest force plate and it replaced the original footrest structure (Figure 3.6b). The configuration used two S-Beam load cells (model S1, Applied Measurements) mounted under a single faceplate. Forces in the toe region were measured using a 1 kN load cell, while a 2 kN load cell measured the force applied in the heel region. The faceplate (170 mm high  $\times$  50 mm wide  $\times$  2 mm thick) was positioned at the same elevation and angle as the original footrest. The force plate was

supported by a bracket that was screw-fixed into the metal wall of the footwell. All metal faceplates were carpeted, concealing the plate's mounting bolts so that the driver experienced no discomfort when bracing. Data were independently recorded from four load cells. The two footrest sensors were summed together during post-experiment data processing to produce a single measure. The instruments were calibrated by perpendicularly applying a known spring load against the force plates. The cables connecting the instrument to the SGM input sockets were kept away from any possible interference with the door's function or the driver's legs and feet during driving or vehicle egress.

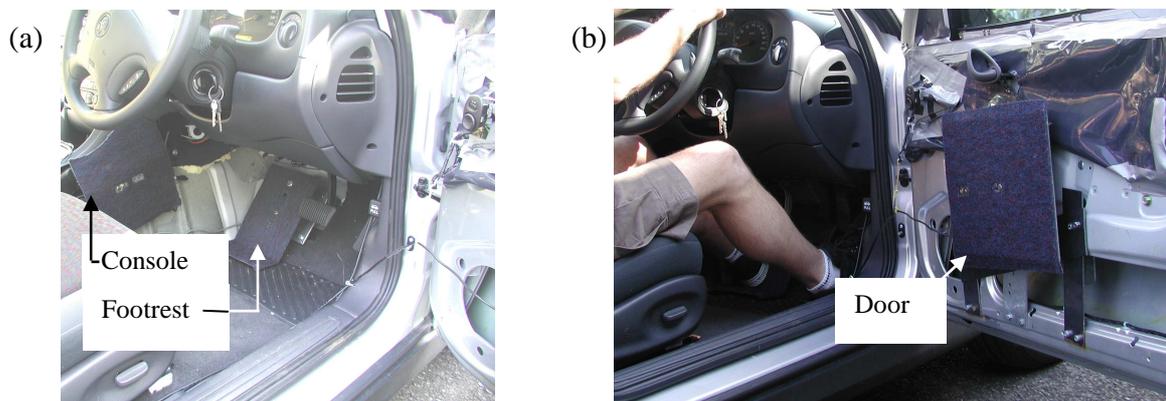


Figure 3.6 Force plates: (a) footrest force plate and console force plate, (b) door force plate.

### **3.6.5. Potentiometers**

Accelerator and brake pedal depressions were individually measured using 45 kOhm resistor linear potentiometers (LTS03, Honeywell). Each linear potentiometer was securely fastened between the dashboard substructure and the respective pedal's lever-arm in line with the direction of pedal depression (Figure 3.7). A potentiometer's piston stroke length was 3 inches (76.2 mm) and due to the way an instrument was fastened, each of the two pistons moved only through a smaller mid-sectional region as a pedal was depressed; 40.0 mm for the accelerator pedal and 35.0 mm for the brake

pedal. This range was measured with hand-held callipers and used to scale the respective pedal depression movements from 0 % to 100 %. The use of mid-section piston stroke reduced the possible risk of electronic signal noise being introduced whenever the piston was at full extension or depression. All cables connecting the instruments to the VIM were kept away from any possible interference with the driver's legs and feet during driving or vehicle egress. Instrument calibration was conducted using the proprietary software from the VIM.

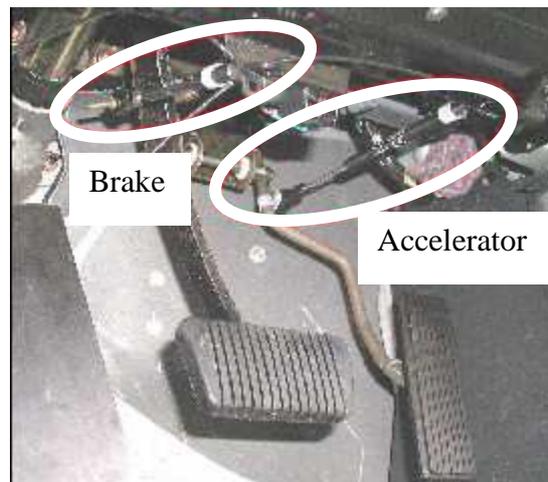


Figure 3.7 Linear potentiometers: brake (left) and accelerator (right) pedals.

### ***3.6.6. Accelerometers***

Two triaxial  $\pm 2$  g accelerometers (CXL02LF3, Crossbow) were used to measure three-dimensional acceleration profiles for the vehicle and driver's torso. One instrument measured vehicle accelerations and was located left of the driver's seat on the centre console within a recessed drink-holder moulding (Figure 3.8a). This site was chosen because it was a stable surface, offered excellent impact protection and was close to a driver's base of seated support. The second instrument was attached to the driver's torso once they were comfortably seated in the vehicle. This accelerometer was secured directly onto the skin over the seventh cervical vertebra (vertebrae prominens)

(Figure 3.8b). This was located as the distinctly posterior bony projection (for most people) at the base of the neck (Moore, 1980).

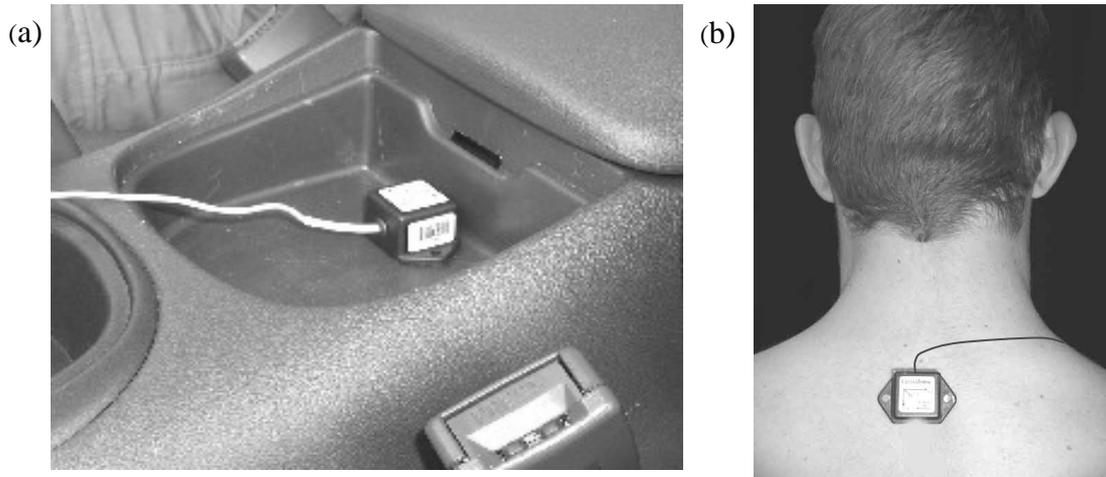


Figure 3.8 Accelerometers: (a) vehicle's centre console (protective cover not in photo)  
(b) driver's torso (strapping tape not in photo).

The orientation of the instruments was horizontal for the vehicle and vertically angled for the driver. The axes of sensitivity were defined as follows: X for the forward movement (anterio-posterior direction), Y for the side-to-side movement (medial-lateral direction) and Z for the vertical movement (caudal direction) regardless of orientation. The instrument in the vehicle was aligned with the x-axis parallel with the centre console. The instrument on the driver was aligned with the z-axis parallel to the spine and the data cable located at the top, extending away from a participant's shirt collar. Z-axis data from the instrument on the driver was used for a trigonometric correction of sensor tilt, which is common practice in other accelerometry studies, such as gait research. Strapping tape (Hypafix, Smith & Nephew) was layered as a long vertical length underneath three horizontal lengths. Pre-tension of skin was performed before the tape was applied over the instrument. All cables connecting the instruments to the VIM were kept away from any possible interference with the driver's actions during driving. The instrument on the driver was removed before the driver exited the vehicle.

Each accelerometer was calibrated by aligning each axis against a known perpendicular surface along a vertical line prior to test sessions.

### ***3.6.7. Handgrip sensors***

Handgrip forces were measured using four pressure sensors (100 lb / 444 N) (FlexiForce, Tekscan). The instruments were calibrated by applying a known force onto the pressure sensor. Once a driver was comfortably seated in the vehicle, he / she pulled a pair of tight fit cotton gloves onto their hands (one set per driver). These gloves were chosen because they did not easily slip across the steering wheel or lead to sweaty hands in comparison to a range of gloves trialled during a pilot study. Once on the hands, each glove then had two sensors located and securely taped (Hypafix, Smith & Nephew) on the palm; one positioned over the middle of the abductor pollicis brevis muscle (thumb region), while the second was positioned over the distal end of the middle finger (Figure 3.9).



Figure 3.9 Location of hand grip sensors: (glove and strapping tape not in photo).

These locations were identified from pilot study observations as the most common places in contact with the steering wheel. Each instrument had a long plastic tail that was curled around and secured to the dorsal side of the glove. Instrument cables were secured along the arm to the shoulder using a series of velcro-straps to minimise

interference with driver's movements. The cable was then secured at the seat headrest before connecting into the VIM. Although the cables were secured, they did not inhibit the driver's actions, posture, or seat belt. Prior to test-sessions, each participant applied their greatest isometric force against each force plate as an individual scaling factor. Instruments were removed before the driver exited the vehicle.

### ***3.6.8. Trigger***

A simple button trigger was used to record the time of specific events during tests, e.g., the time of a verbal command "stop" during emergency brake manoeuvre. The trigger was activated by depressing the button and remained active until released.

### ***3.6.9. Observations***

Protocol deviations, contact with targets, and general comments were noted by an in-vehicle researcher during each participant's test-session, which was referred to during data analysis.

## **3.7. Data collection procedures**

All instrument operations and data collection were controlled and synchronised using a LabView program (Ver. 5.1.1, National Instruments) written by the researcher. A graphic user interface (GUI) was created with LabView for this program, which provided simple button activation for data collection. In addition, active data channels were displayed within four graphs that formed part of the GUI. The data was displayed in groups, (i) bracing, (ii) handgrip pressure, (iii) acceleration profiles, and (iv) both pedal controls and trigger action. Different colours were used to distinguish each

individual data channel within a graph. A fifth display simultaneously screened the GPS NMEA data that were being collected. An important advantage of the GUI's was that data could be inspected to provide an easy method for checking that each instrument was properly operational.

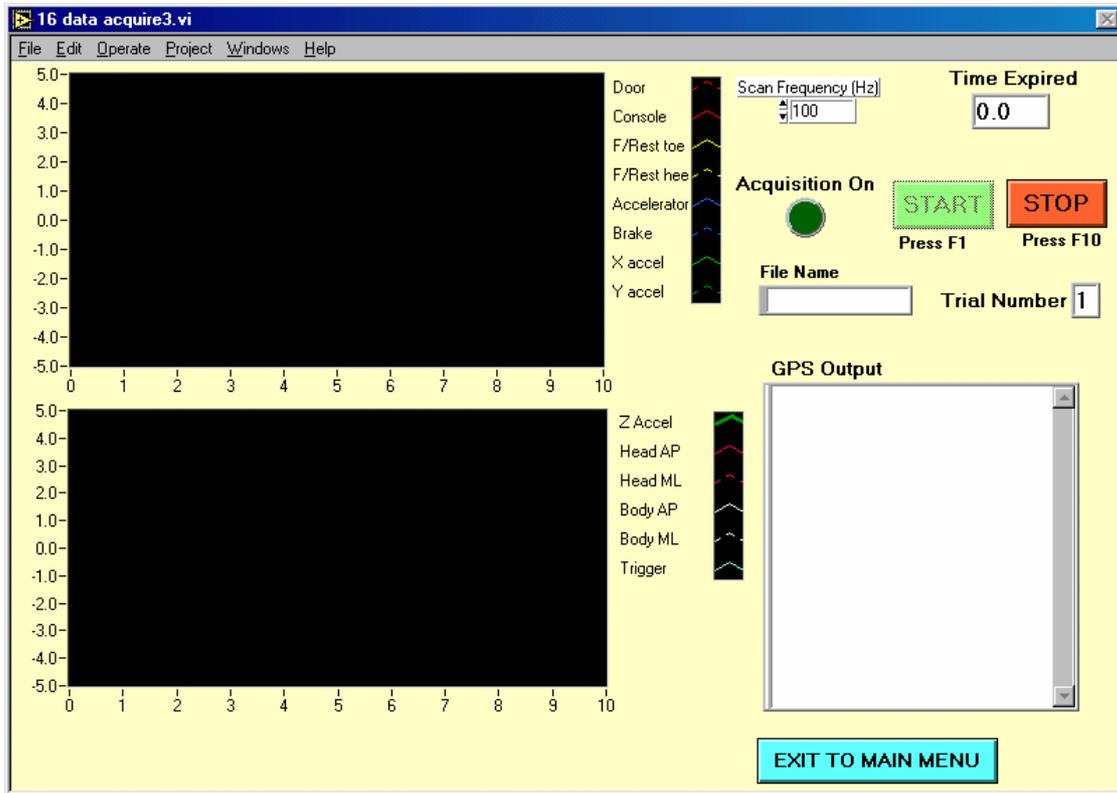


Figure 3.10 LabView graphic user interface.

### 3.8. Data processing procedures

All data files were transferred from the laptop to a desktop computer for processing. The researcher used Matlab (Ver. 6.5 (13), MathWorks) to custom write the syntax for a series of software modules, which linked to form an effective analysis program. The advantage of this modular program was that it could be quickly and easily modified. The modules processed the data from initial raw data into final calculated dependant variables.

The modules were designed and arranged to allow the processing of the data in eight steps as follows. During Step 1, data was manually checked for irregularities, such as crosstalk, which if found resulted in that trial being discarded from further analysis. An excel spreadsheet of all accepted trial names was subsequently created. Using the spreadsheet from step 1, the data was read into MatLab during Step 2. In Step 3, specific columns of data were extracted and allocated a variable name. A dual pass 2<sup>nd</sup> order low pass Butterworth filter with a cut-off frequency of 10 Hz was applied to the ANA data. Also in this stage, the GPS data (10 Hz) was resamples to match the sampling rate of the ANA data (100 Hz). In addition, all raw GPS latitude and longitude data was transformed to eastings and westings using Redfern's formula (Redfern, 1948). The ANA data was converted from volts as measured by the instrument into the engineering units relevant to the data (e.g., g, N, etc). Finally, the brace and handgrip data was normalised as outlined on pages 115 and 143 . In Step 4, the GPS latitude and / or longitude data was used to geographically locate the beginning and end of the task under analysis. ANA data was synchronised to the GPS data and all data truncated to remove excess data before and after a task, e.g., the lead up and exit from a single corner. During Step 5, each of the dependent variables was calculated as explained in the chapters 4, 5, and 6. The resultant data was presented in graphical form during Step 6 and exported to a spreadsheet in Step 7 for statistical analysis.





# Chapter 4

## Experiment 1

### Driver-training and emergency brake performance in cars with anti-lock brakes

“Never drive faster  
than your guardian angel can fly.”

(Anon)



## **4.0 DRIVER-TRAINING AND EMERGENCY BRAKE PERFORMANCE IN CARS WITH ANTI-LOCK BRAKES**

### **4.1. Introduction**

Driver-training and education programs are available in most jurisdictions, and offer the attractive possibility of improved road safety (Mayhew, et al., 1998). However, conclusions based on randomised controlled studies of the effect of post-license driver-training on road injuries and crash statistics tend not to support this view (Ker, et al., 2005). It has even been reported that driver-training can have a negative effect of road safety through the development of overconfidence or underestimation of risk amongst trained drivers (Gregersen, 1996). As a consequence, some researchers have questioned the value of driver-training as an effective road safety intervention strategy (Williams & Ferguson, 2004).

In contrast, others have argued that instead of evaluating old forms of driver-training, attention should be given to the development and evaluation of new driver-training programs (Hirsch, 2003; Robinson, 2002). This development and evaluation process is essential because newer programs are more likely to reflect recent advances in understanding of crash risk factors. Indeed, recent studies report significant benefits of driver-training in terms of reduced crash statistics (Carstensen, 2002) and enhanced simulated driving performance (Dorn & Barker, 2005). Since it is generally acknowledged that basic driving skill is an important requirement for safe driving, the question therefore arises as to what skills should be taught and practiced in driver-training.

An important skill taught within most driver-training programs is correct brake technique. Of primary importance is to avoid wheel lock due to rapid brake pedal depression in order to prevent loss of steering control associated with skidding (Gardner, 1998). The importance of controlling vehicle balance (forward shift of vehicle weight), thereby improving stopping power is also emphasised. In vehicles without antilock braking systems (ABS), this is achieved by brake pressure regulation, which can include the well-known skid countermeasure of pumping the brakes when the driver first feels the wheels lock. In vehicles fitted with ABS, firm brake pedal pressure activates the ABS, which in turn prevents skids by mechanical regulation of brake pressure. ABS has been widely reported to enhance braking and steering, especially on slippery surfaces (Broughton & Baughan, 2002; Mollenhauer, et al., 1997). However there is evidence that drivers of vehicles fitted with ABS adapt their behaviour in ways that offset the intended benefits of the ABS (Sagberg, et al., 1997). Crash statistics also suggest that vehicles fitted with ABS are at greater risk of certain types of accidents such as crashes fatal to their occupants, rear end impacts, single vehicle crashes and run-off-the-road accidents (Delaney & Newstead, 2004; Evans & Gerrish, 1996; Farmer, et al., 1997). It has also been reported that while ABS has the potential to reduce accidents, this may not have been achieved because of limited knowledge and/or improper operation of ABS (Broughton & Baughan, 2002; Harless & Hoffer, 2002). From a driver-training perspective, this raises the question of how drivers should be trained in the use of ABS, and to what extent braking technique is transferable between vehicles with and without ABS.

In addition to teaching braking technique, some driver-training programs emphasise the importance of maintaining postural stability during critical situations. For example, during an emergency brake task, individuals can increase their stability during rapid

vehicle deceleration by the use of brace forces applied by the legs against the vehicle (Treffner, et al., 2002). The rationale for this technique is that a driver who is posturally stabilised via the lower body does not need to stabilise themselves by tightening the grip on the steering wheel, and is therefore able to keep the hands more relaxed and steer more effectively. This transition from a posture where the upper and lower limbs operate as a single, stiffened degree of freedom to one where the upper and lower body can work independently (through a freeing of the relevant degrees of freedom), is seen as an essential component in development of skilled motor performance (Kelso, Goodman, & Southard, 1979; Ko, Challis, & Newell, 2003; Newell, 1986; Newell & McDonald, 1994). The result of this coordination strategy is that the lower limb functions to provide a stable base for more controlled and dexterous motion of the upper limb(s). Examples of other movement tasks where transitional changes in postural coordination have been observed during the learning process include skiing (Vereijken, Van Emmerik, Bongaardt, Beek, & Newell, 1997), pistol shooting (Arutyunyan, Gurfinkel, & Mirskii, 1968), and archery (Stuart & Atha, 1990). It has also been argued that when different parts of the body are no longer constrained to act as a single, tightly coupled unit, the individual is better able to detect and react to relevant perceptual information as they are more dynamically stable (Stoffregen & Bardy, 2001).

The purpose of the present study was to assess the effect of a two-day post-license driver-training program offered by the Holden Performance Driving Centre (HPDC, Norwell, Queensland) on brake performance using a case-control design. This specific driver-training program instructed drivers to avoid skidding during braking with the application of a technique based on a graded application of pedal pressure and emphasised postural stability. An expectation was that, after training, drivers would use a smoother braking profile, have enhanced postural stability during braking, and stop

within a shorter distance compared with untrained drivers. It was envisaged that the results of this study would provide new information that would contribute to the evidence-base for development of skill-based components of driver-training programs.

## **4.2. Methods**

### ***4.2.1. Subjects and experimental design***

Two groups of drivers were recruited to participate in the study, a trainee group (n = 26), and a control group (n = 13). The trainee group consisted of students enrolled in a two-day post-license “Drive to Survive” course conducted by the Holden Performance Driving Centre (HPDC), Norwell, Queensland. The control group was matched to the trainee group by age and driving experience. All drivers held a valid Australian provisional or open driver’s licence at the time of testing. Provisional licence holders are at least seventeen years of age and have previously held a learner licence for at least six months. Provisional licensees are eligible to graduate to an open license after a period of 1-3 years depending on their age. No drivers had not participated in other HPDC training or comparable courses, and provided written informed consent prior to participation in the study. The study was approved by the Griffith University Human Research Ethics Committee, in accordance with National Health & Medical Research Council guidelines (NHMRC, 1999).

The trainee group completed a driving test within fourteen days before and fourteen days after participation in the two-day post-license driver-training course. HPDC driver-training programs focused on development of knowledge for driving, vehicle set-up, vehicle control skill and outcome insights, driving ability attitude, and awareness towards importance of practice through a combination of lectures, demonstrations by

instructors plus driving exercises performed by the student with an instructor in the vehicle such as brake application, corner navigation, and obstacle avoidance. The program is based on principles of safe driving published in the book 'Drive to Survive'. With reference to the brake technique, HPDC trainees were taught to use a graded two-phase application of pedal pressure throughout the deceleration phase, that is, initially depress the pedal quickly and gently almost to maximum depression, and then to steadily apply increased pedal pressure (or "bury" the brake pedal) to maximum depression and hold until the vehicle came to a stop. Additionally, trainees were instructed to stabilise their body by extending their left leg onto the footrest thereby bracing the lower body against the footrest, rather than by tightening the grip on the steering wheel. The control group was tested within the same time period as the trainee group, but did not participate in the driver-training course or receive performance feedback after their first test. At each test session, drivers performed up to six emergency braking trials from each of 80 and 100 km/hr at random locations along various straight sections of a 1.25 km closed circuit track.

#### ***4.2.2. Instrumentation***

All tests were performed in a sedan vehicle (Commodore, Holden) with automatic transmission, power steering, and ABS engaged. The vehicle was instrumented with GPS (Trimble) to measure vehicle position and speed at 10 Hz. Triaxial  $\pm 2$  g accelerometers (Crossbow) attached to the vehicle's centre console (adjacent to the driver's left hip) and the driver's 7<sup>th</sup> cervical vertebrae (vertebrae prominens) were used to measure vehicle and driver deceleration profiles. Pedal and brake depression were measured using linear potentiometers (Honeywell) and S-beam load cells (Applied Measurement) were used to measure brace forces applied to the footrest (Figure 4.1). In

addition, steering wheel grip forces were measured using pairs of flexiforce pressure sensors (Tekscan) taped to the distal and proximal aspect of each palm. All analog data were acquired at 100 Hz using a data acquisition system (DAQBook 200, DBK43A, DBK80, IOtech) attached to a laptop computer.

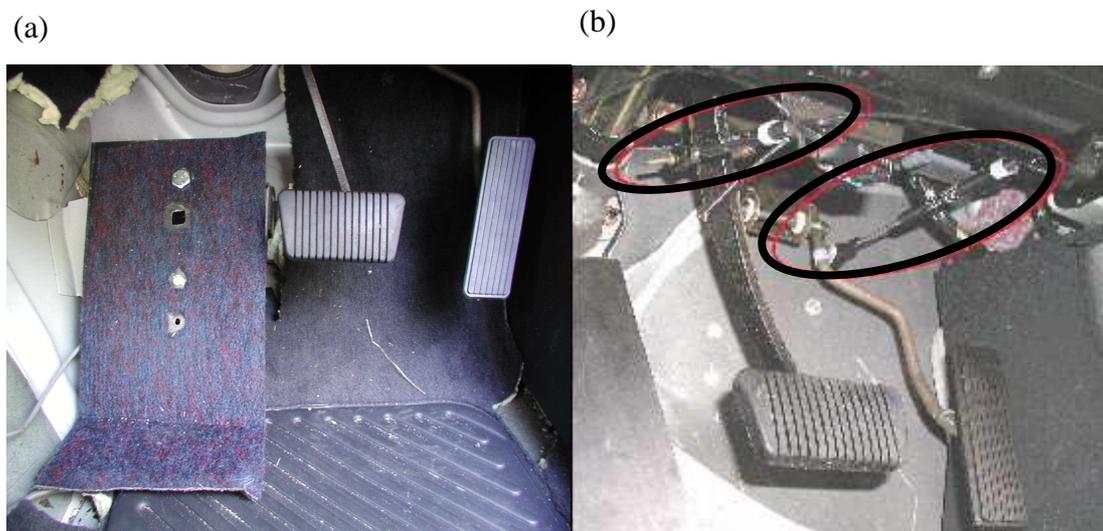


Figure 4.1 Vehicle instrumentation: (a) instrumented footrest brace plate, (b) linear potentiometers attached to accelerator (left) and brake (right) pedals.

### ***4.2.3. Data analysis***

The specific dependent measures assessed in this study were; vehicle speed, distance to react and stop, average vehicle deceleration, footrest brace force, brake pedal technique, and regularity of vehicle and driver deceleration. Vehicle speed was obtained at the command to stop. Distance to react was the measured from vehicle position at command to stop to vehicle position at initial brake depression. Distance to stop was the distance between vehicle position at initial brake depression and the vehicle position where the vehicle came to rest. Average vehicle and driver decelerations and footrest brace force (expressed as a percentage of maximal isometric force) were computed over the brake to stop period. Similarly, brake pedal depression was expressed as a percentage of maximal pedal depression. Brake pedal technique was assessed using the

time between initial brake application and 95% of maximum brake depression. For all trials, comments about hand tension were noted on custom designed observation sheets.

The regularity of deceleration profiles was assessed using an approximate entropy (ApEn) (Pincus, 1991). Values for ApEn range between 0 and 2, with lower values representing greater signal regularity. An irregular signal where time series events unrelated to previous event, such as white noise, will produce a high ApEn value. ApEn was used in the present study to determine regularity of the vehicle deceleration (vehicle ApEn), and driver acceleration (driver ApEn). Low values for vehicle ApEn were interpreted to indicate a smoother vehicle deceleration profile. Driver ApEn was computed from the time series of the difference between the deceleration of the driver and the deceleration of the vehicle. High values for driver ApEn were interpreted to reflect postural instability of the driver relative to the vehicle.

#### ***4.2.4. Statistical analysis***

A mixed full factorial general linear model was used to assess the effect of a group (trainees and controls), and test-session (pre- and post-test), on the dependent measures. Post-hoc pairwise comparisons with Bonferroni corrections were used to identify specific differences between means. All statistical analysis was conducted using SPSS for Windows (Ver. 11.3), with significance accepted at  $p < 0.05$ .

## **4.3. Results**

### ***4.3.1. Subject characteristics***

The control group (n = 13) consisted of six provisional licensee and seven open licensee drivers with a respective mean age and driving experience of  $27.9 \pm 7.8$  and  $9.2 \pm 6.0$  years. The trainee group (n = 26) consisted of thirteen provisional licensee and thirteen open licensee drivers with a respective mean age and driving experience of  $31.7 \pm 10.1$  and  $14.2 \pm 7.6$  years. There was no significant difference in age or driving experience between the two groups.

### ***4.3.2. Descriptive data***

Typical data for a trainee participant braking from 80 km/hr before and after training are presented in Figure 4.2. For this participant there was an initial rapid depression of the brake pedal, followed by a more gradual depression, which resulted in a more gradual vehicle deceleration, and absence of the pulses in acceleration signals from ABS activation in post- compared with pre-test. In addition, footrest brace forces were higher and steering wheel handgrip forces lower following training.

Although not subjected to quantitative analysis, observational data noted that in general, untrained subjects had a tendency to increase handgrip pressure on the steering wheel during the deceleration phase. By contrast, trainee drivers following training tended to use a more relaxed grip throughout the brake period.

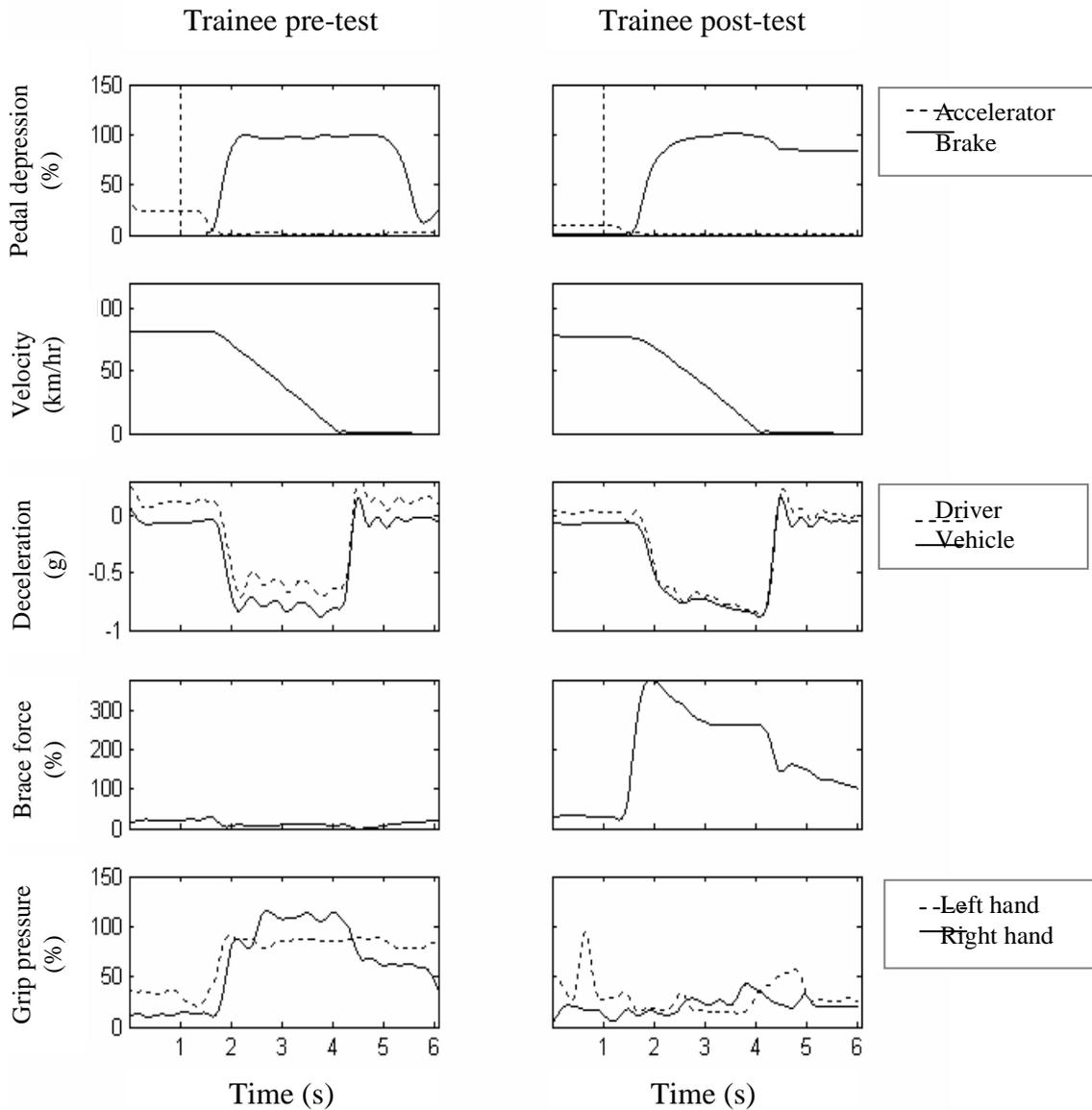


Figure 4.2 Raw braking data from a representative trainee driver. Collected prior to and following participation in the two-day “Drive to Survive” training course. Braking was initiated at 80 km/hr. Dotted line in top line of graph indicates the call to stop.

### ***4.3.3. Effect of group and test session on braking from 80 km/hr***

Summary results for the effect of group (control and trainee) and test-session (pre- and post-test) at the 80 km/hr speed condition are present in Table 4.1. Plots for each of the significant group by test session interaction effects are presented in Figure 4.3.

Post-hoc tests revealed that distance to stop, time to 95% brake, and mean footrest brace force were significantly higher for the trainee group compared with the control group following training. In addition, mean vehicle deceleration, vehicle ApEn and driver ApEn were significantly lower for the trainee group compared with the control group following training. Significant differences were also seen within the trainee group between pre- and post-test exhibiting significantly higher values for time to 95% brake depression, and mean footrest brace force and significantly lower values for mean vehicle deceleration, vehicle deceleration ApEn, and driver ApEn in the post-test condition. No significant differences were revealed between the trainee and control group's pre-test session or between the control group's pre- and post-test sessions.

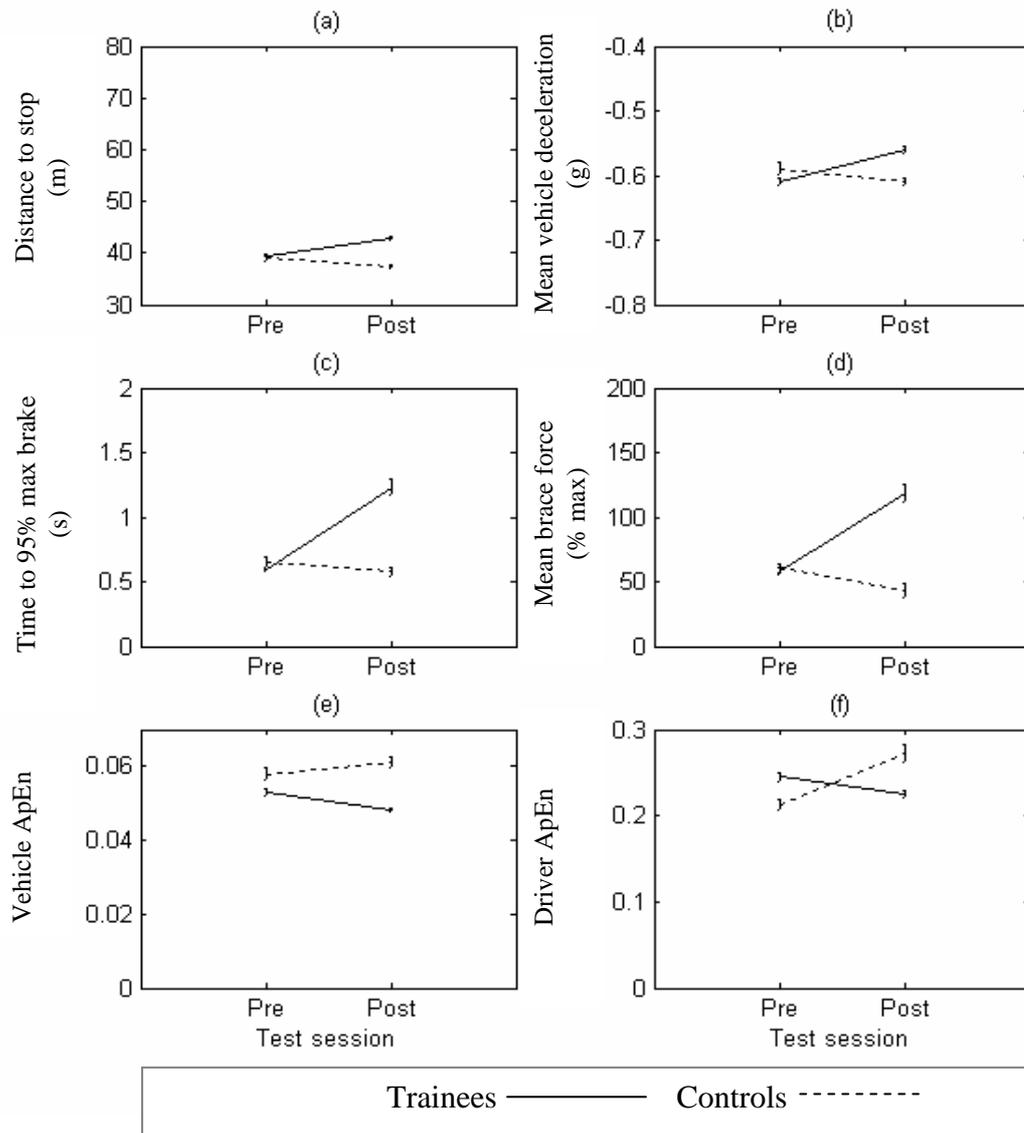


Figure 4.3 Summary of significant interactions between group (trainee and control) and test-session (pre- and post-) at the 80 km/hr speed condition: (a) distance to stop, (b) mean car deceleration, (c) time to 95% brake depression, (d) mean footrest force, (e) car ApEn and (f) driver ApEn. Error bars represent  $\pm$  one standard error of the mean.

Table 4.1 Summary statistics for effect of group, test session, and group × test session on the dependent measures at 80 km/hr. Bracketed terms are one standard error of the mean. NS = not significant.

Variable	Group			Test session			Group x test session
	Controls	Trainees		Pre	Post		
Velocity (km/hr)	79.57 (0.17)	80.29 (0.1)	NS	80.13 (0.15)	79.73 (0.13)	NS	NS
Distance to react (m)	9.95 (0.49)	10.40 (0.3)	NS	10.1 (0.29)	10.26 (0.38)	NS	NS
Distance to stop (m)	38.09 (0.76)	41.17 (0.47)	F = 11.97 p < 0.01	39.24 (0.38)	40.03 (0.66)	NS	F = 18.24 p < 0.01
Mean vehicle deceleration (g)	-0.60 (0.01)	-0.58 (0.01)	NS	-0.60 (0.01)	-0.58 (0.01)	NS	F = 7.85 p < 0.01
Time to 95% brake (s)	0.62 (0.09)	0.91 (0.56)	F = 7.70 p < 0.01	0.62 (0.09)	0.91 (0.06)	F = 7.90 p < 0.01	F = 11.86 p < 0.01
Mean footrest force (N)	51.85 (11.74)	88.47 (7.28)	F = 7.02 p = 0.01	59.32 (5.33)	81.00 (12.07)	NS	F = 9.65 p < 0.01
Vehicle ApEn	0.06 (0.002)	0.05 (0.001)	F = 14.26 p < 0.01	0.06 (0.002)	0.05 (0.001)	NS	F = 5.58 p < 0.01
Driver ApEn	0.24 (0.015)	0.24 (0.009)	NS	0.23 (0.01)	0.25 (0.01)	F = 6.10 p = 0.02	F = 24.41 p < 0.01

#### 4.3.4. Effect of group and test session on braking from 100 km/hr

Summary results for the effect of group (control and trainee), and test-session (pre- and post-test) at the 100 km/hr speed condition are present in Table 4.2. Plots for each significant group by test session interaction effects are presented in Figure 4.4.

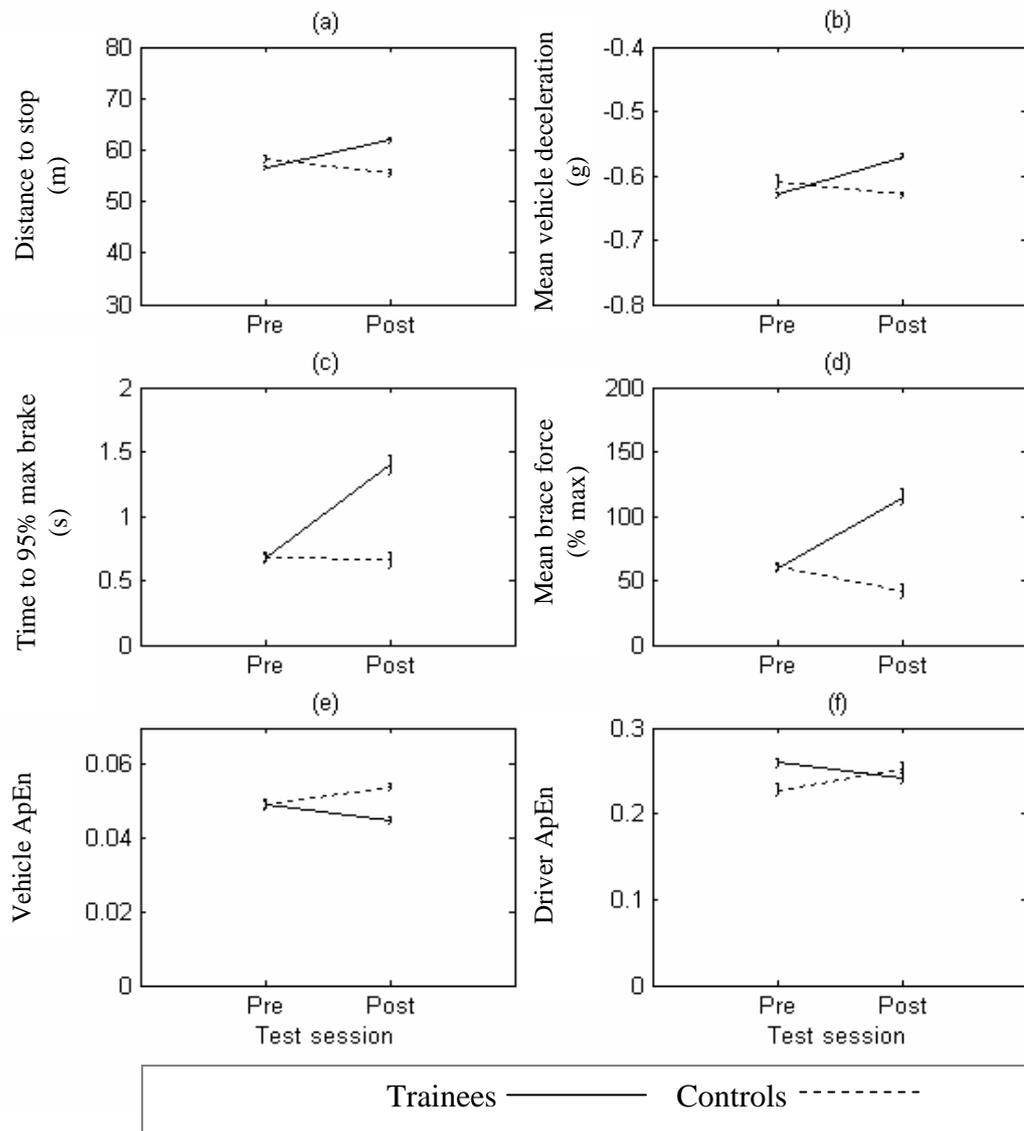


Figure 4.4 Summary of significant interactions between group (trainee and control) and test-session (pre- and post-) at the 100 km/hr speed condition: (a) distance to stop, (b) mean car deceleration, (c) time to 95% brake depression, (d) mean footrest force, (e) vehicle ApEn, and (f) driver ApEn. Error bars represent  $\pm$  one standard error of the mean.

Table 4.2 Summary of results for effect of group, test session, and group  $\times$  test session on the dependent measures at 100 km/hr. Bracketed terms are one standard error of the mean. NS = not significant.

Variable	Group			Test session			Group x test session
	Controls	Trainees		Pre	Post		
Velocity (km/hr)	100.25 (0.28)	99.97 (0.18)	NS	100.48 (0.24)	99.74 (0.18)	NS	NS
Distance to react (m)	11.38 (0.57)	11.76 (0.36)	NS	11.74 (0.42)	11.40 (0.44)	NS	NS
Distance to stop (m)	56.81 (1.11)	59.34 (0.71)	NS	57.46 (0.72)	58.69 (0.9)	NS	F = 17.32 p < 0.01
Mean vehicle deceleration (g)	-0.62 (0.01)	-0.60 (0.01)	NS	-0.62 (0.01)	-0.60 (0.01)	F = 5.23 p < 0.05	F = 13.95 p < 0.01
Time to 95% brake (s)	0.67 (0.11)	1.04 (0.07)	F = 8.48 P < 0.01	0.68 (0.05)	1.03 (0.12)	F = 6.32 p = 0.02	F = 7.09 p = 0.01
Mean footrest force (N)	51.49 (10.92)	87.20 (6.91)	F = 7.64 P = 0.01	60.22 (5.16)	78.46 (10.73)	NS	F = 11.83 p < 0.01
Vehicle ApEn	0.05 (0.002)	0.05 (0.001)	NS	0.05 (0.002)	0.05 (0.001)	NS	F = 7.95 P < 0.01
Driver ApEn	0.24 (0.016)	0.25 (0.01)	NS	0.24 (0.01)	0.25 (0.01)	NS	F = 4.14 P = 0.05

Post hoc tests revealed that distance to stop, time to 95% brake depression, and mean footrest brace force were significantly higher for the trainee group compared with the control group following training. Mean vehicle deceleration, mean driver deceleration and vehicle ApEn were significantly lower for the trainee group compared with the control group following training. The trainee group had significantly higher values for time to 95% brake depression and mean footrest brace force and significantly lower values for mean vehicle deceleration and vehicle ApEn in the post- compared with the pre-test condition. No significant differences were detected between the trainee and control group's pre-test session or between the control group's pre- and post-test sessions.

#### **4.4. Discussion**

Given concerns that ABS fitted vehicles are over-represented in certain types of traffic crashes (Delaney & Newstead, 2004; Evans & Gerrish, 1996; Farmer, et al., 1997) and that drivers in general may have limited knowledge of and skill in the use of ABS (Broughton & Baughan, 2002; Harless & Hoffer, 2002), the aim of this study was to determine the effect of a specific two-day post-license driver-training program on brake performance and postural stability. Training program participants were instructed to use a graded two-phase pedal application whereby the pedal was initially depressed to near maximum, and then steadily “buried” as the vehicle came to a stop. Participants were also encouraged to maintain postural stability during deceleration by pushing against the footrest with the left foot rather than increased steering wheel handgrip tension. It was foreseen that the results of this study would contribute to the currently limited evidence base concerning the effect of a brake technique on braking performance.

##### ***4.4.1. Brake technique***

The emergency brake task assessed in the present study was performed with the ABS activated. There were no differences between the control and trainee groups’ pedal control actions at the initial testing session. However, following training the trainee group required more distance to stop the vehicle than the control group. The mean differences in distance to stop (and time) between the trainee and control groups after training were 5.7 m (0.15 s) when braking from 80 km/hr and 6.4 m (0.37 s) when braking from 100 km/hr. These results for stopping distances are consistent with a lower mean deceleration for the trainee compared with the control group at both speeds following training. The untrained participants activated ABS early in the deceleration phase as evidenced by the rapid brake pedal depression early in the deceleration phase,

thereby relying to a greater extent on the ABS technology to stop the vehicle. This conclusion was supported by the result that untrained participants quickly reached 95% of brake depression and had significantly more irregular deceleration profiles compared with trainees post-test. By contrast, the trained participants tended to activate the ABS either at the end of the deceleration phase, or not at all, which resulted in significantly more regular braking profiles.

Overall, these results indicate the drivers using the trained brake technique were able to stop the vehicle within one vehicle length from the two trial speeds when compared with stop distances assisted by a good quality ABS. What remains unknown is whether the opportunity for further practice of the learnt brake techniques would result in improvements in braking performance in the longer term. Shorter distances to stop compared to the current post-test measures could be expected given that during the early phase of learning a new motor skill there is often a tendency for individuals to focus more on the process of how to perform the new skill rather than completing the task within the desired limits (Newell, 1985, 1986). One consequence of this learning process is that the overall performance of the individuals, as measured by the ability to achieve some final movement outcome, may be more variable, and in some cases less accurate, in comparison to individuals who employ a simpler strategy (Newell & Corcos, 1993; Newell, Liu, & Mayer-Kress, 2001; Vereijken, van Emmerik, Whiting, & Newell, 1992). Trainees may also have been more motivated to demonstrate the newly learnt brake technique rather than to stop as soon as possible (Drummond, 1989; Williams, et al., 1995).

In future it will be of interest to examine braking under more realistic stopping conditions, such as when a lead vehicle suddenly slows down or at traffic lights (Bardy & Warren, 1997; Cavallo & Laurent, 1988; Green, 2000; Summala, et al., 1998; Tresilian, Wallis, & Mattocks, 2004; Warren, 1995) or in different weather conditions (Gonzales, Dickinson, DiGuseppi, & Lowenstein, 2005; Summala, 1996) and on different road surfaces (Broughton & Baughan, 2002) with changes in brake performance assessed over a longer period of time than was assessed in the present study.. In reference to vehicles without ABS, there are obvious risks associated with the more abrupt brake technique advocated for ABS equipped vehicles, namely wheel lockup that results in uncontrolled skids and loss of steering control, that could certainly be avoided using the brake techniques advocated in the training course examined in this study. Although the present study did not assess the effect of training on brake performance with ABS deactivated, we expect drivers using the learned brake techniques would reduce distance to stop, and have enhanced vehicle and postural control compared with the controls' non-ABS assisted performances.

#### ***4.4.2. Postural stability***

In the present study we addressed the question of whether the use of brace forces applied against the footrest by the left foot facilitates postural stability in the upper body, and whether drivers could learn to relax their grip on the steering wheel during emergency braking. The results for driver ApEn confirmed that trained drivers were able to more effectively stabilise their upper body than were untrained drivers. This was at least partly achieved through increased pressure on the footrest with the left foot. The ability to maintain lower body stability without compromising upper body motion was seen as indicative of the development of a more flexible coordination strategy (Newell, 1985, 1986; Newell & McDonald, 1994; Vereijken, et al., 1997; Vereijken,

et al., 1992). Under emergency braking situations, if the subject were able to maintain more constant head acceleration pattern, arguably they would be able to more effectively scan the visual field and steer away from danger. This view that enhanced postural stability assists situational awareness and anticipation of upcoming events is consistent with the modern dynamical systems view that perception and action are intrinsically coupled (Gibson, 1979; Riccio, 1995).

#### **4.5. Concluding remarks**

In this initial study of technique-based driving performance following training, we demonstrated that trainee participants used a significantly smoother brake profile and had enhanced postural stability during braking after training compared with the control group. The trainee groups' greater postural stability during deceleration may enhance perceptual-motor function during braking. It is specifically argued that enhanced postural stability facilitates the detection of relevant information used to guide locomotion and the control actions used to guide the vehicle. The trainee group was also less reliant on the ABS and stopped within approximately one vehicle length with significantly lower mean deceleration compared with stops assisted by good quality ABS. An increasing proportion of new vehicles are fitted with ABS, a technology that overrides the dangerous action of drivers who brake suddenly. However, the widespread mix of older and newer vehicles with and without ABS technology creates a dilemma for driver educators. The optimal brake techniques for ABS and non-ABS equipped vehicles differ and are not necessarily transferable between the two brake systems; hence two techniques may need to be taught. Although the results of the present study suggest drivers stopped sooner by early ABS activation during the deceleration phase, rapidly depressing and holding the brake to the floor is potentially

dangerous in vehicles without ABS, due to increased risk of skidding. As drivers will habitually act during an emergency, there exists a potential for an inappropriate brake strategy to be employed if a driver slams on the brakes in a vehicle without ABS. We therefore believe that because many vehicles presently on the road do not have ABS, especially older or cheaper vehicles often driven by young novice drivers, instruction in a single braking technique is attractive as the driver, rather than technology, is responsible for maintaining control of the vehicle's ability to stop, and the technique can be successfully transferred between both ABS and non-ABS equipped vehicles. However, before the technique assessed in this study could be recommended for ABS equipped vehicles, it would be important to know from future research whether additional practice of the technique would result in further improvements in braking performance comparable or better than the technique reliant on rapid ABS activation.





# Chapter 5

## Experiment 2

Enhanced postural stability following driver-training is associated with positive effects on vehicle kinematics during cornering

“There are two things no man will admit he cannot do well: drive and make love.”

(Sir Stirling Moss)



## **5.0 ENHANCED POSTURAL STABILITY FOLLOWING DRIVER-TRAINING IS ASSOCIATED WITH POSITIVE EFFECTS ON VEHICLE KINEMATICS DURING CORNERING**

### **5.1. Introduction**

Driving is a perceptual-motor task performed in an inertial environment. Unless the driver is rigidly coupled to the vehicle, the driver will experience postural perturbations in the presence of inertial forces. It is known for example that drivers tilt their head during cornering (Zikovitz & Harris, 1999). During turns with higher lateral accelerations, this tilting action becomes harder to control, resulting in oscillatory motion of the upper body relative to the vehicle. Inertial force induced postural perturbations during driving create a number of problems from a perceptual-motor perspective. Perceptual sensitivity to visual and vestibular information is degraded when the head is unstable (Treffner, et al., 2002). Postural perturbations also compromise the capacity to perform critical control actions such as steering (Riccio, 1995). Furthermore, there is a circular causality between perception and action during guided locomotion (Gibson, 1979; Warren, 2006). In this ecological paradigm, postural stability enhances detection of relevant information about the environment, which facilitates appropriate control actions, that in turn facilitates detection of newly revealed information and perception of possible actions (Schöner, et al., 1998). The dynamic relation between driver and vehicle with respect to the environment is therefore considered important, if not vital, for safe driving (Gibson & Crooks, 1938; Lee & Young, 1986; Schiff & Arnone, 1995).

The main outcome variable for assessing the effectiveness of driver-training programs is road crash statistics (Mayhew & Simpson, 2002; Senserrick, 2007). While intuition

would suggest beneficial effects of driver-training, the evidence to date from retrospective studies does not support this view (Williams, 2006). However, a criticism of this research is that many simplistic training programs were assessed, and that some reviews included programs designed to remediate for high-risk drivers (Lund & Williams, 1985; Stuckman-Johnson, et al., 1989). It has therefore been suggested that there is a need to assess the effect of driver-training on more sophisticated driver-training programs based on modern theories and empirical evidence (Watson, 2003). While it is acknowledged that basic perceptual-motor skills must form the basis of a successful driver-training program, the curriculum should also address higher order issues that influence road safety such as attitudes and behaviours (Hatakka, et al., 2002; Laapotti, Keskinen, Hatakka, & Katila, 2001). This multifactorial approach is essential to protect against the problem of “overconfidence” that arises when drivers with increased skill levels also adjust their driving behaviour to maintain the same level of risk (Gregersen, 1996; Sumer, Ozkan, & Lajunen, 2006; Wilde, 1982). In contrast several recent studies demonstrate positive effects of driver-training in terms of safer overtaking (Dorn & Barker, 2005), improved visual searches (Chapman, et al., 2002), improved risk perception and reduced risk taking (Fisher, et al., 2002; McKenna, et al., 2006) and reduced number of crashes especially during the early years of driving (Carcaillon & Salmi, 2005; Carstensen, 2002). Based on the driver-training literature to date it is clear that not all driver-training programs are the same, and so it follows that different training programs will result in different outcomes. In our opinion, evidence to refute or support the efficacy of driver-training programs is limited and therefore warrants further investigation.

An example of a modern multi-factorial driver-training program was assessed in the present study. As well as addressing higher order factors that influence driving attitudes

and behaviour (Hatakka, et al., 2002), the program specifically emphasises the importance of visual scanning, anticipation of and preparation for upcoming events, and the maintenance of postural stability during critical driving situations (Gardner, 1998). In a study on the effect of this training on emergency braking, a trained group of drivers used a smoother braking profile, were less reliant on ABS activation, and had enhanced postural stability following training (Petersen, Barrett, & Morrison, 2006). It was further argued that under emergency braking situations, the ability to maintain a more stable head acceleration pattern would help the driver to effectively scan the visual field and steer away from danger. Since significant inertial forces arise in accelerative driving situations apart from braking, it was of interest to extend our analysis to consider how training influenced postural stability and vehicle kinematics in the presence of lateral accelerations during cornering.

For a circular corner, the lateral accelerations experienced during turning are a function of the speed of travel squared and the curvature of the vehicle trajectory, with loss of traction occurring when the centripetal force exceeds the friction force at the tyre-road interface. A corner of radius 30 m will result in a lateral acceleration of 0.16 g at 25 km/hr and 0.66 g at 50 km/hr. The centripetal (lateral) accelerations experienced for a sedan during normal driving would not be expected to exceed about 0.8 g (Karnopp, 2004). Interestingly new in-vehicle technologies are increasingly being used by parents to monitor lateral accelerations as a way of assessing driving behaviour (McGehee, Raby, Carney, Lee, & Reyes, 2007) with repeated high peak lateral accelerations assumed to be indicative of dangerous driving. A further justification for examining cornering in the present study was that 43% of single vehicle crashes and 31% of multi-vehicle crashes occurred during cornering (Fildes, Logan, Fitzharris, Scully, & Burton, 2003). Chen, Rakotonirainy, Sheenan, Krishnaswamy, and Loke (2006)

similarly stated that 30% of crashes occurred during cornering and also indicated that 63% of these accidents resulted in a fatality.

The purpose of this study was to examine the effects of a two-day post-licence driver-training program on postural stability and vehicle kinematics during cornering. Postural stability was defined according to the difference between the lateral accelerations exhibited by the vehicle and driver during the corner. A driver whose body accelerations were closely matched (coupled) to the vehicle was therefore considered posturally stable. Measures of vehicle speed, lateral accelerations, and their timing were used to characterise vehicle kinematics during the corner. An expectation was that (i) drivers would experience enhanced postural stability following training, (ii) measures of vehicle kinematics would reflect a smoother trajectory through the corner following training, and (iii) that drivers with greater postural stability would experience smoother trajectories during cornering.

## **5.2. Methods**

### ***5.2.1. Participants and experimental design***

Thirty-three volunteer drivers with a valid Australian provisional or full driver's licence were recruited into either a trainee group or control group. Provisional licencees were at least 17 years of age, had previously held a learner licence for at least six months, and were eligible to graduate to a full license after 1-3 years depending on their age. The trainee group was enrolled in a two-day driver-training program conducted at Holden Performance Driving Centre (HPDC), Norwell, Queensland. No trainee or control group member had participated in other HPDC training or comparable courses. In addition, a third group was formed from volunteer instructors who were HPDC trainers

with a minimum six months employment. The trainee group ( $n = 21$ ) consisted of ten provisional and eleven full licence drivers aged  $31.7 \pm 10.1$  years with  $14.2 \pm 7.6$  years driving experience. The control group ( $n = 12$ ) consisted of six provisional and six open licensee drivers aged  $27.9 \pm 7.8$  years with  $9.2 \pm 6.0$  years driving experience. There were no significant differences in age or driving experience between the trainee and control group. The instructor group ( $n = 13$ ) were aged  $39.0 \pm 9.5$  years and had been a driving instructors for  $4.7 \pm 4.1$  years.

The trainee and control groups each attended two driving test-sessions, with the trainee group participating in the two-day driver-training program during the intervening period. Trainees attended the initial test-session  $3.3 \pm 2.3$  days prior to training and the final test-session  $3.1 \pm 2.3$  days following training. The time between the two test-sessions for the control group was  $6.8 \pm 1.8$  days. The instructor group was tested on only one occasion. The test corner was located on a 1.25 km closed circuit track and was U-shaped with an inside radius of approximately 30 m. Drivers were instructed to attain a speed of 70 km/hr at 25 m prior to the corner, after which they were allowed to adjust their speed during the corner as required. At each test-session, data were sampled as participants drove an instrumented vehicle around the test corner on six occasions in each direction. In total trainee drivers travelled around the test corner on 112 occasions (52 in the pre-test, 8 during training, and 52 during post-test) while control drivers drove the same test corner on 104 occasions (52 pre-test and 52 post-test). All drivers provided written informed consent prior to study participation and the study was approved by the Griffith University Human Research Ethics Committee in accordance with National Health and Medical Research Council guidelines (NHMRC, 2004).

### ***5.2.2. Driver-training***

The driver-training course assessed in the present study was based on principles of safe driving published in the book “Drive to Survive” (Gardner, 1998). Training included a combination of lectures, individual and group discussions, demonstrations by instructors, and driving exercises performed by a trainee with an instructor in the vehicle. Each course was limited to twelve trainees with six instructors. With regard to the cornering manoeuvre, trainees were instructed to:

- (i) Stabilise their body in the presence of inertial forces during cornering by bracing the left leg against the centre console for a right turn and the right leg against the driver’s door for a left turn;
- (ii) Maintain a relaxed grip on the steering wheel and avoid using the steering wheel to stabilise their posture;
- (iii) Scan the visual field and assess road curvature as early as possible;
- (iv) Steer a smooth trajectory that minimises changes in vehicle speed and avoids sudden changes in direction.

### ***5.2.3. Instrumentation***

A right-hand-drive sedan (Commodore, Holden) with power steering and automatic transmission was instrumented with sensors to measure vehicle speed, brake and accelerator depression, vehicle and driver accelerations, door and console bracing forces, and handgrip pressure. Vehicle speed were measured using a GPS (Trimble) sampled at 10 Hz. The geographic entry and exit of the corner were identified from GPS coordinates and used to define the beginning and end of a trial. Linear potentiometers (Honeywell) were used to measure accelerator and brake pedal depression. Vehicle and driver lateral accelerations were measured using

triaxial  $\pm 2$  g accelerometers (Crossbow) situated at the vehicle's centre console and the 7<sup>th</sup> cervical vertebra (vertebrae prominens) of the driver. Low-profile force transducers (Applied Measurement) were used to measure brace force created by the driver against the centre console and door. These measures were expressed as a percentage of maximum force that could be produced during a static test. The driver was also instrumented to measure handgrip pressure using two pairs of flexiforce pressure sensors (Tekscan) taped to the distal and proximal aspect of each palm. These measures were expressed as a percentage of maximum force that could be produced during a static test and each hand summed together. All analogue data were acquired at 100 Hz using a data acquisition system (DAQBook 200, DBK 43A, DBK80; IOTech) and stored on a laptop computer (Dell).

#### ***5.2.4. Dependent measures***

Variables related to vehicle kinematic were corner entry velocity, minimum velocity, mean velocity, the peak and mean lateral vehicle accelerations, and the time to peak vehicle acceleration during the corner. To account for possible differences in speed when comparing acceleration data between groups and conditions, lateral accelerations were expressed as multiples of gravitational acceleration (G) divided by the square of the instantaneous velocity vehicle (Units =  $G/(m/s)^2$ ).

Postural stability was defined as the difference between peak vehicle and peak driver acceleration (peak acceleration difference). Variables relating to how postural stability was achieved were peak and mean console (clockwise corner) and door (anticlockwise corner) bracing forces (% max static force) and handgrip pressure. We defined five categories (0-40, 40-80, 80-120, 120-160, >160% maximum static force) based on the

ranges of handgrip pressure observed in pilot testing. Peak console forces and handgrip pressures during driving were expressed relative to maximum static values.

#### ***5.2.5. Statistical analysis***

A mixed general linear ANOVA model was used to assess the effect of group (trainees and controls) and test-session (pre-test and post-test) on the dependent measures. Post-hoc pair-wise comparisons with Bonferroni corrections were used to identify specific differences between means. One-way ANOVA was used to assess the effect of group on post-test dependent measures (instructors, trainee post-test, and control post-test) with coefficient contrasts used to identify specific differences between means. With the exception of peak and mean door and console bracing forces, all dependent measures assessed using ANOVA were collapsed across clockwise and anticlockwise directions. Normally distributed data were reported as the mean  $\pm$  one standard error of the mean. Relations between selected variables were assessed using the Pearson correlation coefficient. Wilcoxon Signed Rank tests were used to assess the effect of group (instructors, trainee, and control) and test-session (pre-test and post-test) on handgrip pressure (categorical variable). Handgrip pressures were reported as the median and inter-quartile range (IQR). All statistical analysis was conducted using SPSS for Windows (Ver. 11.3) with significance accepted at  $p < 0.05$ .

## 5.3. Results

### 5.3.1. Representative data

Representative data for a single corner (clockwise direction) from a trainee driver pre- and post-test and an instructor are presented in Figure 5.1. The drivers applied the brake upon entry and the accelerator pedal during the corner. Vehicle and driver lateral accelerations for trainee post-test and instructors were more tightly coupled compared with the trainee pre-test pattern. In addition, the trainee post-test and instructor applied greater brace force with reduced handgrip pressure compared with the trainee pre-test.

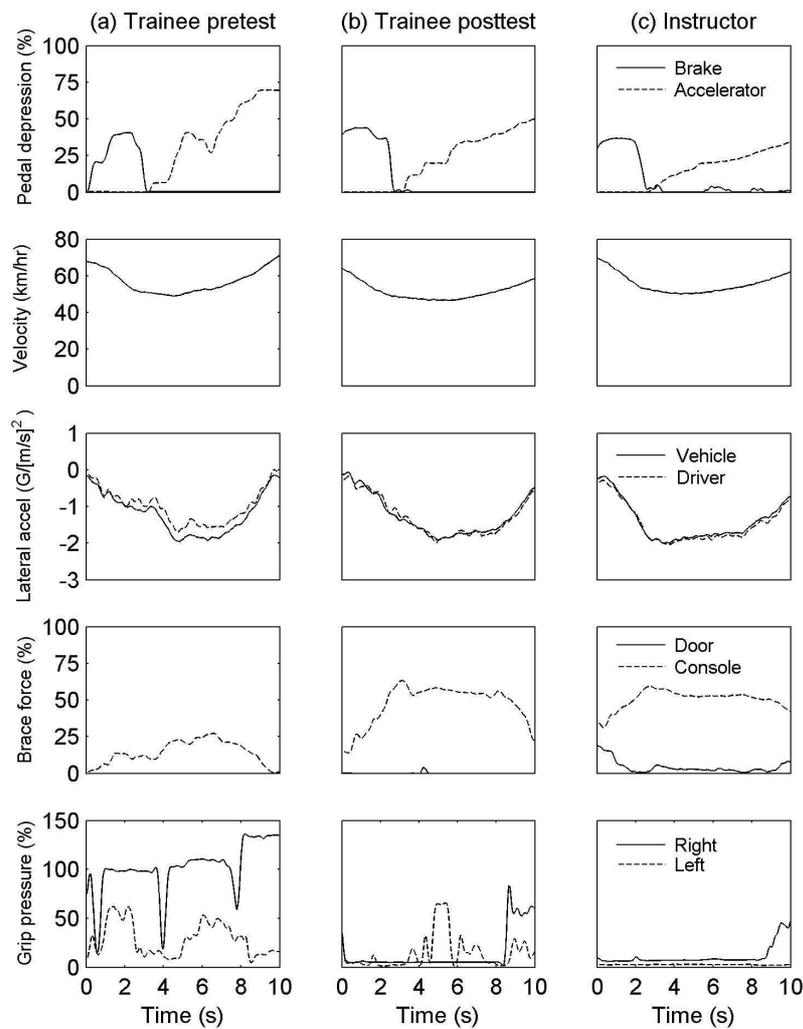


Figure 5.1 Representative data: (a) trainee participant pre-training, (b) trainee participant post-training, and (c) a driving instructor obtained from a clockwise corner.

### ***5.3.2. Effect of group and test-session on dependent measures***

Summary statistics for each dependent measure are presented in Table 5.1. Group (trainees versus controls) had a significant main effect on peak and mean vehicle acceleration, and peak acceleration difference, which were lower for the trainees. A significant increased effect for peak door force during anticlockwise travel was also detected. A significant main effect of test-session (pre- versus post-test) was detected for peak vehicle acceleration, peak acceleration difference, and time to peak acceleration, which were lower for the post-test, and peak door force during anticlockwise travel, which was greater for post-test. Significant group by test-session interactions were revealed for peak vehicle acceleration, peak acceleration difference, time to peak acceleration, and peak and mean console brace force during clockwise travel, and peak and mean door brace force during anticlockwise travel. Post-hoc comparisons revealed trainee post-test significantly reduced peak vehicle acceleration, peak acceleration difference, and significantly increased the respective peak and mean console and door brace forces in respect to trainee pre-test and both control test-sessions. Summary data for those variables where there was a statistically significant group by test interaction effect are presented in Figure 5.2.

Table 5.1 Summary statistics for effect of group, test-session, and group  $\times$  test-session interaction on dependent measures. Bracketed terms are  $\pm$  one standard error of mean. NS = not significant.

Variable	Group			Test-session		Group $\times$ test-session	
	Controls	Trainees		Pre	Post		
Variables related to vehicle kinematics							
Entry velocity (km/hr)	67.78 (0.16)	67.85 (0.11)	NS	67.89 (0.15)	67.74 (0.12)	NS	NS
Mean velocity (km/hr)	55.65 (0.78)	54.45 (0.54)	NS	55.27 (0.62)	54.83 (0.45)	NS	NS
Min velocity (km/hr)	48.65 (0.92)	47.57 (0.64)	NS	48.37 (0.74)	47.85 (0.54)	NS	NS
Peak vehicle acceleration ( $G/(m/s)^2$ )	1.94 (0.02)	1.85 (0.03)	F = 11.45 p < 0.01	1.91 (0.02)	1.88 (0.02)	F = 5.76 p < 0.02	F = 12.37 p < 0.01
Mean vehicle acceleration ( $G/(m/s)^2$ )	1.31 (0.01)	1.25 (0.01)	F = 10.57 p < 0.01	1.27 (0.01)	1.29 (0.01)	NS	NS
Time to peak acceleration (s)	4.96 (0.12)	4.68 (0.10)	NS	5.00 (0.10)	4.65 (0.12)	F = 4.77 p < 0.05	F = 4.84 p < 0.05
Variables related to postural stability							
Peak acceleration difference ( $G/(m/s)^2$ )	-0.46 (0.04)	-0.25 (0.03)	F = 20.19 p < 0.01	-0.46 (0.04)	-0.29 (0.02)	F = 11.68 p = 0.01	F = 13.46 p = 0.01
Peak console force (%max)	104.01 (10.49)	122.62 (7.93)	NS	110.83 (8.29)	120.68 (7.91)	NS	F = 4.31 p < 0.05
Mean console force (%max)	75.13 (8.09)	87.89 (6.12)	NS	77.63 (6.68)	88.87 (5.72)	NS	F = 5.39 p < 0.05
Peak door force (%max)	13.97 (10.25)	53.86 (7.6)	F = 6.84 p < 0.02	21.57 (6.99)	46.14 (7.06)	F = 8.48 p < 0.01	F = 13.29 p < 0.01
Mean door force (%max)	8.87 (6.54)	28.44 (4.85)	NS	12.89 (3.74)	24.34 (5.26)	NS	F = 4.53 p < 0.05

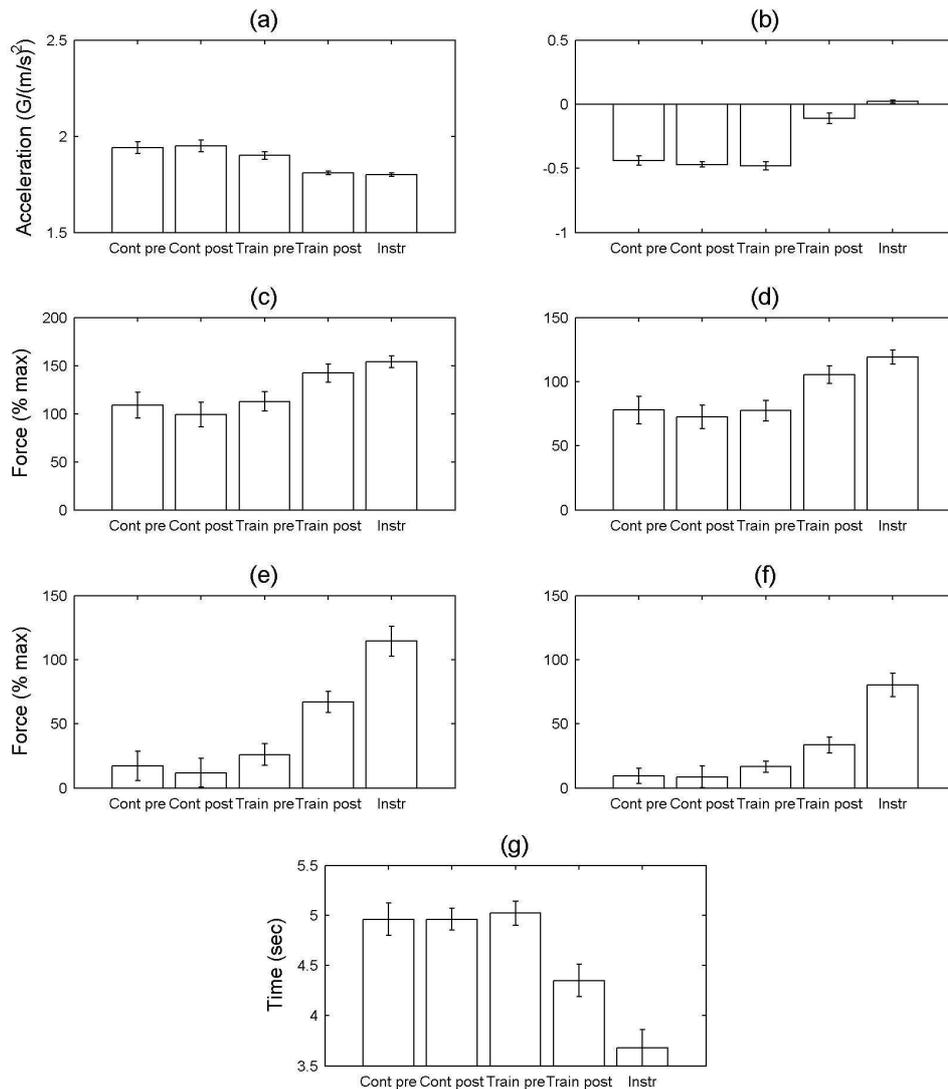


Figure 5.2 Summary data for control drivers, trainee drivers, and instructor drivers. (a) peak vehicle accelerations, (b) peak acceleration difference, (c) peak console brace force, (d) mean console brace force, (e) peak door brace force, (f) mean door brace force, and (g) time to peak vehicle acceleration. Trainee (Train), Control (Cont), Instructor (Instr).

### 5.3.3. Effect of group on post-training dependent measures

The summary statistics for means and standard errors of dependent measures for all groups (instructors, trainees post-test, and controls post-test) are presented in Table 5.2. Statistically significant main effects of group for mean and minimum velocities, peak and mean vehicle acceleration, peak acceleration difference, time to peak acceleration, as well as for peak and mean brace force for console (clockwise) and door (anticlockwise) were detected. Post-hoc comparisons revealed mean velocity data were

significantly lower for trainee post-test compared to instructors and control post-test. Minimum velocities were significantly lower for trainee post-group compared to instructors and control post-test. Trainee post-test and instructors were significantly lower compared to the control post-test for peak and mean vehicle acceleration, peak acceleration difference, and time to peak acceleration, with the instructors significantly lower than trainees for peak acceleration difference and time to peak acceleration. Trainee post-test and instructor groups had significantly higher peak and mean console brace force in the clockwise direction compared to control post-test. Significantly higher values for peak and mean door brace force during anticlockwise travel were revealed for instructors compared to trainee post-test and trainee post-test compared to control post-test.

Table 5.2 Summary statistics for effect of group (control, trainee, instructor) on post-test dependent measures. Bracketed terms are  $\pm$  one standard error of mean. NS = not significant.

Variable	Controls (Post-test)	Trainees (Post-test)	Instructors	Significance
<b>Variables related to vehicle kinematics</b>				
Entry velocity (km/hr)	67.91 (0.25)	67.57 (0.11)	67.48 (0.16)	NS
Mean velocity (km/hr)	55.58 (0.98)	54.07 (0.42)	56.11 # (0.57)	F = 3.45 p < 0.05
Min velocity (km/hr)	48.44 (1.20)	47.25 (0.49)	49.99 # (0.57)	F = 3.97 p < 0.05
Peak vehicle acceleration (G/(m/s) <sup>2</sup> )	1.95 (0.03)	1.82 + (0.01)	1.80 ^ (0.01)	F = 14.20 p < 0.01
Mean vehicle acceleration (G/(m/s) <sup>2</sup> )	1.32 (0.02)	1.27 + (0.01)	1.25 ^ (0.01)	F = 5.53 p < 0.01
Time to peak acceleration (s)	4.96 (0.11)	4.35 + (0.16)	3.68 ^ # (0.18)	F = 12.68 p < 0.01
<b>Variables related to postural stability</b>				
Peak acceleration difference (G/(m/s) <sup>2</sup> )	-0.47 (0.04)	-0.11 + (0.02)	-0.01 ^ # (0.01)	F = 74.62 p < 0.01
Peak console force (% max)	99.12 (12.63)	142.25 + (10.14)	153.92 ^ (6.09)	F = 5.63 p < 0.01
Mean console force (% max)	72.41 (9.12)	105.34 + (6.89)	119.12 ^ (5.38)	F = 7.01 p < 0.01
Peak door force (% max)	11.81 (11.56)	67.00 + (8.42)	114.45 ^ # (11.75)	F = 16.26 p < 0.01
Mean door force (% max)	8.50 (8.45)	33.40 + (6.27)	80.16 ^ # (9.06)	F = 13.09 p < 0.01

+ denotes significant difference between controls and trainees  
# denotes significant difference between trainees and instructors  
^ denotes significant difference between controls and instructors

#### ***5.3.4. Effects of training on relations between postural stability and vehicle kinematics***

Scatterplots and correlation coefficients for peak driver and vehicle lateral accelerations for trainees and instructors are presented in Figure 5.3. Correlation coefficients were

highest for instructors, followed by trainee post-test, and followed by trainee pre-test for clockwise and anticlockwise corners.

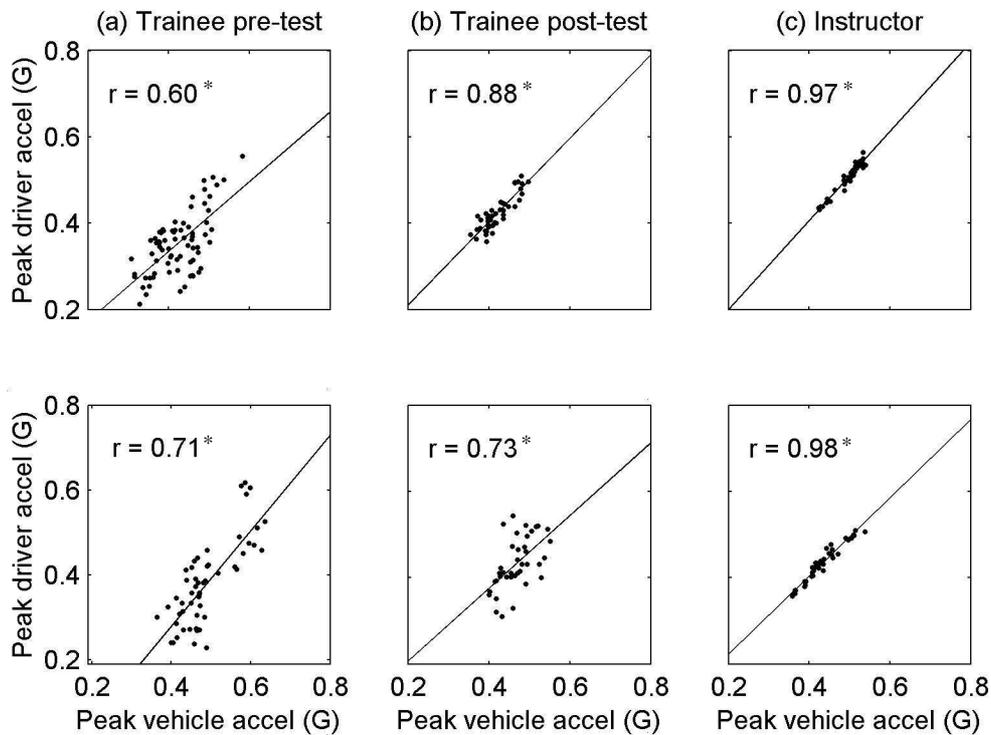


Figure 5.3 Scatterplots with least squares linear regression lines for relations between peak driver and vehicle accelerations by group. Clockwise corners (top row) and anticlockwise corners (bottom row). \* Correlation coefficients - significant at  $p < 0.01$ .

The relations between peak acceleration difference peak vehicle acceleration for the training group are presented in Figure 5.4. A significant positive correlation was detected for the relation between peak acceleration difference and peak vehicle acceleration in the trainee group prior to training ( $r = 0.65$ ,  $p < 0.01$ ). The percentage change in peak acceleration difference and peak vehicle acceleration due to training was also positively correlated ( $p = 0.46$ ,  $p < 0.01$ ).

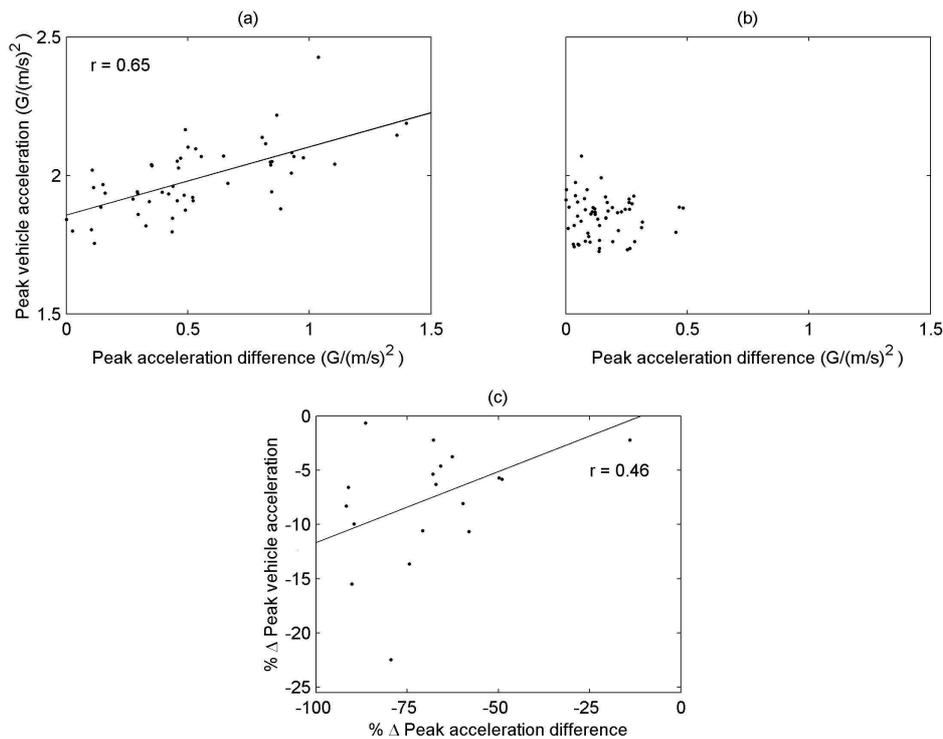


Figure 5.4 Scatterplot with least squares linear regression line for relations between peak vehicle acceleration and peak acceleration difference. Trainees (a) pre training, (b) post training, and (c) percentage change from pre- to post- correlation coefficients are significant at  $p < 0.01$ .

### 5.3.5. Effect of training on handgrip pressure

Results of the Wilcoxin Signed Rank test between group categorical measures revealed significant differences for handgrip pressure. Results for handgrip pressure were not significantly different between groups during the pre-test session. However after training, the trainee post-test were statistically lower compared with pre-test (trainee: pre-test: Median = 3, IQR = - 4; post-test: Median = 3, IQR = 2 - 3,  $Z = -4.26$ ,  $p < 0.01$ ). Trainee post-test was statistically lower compared to control post-test (control: post-test: Median = 4, IQR = 3 - 4,  $Z = -5.23$ ,  $p < 0.01$ ). Instructors had lower handgrip pressure compared to trainee post-test (instructors: Median = 2, IQR = 1 - 2,  $Z = -4.81$ ,  $p < 0.01$ ) and control post-test ( $Z = -4.96$ ,  $p < 0.01$ ).

## 5.4. Discussion

In a previous study we investigated the effect of driver-training on postural stability and vehicle kinematics during emergency braking (Petersen, et al., 2006). The present study extends this analysis to a driving manoeuvre involving lateral accelerations, namely cornering. Cornering is of interest because excessive lateral accelerations are considered dangerous due to an associated with a high proportion of road crashes / injuries (Chen, et al., 2006; Fildes, et al., 2003; Laapotti & Keskinen, 1998) and because the inertial forces have the potential to induce significant driver body motions (Treffner, et al., 2002). The main purpose of the present study was to investigate the effects of a two-day post-licence driver-training program on the motion of the driver and vehicle during a cornering manoeuvre. The training curriculum was based on principles of “insight training” (Gregersen, 1996), which aims to increase the awareness of risks encountered in everyday driving and reduce drivers’ overestimation of their driving skill. A unique feature of the training program was the emphasis placed on resisting postural perturbations in the presence of destabilising inertial forces encountered in driving (Petersen, et al., 2006; Treffner, et al., 2002). The rationale for this approach is that drivers can become more receptive to sensory information (Gibson, 1979; Warren, 2006) and can more effectively perform the required control actions when their body is functionally stabilised (Riccio, 1995). In this stability-based training paradigm the manner in which the body is stabilised is paramount. Drivers were taught to stabilise their body motions against the vehicle with their legs rather than against the steering wheel with their hands, since the latter is believed to be deleterious to steering control (Gardner, 1998). In the present study, we specifically sought to test whether stability training actually improved stability, whether vehicle kinematics were improved following training, as well as the extent to which postural stability and vehicle kinematics were related. A schematic illustrating the proposed conceptual link between

postural stability, perceptual motor abilities, vehicle kinematics, and cornering safety in presented in Figure 5.5. The feedback loop represents the potential for improved vehicle kinematics such as smaller peak accelerations to decrease the challenge to postural stability. Although not directly assessed in the present study, the ultimate goal would be to enhance cornering safety through fewer vehicle crashes. Many other factors such as driver attitudes, risk taking behaviours, and the driving environment would also be expected to influence crash risk (Hatakka, et al., 2002; Laapotti, et al., 2001).

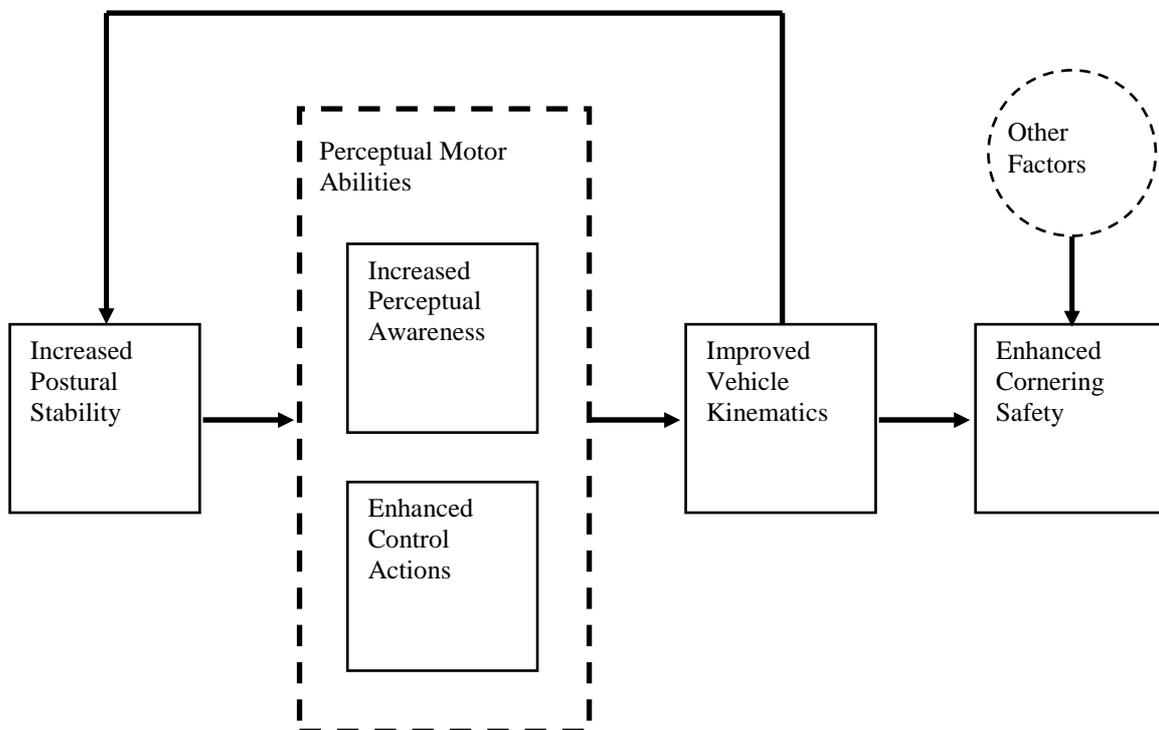


Figure 5.5 Schematic illustrating proposed link between increased postural stability during cornering, perceptual motor abilities, vehicle kinematics, and cornering safety.

Based on road test data from HPDC, the maximum speed through the test corner in the present study obtained in a racing sedan is approximately 70 km/hr. Using simple physics and assuming a radius of 30 m for the corner, this corresponds with lateral accelerations of 1.3 g. For mid-corner speeds of around 50 km/hr, as measured in the present study, the predicted lateral acceleration would be 0.7 g. The peak lateral

accelerations measured in the present study ranged from approximately 0.3 to 0.7 g, which is on average slightly less than the predicted value of 0.7 g based on the assumption of circular motion and constant speed. No participants experienced skids during the corner caused by lateral forces in excess of the maximal friction force limits. However, the untrained and control drivers experienced rapid lateral postural perturbations in response to cornering, which is believed to degrade the detection of perceptual information (Treffner et al., 2002) and compromise the capacity to perform the required control actions (Riccio, 1995). With respects to driver-training, Watson (2003) recommended future research should investigate factors underpinning risk perception and suggested perceptual skills could be enhanced through postural stability.

#### ***5.4.1. Driver-training and postural stability***

Following training, drivers were able to effectively perform the learned technique of bracing with the legs and relaxing their grip on the steering wheel. This bracing strategy is consistent with the view that supporting the lower body provides the stable base for the upper body to act in a more flexible and coordinative manner (Vereijken, et al., 1997; Vereijken, et al., 1992). Importantly, use of the bracing technique resulted in enhanced postural stability as assessed in the present study by greater coupling between the lateral accelerations exhibited by the driver and the vehicle. Prior to training, 84% and 58% of participants had peak acceleration differences (our measure of postural stability) that were respectively more than one and two standard deviations above the mean of the post-test group. Although trainees did not attain the degree of coupling achieved by the driving instructor group, our results provide evidence that stability of the upper body can be achieved by bracing the lower body during cornering.

#### ***5.4.2. Driver-training and vehicle kinematics***

Following training and relative to controls, trained drivers lowered both their peak and mean vehicle lateral accelerations during the corner by 4%. Training was also found to alter the timing of peak lateral acceleration amongst trainees, with the post-test trainees reaching their peak lateral acceleration sooner after entry to the corner compared with pre-test trainees and controls. As none of the velocity measures were statistically different between groups or test-session, and lateral accelerations were normalised to instantaneous velocity, the reduction in and earlier onset of peak lateral acceleration could be at least partially attributed to differences in steering control. A likely explanation for this result is therefore that the trained drivers steered a flatter trajectory that was set-up earlier in the corner than controls, a view which is somewhat consistent with the finding that inexperienced drivers use multiple steering corrections during turning manoeuvres (Macdonald & Hoffman, 1980; McRuer, et al., 1977). It was also noteworthy that peak lateral accelerations coincided with significant increases in vehicle speed for many of the control drivers, thus creating a dynamically more challenging environment in which to maintain postural stability and vehicle control. The instructor drivers had the lowest lateral acceleration with the earliest peak compared to the other groups. Given that the instructor group were trained and highly practiced drivers, the trainees might therefore expect further improvement in vehicle kinematics from ongoing practice.

#### ***5.4.3. Postural stability and vehicle kinematics***

As well as finding that driver-training produced positive effects on postural stability and vehicle kinematics, we found that prior to training, drivers who were more posturally stable tended to experience lower lateral vehicle accelerations ( $r = 0.65$ ). The strength

of this correlation provides a degree of support for the view that the postural stability of the driver has a beneficial influence on vehicle kinematics. While it was not possible to identify the specific mechanism underlying this relation from the results of the present study, we contend that loss of postural stability during driving has deleterious effects on the ability to detect relevant information about the dynamic environment such as speed and road curvature and to perform the required control actions. Since postural stability accounted for 42% of the total variance in vehicle kinematics, clearly other factors are also involved in determining the lateral accelerations experienced during cornering. The driver's ability to effectively use perceptual information (e.g., visual and vestibular) to guide motion would also be expected to influence lateral accelerations through adjustments of vehicle speed and path of travel.

Drivers who were most unstable prior to training, and hence experienced the largest lateral vehicle accelerations, were also found to experience the greatest changes in postural stability and lateral accelerations following training. Put simply, drivers who had the biggest improvements in postural stability tended to experience the greatest reductions in lateral accelerations of the vehicle ( $r = 0.46$ ), which is why the correlation between peak acceleration difference and peak vehicle acceleration was reduced to near zero following training.

While the results of the present study do not demonstrate a definitive, causal relation between postural stability and vehicle kinematics, they provide some preliminary evidence to suggest that postural stability may be an important consideration when instructing individuals on how to effectively and safely negotiate corners. Overall, our results suggest that the practical benefits that might be expected from stability-based training are somewhat related to the degree of postural instability experienced by the

driver before training. Drivers who are markedly unstable, or that achieve postural stability inappropriately by pulling on the steering wheel, would therefore be expected to experience the greatest benefit from the training. In future, it may therefore be useful to screen drivers prior to training on the basis of their postural stability in the presence of inertial forces such as during cornering and braking.

#### ***5.4.4. Limitations and future directions***

A potential limitation of the present study was the potential confound between practice and the training intervention since the number of times the participants drove around the test corner prior to the post-test driving assessments differed between groups (n = 60 for trainee and n = 52 for control groups). However, post-hoc analysis revealed that the learning curves for the trainee and control group drivers were flat during the pre-test assessments, indicating that practice alone did not significantly influence cornering behaviour. This is perhaps not surprising given that the drivers had on average  $13.2 \pm 7.5$  years driving experience and would therefore be expected to have developed stable cornering behaviours prior to participating in the experiment.

While it is widely acknowledged that basic manoeuvring skills are critical for safe driving (Hatakka, et al., 2002; Laapotti, et al., 2001), there have been few attempts in the literature to rigorously define these skills and the optimal techniques for performing them. It therefore remains unclear exactly what skills should be taught in driver-training and how they should be taught. A future challenge will therefore be to use an evidence-based approach to develop techniques for performing basic driving skills as well as effective strategies for learning them well. Recent evidence certainly lends support to the view that driver-training can have beneficial effects on perceptual-motor skills (Dorn & Barker, 2005; Chapman et al., 2002) as well as risk

taking behaviour (Fisher, et al., 2002; McKenna, et al., 2006) and crash statistics (Carcaillon & Salmi, 2005; Carstensen, 2002). In our view, the driver-training program assessed in the present study has a well-defined skill-base that is grounded in a well established theoretical framework. The program reflects the importance of perceptual-motor abilities for safe driving and also addresses higher order psychological, attitudinal, contextual, and environmental factors that are known to influence driving behaviour (Hatakka, et al., 2002; Laapotti, et al., 2001). This is critical because of the possibility that the skill-based benefits of driver-training can be offset by risk compensations arising from increased confidence (Gregersen, 1996). Furthermore, the beneficial effects of the driver-training program assessed are not necessarily restricted to cornering, which accounts for at least 30 % of all crashes (Chen, et al., 2006; Fildes, et al., 2003). The possible benefits of the training instead apply to any driving situation where inertial forces are present including braking and turning in general. Indeed, most crashes would be expected to occur in an inertial field where postural stability of the driver may be compromised. We contend that under such conditions, the ability to detect critical information (e.g., visual and vestibular) about the environment and perform the necessary control actions is compromised. While our study demonstrates some positive influences of stability-based training and adds to the evidence base indicating positive effects of certain driver-training programs, further research is clearly required to determine whether the training investigated has long-term beneficial effects on risk taking behaviour and road crash statistics.

## **5.5. Conclusion**

Based on the result of the present study it was concluded that (i) postural stability, defined by the degree of coupling between vehicle and driver lateral accelerations, was

enhanced following training, (ii) trained drivers reduced the magnitude of vehicle lateral accelerations and had earlier onset of peak lateral accelerations, (iii) prior to training, drivers who were more posturally unstable tended to experience higher lateral accelerations during cornering, and (iv) drivers who had the biggest improvements in postural stability tended to experience the greatest reductions in lateral accelerations of the vehicle during cornering. Importantly, the reduction in lateral accelerations following training in the present study indicates a greater dynamic margin of safety for cornering. Overall findings suggest that the driver-training program produced beneficial effects on cornering kinematics and these effects were associated with enhanced postural stability. Further research is required to determine the influence of the training program on road safety outcome measures.







# Chapter 6

## Experiment 3

Driver-training  
improves  
vehicle dynamics  
and postural stability  
during an evasive  
lane change and  
return manoeuvre

“Automobiles are not ferocious.

It is man who is to be feared.”

(Robbins B. Stoeckel)



## **6.0 DRIVER-TRAINING IMPROVES VEHICLE DYNAMICS AND POSTURAL STABILITY DURING AN EVASIVE LANE CHANGE AND RETURN MANOEUVRE**

### **6.1. Introduction**

An important advantage of driver-training compared with driving experience for learning how to drive safely is that expert feedback can be used to guide the learning process (Ivancic & Hesketh, 2000). Although a number of retrospective studies have examined the relation between post-licence driver-training and the incidence of road crashes (Ker, et al., 2005; Lund, et al., 1986), relatively few prospective studies have investigated the effect of driver-training on perceptual, cognitive, and psychomotor abilities. Prospective studies that used driving simulators have demonstrated evidence of safer driving behaviour and / or improved driving performance following training (Dorn & Barker, 2005; Ivancic & Hesketh, 2000; Roenker, Cissell, Ball, Wadley, & Edwards, 2003; Smiley, et al., 1980). From on-road studies, further evidence exists to suggest that perceptual skills such as visual scanning and hazard detection are improved in trained compared to untrained groups (Chapman, et al., 2002; Underwood, et al., 2002). In addition, training studies with an emphasis on correct application of modern vehicle's technology, such as proper use of anti-lock brakes (ABS), have also demonstrated beneficial training effects (Mollenhauer, et al., 1997).

Example of a modern multi-factorial driver-training program and its theoretical basis were recently described (Petersen, et al., 2006; Petersen, Barrett, & Morrison, in press; Treffner, et al., 2002). As well as addressing higher order factors that influence driving behaviour (Hatakka, et al., 2002), the program specifically emphasises the importance

of skills development in visual scanning, anticipation and preparation of upcoming events, and the maintenance of postural stability during critical driving situations (Gardner, 1998). The unique emphasis of the program on postural stability reflects the modern ecological perspective that postural stability increases sensitivity to the driving environment, especially visual and vestibular information (Fouque, Bardy, Stoffregen, & Bootsma, 1999; Riccio, 1995), which may in turn facilitate enhanced vehicle control as part of the perception-action cycle (Gibson, 1979; Gibson & Crooks, 1938; Schiff & Arnone, 1995; Stoffregen, et al., 2000). Within this paradigm, postural stability provides the necessary physiological and dynamical basis upon which improved attention and perceptual awareness can be built (Michaels & Carello, 1981; Riccio, et al., 1992). These views are consistent with the view that postural stability is an important requirement for effective performance in other motor skill tasks (Stuart & Atha, 1990; Vereijken, et al., 1997)

The purpose of the present study was therefore to investigate the effect of an intensive two-day post-license driver-training program on vehicle dynamics and postural stability during an evasive lane change and return manoeuvre. The evasive lane change and return manoeuvre was chosen for analysis because of the inherent challenge to vehicle control and postural stability that this driving manoeuvre presents. It was hypothesised that postural stability would be improved following training, together with improvements in vehicle dynamics.

## **6.2. Methods**

### ***6.2.1. Subjects and experimental design***

Three groups of drivers were recruited to participate in this study: a trainee group (n = 26), a control group (n = 15), and driver-training instructor group (n = 13). The trainee group consisted of students enrolled in a two-day post-license driver-training course conducted at Holden Performance Driving Centre (HPDC), Norwell, Queensland. The control group was matched by age and driving experience to the trainee group. Each trainee participant completed a driving test within fourteen days before and fourteen days after training. The control group were tested within the same time period as the trainee group but did not participate in the driver-training course. The instructor group were HPDC trainers who had a minimum six months practice of this driving technique and completed only one test. All drivers held a valid Australian provisional or open driver's licence, had not participated in other HPDC training or comparable courses (trainee and control groups only), and provided written informed consent prior to participation in the study. The study was approved by the Griffith University Human Research Ethics Committee in accordance with National Health & Medical Research Council guidelines (NHMRC, 1999).

### ***6.2.2. Driver-training program***

The two-day post-license training program assessed in the present study was based on principles of safe driving outlined by Gardner (1998). The program can be described as a "driver-improvement program" rather than a "learn-to-drive" or "defensive-driving" program (McKnight & Peck, 2003). The general aim of the program is to promote knowledge and skills that maximise safe driving and minimise crash risk. The program is based on a combination of lectures, discussions, demonstrations, and driving

exercises performed by the trainee with an instructor in the vehicle. Classroom and demonstration sessions are designed to increase awareness of the many psychosocial factors that influence crash risk (e.g., personal, social, motivational, and environmental factors), to explain and discuss the basic principles of safe driving (eg. effects of velocity, effects of destabilising accelerations, safe travelling distance, driving trajectory lines, where to look, basic physics of driving, avoiding steering errors) and to introduce a specific driving technique (i.e., sitting position, hand position, visual scanning, pedal controls, braking, steering, and postural bracing). The training exercises provide the opportunity to practise and learn the skills introduced in the classroom sessions and include instruction in cornering, braking, and the evasive lane change and return manoeuvre. With reference to the evasive lane change and return manoeuvre, participants were taught to brace their legs against the centre console and the door in order to counteract inertial forces during turns, while steering and powering a vehicle as smoothly as possible.

### ***6.2.3. Evasive lane change and return protocol***

The evasive lane change and return set-up consisted of a series of traffic markers arranged on a straight section of track (Figure 6.1). An entry velocity of  $60 \pm 3$  km/hr measured at the final approach chute marker was required. Velocity was not constrained once passed the final approach chute marker, which allowed for optional brake and / or accelerator pedal usage during the manoeuvre. Once passed the final approach chute marker, drivers were required to steer the vehicle into the adjacent lane (swerve phase), around the obstacle (recovery phase) and return to the original lane for an exit (exit phase) through the departure chute without contacting any traffic cones twelve times at each test-session (six left and six right in random order).

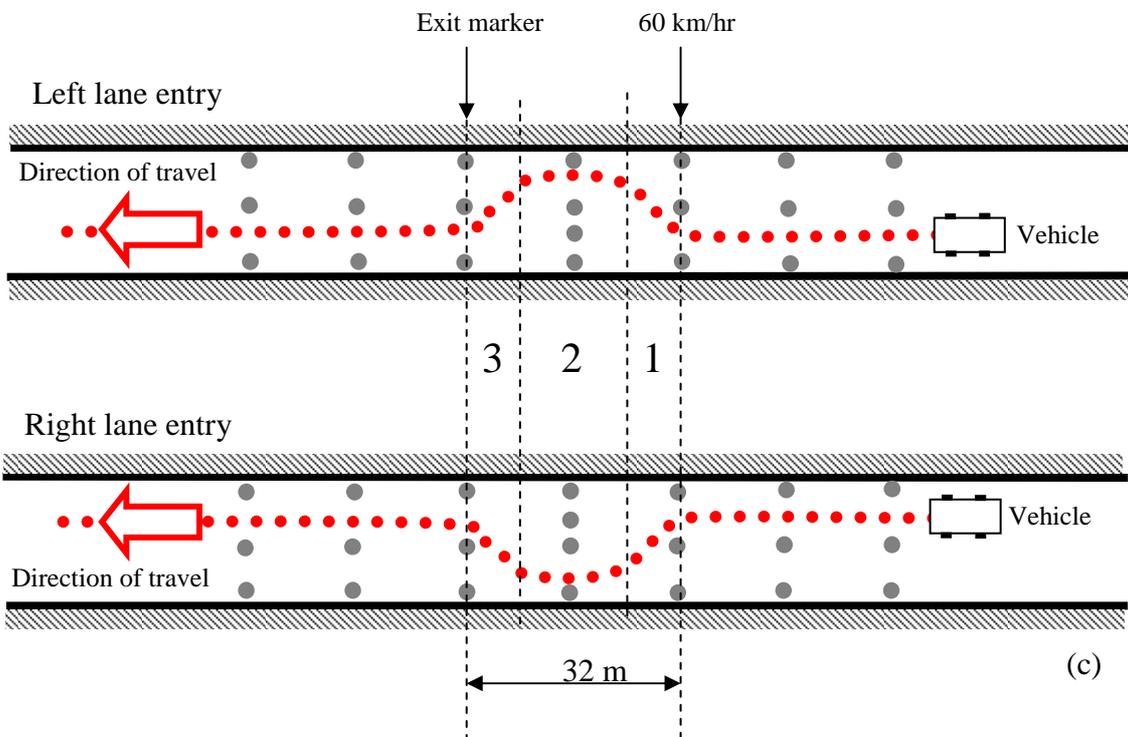
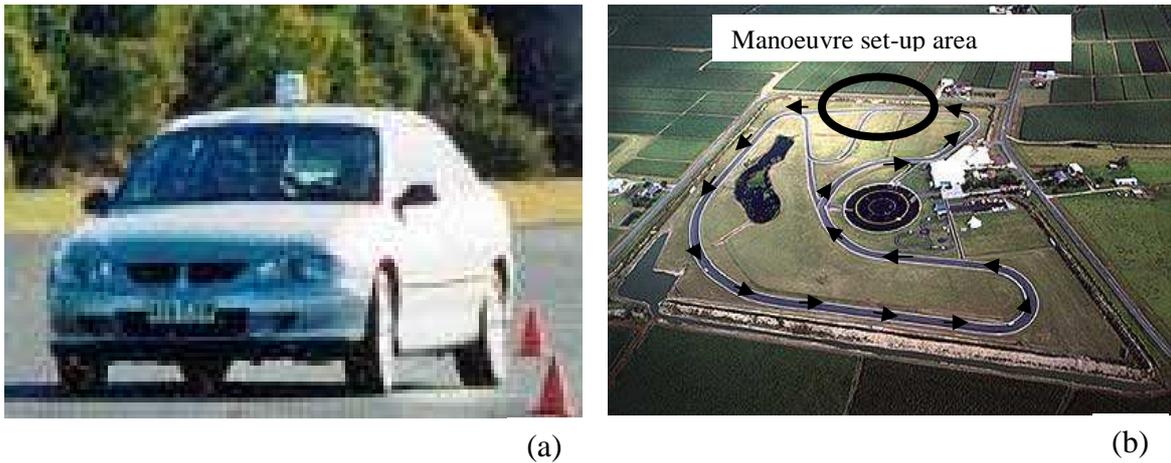


Figure 6.1 Manoeuvre set-up. (a) Research vehicle, (b) Aerial view of HPDC closed circuit track with the manoeuvre set-up area and direction of travel indicated, (c) Scaled set-up for left entry (upper) and right entry (lower) evasive lane change manoeuvre with obstacles. The dotted line represents the vehicle trajectory and the dashed lines indicate the approximate location of the (1) swerve, (2) recovery, and (3) exit phases.

#### 6.2.4. Instrumentation

All tests were performed in a sedan vehicle (Commodore, Holden) that had automatic transmission, power steering and ABS engaged. The vehicle was instrumented with a GPS (Trimble) to measure vehicle velocity, acquired at the rate of 10 Hz. The following analogue data was acquired at 100 Hz using a data acquisition system (DAQBook 200, DBK 43A, DBK80, IOTech). Acceleration profiles were measured for a driver at the 7<sup>th</sup> cervical vertebrae (vertebrae prominens) and the vehicle at the centre console adjacent the driver's left hip independently by the use of two triaxial  $\pm 2$  g accelerometers (Crossbow). Accelerator and brake pedal depression were measured using linear potentiometers (Honeywell). Low-profile force transducers (Applied Measurement) were used to measure brace force against the centre console and the door (Figure 6.2). Steering wheel handgrip pressure was measured using two pairs of flexiforce pressure sensors (Tekscan) taped to the distal and proximal aspect of each palm.

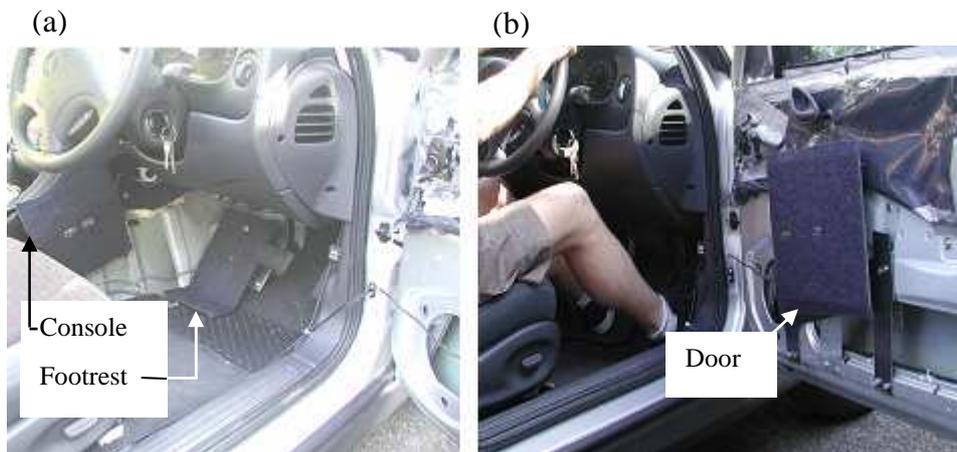


Figure 6.2 Inside the research vehicle. (a) force plate on centre console (footrest also shown), (b) force plate on door.

### ***6.2.5. Assessment of vehicle dynamics and postural stability***

Vehicle motion was quantified using average and minimum vehicle velocity throughout the manoeuvre and peak normalised lateral vehicle accelerations during each phase (swerve, recovery, and exit) of the manoeuvre. Postural stability was assessed by calculating the difference between peak driver and vehicle lateral accelerations during each phase. All lateral acceleration data were divided by the square of the instantaneous velocity in order to normalise for velocity (centripetal acceleration is proportional to the square of velocity). Console and door brace forces were normalised for each driver's maximal isometric brace force that was measured in the vehicle while stationary.

### ***6.2.6. Statistical analysis***

A mixed full factorial general linear model was used to assess the effect of group (trainees and controls) and test-session (pre- and post-test) on the dependant variables. A-priori contrasts with Bonferroni corrections were used to identify specific differences between means. One-way ANOVA was used to assess the effect of group (instructors, trainees, and controls) on second (post-test) set of dependant variables as a comparison for practiced driver-training. All data are reported as means  $\pm$  one standard error of the mean. All statistical analysis was conducted using SPSS for Windows (Ver. 11.3), with significance accepted at  $p < 0.05$ .

## **6.3. Results**

### ***6.3.1. Subject characteristics***

The trainee group ( $n = 26$ ) consisted of 13 provisional and 13 open licensees drivers with a respective mean age and driving experience of 31.7 and 14.2 years. The control

group (n = 15) consisted of eight provisional and seven open licensee drivers with respective mean age and experience of 27.9 and 9.2 years. There were no significant differences in age or driving experience between the trainee and control group. The instructor group (n = 13) were regular HPDC staff with a minimum six months practice of this driving technique.

### ***6.3.2. Representative results***

Typical data during a left lane entry manoeuvre from a representative trainee driver before and after training, and an instructor are presented in Figure 6.3. For this trainee, the post- compared with pre-test results revealed greater mean velocity brought about through reduced deceleration from brake application. The vehicle's peak normalised lateral accelerations (peak lateral acceleration) were greater during the swerve phase, but reduced during the recovery phase, which indicated a smoother overall trajectory. Following training, the trainee applied a resistive brace force with the legs against the door and console in order to be in phase with the peak lateral acceleration acting on the vehicle and driver. The difference between vehicle's peak lateral acceleration and the driver's peak lateral acceleration (peak acceleration difference) revealed less deviation with peaks closely synchronised following training. After training, this participant used reduced handgrip pressure on the steering wheel. By comparison to trainees after training, the instructor also did not use either foot pedal while changing lanes, had similar swerve peak lateral acceleration, lower recovery phase peak lateral acceleration and similar exit phase peak lateral acceleration plus exerted lower bracing forces against the console.

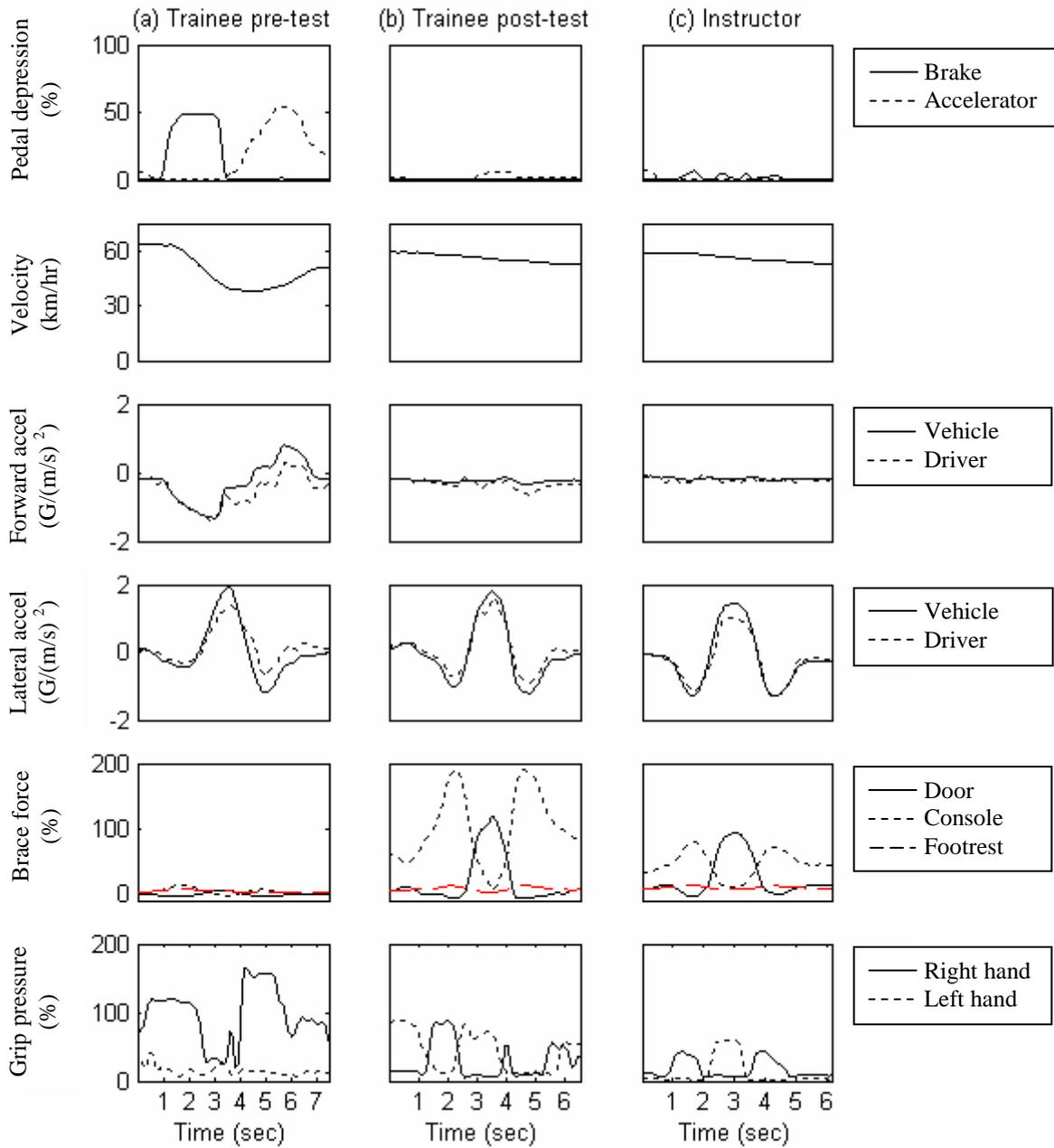


Figure 6.3 Representative data for a left entry lane change manoeuvre. Data are for a trainee participant collected (a) prior to training, (b) following training, and (c) a driving instructor.

The effect of training on accelerations during the lane change and return manoeuvre is further illustrated in Figure 6.4. For a vehicle travelling at constant velocity in a straight line, the normalised forward and lateral directions would be zero. Deviation from zero in each direction therefore represents a change in velocity of the vehicle. Note that during the second test-session the deviation from zero along each axis is reduced for the trainee but not the control participant, with the trainee profile approaching that of the instructor. The extent to which the curves for the vehicle and driver correspond is also an approximate measure of how much the driver is tilted relative to the line of gravity (global vertical). The degree of coupling between vehicle and driver accelerations was enhanced following training, but not to the same extent as for the representative instructor.

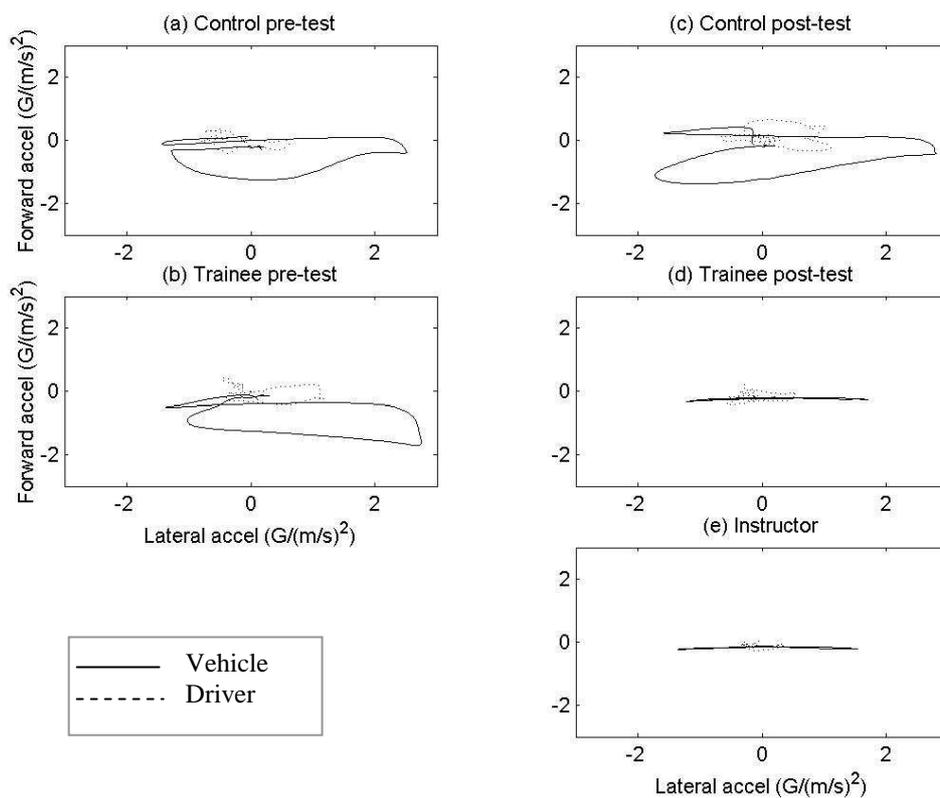


Figure 6.4 Representative vehicle and driver forward acceleration versus lateral acceleration plots for a left entry lane change manoeuvre. Data for a control, trainee, and instructor participant at each test-session (pre- and post-test). All acceleration data are normalised for driving velocity.

### 6.3.3. Effect of group and test-session on vehicle velocity

No significant differences in entry velocity were detected between groups or test-sessions when collapsed across the left or right lane change entry manoeuvres (Table 6.1). However, test-session had a significant effect on mean velocity and minimum velocity. A significant group by test-session interaction effect was also detected for mean velocity and minimum velocity, with a-priori contrasts revealing trainees had significantly higher values than controls in the post- but not pre-test session. Mean velocities were significantly higher for instructors compared to trainees post and controls post. Similarly, minimum velocities were significantly higher for instructors compared to trainees post and controls post (Table 6.2).

Table 6.1 Summary statistics for effect of group, test-session, and group  $\times$  test-session interaction on velocity measures during the manoeuvre. Bracketed terms are one standard error of mean. NS = not significant.

Variable	Group			Test-session		Group $\times$ test-session	
	Controls	Trainees		Pre	Post		
Entry velocity (km/hr)	58.56 (0.14)	58.81 (0.11)	NS	58.88 (0.12)	58.56 (0.14)	NS	NS
Mean velocity (km/hr)	49.82 (1.86)	50.71 (0.95)	NS	49.51 (0.98)	51.02 (0.91)	F = 5.23 P < 0.05	F = 5.07 p < 0.05
Minimum velocity (km/hr)	44.69 (2.47)	45.45 (1.35)	NS	43.73 (1.36)	46.40 (1.23)	F = 8.27 P < 0.01	F = 6.46 p = 0.16

Table 6.2 Summary statistics for effect of group (control, trainee, and instructor) on post-test dependant measures during each phase. Bracketed terms are one standard error of mean. NS = not significant.

Variable	Controls (Post-test)	Trainees (Post-test)	Instructors	Significance
Entry velocity (km/hr)	58.59 (0.19)	58.55 (0.18)	58.55 (0.18)	NS
Mean velocity (km/hr)	49.83 (1.82)	52.20 (0.91)	55.42 <sup>^</sup> (0.56)	F = 4.65 p < 0.01
Minimum velocity (km/hr)	44.84 (2.48)	47.96 (1.23)	52.60 <sup>^</sup> (0.86)	F = 4.86 p < 0.01

<sup>^</sup> denotes significant difference between controls and instructors

#### ***6.3.4. Effect of group and test-session on vehicle motion and postural stability (Left lane entry)***

Summary results for the effect of group (trainee and control), and test-session (pre- and post-test) from left lane approach are presented in Table 6.3. Group had a significant main effect on peak lateral acceleration for the swerve and recovery phase, as well as peak door force during the recovery phase. A significant test-session effect was detected for peak lateral acceleration during recovery and peak console force during exit. In addition, significant group by test-session interactions were detected for peak console force during the swerve and exit phases, peak door force during recovery. Group by test-session plots for each dependent measure are presented in Figure 6.5.

Results of the one-way ANOVA for group (instructors, trainees post, and controls post) revealed significant differences for peak lateral acceleration ( $F = 5.97, p < 0.01$ ) and peak console force ( $F = 6.96, p < 0.01$ ) during the swerve phase, peak lateral acceleration ( $F = 5.95, p < 0.01$ ); peak acceleration difference ( $F = 10.50, p < 0.01$ ), and peak door force ( $F = 7.74, p < 0.01$ ) during recovery; and peak console force during the exit phase ( $F = 5.86, p < 0.01$ ). A-priori contrasts revealed that instructors had significantly higher values than trainees for peak lateral acceleration ( $p < 0.05$ ) and peak console force ( $p < 0.01$ ) during the swerve phase; lower values for peak lateral acceleration ( $p < 0.01$ ) during the recovery phase; and peak console force ( $p < 0.01$ ) during the exit phase. In addition, instructors compared with controls had significantly lower values for peak lateral acceleration ( $p < 0.01$ ) and peak acceleration difference ( $p < 0.01$ ) during the recovery phase and significantly higher values for peak door force during recovery ( $p < 0.01$ ).

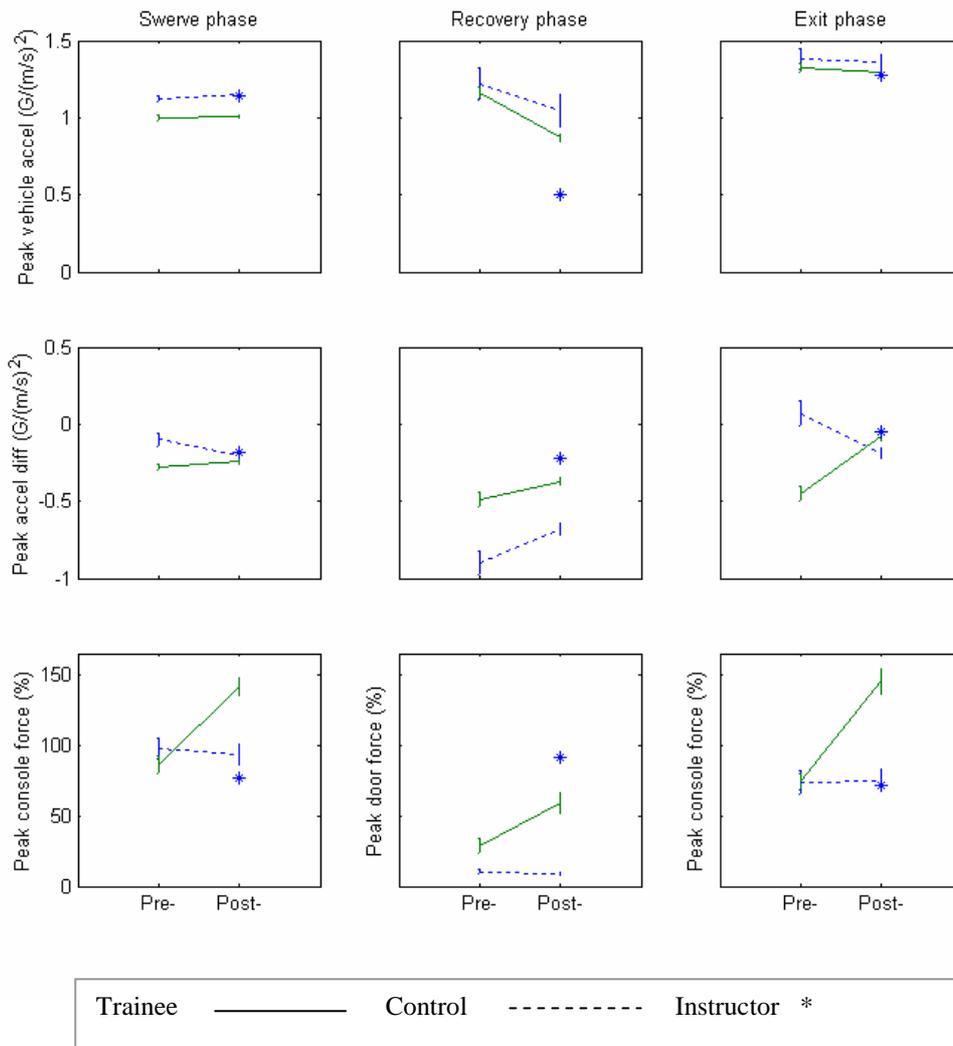


Figure 6.5 Summary of interactions between group (control, trainee, and instructor) for the swerve, recovery and exit phases of the left lane entry condition. Peak vehicle acceleration (top line), peak acceleration difference (middle line), and bracing forces on the console and door (bottom line). Error bars represent  $\pm$  one standard error of the mean.

Table 6.3 Summary statistics from left lane entry for effect of group, test-session, and group × test-session interaction on dependant measures during each phase. Bracketed terms are one standard error of mean. NS = not significant.

Variable	Group			Test-session			Group × test-session
	Controls	Trainees		Pre	Post		
<b>Swerve phase</b>							
Peak lateral accel (G/(m/s) <sup>2</sup> )	1.12 (0.04)	1.01 (0.02)	F = 5.25 p < 0.05	1.09 (0.02)	1.05 (0.03)	NS	NS
Peak accel diff (G/(m/s) <sup>2</sup> )	-0.16 (0.05)	-0.25 (0.03)	NS	-0.19 (0.05)	-0.22 (0.03)	NS	NS
Peak brace console (%max)	99.50 (14.64)	114.60 (10.13)	NS	96.37 (10.57)	117.74 (10.51)	NS	F = 8.48 p < 0.01
<b>Recovery phase</b>							
Peak lateral accel (G/(m/s) <sup>2</sup> )	2.14 (0.14)	2.05 (0.09)	NS	2.21 (0.10)	1.97 (0.08)	F= 15.00 p < 0.01	NS
Peak accel diff (G/(m/s) <sup>2</sup> )	-0.77 (0.10)	-0.46 (0.07)	F = 6.62 p < 0.05	-0.70 (0.09)	-0.53 (0.05)	NS	NS
Peak brace door (%max)	9.58 (13.94)	44.09 (9.64)	F = 4.15 p = 0.05	19.88 (8.29)	33.80 (10.23)	NS	F = 4.39 p < 0.05
<b>Exit phase</b>							
Peak lateral accel (G/(m/s) <sup>2</sup> )	1.41 (0.09)	1.30 (0.06)	NS	1.36 (0.06)	1.36 (0.05)	NS	NS
Peak accel diff (G/(m/s) <sup>2</sup> )	-0.06 (0.08)	-0.26 (0.05)	NS	-0.18 (0.10)	-0.14 (0.05)	NS	F = 5.16 p < 0.05
Peak brace console (%max)	77.51 (19.75)	110.02 (13.66)	NS	77.32 (11.49)	110.20 (14.61)	F = 9.48 p < 0.01	F = 12.43 p < 0.01

### ***6.3.5. Effect of group and test-session on vehicle control and postural stability (Right lane entry)***

Summary results for the effect of group (trainee and control) and test-session (pre- and post-test) from right lane approach are presented in Table 6.4. Group had a significant main effect on peak lateral difference for the recovery phase, as well as peak door force during the exit phase. A significant test-session effect was detected for peak lateral acceleration, peak acceleration difference, and peak console force during recovery. Additionally, significant group by test-session interactions were detected for peak door

force during the swerve phases, peak console force during recovery and peak acceleration difference and peak door force during the exit phase. Group by test-session plots for each dependent measure are presented in Figure 6.6.

Results of the one-way ANOVA for group (instructors, trainees post, and controls post) revealed significant differences for peak lateral acceleration ( $F = 3.31$ ,  $p < 0.05$ ), peak acceleration difference ( $F = 3.79$ ,  $p < 0.05$ ), and peak door force ( $F = 8.56$ ,  $p < 0.01$ ) during the swerve phase; peak lateral acceleration ( $F = 3.65$ ,  $p < 0.05$ ), peak acceleration difference ( $F = 17.11$ ,  $p < 0.01$ ), and peak console force ( $F = 8.63$ ,  $p < 0.01$ ) during recovery; and peak acceleration difference ( $F = 7.01$ ,  $p < 0.01$ ) and peak door force ( $F = 9.47$ ,  $p < 0.01$ ) during the exit phase. A-priori contrasts revealed that instructors had significantly higher values than trainees for peak door force ( $p < 0.05$ ) and lower peak lateral acceleration ( $p < 0.01$ ) during the swerve phase, lower values for peak console force ( $p < 0.01$ ) during recovery, and higher peak door force ( $p < 0.01$ ) during the exit phase. In addition, instructors compared with controls had significantly lower values for peak acceleration difference ( $p < 0.05$ ) and higher peak door force ( $p < 0.01$ ) during the swerve phase, lower peak lateral acceleration ( $p < 0.01$ ) and peak acceleration difference ( $p < 0.01$ ) recovery phase, and lower peak acceleration difference ( $p < 0.01$ ) and higher values for peak door force during recovery ( $p < 0.01$ ).

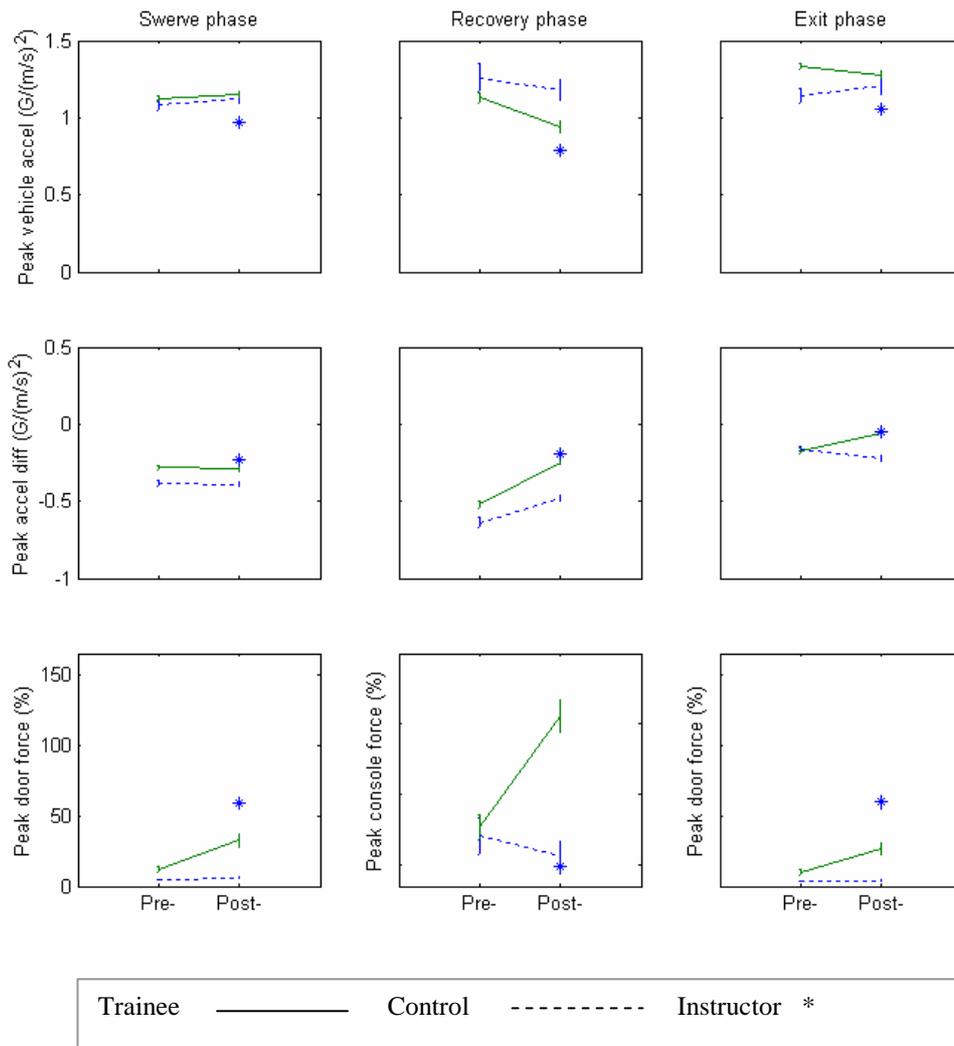


Figure 6.6 Summary of interactions between group (control, trainee, and instructor) for the swerve, recovery and exit phases of the right lane entry condition. Peak vehicle acceleration (top line), peak acceleration difference (middle line), and bracing forces on the console and door (bottom line). Error bars represent  $\pm$  one standard error of the mean.

Table 6.4 Summary statistics from right lane entry for effect of group, test-session, and group  $\times$  test-session interaction on dependant measures during each phase. Bracketed terms are one standard error of mean. NS = not significant.

Variable	Group			Test-session		Group $\times$ test-session	
	Controls	Trainees		Pre	Post		
<b>Swerve phase</b>							
Peak lateral accel (G/(m/s) <sup>2</sup> )	1.10 (0.05)	1.14 (0.04)	NS	1.10 (0.04)	1.13 (0.03)	NS	NS
Peak accel diff (G/(m/s) <sup>2</sup> )	-0.38 (0.04)	-0.28 (0.03)	NS	-0.32 (0.03)	-0.34 (0.02)	NS	NS
Peak brace door (%max)	5.51 (7.06)	22.27 (5.21)	NS	8.42 (3.02)	19.35 (6.24)	F = 6.27 p < 0.05	F = 4.98 p < 0.05
<b>Recovery phase</b>							
Peak lateral accel (G/(m/s) <sup>2</sup> )	2.22 (0.12)	2.07 (0.08)	NS	2.22 (0.08)	2.06 (0.07)	F = 7.92 p < 0.01	NS
Peak accel diff (G/(m/s) <sup>2</sup> )	-0.56 (5.32)	-0.38 (4.12)	F = 6.71 p < 0.01	-0.58 (5.33)	-0.37 (2.52)	F = 18.12 p < 0.01	NS
Peak brace console (%max)	113.62 (24.12)	166.17 (17.81)	NS	123.71 (16.40)	156.08 (13.63)	F = 4.78 p < 0.05	F = 9.79 p < 0.01
<b>Exit phase</b>							
Peak lateral accel (G/(m/s) <sup>2</sup> )	1.17 (0.07)	1.32 (0.05)	NS	1.25 (0.05)	1.24 (0.05)	NS	NS
Peak accel diff (G/(m/s) <sup>2</sup> )	-0.19 (0.04)	-0.12 (0.03)	NS	-0.17 (0.03)	-0.14 (0.02)	NS	F = 8.71 p < 0.01
Peak brace door (%max)	3.99 (6.91)	18.13 (5.10)	F = 4.65 p < 0.05	6.93 (3.32)	15.19 (5.76)	NS	F = 4.65 p < 0.05

## 6.4. Discussion

Most driver-training programs emphasise to some extent the development of driving skill by including instruction in driving manoeuvres (Hatakka, et al., 2002). At present however, few prospective studies have examined how driver-training influences driving performance. Such information has the potential to inform curriculum development in driver-training and contribute to improved road safety (Mayhew & Simpson, 2002; McKnight & Peck, 2003). The purpose of the present study was to investigate the effect of a specific driver-training program on driving performance during an evasive lane

change and return manoeuvre. The multi-faceted two-day post-licence driver-training program assessed in the present study emphasised the importance of postural stability maintenance during critical driving situations in order to facilitate enhanced sensitivity to perceptual information and consequently, enhanced vehicle control (Gardner, 1998; Riccio, 1995). The evasive lane change and return manoeuvre was chosen for analysis because of the inherent challenge to vehicle motion and postural stability that this manoeuvre presented.

#### ***6.4.1. Training and vehicle dynamics***

All drivers reported some velocity reduction. Following training, trainee drivers were more effectively able to maintain entry momentum throughout the lane change and return manoeuvre, resulting in higher average and minimum velocities compared to controls. Instructor drivers, who can be considered trained and highly practiced drivers, tended not to use the pedal controls but rather exploited the vehicle-road friction to reduce velocity, and as such maintained higher average and minimum velocities than controls and trainees (post-test). By comparison, controls tended to deploy the brake, which during sudden turning at the test velocity of 60 km/hr may be dangerous due to the possibility of wheel lock inducing vehicle spin (Sekine & Nagae, 1999) and the increased potential to be hit from behind by a following vehicle (Hiramatsu & Obara, 2000; Parker, West, et al., 1995). This braking strategy may be indicative of control drivers primarily attending to the obstacle (Tresilian, et al., 2004) rather than an escape route (Salvucci & Liu, 2002). In addition, during the exit or return phase, drivers who had previously decelerated via brake application tended to rapidly accelerate to increase their exit velocity, which is also associated with increased risk of loss of vehicle control (Clarke, Ward, & Jones, 1998).

During the evasive lane change and return manoeuvre, all drivers displayed a distinct three-peak pattern of lateral accelerations with an acceleration peak occurring in the swerve phase, recovery phase and the exit phase of the manoeuvre. In general, the largest acceleration peak occurred in the recovery phase as the vehicle was steered back towards the original (entry) lane. Of particular significance was the finding that lateral vehicle accelerations experienced by the trainees after training were significantly lower during the recovery phase than controls for the left and right lane entry conditions. This finding suggests that trainees following training may have more effectively set up the position and velocity of the vehicle for the recovery phase during the preceding swerve phase, which better positioned the vehicle to travel a smoother path (van Winsum, de Waard, & Brookhuis, 1999). Trainees were therefore less likely to lose vehicle control due to excessive lateral acceleration during the return phase (Clarke, et al., 1998).

In contrast, controls who travelled the slowest and consequently had the most time to control the vehicle, demonstrated the highest lateral accelerations. This result indicates more acute trajectory changes during the recovery stage that may be due to poorer trajectory pre-planning during preceding phases and / or focussing upon the obstacle at the end of the recovery phase rather than the path of recovery (Tresilian, et al., 2004). Instructors had the lowest lateral accelerations for all the left and right manoeuvres phases (except the left lane swerve phase, which was similar), indicating a smoother trajectory than the trainees and controls.

As lateral accelerations are known to be positively correlated with crash frequency (af Wåhlberg, 2000; 2004), the reduced lateral accelerations of the trainee group identified in the current study are desirable because they reflect a reduced side-deviating (destabilising) inertial force acting on the vehicle and its occupants. In addition,

controls and trainees (pre-test) exhibited high peak forward deceleration that corresponded with high lateral accelerations during the swerve phase, therefore combining to form large instantaneous resultant (destabilising) accelerations of the vehicle that could exceed the occupant's ability to remain stable (de Graaf & Van Weperen, 1997). While velocity is certainly a significant crash contributor (Holland & Conner, 1996; Jonah, 1997; Lam, 2003), excessive steering and changing velocity that contributes to high accelerations, may also be dangerous (Lajunen, et al., 1997). Overall, these results are supportive of the general view that more highly skilled drivers tend to exhibit smoother vehicle dynamics (Safren, et al., 1970).

#### ***6.4.2. Training and postural stability***

Postural stability was quantified in the present study from the difference between the lateral accelerations of the vehicle and driver. If the vehicle and driver were rigidly coupled, then the accelerations experienced by the vehicle and driver would be identical, and so the difference would be zero. In the present study, driver accelerations prior to training were lower than vehicle accelerations because most drivers tended to tilt the upper body away from the corner. Following training, the trainee group had a reduced difference between vehicle and driver accelerations during the recovery and exit phases, which was related to an increased use of lower body bracing against the door and console of the vehicle. This result suggested that bracing the lower extremity against the vehicle was an effective means for stabilising the upper body during the evasive lane change and return manoeuvre. Of all groups, instructors had the strongest coupling between vehicle and driver accelerations. By remaining coupled, researchers have argued that drivers can become more receptive to the relevant information required for guiding the direction of heading and controlling the vehicle (Fouque, et al., 1999; Riccio, 1995; Stoffregen & Bardy, 2001). During an evasive lane change and return

manoeuvre, improved postural stability prevents rapid transitions in body tilt from one side to the other and back again, which would otherwise distort the patterns of gravito-inertial and visual information that constrains driver actions in controlling the vehicle as part of the perception-action cycle (Paloski, et al., 2006; Riccio, et al., 1992; Stoffregen, et al., 2000).

## **6.5. Concluding remarks**

For the evasive lane change and return manoeuvre assessed in the present study, overall results indicated that training had a significant influence on the driving performance of trainees compared to controls. The adaptations to training made by the trainee group led to reduced inertial forces that acted on the vehicle and were produced using a driving training program that emphasised the importance of maintaining postural stability. The improved vehicle control amongst trainees observed in the present study may be at least partly explained by the corresponding improvement in postural stability following training, a finding that is consistent with ecological theories that there is a circular causality between perception and action. Although at the completion of training the level of driving performance attained by trainees did not match that of instructors, this study has shown that drivers are able to learn and execute new driving skills, and that these new skills resemble to a greater extent the driving characteristics of trained and highly practiced drivers. In future it will be necessary to determine to what extent these skills are retained and can be improved with practice over longer time periods than assessed in the present study. Further, it would be of interest to conduct similar experiments using unanticipated obstacles in a real world situation.





# Chapter 7

## General Discussion

“It is amazing how quickly the kids  
learn to drive a car,  
yet are unable to understand the lawnmower,  
washing machine or vacuum cleaner.”

(Ben Bergor)



## **7.0 GENERAL DISCUSSION**

The purpose of this chapter is to synthesise and discuss the findings presented in the preceding chapters. The discussion addresses the three aims of the research that were presented in Chapter 1 in the context of the experimental findings reported in Chapters 4 to 6. Implications of the results for driver training, limitations of the research, and recommendations for future research are also presented.

### **7.1. Summary of experimental findings**

#### ***7.1.1. Experiment 1 Driver-training and emergency brake performance in cars with anti-lock brakes***

The main results of Experiment 1 were that trained drivers used a significantly smoother brake profile and had enhanced postural stability during deceleration compared with the control group. The trained drivers were also less reliant on the antilock braking system (ABS) and stopped within approximately one car length with significantly lower mean deceleration compared with stops assisted by good quality ABS. Results also confirmed that trained drivers were able to more effectively stabilise their upper body than were untrained drivers. This was at least partly achieved through increased bracing with the left foot onto the footrest. In addition, qualitative analysis of handgrip pressure data suggested that the majority of trained drivers had a more relaxed grip on the steering wheel compared with the controls.

*7.1.2. Experiment 2 Enhanced postural stability following driver-training is associated with positive effects on vehicle kinematics during cornering*

The main results of Experiment 2 were that trainee drivers experienced enhanced postural stability and reduced the magnitude and onset of peak vehicle lateral accelerations following training. Prior to training, drivers who were more posturally unstable tended to experience higher lateral vehicle accelerations and drivers with the biggest improvements in postural stability following training tended to experience the greatest reductions in lateral accelerations of the vehicle. Training led to changes in postural stability that was associated with reduced lateral accelerations during cornering. The reduction in lateral accelerations following training in the present study indicates a greater dynamic margin of safety for cornering. None of these beneficial changes were evident from control drivers although they had experienced the manoeuvre during the two separate test-sessions. By comparison to the trainees and controls, the instructor drivers demonstrated better vehicle kinematics and postural stability that could be attributed to the deliberate practice required prior to instructing the training program. Overall findings suggested that the driver-training programs produced beneficial effects on cornering kinematics and these effects were associated with enhanced postural stability.

### ***7.1.3. Experiment 3 Driver-training improves vehicle dynamics and postural stability during an evasive lane change and return manoeuvre***

The main results of Chapter 6 were trained drivers minimally applied the brake, significantly reduced the lateral acceleration during the recovery phase, reduced the difference between driver and vehicle accelerations during the recovery and exit phases, and in general, improved the coupling between the two accelerations. These drivers also reduced handgrip pressure on the steering wheel as they applied a brace force against the door and console of the vehicle. In contrast, controls who applied the brake upon entry, travelled the slowest, and consequently had the most time to control the vehicle demonstrated the highest level of lateral accelerations and did not brace but rather applied large handgrip pressure on the steering wheel. The instructor group, who demonstrated low levels of lateral acceleration and bracing, had the strongest coupling between vehicle and driver accelerations.

## **7.2. Synthesis of experimental findings**

The specific purposes of the experiments comprising this study as stated in Chapter 1 were to

- (i) Determine the effect of driver-training on vehicle motion;
- (ii) Determine the effect of driver-training on a driver's postural stability, and
- (iii) Examine the relation between postural stability and vehicle motion during emergency braking, cornering, and an evasive lane change and return manoeuvre.

These purposes are now addressed in turn in relation to the findings of the study.

### ***7.2.1. Effects of driver-training on vehicle motion***

Driver-training was found to influence vehicle motion during cornering, evasive lane change, and braking. In regards to the turning manoeuvres, changes in steering technique were observed after training that resulted in reduced lateral accelerations. This was especially noticeable during the evasive lane change and return manoeuvre where it is speculated that trained drivers tended to steer a path of travel during the early stages of a manoeuvre that was conducive to steering a path without sharp directional changes later in the manoeuvre. These results are consistent with the view that trained drivers set-up the position of the vehicle during the initial turn (i.e., swerve) so that a wider trajectory would be possible in second and third turns (i.e., recovery and exit). Trained drivers arguably controlled the vehicle so that relatively low lateral accelerations occurred throughout the manoeuvre (van Winsum, et al., 1999). Previous research concluded that large accelerations were generally unsafe for general travel (Lajunen, et al., 1997; Ritchie, et al., 1968) especially during a return phase of a lane change (Clarke, et al., 1998) while smoother acceleration profiles were reflective of higher skill level of vehicle control (Smiley, et al., 1980).

An additional finding that was common to the two turning manoeuvres was that the trained drivers optimally coordinate their steering control with respect to travel speed. The trained drivers appear to have learned that it was safer (in terms of lower lateral accelerations) to make larger changes in direction when the vehicle was travelling slowly, and conversely, only increase speed when the path of travel was straightening out. Such actions by a trained driver may be associated with an enhanced perception of safe driving affordances (Gibson, 2000; Stoffregen, 2003; Turvey, 1992). In contrast, the control drivers seem to continue to use multiple changes in steering direction, which supports earlier findings that inexperienced drivers used multiple steering corrections

during turning manoeuvres (Macdonald & Hoffman, 1980; McRuer, et al., 1977). Furthermore, these steering changes were at times when the vehicle was increasing its speed that resulted in greater magnitudes of vehicle accelerations, which were potentially dangerous (Lajunen, et al., 1997).

Compared to turning manoeuvres, the emergency brake manoeuvre presented drivers with a different set of challenges for controlling vehicle motion. The trained drivers demonstrated smoother deceleration with a lower mean value when using the taught braking technique, although the distance to stop was slightly longer compared to ABS assisted stops used by the control drivers. Although ABS can assist in deceleration (Broughton & Baughan, 2002; Mollenhauer, et al., 1997), the operation of ABS was found to result in a jerky deceleration that subsequently creates an unfavourable environment for a driver.

An additional benefit of this trained braking technique is the suitability for application in vehicles with or without ABS. At present during an emergency brake situation, drivers must use one of two distinctly different brake application techniques for either an ABS or non-ABS vehicle, assuming that a driver knows which brake systems is available in a vehicle. Importantly, these techniques are not transferable between the two vehicle types and to apply the incorrect technique can lead to less-than-effective stopping power. This is a recognised problem within the literature and is considered as a contributing factor in some vehicle crashes (Broughton & Baughan, 2002; Harless & Hoffer, 2002; Mollenhauer, et al., 1997).

### ***7.2.2. Effects of driver-training on stability of a driver's posture***

Prior research into postural stability during driving is limited. Postural stability is about controlling a body's spatial position with the intention to achieve a stable orientation with its environment, which in this situation, is a vehicle that accelerates. The rationale for achieving and maintaining a stable posture within such a dynamic environment is that a driver has a sturdy foundation capable of supporting (i) all movements required for controlling a vehicle (Gardner, 1998; Treffner, et al., 2002), (ii) improved detection of an array of information, such as visual and gravito-inertial information (Stoffregen & Bardy, 2001), and (iii) enhanced perception of driving situations (Riccio, 1995).

The manner in which postural stability is achieved during accelerative manoeuvre is an important consideration in terms of vehicle control (Gardner, 1998; Higuchi, et al., 2002; Treffner, et al., 2002). Following training, drivers demonstrated the taught leg brace technique, reduced the difference in motion between a driver and vehicle, and improved the coupling between the two. The technique requires a driver to abduct (i.e., brace) a leg onto an adjacent surface (e.g., left leg against centre console) in order to lock the driver into place within the vehicle and resist perturbation (Gardner, 1998). This led to a more stable posture being maintained by trained drivers when perturbed. Apart from stabilising a driver's posture, the leg brace technique as taught in this study permits a driver to relax their handgrip on the steering wheel as their hands are no longer necessary for stabilising a driver. Untrained drivers typically respond to postural instability by firmly gripping the steering wheel and using it as an anchor-point from which to resist perturbation as suggested in previous research (Coelho & Dahlman, 1999; Zikovitz & Harris, 1999). However, there appears to be two potential problems with attempting stabilisation off a steering wheel. The first problem is that an ergonomic conflict can occur whenever the wheel is rotated one way to steer into a turn

while at the same time it is being pulled from the opposite direction as a driver attempts to stabilise their leaning upper body. Apart from the opposing forces acting upon the wheel, using the steering wheel for these two conflicting purposes could compromise one, if not both, actions (Treffner, et al., 2002). A second problem is that drivers typically increase their handgrip pressure on the wheel during this process, which can be considered deleterious to steering control, especially for sudden directional changes that may be required for safe traversing around an obstacle (Gardner, 1998).

### ***7.2.3. Relation between vehicle motion and postural stability***

Vehicle motion and postural stability were found to be related prior to but not following training for the cornering manoeuvre, with the drivers who experienced the biggest improvements in postural stability also experiencing the greatest reductions in lateral accelerations of the vehicle. This is noteworthy as a dynamic relation exists between a driver and vehicle with respect to the environment, which is considered important, if not vital, for safe driving (Gibson & Crooks, 1938; Lee & Young, 1986; Schiff & Arnone, 1995).

Most untrained drivers operated a vehicle such that the in-vehicle environment exposed a driver to high magnitudes of inertial forces, which in turn challenged a driver's ability to remain posturally stable. The typical response was for a driver to lean away from the turn, which became more noticeable as the inertial forces increased. Such motion by a driver was previously noted by Zikovitz and Harris (1999) and Coelho and Dahlman (1999) but not fully examined within their studies. In addition, a driver's ability to remain coupled with a vehicle was further challenged during manoeuvres where inertial forces alternated from side to side (e.g., an evasive lane change) or in the direction of travel (e.g., an emergency brake).

After training, drivers demonstrated changed vehicle control strategies, which effectively reduced the magnitude of inertial forces that affect a driver's ability to achieve postural stability. Trained drivers seemed to have learned that lower inertial force made it possible to achieve postural stability, which potentially improved their ability to control a vehicle, and as a result, maintained inertial forces at lower levels. In other words, drivers seemed to have enhanced their perception of safe driving affordances (Gibson, 2000; Stoffregen, 2000; Turvey, 1992). Furthermore, the trained drivers who were previously exposed to the largest forces, and subsequently demonstrated postural instability, were found to benefit most as they greatly reduced the inertial forces and increased their postural stability. Postural stability therefore contributes a partial role in controlling vehicle kinematics, however from this study; the mechanisms were not fully identifiable.

### **7.3. Implications for driver-training**

Training drivers in skills for improving vehicle motion is a contentious issue although these skills are acknowledged as important for safe driving (Hatakka, et al., 2002). Much of the controversy stems from claims that unsafe driving (e.g., traffic violations and crashes) still occurs after training. However, much of the controversy is based upon negative finding from retrospective investigations into third-party databases, which are not above reproach (Hirst, et al., 2004). Furthermore, some review studies have included and analysed some training programs for problem drivers (Ker, et al., 2005; Lund & Williams, 1985; Stuckman-Johnson, et al., 1989), although these are not comparable to programs suitable for ordinary experienced drivers, yet this is seldom (if at all) mentioned.

Experimental results reported within this thesis revealed that a driver-training program as described here was beneficial for enhancing a driver's postural stability and vehicle motion. Drivers demonstrated an ability to learn and execute new driving skills that replace previous less-effective skill actions, some of which may have been habitual in nature (e.g., firmly gripping the steering wheel when posture is unstable). Furthermore, the newly learned skills resemble to a greater extent the driving characteristics of the instructors who are considered trained and highly practiced drivers.

On the basis of the results of this study, it is recommended that:

- (i) Teaching enhanced postural stability during driver-training appears warranted, especially amongst drivers who are highly unstable;
- (ii) Drivers learn to establish postural stability using a leg-brace technique rather than gripping the steering wheel;
- (iii) Driver-training programs incorporate effective vehicle control strategies, such as, timing changes in steering to coincide with minimal velocity and not relying upon a vehicle's safety technology (e.g., ABS);
- (iv) Drivers develop skills towards anticipation of and preparation for upcoming driving events in order to limit detrimental effects associated with vehicle motion and inertial forces.

On the basis of the literature on driver-training it is further suggested that:

- (i) Skill-based training components are an important part of driver training (Gardner, 1998; Treffner, et al., 2002);
- (ii) Specific attention be given to defining the skills necessary for safe driving and the best methods for learning them (Mayhew & Simpson, 2002; Williams, 2006);
- (iii) Acceleration profiles be used to screen a driver's skill at driving, especially as an initial indicator prior to participation in driver-training (de Graaf & Van Weperen, 1997; Safren, et al., 1970);
- (iv) Postural stability strategies be incorporated into training programs for drivers to improve their detection of driving hazards and perception of driving risks (Watson, 2003);
- (v) Driver-training programs should explicitly address and incorporate higher order crash risk factors, such as a driver's attitudes and risk taking behaviours (Hatakka, et al., 2002).

#### **7.4. Limitations of the research**

A limitation of the current study is that the assessment of the effect of driver-training on vehicle kinematics and postural stability was confined to within two weeks of completing the training program. Consequently, caution needs to be exercised when projecting improvements found in these experiments to safe driving in general. A further limitation was that the attitudes of the participants were not investigated. Apart from an initial screening in order to limit the inclusion of risky drivers, a driver's attitudes before and after driver-training towards safe driving and learning could not be determined. Also, the driving instructor group had a high degree of familiarity and

experience in driving on the test track, which the control and trainee drivers did not have, and may therefore have biased the results. A similar difference in experience in driving on the test track also occurred for the trainee compared to the control drivers. However, for reasons discussed in Chapter 5, this was not considered to significantly bias the findings of the study. Finally, the tests were conducted under experimental conditions that utilised a closed-circuit driving track. In future, it will be of interest to examine changes following driver-training under more realistic on-road conditions.

### **7.5. Recommendations for future research**

A key recommendation for future research is to investigate the potential for this driver-training program to reduce the incidents of unsafe driving using prospective methodology rather than retrospective analysis of third-party databases of traffic violations and / or crashes. This proposed research might specifically investigate the relations between this training program and the enhancement of a driver's ability to detect hazardous situations and perceive risky driving, which have been identified as important direction for future research for safe driving (Watson, 2003). In addition, a further extension to this current project may be to add research pertaining to the general attitudes of drivers before and after training, which may include an individual's particular attitudes to learning during a training program and changing their existing inappropriate behaviours, such as handgrip on the steering wheel instead of leg bracing. Such research can also investigate the attitudes of the control drivers, who in this current study gained experience at the three driving manoeuvres, yet exhibited relatively unchanged results in their second test-session compared to their first. Ultimately, future research in driver-training in general should aim to integrate scientific theories and

research knowledge into the advancement of training programs (Hatakka, et al., 2002; Mayhew & Simpson, 2002; Williams, 2006).

## **7.6. Concluding remarks**

This research project makes a novel contribution to the science of driver-training and driving performance by investigating the effects of a two-day post-licence driver-training program on vehicle motion and a driver's postural stability. Based on the results of the experiments within this study, it was concluded that

- (i) Trained drivers reduced the magnitude of vehicle acceleration by changes in vehicle control strategies, such as timing changes in steering to coincide with minimal velocity and adopting a braking technique that did not rely upon ABS technology,
- (ii) Postural stability was established and maintained by using a lower-leg brace technique rather than the pre-training strategy of increased handgrip on the steering wheel,
- (iii) Postural stability as defined by the degree of coupling between vehicle and driver accelerations was enhanced following training, and
- (iv) Prior to training, drivers who were more posturally unstable tended to experience greater vehicle accelerations.

Overall, these findings suggest that driver-training programs based upon the development of perceptual-motor skills through enhanced postural stability demonstrate positive effects on vehicle motion. An application for this study is to inform and guide advanced curriculum development in driver-training programs. When combined with other important factors, such as practicing the lessons learnt during training and driving with appropriate attitudes towards safety, the driver-training program assessed may contribute to overall safer driving.



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