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Adaptive Brake Lights: an Investigation into their Relative Benefits in regards to Road Safety

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Abstract

The implementation of In-Vehicle Intelligent Transport Systems (ITS) is becoming a common occurrence in modern vehicles. Automobile manufacturers are releasing vehicles with many forms of sophisticated technologies that remove much of the responsibility of controlling an automobile from the driver. These In-Vehicle Intelligent Transport Systems have stemmed from a genuine need in regards to road safety, however there are advantages and disadvantages associated with ITS. Each different form of technology has its own inherent compromises in relation to road safety, driver behaviour and driver comfort.

This thesis outlines the benefits and detrimental effects associated with current In-Vehicle Intelligent Transport Systems and details the development and user interface testing of an adaptive brake light. The adaptive brakelight concept aims to provide drivers with the advantages of an In-Vehicle ITS whilst removing the disadvantages. The technology will help drivers judge the braking pattern of the car in front, thus allowing them to react appropriately and potentially reducing the occurrence of rear-end crashes.

The adaptive brake light concept was tested in comparison to a standard brake light and BMW inspired brake light in a series of user interface tests. The adaptive brake light was shown overall to be an improved method of displaying the varying levels of deceleration of a lead vehicle. Whilst different age and gender groups responded differently to the adaptive brake light, it was shown to be of benefit to the majority and the most at risk groups responded positively to the adaptive brake light.

This research shows that an adaptive brake light can provide a benefit in regards to road safety when compared to a standard brake light interface. It is hoped that further development of variable brake lights will result from this research and possibly lead to the implementation of the technology to automobiles and other forms of transport.
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Statement of Original Authorship

“The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person except where due reference is made.”

Signature: ________________________________
Date: _________________________________
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1.0 Introduction

In regards to research into In-Vehicle Intelligent Transport Systems (ITS) and their relationship to road safety there are two distinct approaches. One group of researchers look at In-Vehicle ITS from a human factors point of view whilst another group seem to be focussed purely on the technological and financial aspects of developing the systems and consider the user as almost an impedance to the perfect functioning of the system (Stanton and Marsden, 1996).

A seemingly common occurrence in the field of Intelligent Transport Systems is that a system is implemented that solves a primary problem but the system may cause secondary effects that are of some concern. For example, an Adaptive Cruise Control (ACC) system achieves the primary goal of reducing unsafe headway distances between vehicles. However the secondary effects of using an ACC system can be slower reaction times to unexpected occurrences, failure to give way to other vehicles and poor attention to lane keeping (Ward, 2000: 401).

This thesis will detail the research, development and user testing of an adaptive brake light display system designed earlier. The adaptive brake light interface attempts to provide drivers with the benefit of an Intelligent Transport System whilst removing the deleterious effects. The benefit of the adaptive brake light is that it provides additional information about the deceleration of a lead vehicle to the driver behind. It is predicted that this will have a positive effect on road safety in the form of a reduction in rear-end accidents. This benefit is also claimed by the implementation of ACC however the driver will not experience the deleterious effects associated with the use of ACC as they are not removed from the driving task.

Rear end crashes account for a significant percentage of road accidents in Australia and internationally. Rear end accidents have been found by Baldock, Long, Lindsay and McLean (2005: 3) to most likely occur in metropolitan and
city areas during peak traffic times on or near cross roads on level and straight roads. During the period from 1998 to 2002 inclusive it was found that rear-end accidents accounted for approximately one third of all vehicular accidents in city and metropolitan areas of Adelaide (Ballock et al, 2005:3).

Whilst it is likely that the overall percentage of rear end crashes will vary between regions and indeed countries, the occurrence of rear-end crashes is a problem that affects all areas where motor vehicle use is prevalent. A product or system that can reduce the occurrence of rear-end crashes would be a welcome and indispensable addition to any transportation network.

1.1 Research Question

The research question that has been refined over the course of study is as follows:

“What are the benefits and potential deleterious effects provided by In-Vehicle Intelligent Transport Systems (ITS), how do these issues affect road safety and will an adaptive brake light display provide a benefit in regards to road safety?”

1.2 Aims and Objectives

The aims of the research are to:

- Investigate the positive and negative aspects of In-Vehicle Intelligent Transport Systems and their impact on driver attention, awareness and road safety.
- Evaluate an adaptive brake light interface against a standard interface and a semi-adaptive interface and determine which is the most effective method of displaying varying levels of deceleration.
The objectives of the research are to:

- Illustrate that most Intelligent Transport Systems are being developed conscientiously in the hope of having a positive impact on road safety.
- Illustrate that some advances in automotive technology, for example Autonomous Intelligent Cruise Control (AICC), are not necessarily the most advantageous solution in regards to road safety and driver attention.
- Analyse an adaptive brake light concept as an alternative or complimentary product to AICC to see if it provides a benefit in regards to driver attention and road safety.

1.3 Structure of this thesis

This thesis is organised to generally reflect the progress of the research. Chapters 2 and 3 explain the two facets of literature that were reviewed as the initial stages of the research. Chapter 4 details the adaptive brake light that was designed earlier and was examined in the brake light interface user testing. Chapter 5 explains the methodology of the brake light interface user testing and the configuration of a driving simulator. Chapter 6 explains the brake light interface user testing in its entirety, with the following chapters examining the results in more detail, with different age and gender groups analysed separately and finally as a whole.

The analysis of the group of technologies known as Intelligent Transport Systems follows in chapter 2.
2.0 Intelligent Transport Systems (ITS)

An Intelligent Transport System (ITS) is any form of technology that aims to either increase the level of road safety, the level of driving efficiency or the level of driver comfort.

Intelligent Transport Systems Australia (2003: 4) define ITS as “the application of computing, information and communications technologies to the vehicles and networks that move people and goods.”

ITS America (2003) define ITS as “a broad range of wireless and wireline communications-based information, control and electronics technologies… these technologies help monitor and manage traffic flow, reduce congestion, provide alternate routes to travellers, enhance productivity and save lives, time and money.”

There are a plethora of acronyms that describe Intelligent Transport Systems and their differing forms; they are also sometimes referred to as Automated Vehicle Control Systems (AVCS), Advanced Vehicle Control and Safety Systems (AVCSS), Road Transport Informatics (RTI), Intelligent Vehicle Highway Systems (IVHS), Advanced Transport Telematics (ATT) or Transport Information and Control Systems (TICS).

There are many arguments supporting the implementation of ITS. Broggi, Bertozzi, Fascioli and Conte (1999: 5) suggest that by automating the driving task, either entirely or in part, it is possible to (a) reach a higher level of road exploitation, (b) reduce the level of fuel and energy consumption and (c) improve the road safety conditions compared to the current situation. Some of the driving tasks that have the ability to be computer controlled are navigation and route finding, vehicle separation, automatic braking and acceleration, cruise control and lane following (Stanton and Marsden, 1996: 35).
2.1 The Future of ITS

The implementation of several In-Vehicle Intelligent Transport Systems into a vehicle such as satellite navigation, external vehicle speed control, lateral positioning and headway control and automatic collision avoidance could result in the car being able to function autonomously. Fuller (2002: 277) proposes that it will be possible for a person to complete a road trip with the only input required being the entry of the destination and desired time of arrival into a central computer. The person would simply have to be at the arranged pick-up point to enter the vehicle and the computer software would handle the rest of the details such as possible routes, speed restrictions, potential congestion and weather conditions.

Janssen, Wierda and Horst (1995: 238) suggest that the development and implementation of In-Vehicle ITS from the present day system to a level of complete automation of major connections will occur in five stages. Stage one will be the introduction of separate part systems, beginning with navigation support and followed by longitudinal support. Stage two will be the introduction of support systems to coordinate these part systems. Stage three will be the extension of these integrated systems with lateral support components that also consider adjacent traffic. Stage four will be the introduction of dedicated lanes where the majority of the driving task can be externally controlled. Stage five will be complete automation of all major road networks. This stage is predicted by Janssen et al (1995: 238) to come into effect around halfway through this century. This prediction is supported by IVsource (2001) which states that dedicated lanes (stage four) will be functional in Europe by 2030.
2.2 In-Vehicle Intelligent Transport Systems

It is possible to divide the field of ITS into two distinct groups of technologies, In-Vehicle ITS and systems that operate externally to the vehicle. This thesis will concentrate primarily on forms of In-Vehicle Intelligent Transport System technology.

The field of In-Vehicle Intelligent Transport Systems can also be divided into two categories; active safety systems and passive safety systems. An active safety system is a form of technology that removes the control of the vehicle from the driver in some manner, generally in an emergency situation. The In-Vehicle ITS active safety systems that will be discussed are Adaptive Cruise Control or Autonomous Intelligent Cruise Control, Active Steering and Collision and Accident Avoidance Systems.

Passive safety systems are forms of technology that provide the driver with additional information about the driving task but do not remove control of the vehicle from the driver. The In-Vehicle ITS passive safety systems that’s will be discussed are Navigation Systems, Head-Up Displays and Inter-Vehicle Communications.

These forms of In-Vehicle ITS technology have all been shown to have various impacts on road safety and driver attention and comfort.

2.3 Adaptive Cruise Control or Autonomous Intelligent Cruise Control

Adaptive Cruise Control (ACC) may also be referred to as Automated Cruise Control or Autonomous Intelligent Cruise Control (AICC). Within this thesis the technology will be referred to only as Adaptive Cruise Control or ACC. It is a sophisticated system that extends the functionality of conventional cruise control. It can control the speed of a vehicle and maintain a constant inter-vehicle distance from the vehicle in front. This is done by controlling the accelerator, engine and vehicle brakes and using radar or laser sensor technology mounted on the front of the car to measure the distance to the
leading vehicle. When there is no lead vehicle the driver is able to set a speed limit similar to regular cruise control (DOTARS, 2002; Marsden, McDonald and Brackstone, 2001; Ohno, 2001; Weinberger, Winner and Bubb, 2001).

Adaptive Cruise Control has an advantage over most other Intelligent Transport Systems in the fact that it can be entirely autonomous, which means that the benefits of the ACC system are obtained independent from other vehicles or roadside systems. The technology is also reasonably simple meaning that the cost to implement the system is comparatively low (DOTARS, 2002; Hoedemaeker et al, 1998).

Marsden et al (2001: 33) discuss Adaptive Cruise Control in relation to simulation investigations and real-world trials using instrumented vehicles. The paper illustrates that using an ACC system can provide considerable reductions in the variation of acceleration compared to manual driving which may equate to a comfort gain for the driver and some environmental benefits. Marsden notes that motor vehicle manufacturers’ primary aims in relation to ACC are to support driver comfort, have no negative impact on safety and add to the selling qualities of their vehicle. However it is also mentioned that ACC systems may not fully meet the requirements of a system designed to enhance the efficiency of traffic flow and may contribute to the degradation of driver performance due to a lack of involvement in the primary driving task. These safety concerns are noted to have not been substantial enough to delay the introduction of ACC systems after 1999 in European vehicles (Marsden et al, 2001: 34-35).

The technological limitations of ACC systems are that they do not detect stationary objects in the lane, and will not function correctly if the laser or radar sensor is obstructed by moisture or debris. The maximum braking capacity of the system is limited and the ACC system may only be able to be utilised within a certain speed interval, for example 30 to 130km per hour (Nilsson, 1995: 1254; Rudin-Brown and Parker, 2004: 62)
2.4 Active Steering

Active Steering is also known as Lateral Positioning or Lane Detection and is part of a group of Intelligent Transport Systems known as Road Following Systems or Lane Support Systems. This technology enables a vehicle to sense where it is on the road and stay in that lateral position as the road curves. It does this by monitoring the lateral position within a lane and instigating corrective steering to control vehicle position in the centre of the lane (Ward, 2000: 397; Stanton and Young, 1998: 1016). Some systems have been designed to work on unstructured roads but Lane Detection generally relies on specific features such as lane markings painted on the road surface (Broggi, Bertozzi, Fascioli and Conte, 1999: 23). The tasks of a lane detection system include localisation of the road, determination of the relative position between the vehicle and the road and analysis of the vehicles direction. Road Following technology also encompasses Obstacle Detection, which can be a vital component of any Lane Detection system and enables the vehicle’s sensors to identify objects in the path of the vehicle. The Obstacle Detection system detects possible obstacles in the vehicles path (Broggi et al. 1999: 21). The system generally will warn the driver of the presence of obstacles but when included as part of an autonomous vehicle may redirect the car to avoid the obstacle.

There are inherent problems with Lane Detection systems in relation to the type of technology used. Vision sensors are required to process the road-based information and these are less accurate in foggy, dark or direct sun conditions. This also means that the sensors will not function properly when shadows from roadside features or other vehicles fall across the path of the sensor (Broggi et al. 1999: 22). This is a problem regardless of whether the Lane Detection system is issuing a warning to the driver or autonomously controlling the vehicle.
2.5 Collision and Accident Avoidance Systems

Collision and Accident Avoidance Systems (CAAS) encompass several forms of technology that aid in lane keeping, car following, curve negotiation and obstacle avoidance (Goodrich and Boer, 2000: 40). Collision Warning Systems are a variation of this technology; the main application of the Collision Warning System is the detection and subsequent warning of an object in a vehicle's blind spot (DOTARS, 2002).

Goodrich and Boer (2000: 40) recognise that the design of CAAS is paramount, as it is possible that in the case of a poorly designed or overly sensitive CAAS a driver may be required to increase their workload. This may lead to a decrease in driver safety, situational awareness and comfort, which is the exact opposite effect that is desired from the CAAS. In regards to Collision Warning Systems, DOTARS (2002) recognises that there needs to be an absolute minimum of false alarms, as if they are triggered inappropriately drivers will tend to ignore the warning and thus the entire system becomes redundant.

2.6 Collision Warning Systems

Collision Warning Systems, whilst a part of CAAS are particularly relevant to this report as there has been some limited study into the use of graduated light displays to warn drivers of an imminent collision.

Seiler, Song and Hedrick (1998) compare two collision avoidance systems developed by Mazda and Honda. Both systems utilise a driver warning that can be followed by automatic braking if necessary.

The system developed by Mazda is a “conservative” system, which means that it attempts to avoid all collisions. The system issues a warning to the driver when the vehicle gets within a predefined warning distance from the rear of the car in front. If the vehicle continues its approach and gets within a predefined braking distance then the brakes are automatically applied.
deleterious effects of a conservative system like this are that many drivers place themselves too close to the car in front; where a collision would be unavoidable if an emergency situation occurred. This means that drivers would be constantly receiving warning and would thus become desensitised to these warnings. The automatic braking could also prove problematic, as it would likely interfere with normal driving manoeuvres (Seiler et al, 1998: 98).

The system developed by Honda is less conservative than the Mazda system; it does not aim to avoid all collisions but attempts to reduce the impact speed of extreme case collisions. Honda recognise that a conservative collision avoidance system may apply the brakes whilst the driver is attempting a steering collision avoidance manoeuvre which could startle the driver and cause them to lose control of the vehicle (Seiler et al, 1998: 99).

Seiler et al (1998) propose a collision warning and avoidance system that incorporates a graduated light display and audio warning. A small band of green lights are displayed to the driver when the driving situation is safe. This is followed by an increasing number of yellow lights as the distance between the vehicle and the car in front decreases. Once the distance between the vehicles is too close to avoid an extreme collision in an emergency situation a red band of lights will be illuminated as well as an auditory warning. If there is still no evasive action detected the system will apply the brakes. Seiler et al (1998: 103) anticipate that the proposed system will not desensitise or startle the driver, and the non-conservative braking distance will not intrude on normal driving manoeuvres.

2.7 Navigation Systems

Navigation Systems, utilising Global Positioning System (GPS) technology, are the most common form of Intelligent Transport System. There are many automobile manufacturers that have released a form of Navigation System in their vehicles and several electronic manufacturers produce navigation systems as aftermarket accessories. The technology generally uses a multi function screen that is mounted on the dashboard and the interface is either
entirely visual or a combination of visual and audio information is used. The screen displays a simple map and the programme utilises the satellite data to obtain directional and location information. The driver can enter their destination into the computer, usually via a remote control mechanism but possibly by voice prompting, and the computer will calculate the best route. The Navigation System then prompts the driver when and where to turn via a visual display or a verbal message. The geographical information is stored on a CD-ROM disc which allows the driver to obtain a CD-ROM disc for any area that they may wish to travel to, providing the disc is available (DOTARS, 2002; Herron, Powers and Solomon, 2001: 250).

The safety benefits of Navigation Systems are less tangible than some of the other driving aids, but they offer the potential of reduced driver distraction and they can assist in reducing traffic congestion. Driver distraction is reduced when compared to the driver using a physical map to determine their direction, but the interface of a Navigation System needs to be discreet enough to allow the driver to concentrate on the road rather than the screen. The optimum safety benefit is achieved when the Navigation System uses auditory or very simple visual displays to provide information to the driver. Entire maps should be used only as a guide (DOTARS, 2002).

2.8 Head-Up Displays

Head Up Displays (HUD), whilst generally not considered as part of the In-Vehicle Intelligent Transport System cluster are relevant because they represent a different method of conveying operational data to the driver. Head Up Displays are a form of instrumentation that allow drivers to keep their eyes primarily on the road ahead; they do not require the driver to lower their eyes to the dashboard to gather information about the state of their vehicle. Generally the relevant information is projected onto the lower section of the windscreen, so as not to obstruct the driver’s line of vision and allow them to only make a simple eye adjustment in order to check the display. The concept was first applied to aircraft as the interface of an aircraft control panel is quite complicated and a HUD is an efficient manner to inform the pilot of the most
important data, but the technology is also used in automobiles (Rockwell, 1972: 159).

Liu (2003: 157) compares Head Up Displays with Head Down Displays (HDD), which are more sophisticated versions of the conventional automotive dashboard. A Head Down Display is becoming increasingly common in modern automobiles and differs from a conventional dashboard interface by incorporating a large multi-functional screen usually located near the air-conditioning or stereo controls. Using a Head Down Display while driving means that the driver must avert their eyes from the road in order to view information provided by the HDD. Using a HUD while driving can result in a reduction of the amount of time the driver is required to avert their eyes from the road.

Head Up Displays have been shown to improve reaction times by elderly drivers when compared with a regular dashboard display as a means of conveying information to the driver (Simões and Marin-Lamellet, 2002: 267).

2.9 Inter-Vehicle Communications

The goal of Inter-Vehicle Communication systems is to transmit information from one vehicle to another whilst in motion. Data such as speed, road condition and warning information could be transmitted from one car to other vehicles on the road, or from a roadside repeater (DOTARS, 2002). Kato, Minobe and Tsugawa (2003: 10) predict that this two-way method of communication will increase safety and efficiency when compared to the traditional one-way traffic communication methods such as stop lights and indicators. Inter-Vehicle Communications can also make the intentions of a driver clear to the surrounding vehicles.

The safety advantages of an Inter-Vehicle Communication system would be considerable. For example, if one car has to brake suddenly in an emergency situation it could alert cars following behind that there is a hazard ahead. The same technology would also alert cars behind if there were something
discrepant on the road that caused the driver to take evasive action. Also, if a
leading car is accelerating without incident the following cars could receive a
positive message from the leading car. However only drivers that choose to
have the technology fitted in their car can enjoy the advantages of an inter-
vehicle communication system. DOTARS (2002) suggest that people are
unlikely to pay for the option of an inter-vehicle communication system if they
must rely on other motorists purchasing the system in order for it to function,
thus the implementation of this technology is not likely in the near future. Kato
et al. (2003: 14) recognise that there needs to be a solution that incorporates
both vehicles with an Inter-Vehicle Communication system installed and
vehicles without.

2.10 Summary

This chapter has outlined most of the current forms of Intelligent Transport
Systems and In-Vehicle ITS. The further development of these technologies is
continuing at a rapid rate and there will undoubtedly be more forms of ITS and
In-Vehicle ITS to be released in the future.

These technologies have stemmed from a genuine need in regards to road
safety, however they are not without shortcomings in regards to human
factors considerations. The development of In-Vehicle ITS seems to work on
the assumption that a technological solution to a problem will provide a more
reliable solution than relying on human operators. Whilst this may be true in
the majority of cases it is not a perfect solution.

Chapter 3 will consider the problems that are caused by the implementation of
In-Vehicle ITS and ITS in regards to human factors research.
3.0 Human Factors and In-Vehicle ITS

An argument against the introduction of automation to vehicles is redundant as many new vehicles are being released with ever-increasing levels of sophisticated automated technology. However there is a depth of Human Factors research that suggests that automation is not necessarily always the best solution to the problem of safety on our roads.

Ward (2000: 395) states that the interaction of the driver with automated technologies alters the fundamental nature of the task process. He acknowledges that whilst the involvement of automated technology may have significant benefits for system performance, the change in task processes may also be disruptive.

Norman (1999: 197) states that whilst automation has its values, it is dangerous when it takes too much control from the user. Too great a degree of automation or “Over-automation” has become a technical term in the study of automated entities. There are three problems that Norman identifies with automated equipment. Firstly the over-reliance on automated equipment can eliminate a person’s ability to function without it, which can have disastrous consequences if an automated technology fails. Secondly the system may not do things exactly as the user would like but the user is forced to accept what happens because it is too difficult to change the way the system operates. The third problem is that a person can become subservient to the system, no longer able to control or influence what is occurring (Norman, 1999: 197).

According to Stanton and Marsden (1996: 36) there are three arguments supporting automation in the automotive context. The first argument is that by automating certain driving activities it could help to make significant improvements to the drivers well being. Secondly, the removal of the human element from the control loop may lead to a reduction of road crashes. Thirdly, automation will enhance the desirability of the product and thus lead to substantial increases in unit sales. Stanton and Marsden (1996: 40) conclude
that automation will be relatively ineffective in relation to improvement of driver skills and automation would make effects of risk homeostasis worse. However automation could be of assistance in relation to reducing attentional demands.

3.1 Situational Awareness

There is a depth of psychological research into the subject of situational awareness (SA). The study of SA is applicable, in varying degrees, to any task in which a human performs an operative role. Situational awareness in regards to automation and specifically automation in automobiles is an area of study that has been approached by several researchers, including Endsley and Kiris (1995), Endsley (1995), Stanton, Chambers and Piggott (2001) and Ward (2000).

Endsley (1995) proposes that there are three levels of situational awareness. Level 1 SA is the perception of environmental information that is relevant to successful task performance. Level 2 SA is the comprehension of the meaning and context of that information. Level 3 SA is the projection of the potential future state of these environmental conditions. These three levels of situational awareness are hierarchically dependent, meaning that the accurate projection of future states (Level 3 SA) is dependent on the correct interpretation of the current environment configuration (Level 2 SA), and so on. A high level of situational awareness at all levels is necessary to support task performance and goal attainment (Endsley, 1995: 36-37; Ward, 2000: 398).

Stanton et al (2001) suggests that the loss of situational awareness is correlated with poor performance and that “people who have lost their situational awareness may be slower to detect problems with the system that they are controlling as well as requiring additional time to diagnose problems and conduct remedial activities when they are finally detected” (Stanton et al, 2001: 199). Endsley and Kiris (1995) refer to this issue as the out-of-the-loop performance problem. Stanton, Young and McCaulder (1997: 156) state that by removing the operator from the control loop of the automated system the
operator may become underloaded and reduce the level of attention devoted to the task. Norman (1990: 588) states that the advent of automatisation technology has changed the role of the human from a manual operator in full control of the system to managers or supervisors that are out of the loop of control. The irony of automation, as stated by Norman (1990: 588) and Stanton et al (1997: 156) is that by removing operators from the control loop they are therefore less likely to detect symptoms of trouble in time to take appropriate preventative action.

In regards to situational awareness whilst operating an automated system Ward (2000: 398) states, “a fundamental premise for the automation of driving task levels is that reduced dependency on the human element will improve operating safety.” By simplifying the tasks that drivers are expected to complete it is also hoped to reduce operator workload and increase comfort. Even if this statement is correct, the premise may actually reduce system safety. Weiner (in Ward, 2000: 399) states that “there is evidence that automated task level functions may increase workload because of the commensurate need to monitor the operation of the automated systems such that operator performance is reduced.” This may mean that the operators of automated vehicles could become complacent as they underestimate the actual task demands, thus leading to reduced arousal levels and a lower invested effort. In the instance of a system failure or a safety critical event outside the capacity of the system the human operator may be hampered by a lack of situation awareness, which may impair the transition between manual and automated operations (Ward, 2000: 400).

Endsley and Kiris (1995) conducted an experiment that involved participants making decisions based on a system with varying levels of autonomy. The hypothesis was that participants’ mental workload and level of situational awareness would decrease with increasing levels of system autonomy. This hypothesis was proven and the out-of-the-loop performance problem was demonstrated with operators being slower to manually perform the task after a failure in the automated system than if they had been constantly operating manually. The out-of-the-loop problem also appeared to be more severe when
operators were utilising full automation instead of partial automation. The level of situational awareness also decreased corresponding to the increased level of automation (Endsley and Kiris, 1995: 390).

Endsley and Kiris (1995: 392) query whether automation should be introduced at all due to the reduction in both situational awareness and decision time, however they acknowledge that this question is nearly academic due to automated systems being introduced in many applications. The authors suggest “implementing automation while maintaining a high level of control for the human operator provides definite benefits in minimising the out-of-the-loop performance problem as compared with full automation.”

In the case of Adaptive Cruise Control (ACC) the driver is no longer responsible for the longitudinal control of the vehicle, the distance from the car in front, or the tactical task levels. In order to analyse ACC in regards to driving task alteration and situational awareness Ward, Fairclough and Humphreys (1995) performed a controlled study in real traffic on a United Kingdom motorway in May 1995. The study used fifteen male participants operating a vehicle with a form of Adaptive Cruise Control technology fitted. The participants were favourable to the concept as an aid to comfort and safety and the results showed that whilst using the technology there were reduced levels of arousal and effort in speed and headway control. The technology also provided a decrease of instances of short following distances. There was no indication that mental workload was affected by the technology but there were more errors observed when using the Adaptive Cruise Control system. This may indicate changes in situational awareness, evident by reduced performance in proper lane maintenance and in the act of yielding to other traffic.
3.2 Behavioural Adaptation

Behavioural adaptation (BA), in the context of In-Vehicle ITS, is a change in a drivers’ behaviour in response to the removal of some aspects of the driving task. It is suggested that people have a preferred level of risk that they try to maintain when driving (Section 3.3). When an automated system is introduced to the driving task that may reduce the level of perceived risk associated with driving, drivers will seek to modify their driving behaviour in order to restore the risk to the preferred level (Ward, 2000: 401). This behaviour that occurs after automation may increase the driver’s exposure to safety critical situations as the riskier driving style may entail higher speeds and shorter headways (Janssen, 1995: 238; Ward, 2000: 402). This behavioural adaptation may actually reduce the level of road safety that should be provided by an automated entity.

Nilsson (1995), Hoedemaeker and Brookhuis (1998), and Rudin-Brown and Parker (2004) have conducted studies on drivers using Adaptive Cruise Control (ACC) systems. These three studies showed that behavioural adaptation does occur when using an ACC system.

Nilsson tested Adaptive Cruise Control in a simulator, where ten people used the ACC system and ten people completed the test unaided by the ACC. The study found that when approaching a stationary queue of traffic people using ACC had more collisions than people driving unsupported (ratio 4:1). However there was no difference between ACC drivers and unsupported drivers when car pulled out in front of them, or a car was braking hard in front of them. Contrary to most studies Nilsson could not explain the collisions by increased workload or a decreased level of alertness. She proposes that a reasonable explanation of the findings would be that drivers had expectations that were too high or were demonstrating over-learned reactions (Nilsson, 1995: 1254).

The Hoedemaeker and Brookhuis (1998) study was a driving simulator study conducted on four groups of drivers who identified their differing driving styles in regards to speed and focus. The study concentrated on the behavioural
adaptation side of using Adaptive Cruise Control and thus there was no testing of technology failure scenarios. All the drivers altered their driving style when using the simulated ACC; they adopted smaller time headways and merging movements were carried out more efficiently. The trial found that the ACC was perceived as more useful by slow driving groups than fast driving groups. This is concerning because people who drive fast are at a higher risk of being involved in an accident and fast drivers should be the group that benefit the most from ACC in terms of road safety (Hoedemaeker and Brookhuis, 1998: 103).

The Rudin-Brown and Parker (2004) study is one of the few studies to actually use real-world driving conditions to evaluate the behavioural adaptation of drivers using Adaptive Cruise Control. It involved driving on a test-track whilst following a lead vehicle using ACC with three different levels of autonomy. Eighteen drivers followed a lead vehicle, first without using the technology and with a self maintained headway of 2 seconds, then using the Adaptive Cruise Control with a short headway of 1.4 seconds and finally using the ACC technology with a long headway of 2.4 seconds.

The results of the study indicate that Adaptive Cruise Control can induce behavioural adaptation in drivers in potentially safety-critical ways and that driver’s trust in the system did not alter even after a simulated failure of the ACC system. The study showed that driver performance can deteriorate when using Adaptive Cruise Control, lane position variability can increase and drivers tend to brake harder, later and more often in response to system override situations. Drivers using the technology also take longer to react to emergency situations and have more collisions than drivers unsupported by the ACC system (Rudin-Brown and Parker, 2004: 62).

Ward (2001: 401) refers to the use of Adaptive Cruise Control as an example of potential behavioural adaptation. The ACC may be perceived by the driver to provide an additional safety benefit over driving normally. In other words, the use of ACC may reduce the perception of risk associated with the driving task. This perceived reduction in driving risk may lead to a riskier driving style
when using the ACC technology, through higher speeds and shorter headways. It is proposed that this behavioural adaptation may actually reduce the level of safety that should be provided by an automated entity such as Adaptive Cruise Control. By enabling drivers to feel comfortable travelling faster speeds and keeping less distance between them and the lead vehicle there is a potential for more accidents to occur, as these factors (high speeds and headway distance) are frequently associated with accident involvement (Ward 2000: 401).

Janssen et al (1995: 238-239) proposes eight separate potential instances of behavioural adaptation that may occur once automation is introduced into a system; (a) drivers will exhibit riskier behaviour after automation, (b) drivers will be aware that they are protected by the automated system and thus decrease their level of alertness, (c) drivers will lose the driving skills that have been replaced by the automated system, (d) potential human error will shift from the driving task to the maintenance and design of the automated system, (e) accidents will become more serious as a result of automated system failure as opposed to driver miscalculations, (f) public concern which is dependent on severity of accidents rather than frequency will see automation as less effective than is the case, (g) drivers using partially automated systems will shift from taking risks voluntarily to have risks forced upon them by the system and (g) people who choose not to drive in certain situations due to safety precautions will choose to drive in these situations due to the promises of increased safety by the automated systems.

3.3 Risk Homeostasis Theory

Risk Homeostasis Theory (RHT) is a hypothesis first posited by Wilde (1976) that explains some aspects of behavioural adaptation in drivers when using an automated system. Wilde (in Ward, 2000: 401) states that individuals “have a preferred target level of risk that they try to maintain”. Ward (2000: 401) states that individuals may modify their behaviour when the perceived level of risk changes from their target level of risk. If an automated system provides a reduction in risk, either actual or perceived, risk homeostasis theory states
that they will adopt a riskier driving style to compensate for the decrease in risk level. Stanton and Marsden (1996: 40) also note that according to RHT, if the environment external to the vehicle becomes more dangerous, drivers will exhibit more cautious behaviour. In regards to the implementation of ACC, if the system is perceived as providing a safety benefit it may reduce the perceived level of driving risk, which may lead to a driving style incorporating higher risk activities such as driving at higher speeds and shorter headways (Ward, 2000: 402).

### 3.4 Locus of Control

The locus of control (LOC) of a driver is determined by the extent to which drivers believe that their own actions are responsible for the outcome of events, rather than the automated system. Drivers of vehicles with some level of automation tend to fall in to one of two possible states in regards to their perceived locus of control (Stanton, 1998: 1024).

People who have an internal locus of control (internals) believe that they are able to act in order to maximise the potential positive outcomes and minimise the potential negative outcomes. In regards to ITS, internals choose to rely on their own inherent skills regardless of how safe or reliable a system appears (Rudin-Brown and Parker, 2004: 60-61). It is generally regarded that people with an internal locus of control perform better than individuals with an external locus of control (Stanton, 1998: 1024).

People who have an external locus of control (externals) may be more likely to delegate control to an external device and possibly become over-reliant on an imperfect system. This means that in a system failure scenario they may fail to react or be slower to react than internals (Rudin-Brown and Parker, 2004: 60-61). Stanton (1998: 1024) uses this theory to explain why some people failed to intervene when an automated system failed in a simulator study whilst others took control of the situation. He refers to people with an internal locus of control as active drivers and people with an external locus of control as passive drivers.
3.5 Stress

In regards to the level of stress experienced by people whilst driving it may seem a logical assumption that a lack of stimuli would create less stress in the driver. However it has been demonstrated by Matthews and Desmond (1995) and Matthews, Sparkes and Bygrave (1996) that in fact the opposite is correct. A driver is more likely to experience stress from a lack of stimuli, referred to in Stanton et al (1998) as task underload, rather than being in a state of task overload.

Matthews and Desmond (1995) make the recommendation that In-Vehicle Intelligent Transport Systems should demand more attention from drivers rather than less. As In-Vehicle ITS technology advances and controls more of the driving task stress and fatigue may increase the level of driver complacency in low-workload conditions. Thus to combat this possibility it is important to keep the driver involved in the driving task (Matthews and Desmond, 1995: 126).

Matthews et al (1996) conducted a driving simulator study on eighty young adults and found that fatigued drivers perform significantly better when the task is difficult than when the task is easy. Drivers in a state of stress adapted efficiently to high levels of task demand, but when the task required little active control the drivers may have been at risk of performance impairment (Matthews et al, 1996: 77).

Stanton et al (1998: 1027) recognises that these findings are contrary to the general emphasis on driver workload reduction that is prevalent in most research and development of vehicle automation.
3.6 In-Car Warning Devices

Driving a modern automobile is a task that many people complete on a daily basis and the technological interface that exists between the driver and the road becomes very familiar to the driver when operating their own vehicle. However the dashboards of modern automobiles are becoming evermore saturated with technological instrumentation. This infiltration of complex instrumentation is the cause of some concern in regards to automotive safety (Baber, 1994: 193). The potential danger of a complex dashboard, now sometimes referred to Head Down Displays or HDDs, is that drivers may become overwhelmed by all the complex technology available within their vehicles and the resultant attentional demands may adversely affect the drivers’ ability to control their vehicle safely (Burnett and Porter, 2001: 522).

The basic idea of in-car warning devices is to provide information to drivers that they would not normally be able to accurately perceive, such as speed and water temperature. This information is generally provided in the forms of dials or coloured lights. Early model cars provided the driver with information about a relatively small number of variables. Advances in technology have allowed contemporary car dashboards to incorporate a plethora of features that all provide information to the driver. This potential glut of information needs to be conveyed to the driver in a beneficial and concise manner so that drivers are not required to concentrate on the dashboard but on the road ahead. Burnett and Porter (2001: 522) state that the increased functionality that is now available to drivers often comes with an increase in visual and mental demands.

Knoll (in Baber, 1994: 194) proposed the following checklist of ergonomic factors to be addressed in in-car information system design: minimum distraction of the driver, readily accessible operating elements, easily readable displays and inscriptions, speedy familiarisation, minimal [prior] knowledge, space saving dimensions and attainability with justifiable outlay using available technologies.
### 3.7 Trust in Automation

Trust in an automated system plays an important role in the interaction between the human operator and the automated system. The issue of trust in automation has been approached by Dzindolet, Peterson, Pomranky, Pierce, and Beck (2003), Muir (1994), Muir and Moray (1996), Parasuraman and Riley (1997) and Stanton (1998).

Appropriate reliance on an automated system occurs when either a human operator trusts an automated system that is more reliable than manual operation, or when a human operator distrusts an automated aid that is less reliable than manual operation (Dzindolet et al., 2003: 699). Inappropriate reliance on an automated system can also occur in two ways. Disuse can occur when a human operator distrusts an automated system that is more reliable than manual operation and misuse can occur when a human operator trusts an automated system that is less reliable than manual operation (Dzindolet et al., 2003: 699; Parasuraman et al., 1997: 230).

Dzindolet et al. (2003) conducted three studies concerning trust in automation with participants interacting with varying levels of system automation. It was found that when operators observe an automated system making errors they may distrust the system unless an explanation of why the error occurred is provided. The knowledge of why an error may occur and the context of the error leads to regained trust in the automated system, even when the trust is unwarranted. Dzindolet et al. (2003: 715) recommends that system designers should realise that operators may be positively biased towards the automated system and that this high level of trust can be hazardous as it may lead to overcompensation by the operator if they observe the system making errors. It is also recommended that automated systems be implemented only with appropriate instruction for the operator as experience with the system can lead to distrust and disuse if it malfunctions in a manner that is unclear to the operator.
Muir (1994) recognises that the operator’s level of trust in an automated system will determine the choice of manual or automated operation, which has significant impact on the performance of the system. She developed a model of the human-machine relationship in regards to trust in automated systems based on a model of trust between humans. Stanton (1998: 1024) debates the extent to which human trust in machines can be based upon human trust in humans but acknowledges that the basis of the model may not be unfounded. Muir’s research into trust in automation spans two papers (Muir 1994 and Muir and Moray 1996). The findings of two experiments conducted on operators trust in automation were that the subjective ratings of trust in the automated system by the operators depended mainly upon their perception of the systems competence. Operators used the automated system for tasks that they trusted it for and used manual control for tasks that they did not trust the automated system for (Muir and Moray, 1996:429).

In regards to the issue of driver trust when using Adaptive Cruise Control, Stanton (1998: 1024) states that “drivers will only use the system in situations where it can be trusted to operate effectively and if the system fails to meet these expectations they may not use it at all.”

### 3.8 Accident Causation Theory

Forbes (1972: 4) states that there are two theories relating to accident causation: The *driver culpability theory* is the most widely accepted theory and is where the driver is blamed for inefficiencies and breakdowns in the system, especially in the occurrence of an accident. The driver is obviously expected to remain alert and make the appropriate judgements and responses to the traffic conditions. However blaming the driver is not the most appropriate reaction in all cases (Forbes, 1972: 4).

The *driver overload theory* considers the possibility that simultaneous errors, misjudgements or lapses on the behalf of several different drivers may be involved in the causation of motor vehicle accidents (Forbes, 1972: 4). This theory can be further interpreted to illustrate that an appropriate judgement
and response by one driver may prevent an accident that may have resulted from an error of another driver. This theory supports the fact that traffic accidents, although much too frequent, are relatively rare when compared with opportunities for accidents presented on the road.

In regards to accident causation theory, Reason (1990: 201) states that the human contribution to system accidents dominates the risk to complex installations, such as an automobile and its inherent technological systems. He acknowledges that any component or piece of equipment has a limited life and that system failures can occur for engineering reasons. However what may appear to be an equipment breakdown can often be traced back to a prior human failure. It can be said that a large proportion of road crashes are caused by human error.

### 3.9 Driving Simulator Studies

There have been many driving simulator studies completed in Australia and internationally to test a wide range of technological solutions and their effect on the participants’ driving performance.

Depending on what exactly is being studied there are many measures of primary vehicle control that can be used to gauge the driving performance of the participants. Driver impairment can be calculated in a driving simulator by measuring steering wheel position, lane position, lateral acceleration, velocity, brake response, speed maintenance, virtual collisions and headway control (George, 2003: 313-314).

The driving performance of the participant can also measured in relation to a secondary task. This is where the participant is asked to complete a task whilst simultaneously controlling the vehicle. The tasks vary between studies but generally require the participant to detect some form of visual object and respond by pressing a button of some sort. For example, Stanton et al (1997: 152) conducted a driving simulator study to measure driver workload whilst driving a vehicle equipped with Adaptive Cruise Control. This study utilised a
secondary task of rotating figures that appeared at the bottom of the virtual windscreen. The participants were instructed to respond to the rotating figures only when they felt they were not required to pay attention to the driving task. The aim of the secondary task was to measure the spare attentional capacity of the participants whilst driving with ACC.

Using a simulator to measure performance is not a perfect method, the participant is always aware that they are in controlled conditions and there is no danger to them regardless of what occurs within the simulation. Closed course experiments are also problematic because the participant is aware that they are being monitored and as such may alter their normal driving behaviour (George, 2003: 313). However, driving simulators offer the best method of determining the effect that a new technology will have on drivers and is indeed the most effective and safest method available to researchers.

The correlation between driver performance and behaviour in a driving simulator study and naturalistic driving varies depending on the configuration of the simulator. Kemeny and Panerai (2003: 36) recommend that for accurate perception of speeds and distances a large field of view is required in the simulator, and that the ideal configuration to measure steering control would involve a moving-base driving simulator.

The driving simulator study to test an adaptive brake light for this thesis will be discussed further in chapter 6. The measurements for the driving simulator are very specific and relate only to the participants’ braking pattern in reaction to a visual display of a lead vehicle that intermittently decelerates. As such the interface testing could not have been completed in a naturalistic environment, as there would have been too many variables introduced.

3.10 Summary

This chapter has outlined the problems associated with some forms of ITS and In-Vehicle ITS by considering human factors research into the deleterious effects of ITS.
The literature review component of this thesis (chapters 2 and 3) has outlined the relationship between In-Vehicle ITS and road safety. It has been demonstrated that most forms of In-Vehicle ITS involve a compromise to some extent in regards to Human Factors considerations.

There is potential for a product or system that delivers the positive aspects of a form of In-Vehicle ITS whilst minimising or removing the possible negative outcomes. The development of an adaptive brake light in response to the shortcomings of an Adaptive Cruise Control system is explained further in Chapter 4.
4.0 The Adaptive Brake Light

The design and specifications for an adaptive brake light were developed earlier. The design was initially referred to as a decelerometer and was designed as an alternative or complimentary product to Adaptive Cruise Control. The design informed the driver of the car behind the vehicle with the technology fitted of the rate of deceleration of the vehicle when it is slowing down. The adaptive brake light was proposed as a viable alternative to Adaptive Cruise Control because it informs drivers with information in regards to the deceleration of the lead vehicle, allowing them to make an informed decision about how much they need to brake in order to avoid a collision. However the technology does not remove the driver from the driving task as some forms of In-Vehicle ITS have been shown to do.

The adaptive brake light is a visual display that is integrated either into the vehicle’s rear windscreen brake light or rear spoiler brake light. It consists of a band of light emitting diodes (LEDs) that illuminate variably depending on the deceleration of the vehicle.

The decelerometer was originally designed to be a product that could be retrofitted to existing automobiles, it was a stand-alone product that used in-built technology to provide road users with an accurate display of a vehicles rate of deceleration. The Computer Aided Design (CAD) model of the decelerometer is shown in figure 1.
The technology utilised by the decelerometer is relatively simple, the display interface comprises a bank of light emitting diodes (LEDs) that are connected to a computer chip that interfaces with a G-Force sensor that can detect any change in velocity and thus illuminate a corresponding number of LEDs. The device is powered by solar panels that constantly charge a pair of high performance rechargeable batteries. By using solar panels and batteries it means that the decelerometer is a stand-alone product that can be fitted to any vehicle.

The technology was shown to work effectively by using a principle simulation mock-up. The mock-up contained a weighted spring attached to a potentiometer to mimic a G-Force sensor, which was then wired to a bank of eighteen LEDs. When the weighted spring moved due to a force being applied, such as deceleration, the LEDs emit light. The number of LEDs that are illuminated corresponds to the amount of force that is applied. The mock-
up demonstrated the function of the decelerometer in a cost effective manner. The principle simulation mock-up in nine different deceleration display settings is shown in figure 2.

Figure 2. Principle Simulation Mock-Up in use
Whilst the original decelerometer was designed as a retrofitted stand-alone product, the manner of application of the adaptive brake light concept was not considered vital for the purposes of this thesis. In regards to the brake light interface user testing and methodology the adaptive brake light is implemented into the rear windscreen of the vehicle, as is the BMW inspired brake light and the standard brake light interface. The concept of an adaptive could be designed as a retrofitted product, or could be implemented by automotive manufacturers into new vehicles. In order for a retrofitted adaptive brake light to be applied to a vehicle the existing rear spoiler or rear windscreen brake light would need to be disabled in order to comply with the Australian Design Rules. Should further research be conducted into adaptive brake lights, particularly actual vehicle trials, the decelerometer design could be utilised.

A physical presentation model was also constructed which illustrated the concept of the decelerometer, with a manual dial attachment for the purposes of demonstration. The decelerometer model is shown in figure 3.
The reason for the implementation of an adaptive brake light would primarily be to help reduce the occurrence of rear-end crashes. However there may be other benefits provided by the adaptive brake light.

An adaptive brake light could be of assistance in reducing the instances of stop-start driving that can occur in congested traffic. Stop-start driving is where people apply an inappropriate level of brakes in reaction to the car in front applying their brakes. Regular brake lights are a simple indicator of braking, they are either on which illustrates that the car is braking, or they are off which illustrates that the car is not under brakes. It is common for drivers to adjust their speed by braking slightly, which alerts the driver behind and causes them to apply their brakes as well. Generally this should not be a
cause for concern, but if people over-react to brake lights they may slow their vehicle at a greater rate than necessary, which then may cause the driver behind them to over-react and the resultant scenario is stop-start driving. By fitting an adaptive brake light to vehicles it will be possible for people to make a better judgement of how much to slow their vehicle, which may increase traffic flow during congested driving conditions. A further advantage gained by reducing the instances of stop-start driving will be a reduction of fuel consumption and emissions that are caused by cars accelerating from a static position.

The application of the adaptive brake light and its functional characteristics as well as the development of a brake light interface user testing programme is explained further in chapter 5.
5.0 Brake Light Interface Testing Methodology

The purpose of the brake light interface testing is to determine whether a variable brake light display will provide a benefit in regards to road safety. Three different brake light interfaces were tested.

The first brake light display tested was a standard brake light configuration that only has one level of brake light representation, either on or off. This interface is used as a benchmark to compare the benefits of the other two configurations.

The second brake light interface is based on the BMW “Brake Force Display” technology which is available on most new BMW models. This interface increases the brake light area when the vehicle is under hard or emergency braking where the deceleration exceeds five m/s².

The third interface is based on the adaptive brake light that shows the rate of deceleration by illuminating a variable brake light display. This interface displays all levels of deceleration. For example, illuminating a small area of light represents a small amount of deceleration and a large area of light is illuminated to represent a large amount of deceleration (Chapter 4).

Figure 4 is a graphical illustration of the three brake light interfaces that were tested. The first column illustrates the standard brake light configuration, common to every vehicle on Australian roads except late model BMWs with Brake Force Display. The standard brake light has two settings; on and off, where the same area of light is illuminated regardless of the rate or level of deceleration. The second column illustrates the BMW inspired brake light configuration. This brake light operates in the same manner as a standard brake light until the vehicle is decelerating at 5 m/s² or more, in which case an extra row of light is illuminated. Deceleration of 5 m/s² or more is a significant level of brake, consistent with an emergency stop. The third column illustrates
the adaptive brake light concept. This is a variable brake light display that can quickly show the car behind the level of deceleration.

<table>
<thead>
<tr>
<th>RATE OF DECELERATION</th>
<th>Standard (Binary: on/off)</th>
<th>BMW Inspired (Light increase at 5 m/s)</th>
<th>Adaptive (Variable light display)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 m/s²</td>
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<tr>
<td>1 m/s²</td>
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<td>6 m/s²</td>
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<tr>
<td>7 m/s²</td>
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</tbody>
</table>

Figure 4. User Test Interfaces

5.1 Driving Simulator Configuration

The goal of the driving simulator is to measure the level of brake that the participants apply in reaction to the deceleration of the lead vehicle. The participants' reaction can then be classified as appropriate braking, under braking, over braking or excessive braking.

The hardware required to run the test is a computer to run the programme, a monitor or data projector, computer gaming pedals (automatic configuration) and a computer gaming steering wheel.
The computer programme measured the participant’s level of brake application in reaction to the lead vehicle and responded in a realistic manner. This meant that the relationship between the deceleration of the lead vehicle and the participants’ vehicle was also measured in reference to time.

The relationship between the lead vehicle and the participants’ vehicle is determined by the computer programme in relation to three factors; (a) the distance between the vehicles, (b) the speed of the vehicles and (c) the pedal pressure applied by the participant in reaction to the deceleration of the lead vehicle. Figure 5 represents this relationship.

The computer interface is relatively simple; a rudimentary landscape and road is shown along with the rear of a vehicle on which the different brake light configurations can be applied. The graphics of the computer programme simulate daylight driving conditions with the brake light interface clearly displayed on the rear of the vehicle. Figure 6 illustrates the basic layout of the driving simulator interface in the default position, which is a vehicular separation of 14 metres whilst travelling at 60km/hr. This is the position that
the participant is to strive to maintain by braking appropriately in reaction to the lead vehicle’s deceleration.

Figure 6: The Virtual Road Environment in the Default position

The computer programme displays a vehicle under varying levels of brakes. It does this by showing the vehicle getting closer the virtual windscreen and by displaying the appropriate brake light configuration. There is no engine noise or tyre screech associated with the lead vehicle, thus the participants’ assessment of the speed of the lead vehicle is predominantly visual. The participant is required to react to the lead vehicle’s deceleration in order to avoid a collision. Figure 7 illustrates the context from which the interface is derived.
In order for the computer to display the correct brake light interface on the rear of the lead vehicle it is necessary to treat the two virtual vehicles as separate entities. Thus the lead vehicle will behave in a manner preset by the programme, whilst the actual display shown to the participant will be determined by their reaction to the lead vehicle's actions.

In the case of displaying the standard brake light interface there are only two possible brake light scenarios to display: (a) if the lead vehicle is not decelerating then there are no brake lights shown on the rear of the vehicle, and (b) if the lead vehicle is decelerating then a standard brake light configuration will be displayed. Figure 8 shows the possible scenarios of the standard brake light configuration.
In the case of the BMW inspired brake light configuration there are three possible brake light configurations to display: (a) if the lead vehicle is not decelerating then there are no brake lights shown on the rear of the vehicle, (b) if the lead vehicle is decelerating at a rate from 1m/s² to 4m/s² then a standard brake light configuration will be displayed, and (c) if the lead vehicle is decelerating at a rate of 5m/s² or greater then an enlarged brake light interface is displayed. Figure 9 shows the possible scenarios of the BMW inspired brake light configuration.

![Figure 9. Possible BMW Inspired brake light configurations](image)

In the case of the adaptive brake light configuration there are many possible brake light configurations to display. In the interests of simplicity the adaptive brake light will be shown in eight possible configurations, from a rate of deceleration of 0m/s² to 7m/s²: Figure 10 shows eight of the possible scenarios of the adaptive brake light configuration.

![Figure 10. Eight possible adaptive brake light configurations](image)
It is important to keep in mind that the above interfaces shown in Figure 7 do not occur in isolation; in order for the lead vehicle to decelerate at 5m/s² it must first decelerate at 1m/s² then 2m/s² and so on. The lead vehicle will also be getting closer to the virtual windscreen as the rate of deceleration increases. It was hoped that the adaptive display coupled with the decreasing distance between the vehicles would prompt the participant to apply a more appropriate level of brakes than when interacting with the other two brake light configurations.

The computer programme calculates the results of each user test and generates a text file that includes a report showing details of the entire test and a summary of the final results.

The full report shows the following information:

- The time in milliseconds at 4 millisecond intervals starting from the point at which the lead vehicle begins decelerating until five seconds after the lead vehicle has stopped decelerating.
- The distance between the vehicles at each time interval,
- The velocity of the lead and participant vehicle, and
- The participants’ level of brake application that is shown as a percentage. The percentage ranges from 0%, which is where the participant is not applying the brake to 100%, where the participant is applying the brakes to the maximum level. The brake level measurement also shows negative values, such as –35%, which occurs when the participant is actually accelerating or still has their foot on the accelerator pedal when the lead vehicle starts decelerating.

The final result summary details the amount of time the participant spent in the default position whilst the lead vehicle was decelerating and then accelerating back to the standard 60km/hr. This is displayed as the amount of seconds spent inside the default position for the 29 seconds that the lead vehicle is decelerating overall and the 65 seconds after the lead vehicle stops
decelerating (as there are 13 instances of deceleration during the test). This is also shown as a percentage of time that is used as the main point of comparison.

In order to calculate a more realistic percentage of time spent in the default position the computer programme expands the default position from 14 metres to a distance range of 11 metres to 14 metres. This is done because the physics of the programme are not able to return to the vehicles to the exact default position, but the programme is able to return the vehicles to the approximate default position. If the programme calculated the percentage of time spent in the default position as only a vehicular separation of exactly 14 metres the final percentage would be very low and not indicative of the participants overall driving behaviour. Thus the acceptable range for the calculation of the time spent in the default position percentage is expanded to include instances where the vehicles are separated by a significant distance, which is not necessarily exactly 14 metres.

The computer programme was designed to accept input from the participant in reaction to the lead vehicle’s deceleration. This was done by enabling the participant to control the level of deceleration of their virtual vehicle during the “active” time; the time when the lead vehicle was decelerating. The programme then resumes control of both vehicles and returns them to the default position at a constant rate. The participants’ driving style determines how quickly the vehicles return to the default position. If the participant brakes appropriately during the active time then the return to the default position is quite rapid, and thus the percentage of time spent in the default position is high. If the participant is over-braking or under-braking it takes more time to return to the default position and thus the percentage of time spent in the default position is reduced.

In the case of a participant under-braking the programme controls the speed of their vehicle after the “active” time by limiting it to 40km/hr until the lead vehicle returns to 60km/hr with a vehicular distance of 14 metres; the default position. How long the programme takes to return to the default position
depends on how much the participant has under-braked. In the case of extreme under-braking it may take several seconds for the vehicles to return to the default position. In the case of minor under-braking the programme will only take a fraction of a second to return to the default position.

In the case of a participant over-braking the programme increases the speed of the participants’ vehicle to 80km/hr until the vehicles are back in the default position. If the participant has over-braked significantly the distance between the two vehicles will have increased substantially and thus it may take several seconds to return the vehicles to the default position. In the case of minor over-braking the programme will only take a fraction of a second to return to the default position.

It is pertinent to note that the participants’ reaction time has a marked effect on how quickly the programme can return the vehicles to the default position. When a participant has a fast reaction to the lead vehicle decelerating then there is more time for them to apply the brakes within the active time period. When a participant reacts slowly to the lead vehicle decelerating there is less time for an appropriate reaction, resulting in an under-brake situation.

A compounding factor to reaction time is the fact that it was possible for the participants to apply pre-brake acceleration, which is where they have their foot on the accelerator before the lead vehicle starts to brake. This pre-brake acceleration was an issue depending on the participants’ driving style. If a participant has their foot fully on the accelerator immediately before the lead vehicle decelerates then it was possible for their vehicle to accelerate which will affect not only their reaction time but also means that they will have to over-brake in order to compensate. If a participant does not have their foot on the accelerator or is only resting their foot on the accelerator then the issue of pre-brake acceleration is negligible.

The above-mentioned issues will only cause a problem with the results if the participant who displays these particular driving styles does not do it consistently across all three interface tests. If a driver consistently displays the
tendency to apply pre-brake acceleration across all three brake light interfaces then their results may be lower than average but will be consistently lower. However if a driver only displays pre-brake acceleration on one or two interfaces then the results will be skewed towards the interface tests on which the behaviour was not shown.

5.2 Driving Simulator Interface Testing Protocol

The driving simulator was assembled in the Human-Centred Design Research and Usability Laboratory at the Gardens Point Campus of Queensland University of Technology (QUT). The room features state-of-the-art video recording facilities that allowed each test to be recorded. The recordings could then be referred to at a later date if further information was required about a particular Interface test.

The simulator consisted of a table and chair with the steering wheel located on the table and the pedals positioned on the floor in front of the chair. A computer hard drive was located on an adjacent table along with some speakers for the auditory feedback. A data projector was set up on a trolley behind the chair and was aimed over the participants shoulder at the blank wall in front of the participant. The pedals had Velcro attached to the bottom to stop them from sliding along the carpet but were easily detached and able to be moved to suit the participant. There was also a range of chairs available for the participant to choose so they could replicate their own preferred driving position as closely as possible. Figure 11 shows a photograph of the driving simulator set up in the laboratory.
Upon entering the testing area the participant was asked to complete a questionnaire that requests some basic information about the participant such as their age, gender, driving experience and how they rate themselves as a driver in regards to confidence, ability and attentiveness. The questionnaire is included as Appendix A. They are then asked to peruse a standardised information sheet that details the aims of the project and were asked to sign a statement of consent.

After completing the questionnaire and information sheet the participant was guided through a “warm-up” exercise that familiarised them with the driving simulator software and hardware that they will be interacting with. The participants were told that they are to assume a comfortable driving position and to react to the deceleration of the lead vehicle by applying the brakes of the simulator. The participants were told that they do not have any lateral control of the vehicle and are not able to accelerate during the non-active periods, but they are requested to keep their hands on the steering wheel and
their right foot above or lightly on the accelerator (when not braking) in order to make the simulator as realistic as possible.

The warm-up period is a short exercise where the participant has to react to the deceleration of the lead vehicle for two minutes. Within this time the lead vehicle performs a condensed version of the actual test with six instances of deceleration. The aim of this warm-up exercise is to familiarise the participants with the interface and how their use of the pedals affects the simulator. The warm-up exercise displays the same brake light interface as the first test that the participant is to complete. The warm-up exercise was repeated until the participant was comfortable with the requirements of the task and then the actual test was initiated.

The initial pilot study and revised pilot study (Chapter 6.0) lasted for twelve minutes for each interface and the lead vehicle behaved in an identical manner for each test, which ensured that the results for each test can be compared directly to the other interfaces. The duration of the interface tests was reduced for the initial interface tests and revised interface tests to eight minutes as the twelve-minute test was deemed to be an inefficient use of time. The lead vehicle deceleration instances and time points for the eight-minute tests are shown in Table 1.
Table 1. Lead Vehicle Deceleration Instances and Time Points

<table>
<thead>
<tr>
<th>Time (min:sec)</th>
<th>Lead Vehicle Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>Begin in default position</td>
</tr>
<tr>
<td>0:20</td>
<td>Decelerate at 2/ms² for 2 seconds (from 60km/h to 45.6km/h over 2 secs)</td>
</tr>
<tr>
<td>0:40</td>
<td></td>
</tr>
<tr>
<td>1:00</td>
<td>Decelerate at 3/ms² for 3 seconds (from 60km/h to 27.6km/h over 3 secs)</td>
</tr>
<tr>
<td>1:20</td>
<td></td>
</tr>
<tr>
<td>1:40</td>
<td>Decelerate at 1/ms² for 1 seconds (from 60km/h to 56.4km/h over 1 secs)</td>
</tr>
<tr>
<td>2:00</td>
<td>Decelerate at 4/ms² for 3 seconds (from 60km/h to 16.8km/h over 3 secs)</td>
</tr>
<tr>
<td>2:20</td>
<td></td>
</tr>
<tr>
<td>2:40</td>
<td>Decelerate at 2/ms² for 2 seconds (from 60km/h to 45.6km/h over 2 secs)</td>
</tr>
<tr>
<td>3:00</td>
<td></td>
</tr>
<tr>
<td>3:20</td>
<td>Decelerate at 1/ms² for 2 seconds (from 60km/h to 52.8km/h over 2 secs)</td>
</tr>
<tr>
<td>3:40</td>
<td></td>
</tr>
<tr>
<td>4:00</td>
<td></td>
</tr>
<tr>
<td>4:20</td>
<td>Decelerate at 5/ms² for 3 seconds (from 60km/h to 6km/h over 3 secs)</td>
</tr>
<tr>
<td>4:40</td>
<td>Decelerate at 2/ms² for 2 seconds (from 60km/h to 45.6km/h over 2 secs)</td>
</tr>
<tr>
<td>5:00</td>
<td></td>
</tr>
<tr>
<td>5:20</td>
<td></td>
</tr>
<tr>
<td>5:40</td>
<td>Decelerate at 6/ms² for 2 seconds (from 60km/h to 16.8km/h over 2 secs)</td>
</tr>
<tr>
<td>6:00</td>
<td>Decelerate at 2/ms² for 2 seconds (from 60km/h to 45.6km/h over 2 secs)</td>
</tr>
<tr>
<td>6:20</td>
<td></td>
</tr>
<tr>
<td>6:40</td>
<td>Decelerate at 2/ms² for 3 seconds (from 60km/h to 38.4km/h over 3 secs)</td>
</tr>
<tr>
<td>7:00</td>
<td></td>
</tr>
<tr>
<td>7:20</td>
<td>Decelerate at 7/ms² for 2 seconds (from 60km/h to 9.6km/h over 2 secs)</td>
</tr>
<tr>
<td>7:40</td>
<td>Decelerate at 2/ms² for 2 seconds (from 60km/h to 45.6km/h over 2 secs)</td>
</tr>
<tr>
<td>8:00</td>
<td>Finish</td>
</tr>
</tbody>
</table>

It was initially proposed that a minimum of thirty people are tested, with at least ten people completing each of the three brake light interface tests. This methodology was used for the initial pilot study (Section 6.2). However it was decided that superior results would be attained by having each participant complete each interface test in a rotating order, thus eliminating the possibility of individual biases for a particular interface. The order of the tests that each participant will complete will be a rotation of six orders: ABC, ACB, BAC, BCA,
CAB, CBA where A is the standard interface, B is the BMW inspired interface and C is the adaptive interface.

This method was used for the revised pilot study (Section 6.3) and the remaining interface tests. This ensured that the only variable in the user-testing phase is how the participants react to the deceleration of the lead vehicle, as reaction times and driving styles particular to each individual participant would hopefully be consistent over the three interface tests. The data can then be used to determine which brake light interface is the most effective.

5.3 Interface Testing Hypotheses

There are five hypotheses that will be considered in the analysis of the interface testing results.

The first hypothesis to be considered will be the order of the interface testing and how the order may influence the results. General observations of the participants outlined a trend that during the first interface test the participant may still be gaining familiarity with the simulator and still learning how to interact with the hardware, which may adversely affect the results. Conversely during the third interface test the participant is very familiar with the simulator and may in fact be fatigued and less interested in the manner in which they are responding to the simulator. This may be due to the fact that they have already sat through two eight-minute tests that are identical except for the rear windscreen brake light and may also adversely affect the results. Thus it hypothesised that the interface test that is completed second may be the most successful test in regards to the participants’ level of attention and vigilance. This is however a very broad statement and it is hoped that the difference between the actual interface test brake light displays will minimise the affect that the order of the tests will have. This hypothesis, if proven to be correct, will also have an affect on the results of age and gender groups that did not have a randomised order of the interface tests within the orders for the four participants. As the order of the interface tests was assigned to each
participant in regards to the sequence in which they were recruited it was possible for some age and gender groups to have a non-randomised allocation of interface orders. Thus if the hypothesis is found to be accurate the age and gender groups who have a non-randomised order of interface tests may actually have biased the results to some extent.

The second hypothesis to be considered will be that younger participants may be more successful in the driving simulator study than older participants. This may be due to two factors; younger drivers may be more familiar with the physical aspects of the driving simulator as they may have used computer gaming pedals and steering wheels previously by playing computerised driving games or arcade style driving games. This would mean that they may be more comfortable interacting with the inherently artificial environment created by driving within a virtual environment. Younger drivers may also be more successful than older drivers due to the fact that they have less driving experience and thus less experiential knowledge of how to react to an instance of lead vehicle deceleration. An older driver will be very familiar with the standard brake light configuration as they would have been interacting with this configuration for many years, and thus they may be unable to change their habitual driving style to incorporate the processing of new and unfamiliar information provided by the two variable brake light interfaces. Younger drivers conversely do not have a large amount of experiential knowledge gained from many years of driving and thus they may be better able to adapt their driving style in reaction to the extra information provided by the two variable brake light interfaces.

The third hypothesis that will be considered is that each participant will tend to yield results within a relatively close range for each interface test. If the participants are interacting with the driving simulator consistently throughout all three tests then the results should all have a differentiation of less than ten percent. This is because each participant will have their own natural driving style and be comfortable to interact with the driving simulator in a particular manner. If there is a large difference between the results for one participant
then it may be the case that they have changed their driving style to some extent and thus biased the results.

The fourth hypothesis that will be considered in the analysis of the brake light interface testing results is that some participants who were not instructed to pay attention to the changing rear windscreen brake light would not notice the variations in the brake light interfaces. This is because the computer programme graphics were designed in a way that was consistent with current automotive brake light configurations, where there are three similarly bright brake lights that illuminate on the rear of a vehicle when it is decelerating, and that these brake lights are of a similar size. The BMW Brake Force Display brake light illuminates a secondary band of light around the taillights, but this is of a similar scale and brightness to the standard brake lights, meaning that the extra band of lights is deemed enough to alert drivers of emergency braking. It was possible for the computer programme to exaggerate the rear windscreen brake light interfaces of the two variable interface tests, however it was thought that by doing this the results may be biased towards the variable interfaces. Thus the two variable brake light interfaces were programmed to increase in size, as previously explained in chapter 5.0, but the differences between the rear windscreen brake lights and the taillights were kept to a minimum in order to replicate how the brake light interfaces would appear should they be applied to a real vehicle. Therefore as the interface testing was using two variable brake light interfaces; the BMW inspired interface that people may not be aware of and the adaptive interface that people would not be aware of as it does not exist on any road going vehicles, it was deemed appropriate to tell people where the point of differentiation between the three tests existed. It is worth mentioning again that the participants were not told what each brake light was displaying before the interface testing, they were just that the rear windscreen brake light would be providing them with more information in some of the tests.

The fifth hypothesis states that participants who are diligent during the driving simulator study will yield better results than those who are not diligent. A diligent participant for the purpose of this research will be defined as one who
concentrates on the driving simulator task consistently throughout the entire testing period. This hypothesis is based on empirical observations of the participants but will be an important factor in differentiating between certain age and gender groups.

5.4 Summary

This chapter has outlined the methodology of the brake light interface user testing and explained the functionality of the three different brake lights that were tested; the standard, BMW inspired and adaptive brake light.

The driving simulator configuration and computer programme has also been explained along with the protocol that was used for the brake light interface user testing.

Chapter 6 will outline the pilot study that was undertaken and detail the developments and changes that were made to the computer programme and interface testing protocol before actual interface user testing was initiated.
6.0 Brake Light Interface Testing

The brake light interface testing phase consisted of a pilot study which was revised to accommodate issues learned during the pilot study, and actual brake light interface user testing, which was also revised during the course of the research. This chapter outlines the brake light interface user testing stages and details the iterative process that was undertaken.

6.1 Pilot Study

A pilot study was conducted once the computer programme had been developed to a stage where it was almost finalised. Three participants were recruited for the pilot study from the university postgraduate community. As the main focus of the study was to ensure that the computer hardware and software was operating correctly it was not deemed essential to screen the participants to the level that would be required for the actual interface tests.

6.2 Initial Pilot Study

An Initial Pilot Study was carried out to ensure that the interface-testing task was sound and that the results of the testing were accurate and suitable to use for direct comparison of the three interfaces.

Three people were recruited for the pilot study with each person completing a different interface test. The initial results were promising as the adaptive interface (referred to as interface C) proved the most successful with the participant spending 57.18% of the “active” time in the default position. The BMW inspired interface (referred to as interface B) was the next most successful interface with 48.10% of the “active” time spent in the default position and the standard interface (referred to as Interface A) proved to be the least successful with the participant spending 42.83% of the “active” time spent in the default position. Figure 12 illustrates the results of the pilot study.
The pilot study participants were asked their opinion of the interface test and whether they had any suggestions to improve the interface or testing procedure. The two participants that completed the adaptive and BMW inspired interfaces were asked if they noticed that varying brake lights and both replied that they did not notice the light specifically but felt that it was clear when the lead vehicle was under extreme deceleration. The participants were all positive about the test overall and offered some valuable feedback as shown below.

The pilot test participants suggested:

- To fix the brake and accelerator pedals to the ground, as they were able to move along the carpeted floor when pushed suddenly.
- The landscape was monotonous and could use some extra detail to improve the believability of the test.
- The test was boring and could include some form of audio interaction, either as a screech of tyres when under extreme deceleration or to include a radio to add to the realism of highway driving as two of the three participants would normally to listen to music when driving.
These suggestions were considered and it was decided that a detailed audio programme that simulated the participants’ car engine, brake application (tyre screech) and a collision noise would be added to improve the realism of the simulator. It was also decided that the test would be reduced to eight minutes for each interface instead of twelve.

In regards to the quality of the interface-testing results it was also decided to trial how people reacted to all three interfaces instead of just one. This meant that the initial pilot study participants were asked to return and complete the other two interface tests so that the results for each interface test were not affected by characteristics particular to each person.

6.3 Revised Pilot Study

The revised pilot study was completed and yielded some interesting results as shown in Figure 13. Two of the three participants actually related better to the standard brake light interface than the BMW inspired interface but all three related to the adaptive brake light interface the best.

![Figure 13. Revised Pilot Study Results](image)

The methodology of the revised pilot study was deemed to be appropriate and appeared promising, thus a recruitment drive for a further thirty-two
participants was initiated. Thirty-two participants were required as the interface testing was to be divided in regards to age and gender into eight groups of four participants. Four male and four female participants were required for each age group (18-25, 26-35, 36-45 and 46+).

6.4 Pilot Study Summary

This pilot study section has outlined the process of the initial and revised brake light interface pilot studies and detailed the amendments and revisions that occurred prior to the actual interface testing. The issues uncovered in the pilot studies were vital to the success of the actual interface testing, which will be explained in section 6.5.

6.5 Actual Brake Light Interface Testing

The brake light interface testing was initiated in December 2005 and a total of thirty-four participants were recruited. The interface testing phase concluded in February 2006 with thirty-two participants yielding unbiased results. Two participants were not included in the final result analysis, as they would have adversely affected the results.

The first participant to not be included in the analysis had held a learners permit for three years but had not yet attained an open drivers license. This was deemed to be a concern as the experience gained with a learner permit does not extend to driving unaccompanied and thus the participant did not have enough driving experience to be compared with the other licensed participants.

The second participant was removed from the analysis due to the fact that they admitted that during the first interface test (interface A) that they kept their foot on the brake for the first half of the test. This was apparent in the results, as there was a striking difference between the results of interface test A and the other two interfaces. The result for Interface A was twenty per cent higher than interface B and C which is consistent with a person having near perfect
reaction time for half of the test due to the fact that the brake pedal was already depressed when the lead vehicle decelerated.

This section has been divided into three main parts, initial interface testing, revised interface testing and overall interface testing. This has been done because the testing procedure changed after the first eleven tests when it was realised that the participants were not noticing the changing rear windscreen brake light on the BMW inspired interface and the adaptive interface. The first eleven participants were not instructed to pay attention to the rear windscreen brake light; whereas the remaining participants were all told that the rear windscreen brake light would provide more information in some tests. The final part of this section is overall interface testing, where the initial and revised interface testing results are combined and analysed as a whole.

6.6 Initial Interface Testing

The first recruitment yielded eleven participants from the general university population. There were eight males and three females of varying ages and driving experience.

The initial protocol as outlined in section 5.2 did not include instructing the participants as to where the varying brake lights would be shown and it was left up to the individual to notice the changing rear windscreen brake light. This methodology was proven to be problematic in the initial interface testing as many participants did not notice the changing rear windscreen brake light and thus were reacting to the lead vehicle based on it’s proximity to the virtual windscreen and the illumination of the standard brake lights. This phenomenon was noticed whilst analysing the results after the first day of testing where four people completed the test. Therefore on the second day, where a further seven participants were tested, they were asked at the end of the tests whether they had noticed the changing rear windscreen brake light. Three of the seven participants stated that they had not noticed the varying rear windscreen brake lights of the BMW inspired test (interface B) and the adaptive test (interface C). It was hypothesised that a number of the first four
participants may also not have noticed the changing rear windscreen brake light. This lead to further discussion with the supervisory team in regards to altering the protocol so that each participant was aware of which brake light to pay attention to.

The results of the initial interface testing show that on average the participants reacted to each different brake light interface in a similar manner. This indicates that perhaps a substantial number of the participants were not paying attention to the varying rear windscreen brake light.

Upon consultation with the supervisory team it was decided that in the next round of interface testing the participants would be instructed to pay attention to the rear windscreen brake light.

The initial interface testing phase comprised eleven participants of varying ages and driving experience. Eight of the participants had experience relative to their age; meaning that in general each of them had started driving when they were of licensable age (17 to 18). Three of the participants started driving later, when they were 21 to 23 years of age. The initial interface testing participant age and gender matrix can be seen below in table 2.

<table>
<thead>
<tr>
<th>Participants</th>
<th>18 - 25</th>
<th>26 - 35</th>
<th>36 - 45</th>
<th>46 +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Female</td>
<td>2</td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

The overall results of the initial interface testing phase are shown below in section 6.7. The results for each individual participant will be analysed in more detail in section 8.0; this section will also take into account how each participant interacted with the driving simulator and whether the participant biased the results by altering their driving style during the interface tests.
6.7 Initial Interface Testing Results

The initial interface testing results as shown in figure 14 illustrate that most people reacted in a relatively similar fashion to each brake light interface. The participants that indicated that they did not notice the changing brake light interface were participant 008, 012 and 014.

![Figure 14. Initial Interface Testing Results](image)

The resultant average of the initial interface testing as shown in figure 15 demonstrates the hypothesis that a proportion of the participants were not paying aware of the varying rear windscreen brake lights on interface tests B and C. The computer programme graphics did not emphasise the top rear windscreen brake light above the rear tail-lights; all three lights had the same intensity and colour. This was done purposely but proved problematic, as some people who were not aware of the changing rear windscreen brake light did not notice the extra information that the brake light provided. As the brake light interfaces being tested were essentially new forms of technology, particularly the adaptive interface C, it was deemed acceptable to tell people not what the function of each brake light was, but that in some interface tests the top rear windscreen brake light was changing and providing more information.
It was hypothesised that the revised interface testing would yield different results given that the participants would be told to pay attention to the top rear windscreen brake light. The results of the revised interface testing are discussed in section 6.8.

### 6.8 Revised Interface Testing

The revised interface testing consisted of twenty-one participants from the general university community. At first the participants were accepted as they responded but as the age and gender sections began to reach the desired four participants each more specific requests were made for people of the required ages and genders. As a result of this participant screening there were more female participants required for the revised interface testing, as the initial interface testing participant pool was predominantly male. However as the results will ultimately be combined and analysed together this was not deemed to be a significant issue. The revised interface testing participant age and gender matrix is shown in table 3.
The majority of the participants had driving experience that was relative to their age with seventeen of the twenty-one participants attaining their licenses when they were of licensable age (17-18). The remaining four participants attained their licenses when they were 19-25 years of age.

6.9 Revised Interface Testing Results

The revised interface testing results were more positive towards the adaptive interface and BMW inspired interface. There was more variation in the way that the participants responded to each interface and some participants still performed better on the standard brake light interface. More detailed analysis starting in section 8.0 will outline trends that are specific to each age and gender group. The individual results for each of the participants of the revised interface testing can be seen below in figure 16. The participants that were excluded from the final results are participant 027 and 029.

Figure 16. Revised Interface Testing Results
The revised interface testing average results can be seen in figure 17. There is a slight positive progression towards the adaptive interface C that is in contrast to the initial user testing results.

![Figure 17. Revised Interface Testing Average Results](image)

The results for the revised interface testing phase were more positive towards the two adaptive interfaces. This means that the act of instructing participants to pay attention to the rear windscreens brake light was a worthwhile endeavour.

The average results for the revised interface testing show a slight positive progression due to the fact that whilst some age and gender groups exhibited a strong performance increase for the variable brake light interfaces, other age and gender groups performed better overall on the standard brake light interface. A better indication of the success of the variable brake light interfaces will follow in chapter 8, where the different age and gender groups are analysed separately and the individual results for each participant are considered.
6.10 Overall Interface Testing

The overall user testing project yielded results from thirty two participants. These participants were evenly distributed between the eight age and gender ranges. By having four participants in each age and gender group the results for each group can be compared with the other groups relatively directly. While there were variations within the groups in regards to driving experience, age and occupation, the four participants in each group can be said to be somewhat representative of the same age and gender group in the general community. The age and gender matrix can be seen in figure 18.

<table>
<thead>
<tr>
<th>Participants</th>
<th>18 - 25</th>
<th>26 - 35</th>
<th>36 - 45</th>
<th>46 +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

The aim of the research was to provide some indication of how people would react to different brake light interfaces, and to possibly outline some trends that are specific to different age and gender groups. The results provided are indicative only and more research may be necessary to further articulate the findings.

6.11 Overall Interface Testing Results

The overall results for the interface testing are relatively similar when looked at as an average results as shown in figure 18. The BMW inspired interface scored the highest with 60.65, followed by the adaptive interface at 60.59 and then the standard brake light interface at 60.28. Whilst it can be said that overall the results are positive for the two variable brake light interfaces based solely on this average score, it is more useful to view the results in the context of how different age and gender groups responded to the three different interfaces.
The detailed analysis of individual age and gender groups will follow in chapter 8. The analysis will look at how each participant interacted with the driving simulator, and whether they may have biased the results in any way. The analysis will also consider any possible trends or tendencies that may be applicable to each age and gender group and how these trends may influence the acceptance and understanding of the three different brake lights.

6.12 Summary

This chapter has looked at the brake light interface user testing as a whole and dealt with the entire group of participants collectively. More information is available when looking at how individual age and gender groups responded to the different brake light interfaces.

Chapter 7 will explain how the individual age and gender groups will be analysed in regards to how they interacted with the driving simulator and whether the participants affected the results in any way by altering their virtual driving style.
7.0 Analysis of Interface Testing Results

A detailed analysis of the brake light interface testing for the thirty-two participants will follow. The participants are divided into eight groups of four, in relation to their age and gender. The analysis also takes into account how each participant interacted with the simulator hardware, and the order of the interface testing that each participant completed.

The analysis of each participant group will also comprise a detailed scrutiny of how each participant interacted with the simulator hardware and how well they applied the brakes in reaction to the instances of lead vehicle deceleration. As previously mentioned it will be discovered whether the participant over-braked, under-braked or braked appropriately. The analysis will outline whether the participant applied excessive brakes, which is a phenomenon that occurs when the participant consistently brakes to the full level of 100% brake application. The analysis will also take into account whether the participant applied pre-brake acceleration, and if so, whether the application of pre-brake acceleration was consistent throughout the three interface tests. The “driving style” of each participant will be analysed in regards to how well they matched the lead vehicle’s deceleration and will be classified as either having predominately over-braked, under-braked or having braked appropriately.

In order to determine the driving style of each participant the output file that is generated at the end of each interface test will be analysed. At each instance of lead vehicle deceleration the output file will be examined to see how the participant has reacted in regards to the relative speeds of the two vehicles and the distance between the vehicles, as well as the time taken by the participant to react.

Appropriate braking will be classified to be where the participants’ vehicular speed is close to the speed of the lead vehicle, or when the distance between the vehicles is not less than 13 metres. This will be shown in the output file as relatively similar figures of deceleration, and there will have been no need for
the programme to resume control of the participant’s vehicle by either limiting it to 40 km/hr while the lead vehicle returns to the default position or by accelerating the participant’s vehicle to 80 km/hr in order to return to the default position.

Under-braking will be where the participants’ vehicular speed is generally above the lead vehicles speed as it decelerates. The output file will illustrate this under-braking by showing how the computer programme has limited the participant’s vehicle to approximately 40 km/hr while the lead vehicle returns to the default position.

Over-braking will be where the participants’ vehicular speed is generally below the lead vehicles speed as it decelerates. The output file will illustrate the instances of over-braking by showing the computer programme accelerating the participant's vehicle at approximately 80 km/hr in order to return the vehicles to the default position.

Pre-brake acceleration occurs when a participant has their foot on the accelerator during the active periods, where the lead vehicle is decelerating. This was a behaviour that had the potential to bias the results if the participant did not interact with the driving simulator consistently throughout all three interface tests. Whilst it was not possible for the participant to accelerate during the non-active periods, it was possible to accelerate during the active periods due to the computer programme accepting input from the participant when they were braking or accelerating. If the participant was pressing the accelerator during the non-active periods, then when the lead vehicle decelerated the participant would be accelerating towards the lead vehicle until they removed their foot from the accelerator and applied the brakes. Pre-brake acceleration is not a major concern if the participant is consistent across all three interface tests, as although the results will be affected somewhat, the results for each interface test would be affected in the same manner. If however the participant changes their driving style during the interface testing and applies pre-brake acceleration during only one or two interface tests, then the results will be biased towards the test that during which the participant did
not apply pre-brake acceleration. The application of pre-brake acceleration, and whether a participant affected the results of the interface testing will be discussed in the age and gender group analysis section starting in section 8.1.

The classification of each participants driving style will include their reaction time; how quickly the participant reacts to the instances of lead vehicle deceleration has a marked effect on the overall outcome. For example, if a participant takes a significant amount of time to react to the lead vehicle, they are forced to over-brake in order to compensate for their late reaction. If they do not over-brake then even if they slow their vehicle at the same rate as the lead vehicle is decelerating they will take longer to return to the default position, due to the fact that when they started to brake the lead vehicle was already closer to their virtual windscreen. The participants’ reaction time goes some way towards explaining why a participant who may be classed as having mainly braked appropriately but with slow reaction times may have lower results than someone who has over-braked or under-braked but reacted quickly. However as a general rule it is expected that a participant who mainly brakes appropriately will receive higher percentage scores than a participant who has under-braked or over-braked.

The reaction time component of the results is integral in the computer programme and is one of the determinants of the “overall percentage of time spent in the default position” calculation. Reaction time is a fundamental element of the calculation and influences the final results where any time that the lead vehicle is decelerating and the participant is not responding by applying the brakes the amount of time that they vehicles are outside the default position is being measured.

It is also important to re-state at this juncture that the results to be analysed in the following chapters are indicative only. It is hoped that the participants are representative of their respective age and gender groups however the sample size of four participants per age and gender group means that although the results may outline some interesting trends, these trends are indicative only.
8.0 Analysis of Participants 18-25

The following analysis of the male and female 18-25 participants will consider all factors that may have had some influence on the final results for these age and gender groups. The analysis will include the order of the interface tests for each participant, their relative driving experience, whether they took part in the initial interface testing phase or the revised interface testing phase. The analysis will also consider how each participant may have affected the results by altering the way in which they interacted with the driving simulator during the testing period.

8.1 Analysis of Male 18-25 Results

The overall result of the male 18-25 group was positive, however there were interesting variations in the way that the participants responded to the interface testing. The first two participants (participant 010 and 012) completed the interface testing in the initial interface testing stage and thus were not instructed to pay attention to the varying rear windscreen brake light. Both these participants responded best to interface B and worst to interface C, with interface A receiving the intermediate responses. The remaining two participants (participant 034 and 035) responded in a converse fashion by responding best to interface C and worst to interface B, with interface A receiving the intermediate responses.

It can be hypothesised that the fact that the first two participants were not instructed to pay attention to the rear windscreen brake light may have affected the outcome, but overall the results were still ultimately positive towards the adaptive interface C. This occurred because the participants that responded best to interface C did so with a larger percentage difference between interface C and the other two interfaces. The first two participants who responded best to interface B did so with a less significant difference between the results for the other two interfaces.
The results for participant 010 and 012 were also affected by the two participants adopting a different driving style for the third test that they completed (interface C), which may also have adversely affected the result of this interface. This will be explained further in the analysis of each participant’s driving style. The average results for the male 18-25 group can be seen in figure 19.

![Figure 19. Male 18-25 Average Results](image)

Further analysis of the male 18-25 interface testing results also reveals another issue that may have had some influence on the results. The order of the interface tests for this group followed in the random pattern already outlined. However the order of the interface tests for the participants of the 18-25 group was not uniformly spread between the six possible interface testing orders. This occurred because the whilst all participants were assigned an interface order according to the numerical order in which they arrived to partake the interface tests, the 18-25 group all happened to sit for similar interface orders. Table 5 illustrates that the first three participants had interface C as the last test and the fourth participant (035) had interface C as the second test. There was no instance in this group of a participant sitting for one of the two interface orders that started with interface C. It is hypothesised that this may also have affected the results because, as previously mentioned,
a general observation of the participants during the interface testing is that they were most fatigued during the last test of the session, which may affect their reaction times.

Table 5. Male 18-25 Results

<table>
<thead>
<tr>
<th>18-25 Male</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 010</td>
<td>70.86</td>
<td>73.36</td>
<td>70.61</td>
<td>ABC</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Participant 012</td>
<td>61.77</td>
<td>63.3</td>
<td>59.69</td>
<td>BAC</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>Participant 034</td>
<td>61.35</td>
<td>61.14</td>
<td>66.12</td>
<td>ABC</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>Participant 035</td>
<td>48.74</td>
<td>45.13</td>
<td>49.12</td>
<td>ACB</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td><strong>Mean Results</strong></td>
<td><strong>60.68</strong></td>
<td><strong>60.7325</strong></td>
<td><strong>61.385</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 20 demonstrates the differences between participants 010 and 012 from the initial user testing phase and participants 034 and 035 from the revised user testing phase. The strong positive result for interface C shown by participant 034 and the less marked but still positive interface C result shown by participant 035 is the reason interface C is deemed the most effective interface for the male 18-25 age group. The line graph also demonstrates the tendency of the results for each participant to be located within a certain range. Participant 010 showed consistently high results for each of the interfaces while participant 035 showed consistently low results for each interface. This goes some way to support the hypothesis that the different driving styles of each participant will remain consistent across the three interface tests. Thus when the average results for each age and gender group is calculated the results are a true indication of the trends shown for each age and gender group.
Further investigation of the output results files calculated by the computer programme showed that participant 010 demonstrated a tendency to over-brake, which was shown in the simulator output file as many instances of the participants’ vehicle having to accelerate at 80km/hr to get back to the default position after the lead vehicle had stopped decelerating. This tendency was most prominent during the first test (interface A) and was occurring less frequently during the second test (interface B). Throughout the third test (interface C) the participant adopted a different driving style; they kept their foot on the accelerator pedal during the inactive time periods which meant that when they had to react to the lead vehicle decelerating their car actually would start to accelerate. This affected the results of the interface C test because it meant that the participants reaction time was in effect larger, as they not only had to remove their foot from the accelerator pedal and then press the brake, but they then had to over-react to the lead vehicles deceleration in order to match the lead vehicles deceleration. The results were affected by this behaviour because it was an alteration in the way that the participant interacted with the simulator; had he been consistent with how he used the pedals the results would have been more accurate. Participant 010 did not have the accelerator pedal fully depressed however; typically there was 5-
20% depression of the accelerator, which is not as critical as when a participant applies full pressure to the accelerator pedal.

Participant 012 showed a strong tendency towards under-braking, with the vast majority of all braking instances being classified as under-braking. The participant also displayed an interesting tendency to keep the accelerator pedal depressed more frequently as the testing progressed. The order of the tests completed by participant 012 was BAC, during the first test (interface B) there was once instance of pre-brake acceleration, and during the second test (interface A) there were four instances of pre-brake acceleration. Throughout the final test (interface C) there were 10 instances of pre-brake acceleration, which affected the results of the final test. The effect of this behaviour on the results of interface C was compounded by the fact that as the instances of pre-brake acceleration increased, the tendency to under-brake did not change. This meant that the participant’s vehicle was outside the default position more often than in the first two tests, because in order to compensate for an instance of pre-brake acceleration it is generally necessary to over-brake so that the distance between the vehicles is increased. Therefore the results of the third test (interface C) were adversely affected by the participant’s change of driving style.

Participant 034 showed a consistent tendency to apply excessive brakes, with almost every instance of brake application being at the full 100% level of pedal depression. There were also frequent instances of applying the brakes more than once in reaction to the deceleration of the lead vehicle. This occurred when the initial excessive brake application was recognised by the participant and so in reaction they removed their foot from the brake, only to have to reapply the brakes as the lead vehicle was still decelerating at a uniform rate and was thus still getting closer to the virtual windscreen. Participant 034 also displayed a tendency to apply the accelerator during the inactive times, resulting in pre-brake acceleration which had to be compensated for. The fact that the participant was frequently applying excessive brakes did help alleviate this situation. It is also interesting to note that although excessive brakes were being applied at every instance of lead
vehicle deceleration, this does not mean that each brake application was necessarily over-braking. In reaction to a small lead vehicle deceleration instance the reaction was definitely over-braking, however in reaction to a large instance of lead vehicle deceleration it was often an appropriate level of brake application. The success of the final interface test was due in part to the fact that the participant had ceased applying the pre-brake acceleration. The success was also due to the fact that although the participant was applying excessive brakes, he was releasing the pedal as soon as the lead vehicle had stopped decelerating. This means that the lead vehicle and the participant’s vehicle returned to the default position quickly due to the computer programme controlling both vehicles. During interface C the participant also did not react as quickly to instances of small lead vehicle deceleration, he instead waited for the brake light interface to increase to a level that illustrated more deceleration.

Participant 035 displayed an interesting propensity for applying near excessive brakes, which was actually a reaction to the fact that the participant had the accelerator pedal fully depressed during the non-active periods. The participant was actually under-braking for the vast majority of instances even though they were applying the brakes at 100% due to the fact the amount of time that elapsed between the start of the lead vehicle deceleration instances and the reaction of the participant were substantial. This affected the results quite markedly as when the participant is slow to remove their foot from the accelerator pedal whilst the lead vehicle is decelerating the participants vehicle actually accelerates. This will occur for every participant that has his or her foot pressing on the accelerator instead of resting on or above the accelerator, but it was most noticeable for participant 035 because the slow reaction times allowed the participants vehicle to increase in speed in some instances past 75km/hr. Thus to counteract this increase in speed the participant had to brake excessively to avoid collisions and remain in the default position. This explains the low results for participant 035, but as the same driving style was adopted for each test the adaptive interface C still proved to be the most effective.
8.2 Analysis of Female 18-25 Results

The overall results of the female 18-25 age group was positive, showing a clear preference firstly for the BMW inspired interface and secondly for the adaptive interface over the standard brake light display. Participants 032 and 036 both performed best on the BMW inspired interface (B) and participants 025 and 037 both performed best on the adaptive interface C.

All four participants took part in the revised interface tests and thus were all instructed to pay attention to the rear windscreen brake light. This does support the hypothesis that when instructed to pay attention to the changing rear windscreen brake light the participants do respond to the extra information provided by the BMW inspired interface and the adaptive interface. The average results for the female 18-25 age group interface tests can be seen below in figure 21.

![Figure 21. Female 18-25 Average Results](image)

The order of the interface tests was also not an even distribution for this age group, with interface A not occurring as the first interface test. Interface B was the first test for three of the participants and interface C was the first test for participant 032. The hypothesis of participant performing the best on the
interface that they sat second is supported by the results for participant 025 and 037, however the second interface in these instances was interface C which may mean that the participants were responding best to the interface that provided the most information. The results for each participant and the interface test orders can be seen in table 6.

<table>
<thead>
<tr>
<th>18-25 Female</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 025</td>
<td>63.56</td>
<td>64.37</td>
<td>65.21</td>
<td>BCA</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>Participant 032</td>
<td>50.48</td>
<td>54.68</td>
<td>49.45</td>
<td>CAB</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>Participant 036</td>
<td>68.1</td>
<td>73.36</td>
<td>69.03</td>
<td>BAC</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Participant 037</td>
<td>62.58</td>
<td>64.79</td>
<td>67.16</td>
<td>BCA</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>Mean Results</td>
<td>61.18</td>
<td>64.3</td>
<td>62.7125</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The female 18-25 results comparison as shown in figure 22 illustrates the strong positive results for interface B shown by participant 032 and 036. It also illustrates the positive progression towards interface C shown by participants 025 and 037. The line graph also demonstrates the tendency of the results for each participant to be located within a certain range, which supports the hypothesis that the different driving styles of each participant will remain consistent across the three interface tests.
Further investigation of the output results files calculated by the computer programme showed that participant 025 exhibited a tendency to under-brake and to apply appropriate levels of brake, with very few instances of over-braking or excessive braking. The reaction times for this participant were impeded by the fact generally that they returned their foot to the accelerator once the lead vehicle finished braking and kept the accelerator pedal depressed until the lead vehicle started to brake again. This pre-brake acceleration was done consistently throughout all three of the tests for roughly half of the active time periods. The results are relatively high for participant 025 and would have been higher had their reaction times been faster. During the first test (interface B) there were several instances of over-braking followed by a compensatory removal of their foot from the brake, then a reapplication of the brake pedal in reaction to the fact that the lead vehicle was still decelerating. However the participant stopped this behaviour midway through the first test as she became more familiar with how her actions affected the driving simulator programme. It can be hypothesised that had this participant not displayed this learning behaviour during the first test then the results for interface B may have been slightly higher.
Participant 032 displayed a strong and consistent tendency to under-brake, which was compounded by the fact that she applied pre-brake acceleration consistently throughout all the interface tests. The results for participant 032 were also reduced by the fact that her reaction time was quite slow, sometimes up to one second passed before the participant reacted. The interface test order for participant 032 was CAB, and although pre-brake acceleration was applied consistently across all three interface tests, the instances were more extreme for the first test (interface C) than the other two interface tests. All these factors contributed to the low results for this participant, but as the driving style was reasonably consistent throughout all three interface tests the results were slightly biased away from interface C.

Participant 036 scored quite highly in regards to overall percentage spent in the default position. This was due to several factors; firstly she did not keep their foot pressed down on the accelerator during the “non-active” periods, which means that the car did not accelerate before she had time to react to the lead vehicle. Secondly the participant showed a tendency to consistently over-brake or brake appropriately. Most commonly the participant over-braked and then removed her foot from the brake pedal which meant that the lead vehicle and the participants vehicle had time to return to the default position whilst still in the “active” time period, meaning that the results showed more time spent in the default position. The participant performed consistently well over all the interface tests except for one collision that occurred during the last test (interface C) where she accidentally pressed the accelerator instead of the brake in reaction to a large deceleration instance of the lead vehicle. Had this not occurred the results for interface C would have most likely been higher.

Participant 037 began the testing showing a balanced distribution of the two braking styles. Throughout the first two tests, interfaces B and C, the participant over-braked and under-braked consistently, with approximately six instances of each braking style per test. However during the final test (interface A) the participant tended to predominantly under-brake. This was due to the fact that participant applied pre-brake acceleration during the final
test, which meant that the reaction time deteriorated and thus the resultant late braking was under-braking. The participant’s reaction time was reasonably slow throughout the three interfaces, but the application of pre-brake acceleration during the final interface test explains why the results for interface test A were lower than the other two interfaces.

8.3 Comparison of Male and Female 18-25 Results

When comparing the average results of the male and female 18-25 groups it is interesting to note that although the actual trends are somewhat different, the numbers are relatively similar with the results for both groups. The average results are both within the 60-65% range of time spent in the default position, which is a high score. This supports the hypothesis that younger participants may yield high results due to their familiarity with computerised driving simulator interfaces, and also their ability to process new information may be greater than older drivers.

The line graph showing the average results comparison for the male and female 18-25 groups can be seen in figure 23. The overall preference for the BMW inspired interface shown by the female 18-25 group is illustrated, as is the less marked preference for the adaptive interface shown by the male 18-25 group.
When looking at the results of the male and female 18-25 groups as a whole, the results are ultimately positive towards the two variable interfaces. It is possible that if the participants had maintained a consistent driving style throughout the three tests, the results may have been more positive towards the adaptive interface. This will be explained further in section 8.4.

8.4 Findings

Whilst the overall results for the male and female 18-25 groups were positive towards the variable brake light interfaces, the results were actually biased away from these two interfaces.

In the male 18-25 group two participants changed their driving style during the testing in a manner that affected the success of the adaptive interface. Both participant 010 and 012 applied pre-brake acceleration during the test for the adaptive interface C, and either did not apply pre-brake acceleration at all during the other two tests, or applied it to a lesser extent. Participant 034 applied pre-brake in a contrasting manner, with more instances of pre-brake acceleration being applied during the standard interface than the BMW.
inspired interface, and actually did not apply any pre-brake acceleration for the adaptive interface. These factors meant that the overall results were biased slightly away from the two variable interfaces.

In the female 18-25 group a similar situation, with three participants displaying driving style changes that biased the results away from the variable interfaces and one participant displaying behaviour that biased the results towards the standard interface. Participant 025 displayed a learning behaviour of applying the brake pedal intermittently during the BMW inspired interface, which affected the results for this test as they ceased the behaviour midway through the test. Participant 032 displayed significantly slower reaction times during their first test (interface C) and improved their reactions times as the testing progressed. Participant 036 had a virtual collision during interface C, when they pressed the accelerator pedal instead of the brake pedal, which affected the results of interface C in a negative manner. Participant 037 affected the results negatively for interface A, by applying pre-brake acceleration during this test, but not for the other two tests. The factors meant that the female 18-25 group also biased the results away from the two variable interfaces, particularly interface C.

Thus although the results for the male and female 18-25 group were positive towards the variable interfaces, had the participants not displayed behaviour that affected the results in a negative manner to the two variable interfaces, the results would likely have been higher.

The difference between young male and female drivers has been studied broadly, as has the difference between young drivers and more experienced drivers. There is much evidence to suggest that younger drivers are at greater risk on our roads than more experienced drivers.

This has been found by Bina, Graziano and Bonino (2006) to be due in part to the fact that there is a correlation between the lifestyles of younger people and risky driving behaviours. The authors conducted a self-report questionnaire in Italy and found that young people who displayed risky driving practices were
also likely to partake in a lifestyle that involved behaviours and leisure activities that were of a health risk. These antisocial behaviours included tobacco smoking, drug use, comfort eating and non-organised activities with peers (Bina et al, 2006: 472). The most common traffic offences committed by young drivers were found to be exceeding the speed limit and not maintaining a safe braking distance, which is troubling due to the fact that these two behaviours account for a large percentage of traffic accidents (Bina et al, 2006: 479).

Clark, Ward, Bartle and Truman (2006) conducted a study that analysed data from 3000 accident cases involving drivers aged 17-25 years over a two year period in the United Kingdom. The authors state that young drivers are over-represented in traffic accidents, particularly young males, and the research found that a large number of accidents involving young people were associated with voluntary risk-taking behaviours and recreational driving (Clark et al, 2006: 1). Also of note was the fact that younger drivers, aged 17-19 years, were more likely to be involved in rear-end accidents when compared to older drivers aged 20-25 years (Clark et al, 2006: 7).

Ozkan and Lajunen (2006) conducted a questionnaire study on 217 young Turkish drivers and found that risky driving was more prevalent in young male drivers and less prevalent in female drivers. The study also demonstrated that young male drivers had a higher level of perceptual motor skills, whereas young female drivers had a higher level of safety skills (Ozkan and Lajunen, 2006: 275).

Due to the elevated level of risk associated with younger drivers, particularly young males, the positive response to the adaptive brakelight and BMW inspired brake light justifies further development of the adaptive brakelight.
8.5 Summary

The chapter has analysed the results for both the male and female 18-25 groups, both individually and as a comparison between the two groups. The way that each individual participant responded to the driving simulator has been analysed, as has whether any of the participants exhibited behaviours that may have adversely affected the results for any one or two brake light interfaces. Overall the results were positive towards the two variable interfaces, and may have been higher had all participants responded in a uniform manner to each brake light interface.

Chapter 9 will analyse the results for the male and female 26-35 groups.
9.0 Analysis of Participants 26-35

The following analysis of the male and female 26-35 participants will consider all factors that may have had some influence on the final results for these age and gender groups. The analysis will include the order of the interface tests for each participant, their relative driving experience, whether they took part in the initial interface testing phase or the revised interface testing phase. The analysis will also consider how each participant may have affected the results by altering the way in which they interacted with the driving simulator during the testing period.

9.1 Analysis of Male 26-35 Results

The overall results of the male 26-35 age group were positive towards the variable brake light interfaces, with participants 011 and 013 performing best on the BMW inspired interface and participant 006 showing a strong preference for the adaptive interface. Participant 022 performed the best on interface A, but the variation between the results of each of the three interfaces were quite small for this participant; which meant that the mean results showed that interface C was the most successful interface, followed by the BMW inspired interface, and then the standard brake light interface.

Both participant 006 and 011 took part in the interface tests during the initial interface testing phase, which means that they were not instructed to pay attention to the changing rear windscreen brake light. Analysis of the results for these two participants shows that participant 006 responded well to the two variable brake light interfaces and thus it can be said that they may have noticed the changing rear windscreen brake light. The results for participant 011 are less clear and it can be said that they may not have paid attention to the changing rear windscreen brake light. The average results for the male 26-35 age group can be seen in figure 24.
The order of the interface tests for the male 26-35 group was not an even distribution, which may have influenced the results. Interface A was the first test for two participants and interface B being the first test for the remaining two participants. Interface C did not occur as the first test for this age and gender group. However the interface tests were more evenly distributed for the second and third order. The hypothesis that a participant may achieve the highest results for the interface tests that they sat for second is not supported by the male 26-35 age group, as the second test sat by all participants was not the highest results in any case. The results for each participant and the interface test orders can be seen in Table 7.

Table 7. Male 26-35 Results

<table>
<thead>
<tr>
<th>26-35 Male</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 006</td>
<td>58.92</td>
<td>63.82</td>
<td>70.61</td>
<td>BAC</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>Participant 011</td>
<td>50.78</td>
<td>52.77</td>
<td>51.71</td>
<td>ACB</td>
<td>31</td>
<td>13</td>
</tr>
<tr>
<td>Participant 013</td>
<td>55.45</td>
<td>57.01</td>
<td>54.73</td>
<td>BCA</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td>Participant 022</td>
<td>43.51</td>
<td>42.66</td>
<td>42.07</td>
<td>ABC</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>Mean Results</td>
<td>52.165</td>
<td>54.065</td>
<td>54.78</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The male 26-55 results comparison as shown in figure 25 illustrates the strong preference for the adaptive interfaces shown by participant 006, and the relatively similar results for the remaining participants. The hypothesis that individual results will generally fall within a close range of each other is supported by participants 011, 013 and 022. The results yielded by participant 006 is the main reason that the average results for this age and gender group were positive towards interface C. More detailed analysis of the individual results for each participant will follow however it can be said that the results for participant 006 were not affected by any driving style changes such as pre-brake acceleration or excessive braking.

![Figure 25. Male 26-35 Results Comparison](image)

Further investigation of the output results files calculated by the computer programme showed that participant 006 had a strong tendency to under-brake during the first two interface tests (interfaces B and A). The results for interface C were more evenly spread between under-braking and over-braking, and there were also more instances of appropriate braking for interface C. It can be hypothesised that the extra information provided by interface C may have allowed the participant to judge how much braking was
needed to maintain the default distance between the two vehicles. Thus in
response to a large lead vehicle deceleration instance the participant over-
braked and in response to a small lead vehicle deceleration instance the
participant under-braked. This explains the high results for interface C that the
participant achieved.

Participant 011 showed a strong tendency to under-brake, which was due to
the fact that he applied pre-brake acceleration consistently throughout the
testing time for all three interfaces. The output files for all three tests were
almost identical, with the only difference being that the participant over-braked
slightly more during interface test B than the other two interfaces. This may
explain why the results for interface B were slightly higher, however the
participant reacted very similarly for all interface tests.

Participant 013 consistently applied pre-brake acceleration during all three
interface tests, and then compensated for this by applying excessive brakes in
reaction to the lead vehicle decelerating. The results for this participant were
ultimately an under-brake classification due to the fact that even though he
was applying excessive brakes, the reaction time was not quick enough to
reverse the effects of the pre-brake acceleration, and thus the distance
between the vehicles was consistently reduced to near-collision levels. There
were two instances of over-braking for each of the three interface tests, which
occurred when the participant continued the pre-brake acceleration and then
excessive brake application to small instances of lead vehicle deceleration.

Participant 022 also displayed a strong tendency to apply pre-brake
acceleration. All three tests were affected by the pre-brake acceleration and
the reaction of the participant was not sufficient to regain the default distance
from the lead vehicle, and thus all braking instances were classified as under-
brake. There was no discernable difference between the output files for each
of the three tests, except for the fact that the reaction times shown by the
participant tended to get slower towards the end of the testing period. This is
shown by the steady degradation of the results from the first test (interface A)
to the third test (interface C).
9.2 Analysis of Female 26-35 Results

The overall results for the female 26-35 group were positive towards the standard brake light interface with participant 004, and 031 performing best on the standard interface. Participant 026 performed best on the BMW inspired brake light interface and participant 007 performed best on the adaptive brake light interface, albeit by a small margin.

Participants 004 and 007 took part in the interface testing during the initial interface testing phase which may have had an influence on how they interacted with the driving simulator. Further investigation to follow will show that the results for these two participants are consistent with a participant who is not paying attention to the changing rear windscreen brake light. The average results for the female 26-35 group are shown below in figure 26.

![Figure 26. Female 26-35 Average Results](image)

The order of the interface tests sat by the female 26-35 group were of a reasonably random distribution, with each interface test occurring at least once in each positional order.
There was also an interesting distribution of driver experience in this group as only two of the participant obtained their drivers license when they were of licensable age. Participants 004 and 031 obtained their licenses when they were twenty-three and twenty-one respectively. The results for each participant and the interface test orders can be seen below in figure 31.

<table>
<thead>
<tr>
<th>26-35 Female</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 004</td>
<td>58.95</td>
<td>56.16</td>
<td>52.9</td>
<td>ABC</td>
<td>27</td>
<td>4</td>
</tr>
<tr>
<td>Participant 007</td>
<td>66.07</td>
<td>65.94</td>
<td>66.2</td>
<td>BCA</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>Participant 026</td>
<td>45.85</td>
<td>49.34</td>
<td>46.52</td>
<td>CAB</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td>Participant 031</td>
<td>56.43</td>
<td>50.82</td>
<td>53.11</td>
<td>BCA</td>
<td>33</td>
<td>12</td>
</tr>
<tr>
<td><strong>Mean Results</strong></td>
<td><strong>56.825</strong></td>
<td><strong>55.565</strong></td>
<td><strong>54.6825</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The female 26-55 results comparison as shown in figure 27 illustrates the steady decline of the results for participant 004 as they progressed throughout the interface testing. It also illustrates the consistent manner in which participant 007 interacted with the driving simulator irrespective of which brake light interface was being tested. The line graph also demonstrates the preference for the two variable brake lights shown by participant 026, and the clear preference for the standard brake light shown by participant 031.
Further investigation of the output results files calculated by the computer programme showed that participant 004 exhibited a very strong tendency to under-brake. The results for this participant were also affected by the fact that she applied pre-brake acceleration for all tests, with the occurrences getting more frequent as the testing progressed. There were five instances of pre-brake acceleration for the first test (interface A), six instances for the second test (interface B) and eleven instances for the third test (interface C). The participant’s reaction time also increased as the testing progressed. All these factors contributed to the steady decline in the results from interface A to interface C. It can be hypothesised that a more positive outcome would have been possible for interface B and C if the participant had maintained a consistent driving throughout all the interface tests.

Participant 007 showed a tendency to predominantly under-brake and the results were relatively consistent across the three interface tests. There were no instances of pre-brake acceleration or slow reaction times, which explains why the results for participant 007 were high. There were slightly more instances of appropriate braking for the two adaptive interfaces (interface B and C), and there were more instances of over-braking in interface A. The
participant adopted a consistent driving style and reacted very similarly to each interface. This consistent driving style is clearly shown in figure 24.

Participant 026 showed a strong tendency to under-brake and also applied pre-brake acceleration during all the interface tests. These trends were consistent throughout all the interface tests. The interface order for participant 026 was CAB and the participant displayed some instances of slow reaction times during interface C, with the reactions times improving during the other two tests. This means that the results for participant 026 are biased away from interface C to a small extent.

Participant 031 also showed a strong tendency to under-brake, which was compounded by a consistent tendency to apply pre-brake acceleration. The participant also had some extreme occurrences of slow reaction times, at some points up to 1.5 seconds. The driving style exhibited by participant 031 was very similar for the first two tests (interface B and C). The final test (interface A) was slightly different, having one instance of appropriate braking and one instance of over-braking. This explains the higher results for interface A.

9.3 Comparison of Male and Female 26-35 Results

When comparing the results of the male and female 26-35 results it is also interesting to note that the results fall within a similar range, of approximately 52-57% of time spend in the default position. This is a lower percentage than the 18-25 group, but is still supportive of the hypothesis that younger participants may yield high results due to their familiarity with computerised driving simulator interfaces, and also their ability to process new information may be greater than older drivers.

The average results comparison for the male and female 26-35 groups can be seen below in figure 28. The overall preference for the adaptive brake light shown by the male group is illustrated, as is the preference for the standard brake light shown by the female 26-35 group.
When looking at the results of the male and female 26-35 groups as a whole, the results are positive towards the variable interfaces for the male group, and positive towards the standard brake light interface for the female group. It is possible that if the participants had maintained a consistent driving style throughout the three tests, the results may have been more positive towards the adaptive interface. This will be explained further in section 9.4.

### 9.4 Findings

The results of the interface testing for the male and female 26-35 groups were positive towards the adaptive interface in the male group, and positive towards the standard brake light interface in the female group. Both the male and female groups were actually biased away from the variable interfaces due to some of the participants’ changing their driving style during the interface testing.

The male group was relatively unaffected by driving style alterations that could have influenced the results. The only point of note was that participant 022
showed a steady decline in reaction time from the first to the last test. The interface order for this participant was ABC, so there was a slight bias away from the adaptive interface due to this degradation in reaction time.

The result for the female 26-35 group was affected by two participants altering their driving styles in a manner which negatively affected the results for the variable interfaces. Participant 004 applied pre-brake acceleration for each test but in a steady progression from the first test to the last. The interface test order for this participant was ABC and thus more pre-brake acceleration was applied for the two variable interfaces, with interface C being the most affected. Participant 026 displayed several instances of slow reaction during the first test (interface C), a behaviour that stopped during the other two tests, so a slight bias away from interface C was exhibited by participant 026.

Therefore the results for the male and female 26-35 groups were biased slightly away from the adaptive interface C, but to a relatively small extent.

The difference between male and female drivers has been widely researched and there seems to be some trends specific to gender that remain constant regardless of the drivers’ age. Laapotti and Keskinen (2004) studied accident patterns between male and female drivers over a time frame of sixteen years with the aim of determining whether the difference in accident patterns between male and female drivers has changed or remained consistent from 1984 to 2000. The authors looked at all motor vehicle accidents for which damages were paid between 1987 and 2000, and also looked at all fatal accidents between 1984 and 2000 in Finland. The data was analysed in regards to the drivers’ age and divided into young drivers (18-25) and middle-aged drivers (35-55). It was found that female drivers had more accidents that involved vehicle manoeuvring and control of traffic situations such as reversing and loss of control accidents whilst not speeding. Male drivers tended to have more accidents that involved speeding and alcohol consumption, and also had more previous traffic offences than female drivers (Laapotti and Keskinen, 2004: 577).
When comparing young drivers with middle-aged drivers Laapotti and Keskinen (2004: 582) found that “overall young drivers had more accidents of all kinds compared to the middle-aged drivers”. The authors also found that differences between male and female drivers were more pronounced in younger drivers than middle-aged drivers in regards to risky driving behaviours such as speeding accidents and traffic offences (Laapotti and Keskinen, 2004: 582).

The results for the interface testing for the 26-35 age groups illustrate the differences between the male and female participants, with the male participants showing a steady improvement with the variable brake light interfaces, and the female participants showing a clear performance increase with the standard brake light interface. The fact that the male participants performed better with the adaptive interface is heartening as statistically male drivers are involved in more crashes that involve risk factors such as speeding and lack of headway distance. Rear-end crashes are commonly associated with these behaviours and thus the implementation of an adaptive brake light that could potentially reduce the occurrence of rear-end crashes would be of benefit to the male 26-35 group.

9.5 Summary

The chapter has analysed the results for both the male and female 26-35 groups, both individually and as a comparison between the two groups. The way that each individual participant responded to the driving simulator has been analysed, as has whether any of the participants exhibited behaviours that may have adversely affected the results for any one or two brake light interfaces. The results for the male tests were positive towards the adaptive interface and the female tests were positive towards the standard brake light interface, however the results for interface C may have been higher for both groups had some participants not altered the way in which they interacted with the driving simulator.

Chapter 10 will analyse the results for the male and female 36-45 groups.
10.0 Analysis of Participants 36-45

The following analysis of the male and female 36-45 participants will consider all factors that may have had some influence on the final results for these age and gender groups. The analysis will include the order of the interface tests for each participant, their relative driving experience, whether they took part in the initial interface testing phase or the revised interface testing phase. The analysis will also consider how each participant may have affected the results by altering the way in which they interacted with the driving simulator during the testing period.

10.1 Analysis of Male 36-45 Results

The overall result of the male 36-45 group was positive towards the adaptive brake light interface, with very little differentiation between the adaptive and BMW inspired interface when looking at the results as an overall average. Within this group there were two participants who took part in the initial interface testing phase, and two that took part in the interface testing during the revised testing phase. Both of the participants involved in the initial testing phase (participants 005 and 009) performed worst on the adaptive brake light interface, thus it can be hypothesised that had been informed that the rear windscreen brake light was the one point of differentiation between the three tests they may have performed better on the two variable interfaces.

In regards to driving style alterations during the interface testing for the male 36-45 group there were two participants who may have biased the results. However one of these participants changed their driving style in a manner that biased the results away from the variable interface, and the other changed their driving style in a manner that biased the results towards the variable interfaces. Further explanation of the participants’ driving style will follow, the average results for the male 36-45 group can be seen in figure 29.
The order of the interface tests were a reasonably random distribution between the six possible interface orders, with each interface test appearing at least once in the first, second and third order. The hypothesis that a participant may perform best on the interface test that they sat for second is not supported by the male 36-45 group, with only participant 018 performing best on the second interface test. The results for each interface and the individual test orders can be seen in Table 9.

<table>
<thead>
<tr>
<th>36-45 Male</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 005</td>
<td>58.84</td>
<td>61.03</td>
<td>57.27</td>
<td>ACB</td>
<td>45</td>
<td>28</td>
</tr>
<tr>
<td>Participant 009</td>
<td>49.07</td>
<td>43.38</td>
<td>44.24</td>
<td>CBA</td>
<td>36</td>
<td>19</td>
</tr>
<tr>
<td>Participant 018</td>
<td>71.71</td>
<td>67.42</td>
<td>66.36</td>
<td>BAC</td>
<td>36</td>
<td>11</td>
</tr>
<tr>
<td>Participant 020</td>
<td>55.91</td>
<td>63.61</td>
<td>69.28</td>
<td>CAB</td>
<td>36</td>
<td>19</td>
</tr>
<tr>
<td>Mean Results</td>
<td>58.8825</td>
<td>58.86</td>
<td>59.2875</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 30 shows the preference for the adaptive interface illustrated by participants 009 and 018. It also shows the very strong progression towards
the variable brake light interfaces by participant 020 and the preference for the BMW inspired interface shown by participant 005.

Further investigation of the output results files calculated by the computer programme showed that participant 005 reacted in a similar manner for all three interface tests. They showed a strong tendency to under-brake in reaction to the vast majority of lead vehicle deceleration instances. There were no major instances of pre-brake acceleration or slow reaction times so overall the results were unbiased for this participant. The interface testing for participant 005 did take place during the initial interface testing phase where the participants were not instructed to pay attention to the changing rear windscreen brake light which may explain why the results are generally similar for each interface test.

Participant 009 consistently applied pre-brake acceleration during all three of the tests, and thus each braking instance was classified as under-braking in reaction to the lead vehicle deceleration instances. The main factor that influenced the results in favour of the final test, interface A, was that the participant’s reaction time was faster during this test and thus the effects of
the pre-brake acceleration was reduced by the fact that the participant tended
to apply the brakes more quickly than in the other two interface tests.

Participant 018 displayed a tendency to under-brake for the majority of the
interface tests. The interface test order for this participant was BAC and the
participant did apply some pre-brake acceleration during the first test but
ceased this behaviour for the remaining interface tests. There were slightly
more instances of over-braking during the interface C, and more instances of
appropriate braking during interface A. Overall there were no major factors
that influenced the results for participant 018, however the pre-brake
acceleration displayed during interface test B may have adversely affected the
results for this interface test.

The results for participant 020 show a very strong preference towards the two
variable brake light interfaces. This was due in part to the fact that the
participant applied pre-brake acceleration consistently during interface A and
intermittently during interface B, whilst they did not apply pre-brake
acceleration during interface C. There were also more instances of
appropriate braking during interface C and to a lesser extent during interface
B. Thus the results for participant 020 are biased towards the adaptive
interface.

10.2 Analysis of Female 36-45 Results

The overall results for the female 36-45 group were very positive towards the
two variable brake light interfaces, with a clear preference for the adaptive
interface C. All four participants performed best on interface C, and three of
the four participants showed a clear progression in results with the standard
interface yielding the lowest results, the BMW inspired interface yielding the
second highest results and the adaptive interface yielding the highest results.
Participant 024 was the only person to perform better on the standard
interface than the BMW inspired interface.
All four of the participants took part in the revised interface testing phase, so all were instructed to pay attention to the changing rear windscreen brake light. This supports the hypothesis that people who were made aware of which brake light to pay attention to would perform better on the two variable brake light interfaces.

The female 36-45 group were an exceptionally conscientious group, all asking many questions and paying attention to the driving simulator task throughout its entirety. The results for this group support the hypothesis that participant who are diligent throughout the testing phase will yield high results, as this group was most certainly the most diligent.

The results for the female 36-45 group were also not biased in any way by the participants changing their driving style during the interface testing. For this reason the 36-45 female group was the most successful group to partake in the interface tests. The average results for the female 36-46 group are shown below in figure 31.

![Figure 31. Female 36-45 Overall Mean Results](image)

The order of the interface tests were a reasonably random distribution between the six possible interface orders, with each interface test appearing
at least once in the first, second and third order. The hypothesis that the participants may perform best on the interface test that they sat for second is not supported by the female 36-45 group, with only participant 023 sitting for the adaptive test in the second interface order. The hypothesis that the interface test that occurs last in the order may be the least successful is supported by participants 015 and 019, however the overall trend for this group to perform best on the adaptive interface seems to negate the hypotheses that are concerned with the interface orders. The results for each interface and the individual test orders can be seen in Table 10.

<table>
<thead>
<tr>
<th>36-45 Female</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 015</td>
<td>62.56</td>
<td>70.39</td>
<td>71.27</td>
<td>CBA</td>
<td>39</td>
<td>22</td>
</tr>
<tr>
<td>Participant 019</td>
<td>62.3</td>
<td>63.19</td>
<td>67.76</td>
<td>BCA</td>
<td>38</td>
<td>18</td>
</tr>
<tr>
<td>Participant 023</td>
<td>61.35</td>
<td>64.91</td>
<td>69.11</td>
<td>ACB</td>
<td>43</td>
<td>25</td>
</tr>
<tr>
<td>Participant 024</td>
<td>65.17</td>
<td>63.9</td>
<td>71.24</td>
<td>BAC</td>
<td>44</td>
<td>27</td>
</tr>
<tr>
<td>Mean Results</td>
<td><strong>62.845</strong></td>
<td><strong>65.5975</strong></td>
<td><strong>69.845</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 32 further illustrates the very strong tendency of the female 36-45 group to perform best on the two variable brake light interfaces. The slight deviation from this trend by performing better on the standard interface than the BMW inspired interface shown by participant 024 is also illustrated.
Further investigation of the output results files calculated by the computer programme showed that participant 015 interacted very positively to the two variable brake light interfaces and not as well to the standard brake light interface. The high results for interface C were influenced slightly by the fact that the participant had their foot partially on the brake pedal before the lead vehicle began to decelerate for three instances, however the amount of pressure applied to the brake pedal was minimal and thus did not have a marked effect on the results. The participant had high levels of appropriate braking for the two variable brake light interfaces and some instances of over-braking, with the remaining instances under-braking. The instances of over-braking and under-braking were quite mild in comparison to most other participants, which was reflected by the high results for interfaces B and C. During interface A the participant did not respond as well as the variable interface tests, with the majority of braking instances being under-braking and only one instance of over-braking or appropriate braking.

Participant 019 also responded well to the two variable brake light interfaces, performing the best on the adaptive interface C. The braking style classification table showed an almost balanced distribution of under-braking
and over-braking across all three tests, with over-braking being slightly more predominant. Interface C had the most instances of appropriate braking, followed by interface B and then interface A. The other main point of differentiation between the three brake light interface tests was that the instances of over-braking and under-braking were less extreme in the two variable interfaces than the standard brake light interface. The participant did not respond as well to interface A, which is shown by longer periods of time taken to return to the default position when compared to interface B and C.

Participant 023 showed a tendency to mainly over-brake, especially during the two variable interface tests. During interface A the participant had a balanced distribution of under-braking and over-braking, with generally large instances of each. Whilst the participant over-braked mainly during interface B and C the magnitude of these instances was less that during interface A.

Participant 024 also showed a tendency to over-brake but there also a smaller number of under-brake instances. Interface C was the most successful interface and this is illustrated by the fact that were three instances of appropriate braking during this test, whilst there was one instance of appropriate braking for interfaces A and B.

10.3 Comparison of Male and Female 36-45 Results

When comparing the results of the male and female 36-45 groups there is a very obvious difference between the two groups. The female group displayed a very consistent positive trend towards the adaptive interface, and whilst the male group results were also positive towards the adaptive interface, it was to a much lesser extent.

The results for both the male and female groups are quite high, the female results are the highest throughout the entire age and gender range, and the male results are higher than the 26-35 groups, but lower than the 18-25 groups. Thus the hypothesis that younger drivers will perform better than older drivers is supported, but is dependent on the definition of older drivers. The
line graph showing the average results comparison for the male and female 36-45 group can be seen in figure 33.

![Line graph showing the average results comparison for the male and female 36-45 group](image)

**Figure 33. Male and Female 36-45 Mean Results**

When looking at the results of the male and female 36-45 groups as a whole, the results are positive towards the variable interfaces for the male group, and very positive towards the variable brake light interfaces for the female group. It is possible that if the male participants had maintained a consistent driving style throughout the three tests, the results may have been more positive towards the standard interface. This will be explained further in section 10.4.

### 10.4 Findings

The overall results for the male and female 36-45 were positive towards the variable interfaces. The results for the female group were not biased in any way, with all four participants responding consistently to the driving simulator, and all four participants being very diligent and concentrating throughout the three interface tests. The results of the male 36-45 group were actually biased slightly away from the standard interface with one participant altering their driving style in a manner that favoured the two variable interfaces.
The results for the male 36-45 group were affected by participant 020 applying pre-brake acceleration inconsistently throughout the interface tests. The participant applied pre-brake acceleration consistently during interface A and intermittently during interface B, whilst they did not apply pre-brake acceleration during interface C.

This means that the results for the male 36-45 group were biased away from the standard interface, and had the participant maintained a consistent driving style throughout the testing the results may have been higher for interface A.

Vigilance whilst driving and the correlation between driver errors and vigilance level has been addressed by Campagne, Pebayle, and Muzet (2004). The authors conducted a driving simulator study with forty-six male drivers from three age groups in order to compare the level of vigilance displayed by drivers 20-30, 40-50 and 60-70 years of age. The study involved a 350 kilometre night driving exercise and the participants were monitored with an electroencephalography (EEG) machine in order to measure the level of fatigue and drowsiness displayed by the participants Campagne et al (2004: 515). The study found a direct correlation between the drivers’ level of vigilance and driving performance; a low state of arousal was shown to be a main factor of driving performance degradation Campagne et al (2004: 522).

Whilst the study conducted by Campagne et al (2004) concentrated on the participant’s level of wakefulness and arousal, the findings can be said to correlate to the level of attention applied to the driving task. The positive results of the female 36-45 group are consistent with drivers who are alert and apply themselves to the driving task.

The responsibility for traffic crashes that cause damage, injury or death is disproportionately weighted towards younger drivers, particularly male drivers (Williams and Shabanova, 2003: 527). Elderly drivers are also responsible for an unbalanced proportion of traffic crashes. Thus it can be said that the age
and gender group at the least risk of being involved in a traffic incident are middle-aged drivers.

The success of the male and female 36-45 groups in the driving simulator study shows that drivers with a high level of experiential knowledge, and whom are not yet hampered by physical attributes specific to older drivers are likely to be less at risk on the road.

10.5 Summary

The chapter has analysed the results for both the male and female 36-45 groups, both individually and as a comparison between the two groups. The way that each individual participant responded to the driving simulator has been analysed, as has whether any of the participants exhibited behaviours that may have adversely affected the results for any one or two brake light interfaces. Overall the response from this age group was positive towards the adaptive interface.

Chapter 11 will analyse the results for the male and female 46+ groups.
11.0 Analysis of Participants 46+

The following analysis of the male and female 45+ participants will consider all factors that may have had some influence on the final results for these age and gender groups. The analysis will include the order of the interface tests for each participant, their relative driving experience, whether they took part in the initial interface testing phase or the revised interface testing phase. The analysis will also consider how each participant may have affected the results by altering the way in which they interacted with the driving simulator during the testing period.

11.1 Analysis of Male 46+ Results

The average results for the male 45+ group were positive towards the BMW inspired interface with two participants (008 and 033) performing the best on this interface. The remaining two participants performed best on the standard interface.

Closer examination of the results to follow will illustrate the large variations in results for individual participants which may support the hypothesis that older drivers may be less familiar with the computerised driving simulator, and also may be over-reliant on their bulk of experiential knowledge in regards to responding to lead vehicle deceleration instances.

The first participant (008) took part in the interface testing during the initial interface testing phase, with the remaining three participants taking part in the revised interface testing phase. This may have had some affect on the overall results but is overshadowed by other factors that may have influenced the results for this group. The average results for the male 46+ group can be seen in figure 34.
The order of the interface testing was not a random distribution for the male 46+ group. Three of the four participants started the interface testing with the adaptive brake light interface. This may have had some affect on the results; not only because of the hypothesis that the first interface test that the participants may be the lesser scoring test because they are still gaining familiarity with the driving simulator. The hypothesis that older drivers may be less familiar with the computerised driving simulator and thus not perform as well as their younger counterparts might have compounded the above-mentioned affect on the results. The results for each interface and the individual test orders can be seen in table 11.

<table>
<thead>
<tr>
<th>46+ Male</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW Inspired)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 008</td>
<td>45.34</td>
<td>48.23</td>
<td>39.74</td>
<td>CAB</td>
<td>50</td>
<td>32</td>
</tr>
<tr>
<td>Participant 017</td>
<td>70.6</td>
<td>63.33</td>
<td>70</td>
<td>ACB</td>
<td>49</td>
<td>31</td>
</tr>
<tr>
<td>Participant 021</td>
<td>69.12</td>
<td>68.95</td>
<td>60.97</td>
<td>CBA</td>
<td>51</td>
<td>36</td>
</tr>
<tr>
<td>Participant 033</td>
<td>56.84</td>
<td>63.43</td>
<td>63.01</td>
<td>CBA</td>
<td>57</td>
<td>40</td>
</tr>
<tr>
<td>Mean Results</td>
<td>60.475</td>
<td>60.985</td>
<td>58.43</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 35 shows the quite erratic result pattern for the male 46+ group. The hypothesis that each participant will tend to yield results within a relatively close range is disproved in this group, with the results for each participant distributed over a comparatively large range.

![Figure 35. Male 46+ Results Comparison](image)

Further investigation of the output results files calculated by the computer programme showed that participant 008 reacted in the same manner for each interface test. The participant consistently applied pre-brake acceleration across all three interface tests, and thus the resultant braking instances were all classified as under-braking. The testing took place during the initial interface testing phase and so the participant was not instructed to pay attention to the changing rear windscreen brake light, which may explain the low results for the adaptive interface C.

Participant 017 was consistent for in their interaction with the programme for the first two tests that they completed; interfaces A and C. During the first test (interface A) there was no application of pre-brake acceleration and there was only minor instance of pre-brake acceleration during interface C. Thus the results for these two tests were unbiased and the driving style classification
table showed a relatively balanced distribution of under-brake and over-brake instances. There were two instances of appropriate braking during interface A and three instances of appropriate braking during interface C. During the final test (interface B) the participant did change their driving style slightly by applying pre-brake acceleration during four instances of lead vehicle deceleration, which meant that the instances of under-braking were higher and there were no instances of appropriate braking for interface B. Thus the results for participant 017 were biased away from interface B, which is clearly shown in the results for this participant as shown in figure 31.

Participant 021 interacted with the programme in a mildly inconsistent manner; with pre-brake acceleration being applied more often as the interface testing progressed. The order of the testing for participant 021 was CBA, and pre-brake acceleration was applied twice during interface C, four times during interface B and six times during interface A. This meant that there were more instances of under-braking during interface A and B as a result of this pre-brake acceleration application. The results for participant 021 do not reflect this behaviour, showing a clear preference for interfaces A and B and comparatively low results for interface C. It is possible that the fact that interface C was the first interface to be tested and the participants’ unfamiliarity with the computer programme affected the first interface test in a negative manner, supporting the hypothesis that the first interface test that the participants complete will yield the lowest results.

Participant 033 interacted with the programme in a consistent manner for all three interface tests. There were no instances of over-braking displayed and only one or two instances of appropriate braking for each test, with the majority of braking instances being classified as under-braking. One point of interest to note is that participant 033 requested to repeat the warm-up exercise three times. Several participants requested a second warm-up and several actually did the warm-up exercise before each test but participant 033 was the only participant to request more than two warm-ups. This may have worked in the favour of interface C as that was the first test and thus the warm-up exercise also displayed the interface C brake light configuration.
Participant 033 became more familiar with interface C than the other two participants from this age and gender group that also started with interface C, which may explain the higher result for interface C when compared with the other participants from this age and gender group.

11.2 Analysis of Female 46+ Results

The overall results for the female 46+ group were ultimately positive towards the standard brake light interface with all four participants performing best on this interface. Three of the four participants illustrated a clear downward progression from the standard interface to the BMW inspired interface then to the adaptive interface. Participant 014 was the only participant to perform better on the adaptive interface than the BMW inspired interface, and this was by a significant amount.

All four participants took part in the revised interface tests and thus were all instructed to pay attention to the rear windscreen brake light. However this does not support the hypothesis that when instructed to pay attention to the changing rear windscreen brake light the participants will respond to the extra information provided by the BMW inspired interface and the adaptive interface.

The results of the female 46+ group may support the hypothesis that older drivers may be less familiar with the computerised driving simulator, and also may be over-reliant on their bulk of experiential knowledge in regards to responding to lead vehicle deceleration instances. The average results for the female 46+ age group interface tests can be seen in figure 36.
The order of the interface tests for the female 46+ group were not a random distribution, with three of the four participants having interface C as their final test. This does support the hypothesis that the final test sat by the participant may be lower scoring due to fatigue. This hypothesis is also supported by participant 014, who had interface B as the final interface and had the lowest result for this interface test. It is also interesting to note that participant 014 was the only participant to start the interface testing with interface C, and was the only participant to have results contrary to the trend for this group. The interface order for this group may have had a significant affect on the results. The results for each interface and the individual test orders can be seen in table 12.
### Table 12. Female 46+ Results

<table>
<thead>
<tr>
<th>46+ Female</th>
<th>Interface A (Standard)</th>
<th>Interface B (BMW)</th>
<th>Interface C (Adaptive)</th>
<th>Order</th>
<th>Age</th>
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The female 46+ group as shown in figure 37 illustrates the strong tendency for this group to perform best on the standard interface A, and shows the strong downward trend from the standard interface. It also clearly shows how participant 014 was the only participant to not follow the overall trend for this age group.

![Figure 37. Female 46+ Results Comparison](image)

Further investigation of the output results files calculated by the computer programme showed that participant 014 was relatively consistent with her reactions to the lead vehicle deceleration instances across all three of the interface tests. The majority of the braking instances were classified as under-
braking, with some instances of over-braking and appropriate braking during all three of the interface tests. There were no instances of pre-brake acceleration and the only inconsistency in the manner in which the participant applied brakes was during the final test (interface B) where the reaction times were slower than in the in the first two tests. This explains the lower results for interface B for participant 014.

Participant 016 was inconsistent in the way that she interacted with the computer programme. The results for this participant as shown in figure 46 show a steady downward curve from interface A to interface C. This is due to the fact that the participant changed their driving style as the testing progressed. The most successful interface for participant 016 was interface A; during this test the participant applied a moderate level of pre-brake acceleration (eight instances) and had nine instances of excessive braking. The resultant reactions were distributed relatively evenly between over-braking and under-braking. The magnitude of the pre-brake acceleration and excessive braking was less for interface A than the remaining two instances. During interface test B the participant applied similar levels of pre-brake acceleration and excessive braking, however they were larger in magnitude, with more pedal pressure during the pre-brake acceleration and thus larger instances of excessive braking to compensate. The majority of the braking instances for interface B were classified as over-braking, because the participant was able to apply the brakes (albeit to an excessive level) in time to react to the lead vehicle’s deceleration. During interface C the participant applied pre-brake acceleration and excessive braking during all lead vehicle deceleration instances to a large degree. The participant did not react in time with the excessive braking to halt the approach of the lead vehicle and thus the braking instances for interface C were mainly all under-braking. The results for participant 016 are biased towards the standard brake light interface and to a lesser degree the BMW inspired interface due to the participants change in driving style during the test.

Participant 028 was relatively consistent in their reaction to the computer programme across all three interface tests. There were no instances of pre-
brake acceleration and no instances of excessive braking. The main factor that caused the lower results for interface B and C was that the participant’s reaction time grew slower as the testing progressed. The interface test order for participant 028 was ABC and the reaction time for interface A was generally higher than it was for interface B and interface C. There were three instances of slow reaction logged for interface tests B and C, which means that it took more than one second for the participant to apply the brakes, however there was a general trend for the reaction time to be slower during these two tests, particularly the final test (interface C). The results overall for participant 028 are unbiased though, as there was no pre-brake acceleration or other behavioural changes to affect the results.

Participant 030 was also relatively consistent in their reaction to the driving simulator. The vast majority of braking instances were classified as under-braking, with two instances per test of appropriate braking. The only factor that may have influenced the results in a negative manner was that during the final test, interface C, the participant applied pre-brake acceleration twice, which have biased the results slightly away from interface C.

11.3 Comparison of Male and Female 46+ Results

When comparing the results of the male and female 46+ groups the trends appear to be somewhat similar. Both the groups exhibit a large gap between the standard and the adaptive brake light interface. The female 46+ group shows a steady degradation from the standard brake light; to the BMW inspired and then the adaptive brake light interface. The male group still has a decline from the standard interface to the adaptive interface, however the results for the BMW inspired interface are higher than the standard interface. This supports the hypotheses that older drivers may not be as successful at interpreting new information provided to them by the variable lights due their large bulk of experiential knowledge.

The average results for the interface tests for both groups are relatively high, so the hypothesis that younger drivers will score higher than older drivers due
to their familiarity with computerised driving simulators is not supported by these average results. The average results comparison for the male and female 46+ age group can be seen in figure 38.

![Figure 38. Male and Female 46+ Mean Results Comparison](image)

When looking at the results of the male and female 46+ groups as a whole, the results are positive towards the standard interface tests for both groups. It is possible that if the participants had been consistent in their interaction with the driving simulator the results would have been so conspicuous towards the standard interface. This will be explained further in section 11.4.

### 11.4 Findings

The results for the male and female 46+ groups were both positive towards the standard brake light interface, however some participants altered the way they interacted with the driving simulator throughout the testing, which biased the results further towards the standard interface.

In the male 46+ group participant 017 applied pre-brake acceleration during the BMW inspired interface test, which biased the results away from interface
B. The remaining participant responded consistently throughout the three interface tests, at least as far as behaviour that can bias the results is concerned.

In the female 46+ group two participants exhibited behaviour that biased the results away from the two adaptive interfaces. Participant 016 applied pre-brake acceleration inconsistently throughout the interface tests. There was a steady increase in the amount and level of pre-brake acceleration from interface A to interface C, with relatively small amounts applied during interface A and consistently large application of pre-brake acceleration applied during interface C. Participant 030 may have slightly biased the results of the interface C test by applying pre-brake acceleration to a large extent on two occasions, whilst there was no application of pre-brake acceleration during the other two interface tests.

Therefore the results for the male and female 46+ groups were biased towards the standard brake light interface. This would most likely not have affected the results to the extent where another interface would be deemed more successful, however it may have reduced the differential in results between the three interface tests.

The acceptance of in-vehicle technology by middle aged and older drivers has been studied by Donmez, Ng Boyle, Lee and McGehee (2006). The authors conducted a study to assess driver acceptance and trust of distraction mitigation strategies, which are intended to reduce the distraction caused by in-vehicle warning systems. The research found that older drivers were more trusting of in-vehicle technology, even when the system was shown to be flawed, whereas the middle aged drivers trusted the technology less (Donmez et al, 2006: 1).

Generally speaking middle-aged drivers have a large base of experiential knowledge to draw from when driving. This is true of the 46+ age group tested, with all drivers having decades of driving experience. The high results for the standard brake light interface support the assumption that older drivers
are more likely to have high levels of confidence when driving due to this experiential knowledge and may not feel it necessary to change their driving behaviour in response to a different type of brake light interface.

Another factor that may have contributed to the lower scores for the variable brake light interfaces is that drivers of this age group are less likely to be familiar with computer gaming software. The participants may have been applying a higher cognitive load to their interaction with the software and hardware and not been concentrating specifically on the brake light interfaces.

11.5 Summary

The chapter has analysed the results for both the male and female 46+ groups, both individually and as a comparison between the two groups. The way that each individual participant responded to the driving simulator has been analysed, as has whether any of the participants exhibited behaviours that may have adversely affected the results for any one or two brake light interfaces.

Overall the results were positive towards the standard interface to a large degree. As mentioned earlier the results were also biased towards the standard interface but it is unlikely that the participant behavioural changes would have affected the results enough to show a positive result for one of the variable brake light interfaces.

Chapter 12 will analyse the results overall and give a comparison of the overall male and female results.
12.0 Overall Analysis

A comparison of the average results for the overall user testing will follow. Whilst there is a relatively small percentage difference between the average scores for each interface test, it is still a worthwhile exercise to compare the most successful interface for females against the most successful interface for the male participants. The overall most successful interface will also be discussed, although it is pertinent to remember how the different age and gender groups responded to each individual interface, and how the differences between them was that each age and gender responded is not represented in overall average results.

12.1 Analysis of Overall Male Results

The overall analysis for the male participant average results shows that the most successful interface was the BMW inspired interface with participants spending an average of 58.66% of the time in the default position. The adaptive interface was the second most successful interface with participants spending 58.47% of the time in the default position. The least successful interface overall was the standard interface with male participants spending an average of 58.05% of the time in the default position.

The overall male interface testing average results can be seen in figure 39.
Whilst it has been shown in the previous chapters that there is a large variation in how different male age groups responded to the three different brake light interfaces, the overall results are still positive towards the two variable brake light interfaces.

12.2 Analysis of Overall Female Results

The overall analysis of the female average results shows that the most successful interface was the adaptive interface with the participants spending an average of 62.57% of the time in the default position. The second most successful interface was the standard brake light interface with participants spending an average of 62.50% of time in the default position. The least successful interface for the female participants was the BMW inspired interface, with participants spending an average of 62.49% of the time in the default position.

The overall female interface testing average results can be seen in figure 36.
Whilst it has been shown in the previous chapters that there is a large variation in how different female age groups and indeed individual participants responded to the three different brake light interfaces, overall the results are positive towards the adaptive brake light interface.

### 12.3 Comparison of Overall Male and Female Results

The average of the male and female results when compared together show an interesting trend for the female results to be consistently higher than the average male results. This may be consistent with the hypothesis that the participants who were diligent in their interaction with the driving simulator would achieve high results. It is an empirical observation but it can be said that the female participants overall were more diligent than the male participants.

Perhaps this is due to males in general being more confident of their driving ability and thus feeling that they do not need to apply themselves to the driving task as much as the female participants felt that they needed to.
The overall female and male average results comparison can be seen in figure 41.

![Figure 41. Overall Male and Female Mean Results Comparison](image)

The average female and male results are representative of the user testing in its entirety, however the preceding detailed analysis of individual age and gender groups give a more accurate depiction of the brake light interface user testing results.

### 12.4 Findings

It can be said that the brake light interface user testing was a successful exercise, showing that an adaptive brake light and a semi adaptive brake can provide more information to drivers, and that most drivers can respond appropriately to the extra information provided by these variable brake lights.

When looking at the results overall they are not as lucid as was hoped, however when looking at how different types of drivers respond to variable brake lights the success of the brake light interface testing becomes more apparent.
The differences between male and female drivers, and the effects of the drivers’ age has been well documented and mentioned previously. Generally speaking very old and very young drivers are much more likely to be involved in a traffic incident than middle aged drivers (Kim, Li, Richardson and Nitz, 1998: 171). Also young males are more at risk than young female drivers, and older female drivers are more at risk than older male drivers (Kim et al, 1998: 172).

These differences in driver risk in regards to age and gender have been reflected somewhat in the results of the interface testing. However whilst a high result for the adaptive interface by an age or gender group that is at a lower comparative risk level may support the existing research, the most promising outcome occurs when an age or gender group that is at risk performs well on the adaptive brake light interface. Therefore even though the female 36-45 group performed the best on the adaptive interface and were by far the most successful group, the fact that the younger male groups performed well on the adaptive interface is the most promising result as these groups are most at risk on our roads and would benefit from the application of an adaptive brake light.

12.5 Summary

This chapter has analysed the overall results for the male and female participants. Overall the results were positive towards the adaptive brake light interface for the female participants and the BMW inspired interface for the male participants.

This does illustrate that variable brake light interfaces can potentially provide a benefit to society in regards to road safety. The fact that the adaptive brake light was well received by the most at risk age and gender groups warrants further investigation into this type of passive brake light interface technology.
13.0 Conclusion

This thesis has outlined the relationship between In-Vehicle Intelligent Transport Systems and road safety and demonstrated that whilst most forms of In-Vehicle ITS are beneficial, there are some that adversely affect driver concentration and attentiveness. The adaptive brake light concept was initiated in reaction to the potential deleterious effects of some forms of In-Vehicle ITS and provides drivers with more information about the deceleration of the lead vehicle without relying on complex technological solutions that may remove the driver from the driving task.

The research question motivating this thesis was “what are the benefits and potential deleterious effects provided by In-Vehicle ITS, how do these issues affect road safety and will an adaptive brake light display provide a benefit in regards to road safety?” The first aim of the research was to investigate the positive and negative aspects of In-Vehicle ITS and their impact on driver attention, awareness and road safety. The second aim was to evaluate an adaptive brake light interface against a semi-adaptive interface and a standard interface and determine which is the most effective method of displaying varying levels of deceleration.

The methodology and protocol of the user interface testing of the adaptive brake light in comparison with a standard brake light interface and a BMW inspired brake light has been explained. The individual results of each participant were analysed and the manner in which each participant interacted with the driving simulator was taken into account, including any behaviour that may have biased the results. The interface testing results were also considered in regards to different age and gender groups and any trends that were unearthed that were specific to a particular age and gender group were discussed. The overall results were also discussed, although it is pertinent to note that the different age and gender group results yielded results that are far more indicative of how different people may react to an adaptive brake light interface. This was due to the fact that high results by some age and gender
groups were negated by low results that were attained by other age and gender groups.

The different age and gender groups responded differently to the three brake light interfaces that were tested. In some cases the hypotheses that were proffered were supported such as the hypothesis that people who were more diligent in their interaction with the driving simulator would yield higher results than those who were not diligent. In other cases the hypotheses were proved incorrect such as the proposition that younger drivers would perform better during the driving simulator task than older drivers due to their familiarity with computerised driving interfaces. The age and gender group with the highest results was the female 36-45 group, whom all showed a large degree of diligence and concentration whilst interacting with the driving simulator. However the younger drivers, who are most at risk on our roads, showed a positive reaction to the two variable brake light interfaces, which warrants the further study of an adaptive brake light interface. This research has shown that the application of an adaptive brake light interface can improve driver performance and help drivers to better judge the level of deceleration of the vehicle in front.

The adaptive brake light has the potential to improve road safety by reducing the occurrence of rear-end crashes. Whilst statistics vary between regions and countries, rear-end crashes account for a significant number of crashes in all areas where automobile use is prevalent. A reduction in the number of rear-end crashes on our roads would provide a substantial benefit by reducing the number of fatalities, injuries and loss or damage to property caused by rear-end crashes. This would potentially save governments and the private sector reasonable amounts of money that could be channelled back into the community in the form of road improvements and other road safety initiatives.

Although not tested in the user interface tests a secondary benefit provided by the adaptive brake light is that it may reduce instances of stop-start driving in congested traffic as it allows drivers to better judge the deceleration of the car in front and thus not over-react to a minor braking instance.
Further research into the effectiveness of the adaptive brake light is recommended. It would be of benefit to test the adaptive brake light in a virtual scenario that represents real world driving in a more realistic context. User interface testing in a driving simulator that includes more virtual vehicles and various traffic hazards would yield results that represent how drivers would react to the adaptive brake light should it be implemented into road going vehicles. This type of testing would also illustrate whether stop-start driving would be reduced in congested traffic conditions. A larger sample size of participants would also be of benefit to ensure that the adaptive brake light is well received by all members of the driving public.

A further progression for research into the adaptive brake light would be to apply the technology to an actual vehicle and test driver response in controlled real-world conditions. Should the adaptive brake light again prove to be a more effective brake light than a standard brake light after further research then the implementation of the technology into automobiles and other forms of transportation should be considered.
References


Appendix A: Participant Information Sheet and Consent Form

Participant Information Sheet

“In-Vehicle Intelligent Transport Systems (ITS) and their Relationship to Road Safety”

Craig Roughan BBE GDID
c.roughan@student.qut.edu.au
0438 392047

Description
This project is being undertaken as part of a Masters project for Craig Roughan.

The purpose of this project is to determine the relationship between different vehicular brake light configurations and their impact on road safety.

The research team requests your assistance in identifying how drivers respond to different displays of deceleration.

Participation
Your participation will involve a questionnaire and then a driving simulator task which will take approximately 15 minutes. The driving simulator task will take place in Room D408, the Human-Centred Design Research and Usability Lab at QUT Gardens Point Campus.

Expected benefits
It is expected that this project will not benefit you immediately. However, it will provide valuable information to automobile designers and researchers that will help them design safer automobiles.

Risks
There are no risks associated with your participation in this project.

Confidentiality
All comments and responses are anonymous and will be treated confidentially. The names of individual persons are not required in any of the responses.

Voluntary participation
Your participation in this project is voluntary. If you do agree to participate, you can withdraw from participation at any time during the project without comment or penalty. Your decision to participate will in no way impact upon your current or future relationship with QUT.

Questions / further information
Please contact the researchers if you require further information about the project, or to have any questions answered.

Concerns / complaints
Please contact the Research Ethics Officer on 3864 2340 or ethicscontact@qut.edu.au if you have any concerns or complaints about the ethical conduct of the project.
Participant Information Sheet

“In-Vehicle Intelligent Transport Systems (ITS) and their Relationship to Road Safety”

Craig Roughan BBE GDID
c.roughan@student.qut.edu.au
0438 392047

Statement of consent

By signing below, you are indicating that you:

• have read and understood the information sheet about this project;

• have had any questions answered to your satisfaction;

• understand that if you have any additional questions you can contact the research team;

• understand that you are free to withdraw at any time, without comment or penalty;

• understand that you can contact the research team if you have any questions about the project, or the Research Ethics Officer on 3864 2340 or ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project;

• agree to participate in the project.

Name

Signature

Date  _____ / _____ / _____
Appendix B: Brake Light Interface User Test Questionnaire

Queensland University of Technology
BN71 Masters of Applied Science (Research)
Craig Roughan BBE GDID

Investigator Use

Date: _____  Test Order: A B C  B C A
Time: _____  A C B  C A B
Participant Number: _____  B A C  C B A

1. Age: _____  2. Gender:  F  M

3. Occupation: _____
   (If student please state what you are studying)

4. How long have you been a licensed driver? _____
   (not including learners permit)

5. On a scale of 1-10 how would you rate your driving?
   • Confidence: _____
   • Ability: _____
   • Attentiveness: _____

Thank you for your participation

Results:  A: _____  B: _____  C: _____
### Appendix C: Interface Test Output File Examples

This output text file example has been taken from the file generated for participant 017 and illustrates his reactions to the computer program during the first instance of deceleration and the last instance during Interface Test B (BMW Inspired).

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<td>15.30 60.00 / 80.00</td>
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**Appendix C:** Interface Test Output File Examples

This output text file example has been taken from the file generated for participant 017 and illustrates his reactions to the computer program during the first instance of deceleration and the last instance during Interface Test B (BMW Inspired).
## Appendix D: Participant Driving Style Classification Table

<table>
<thead>
<tr>
<th>Group</th>
<th>Participant</th>
<th>Order</th>
<th>Pre-Brake Acceleration</th>
<th>Excessive Braking</th>
<th>Appropriate Braking</th>
<th>Slow Reaction Time</th>
<th>Under-Brake</th>
</tr>
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<td>Male 18-25</td>
<td>010</td>
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</tr>
<tr>
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<td>ABC</td>
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</tr>
</tbody>
</table>

Note: The table continues with additional columns for each participant, indicating their classification for each driving style category.