LOUGHBOROUGH UNIVERSITY

# A HUMAN FACTORS SYSTEMS APPROACH TO EXPLORING VEHICLE ROLLAWAY

Valerie G. Noble

February 2018

Loughborough Design School
Loughborough University

Doctoral Thesis

This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy of Loughborough University

# Abstract

Failure of a parked unattended vehicle to remain stationary, otherwise known as vehicle rollaway, can result in property damage, injury or even fatality. Although the incidence of vehicle rollaway may be under reported, around 8% of drivers and 13% of Approved Driving Instructors surveyed indicated they had experienced a vehicle rollaway event.

Unlike previous studies which focused only on the mechanical factors that may contribute to this phenomenon, the research presented in this thesis employed a more comprehensive, systems approach to explore additional factors related to the driver's interaction with the parking brake system at various interface levels.

A mixed methods strategy collated data through two online surveys and three observational studies to explore the organisational, mechanical and driver related factors identified in a fault tree framework. The results indicated that current driver practice and interaction with the parking brake system may be contrary to legislative requirements and manufacturer's instruction. The findings also suggested that past experience, such as that of vehicle rollaway or parking brake system failure, had a statistically significant influence on whether the driver complied with recommended practice.

Driver interaction and the holding capability of the parking brake system was observed in 53 vehicles parked on three test gradients. The observations indicated that drivers were able to apply sufficient force to the parking brake lever to hold the vehicle stationary and that an additional degree of confidence in the system was provided by parking in gear. But, after driving a short commuting route, when the vehicle was parked with the parking brake lever applied to the lowest position to hold the vehicle and a gear was not selected, 63% of vehicles fitted with disc brakes rolled as the temperature returned to ambient.

Discussion relates to the organisational, driver related and mechanical components of the parking brake system and in reference to Reason's Swiss Cheese model, considers how latent failures within the defensive layers of the system can contribute to rollaway. The research findings contributed to a change in UK driving standards and since 2015, drivers are recommended to park in gear at all times to reduce the

risk of rollaway. This recommendation is likely to require a change in practice for up to 80% of Approved Driving Instructors who would not normally instruct new drivers in this way.

Although this research focused on the manually operated parking brake system, the studies have uncovered results that can contribute to knowledge and are applicable to interaction with electronic parking brake systems. As parking brake systems develop, the Human Factors systems approach can be applied retrospectively and proactively to explore that interaction and prevent passenger vehicle rollaway.

# Dedication

For Mum.

## Acknowledgements

My husband, family and friends for their patience, understanding and support

Richard Frampton and John Richardson, Supervisors for guidance and support

Eddie Curry and Ben Suffolk at MIRA

Allan Morgan (husband) for his electronics expertise

The staff at St Luke's Hospice, Plymouth for their support and participation

Ron Spence and the staff at Cornwall Mobility Centre

Pen Davies-Gregory for her support and assistance in collecting data

Car Park Managers and staff:

- Derriford Hospital, Plymouth
- Addenbrookes Hospital, Cambridge
- Raigmore Hospital, Inverness
- Birmingham City Hospital
- Gloucester General Hospital

Sue Duncan, Lynn Barrie, Approved Driving Instructor National Joint Council

Helen Luker, Ian Holden, Driving Standards Agency

Dr Bernie Masters for his continued support

# Project Outcomes

## Driving Standards

Presentation of interim results and communication with Education Advisers of the Driving Standards Agency has contributed to a change of wording and instruction in the Driving Standards. The 2015 edition of *The Official DVSA Guide to Driving – the essential skills,* now states " when you park your vehicle, always leave it in gear and make sure that the parking brake is fully on" (DVSA, 2014, pp. 57-58, 240).

## Publications

Noble, V.G., Frampton, R.J., Richardson J.H., 2015. Exploration of the Factors Associated with a Parked Unattended Vehicle Failing to Remain Stationary – Brake Cooling Effects. In: *EuroBrake 2015 Conference Proceedings.* Dresden, Germany, 4-6 May 2015. London: International Federation of Automotive Societies (FISITA) ISBN 978-0-9572076-0.

Noble, V.G., Frampton, R.J., Richardson J.H., 2014. Ergonomics of Parking Brake Application –Factors to Fail? In: S. Sharples, S.T. Shorrock S.T., eds. 2014. *Contemporary Ergonomics and Human Factors*. London: Taylor & Francis pp. 48-488. *http://www.crcnetbase.com/doi/abs/10.1201/b16742-84.*

Noble, V.G., Frampton, R.J., Richardson J.H., 2013. Ergonomics of Parking Brake Application: An Introduction. In: L. Dorn, M. Sullman, eds. *Driver Behaviour and Training Vol VI.* Surrey: Ashgate pp.187-206.

Noble, V., 2014. "Now where did I park my car?" *The Ergonomist*, 523, pp. 4-5.
The Institute of Ergonomics and Human Factors (IEHF), ISSN: 0268-5639.

## List of Abbreviations

The following list describes the various abbreviations and acronyms used throughout the thesis.

| **Abbreviation** | **Meaning** |
|---|---|
| ADI | Approved Driving Instructors |
| ADINJC | Approved Driving Instructor National Joint Council |
| DfT | Department for Transport |
| DSA | Driving Standards Agency |
| DVSA | Driver and Vehicle Standards Agency |
| ECE | Economic Commission for Europe |
| EPB | Electronic Parking Brake |
| FOI | Freedom of Information |
| HC | Health Care Workers |
| IAM | Institute of Advanced Motorists |
| LU | Loughborough University |
| MOT | Ministry of Transport |
| MIRA | Motor Industry Research Association |
| N | Newton |
| NHTSA | National Highway Traffic Safety Administration |
| PB | Parking Brake |
| PING | Park in Gear |
| RAIB | Rail Accident Investigation Branch |
| ROSPA | Royal Society for Prevention of Accidents |
| RPE | Rating of Perceived Exertion |
| SAR | Static Assessment Rig |
| SLH | St Luke’s Hospice |
| SMMT | Society of Motor Manufacturers and Traders |
| UNECE | United Nations Economic Commission for Europe |
| VSB | Vehicle Safety Branch |
| VOSA | Vehicle and Operators Services Agency |

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# Chapter 1: Introduction and Background

## 1.1 Introduction

The Parking Brake system of a passenger vehicle, regardless of the operating mechanism, must be able to hold the vehicle stationary, even in the absence of the driver (Brooks and Barton, 2001; UNECE, 2008, p.11).

Failure of the system, whether related to mechanical, human or organisational and environmental factors, compromises the holding force and may result in the unintentional movement of the parked, unattended vehicle, herein referred to as vehicle rollaway. The consequences of such can range from minor property damage to serious injury or even fatality.

Previous research related to UK passenger vehicle rollaway, focused on the mechanical components of the manually operated parking brake system (McKinlay et al., 2004; McKinlay, 2007; Rozaini et al., 2013). Studies were of an experimental nature in design and did not involve drivers interacting with their own vehicles. McKinlay (2007) identified the ‘cooling effect’ of rear disc brakes to be a contributory factor to vehicle rollaway and indicated that the increased use by vehicle manufacturers of rear disc instead of drum brakes in new car designs increased the potential for rollaway.

The World Health Organisation (Peden et al., 2004) identified the need to explore multiple interacting factors which contribute to an accident and Larsson, Dekker and Tingvall (2012) concluded that a systems approach to road safety could address this requirement.

Employing an ergonomics and human factors systems framework enables a holistic exploration of how the various components of a task and system interact (Leveson, 2002; Salmon et al., 2010; Dul et al., 2012). The system represents the organisational, physical and cognitive components that the driver interacts with and the focus is on how its design fits human requirements, capabilities and limitations.

Despite developments in parking brake design and the potentially catastrophic consequences of system failure, there is a paucity of literature evidence addressing the ergonomics and human factors involved in operating the parking brake system.

Therefore, to explore the factors associated with vehicle rollaway, this research focused on driver interaction with the lever operated parking brake system at different interface levels using an ergonomics and human factors, systems approach.

## 1.2 Background

For the manually operated parking brake, Economic Commission for Europe (ECE) Regulation 13-H specifies that vehicles at gross weight must be capable of being held for 5 minutes on a 20% gradient with a maximum force of 400N applied at the hand lever (UNECE, 2008, p.37). However, anecdotal reports suggest that when an unattended parked vehicle fails to remain stationary, the period of time which has lapsed may be more than 5 minutes, and the gradient on which the event occurs may be less than 20% (Laing, 2011; Richards, 2014).

Where a vehicle rollaway has resulted in injury, there is likely to be police involvement and traffic collision records (e.g. STATS19), record contributory factors under predetermined categories such as environment, driver and vehicle defects. An investigation will include a mechanical assessment of the vehicle to establish compliance with relevant legislation, its current operational state and level of maintenance. If no mechanical fault is identified, the causative factor may lie with the driver whose duty it is to comply with the Highway Code. That is, the driver must apply the parking brake before leaving the vehicle and if parked on a hill should also put the car in the appropriate gear (manual transmission) or park mode (automatic) and turn the wheels of the car in the appropriate direction (DFT, 2007 sections 238-252). Failure to do so may be judiciously considered to be the result of human error and a traffic violation under section 42 of the UK Road Traffic Act 1988 (Laing, 2011) and section 107 of the Road Vehicles (Construction and Use) Regulations 1986.

Inconsistent reporting and recording of related incidents makes it difficult to fully determine the magnitude of vehicle rollaway incidents in the UK, but information gained from police databases, media reports, Vehicle Operations Service Agency (VOSA) recalls and driver surveys, indicate this is not a rare phenomenon with up to 13% of drivers surveyed indicating experience of a vehicle rollaway.

A review of UK media reported rollaway incidents between July 2008 and September 2011 indicated that 12 of these resulted in a fatality. Responses from four police constabularies to a request made using the Freedom of Information Act 1998, indicated that the number of incidents could range from one to 10 in a 12 month period dependent on how the incidents were reported and recorded (Noble, 2011).

The Vehicle Operations Service Agency (VOSA) listed 19 passenger/light goods vehicle recalls from several manufacturers for parking brake faults in the three year period from January 2008 to December 2010 (VOSA, 2011). Media attention was drawn to the issue in 2007 by the BBC consumer affairs programme "Watchdog", and the consumer rights publication "Which" (Which, 2007). Specific advice was provided to drivers of the vehicles affected, that was not to depress the release button when pulling the parking brake lever up and to park in gear on a hill. However, reports of faults or malfunction of parking brake systems continued both by manufacturers (Vauxhall, 2010; 2014) and on social networking sites and consumer user forums in vehicles that have not been recalled (motortrader (2008), consumer action group (2008), RAC (2011), cvinfo (2011), golfmk7 (2014), MSE (2015)).

The extent of passenger vehicle rollaway and incidents where the parking brake system has failed to maintain the vehicle stationary remains an area that is relatively unexplored requiring further investigation.

This chapter introduces the scope of the research and details how ergonomics and human factors methodology was employed to explore the factors associated with vehicle rollaway. A multi-study strategy was developed which will further inform and contribute knowledge to the issue of parked unattended vehicles failing to remain stationary.

## 1.3 Ergonomics and Human Factors

### 1.3.1 Definition

According to the International Ergonomics Association (IEA), Ergonomics or Human Factors is defined as:

"the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance” (IEA, 2004).

The system within this definition represents the organisational, physical and cognitive components that people interact with.

Exploration of a system employs the three major domains of Ergonomics and Human Factors being:

- organisational ergonomics - concerned with socio-technical system design
- physical ergonomics - concerned with physical activity
- cognitive ergonomics - concerned with mental processes (Carayon, 2012)

Figure 1.1 illustrates how this model can be applied to explore the potential contributory factors for failure of the parking brake system.

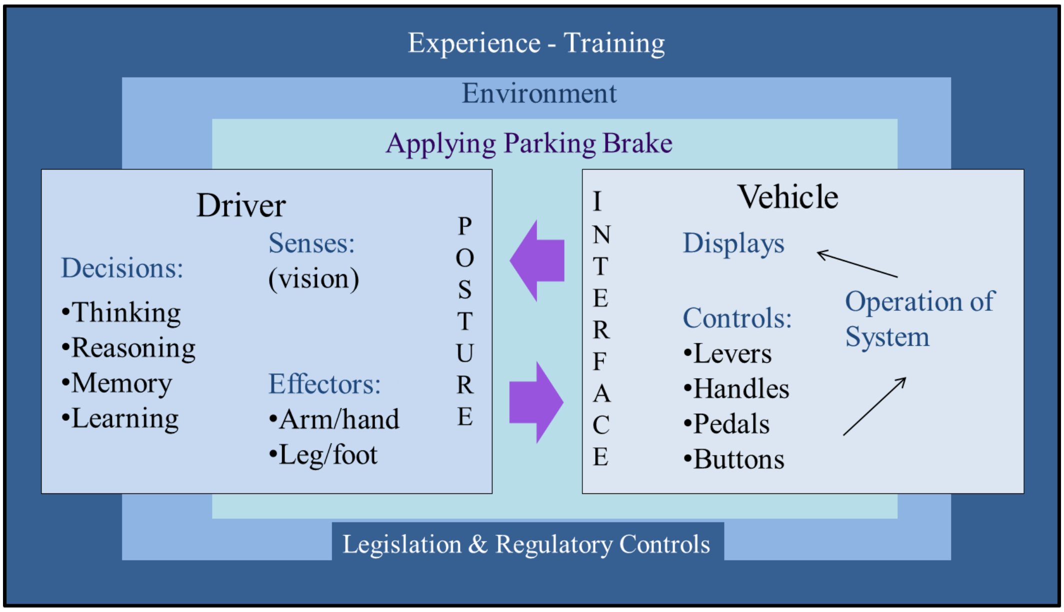



*Figure 1.1 Ergonomics model of interaction with parking brake system*

### 1.3.2 Ergonomics exploration of the parking brake system

This thesis explores how recognised ergonomics and human factors principles may be applicable for both manual and electromechanical parking brake (EPB) systems, the characteristics of the systems employed across manufacturers and the driver interaction with current and proposed systems.

A number of studies within a flexible approach were designed to evaluate the cognitive, physical and organisational factors which may be influential in the safe and effective means of holding a vehicle stationary. Real life research methodology was employed to explore how the driver interacts with the parking brake system at different interface levels.

### 1.3.3 Description of the task: parking a vehicle to leave it unattended

The driver's goal, and the overall objective of the parking brake system, is to park the vehicle safely and securely. Task analysis is fundamental to exploring the factors that may contribute to system failure and an initial or gross task analysis (see Figure 1.2) began with a description of the tasks required to meet the system objectives and linkages among them (O'Brien and Malone, 2002).

This initial task description provided a framework to explore the system demands for each task level. Information for the more detailed task analysis was derived from observation, structured and unstructured interviews, analysis of operating procedure, incident investigation data, structured walk-throughs or talk-throughs and relevant documentation (Kirwan, 1990; Stanton et al., 2013 pp. 39-68).

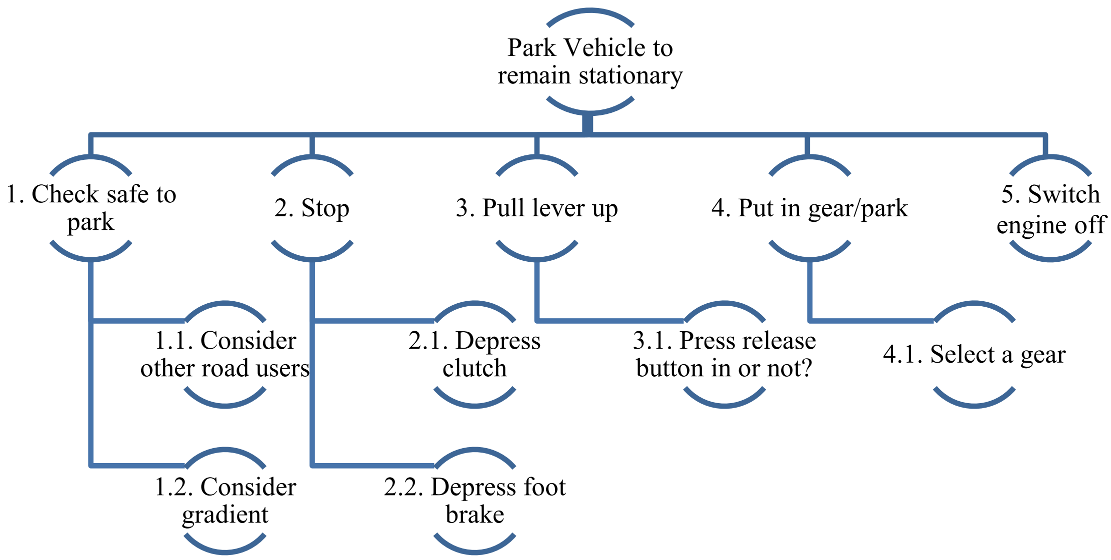



*Figure 1.2 Task description of parking a vehicle to remain stationary*

When parking a vehicle so that it remains stationary when left unattended, the driver initially has to decide whether it is safe to park in the desired location. That information is gained directly from the surrounding features and indirectly from previous experiences or learning. Further decisions are made in relation to perception of the incline, ability to apply the parking brake, what combination of subtasks are required and what are the potential consequences if these are missed or the parking brake is not applied, or insufficiently applied.

Once the decision to park the vehicle has been made, the driver then has to decide how to apply the parking brake, in what order the subtasks are performed, or controls operated, and how they are performed or operated. The driver may decide to violate the rule based on previous experience e.g. parking in an area where vehicles get ‘nudged’ may persuade the driver not to apply the parking brake to minimise any damage. His/her violation may be influenced by direct information about the environment and conditions to avoid an unwanted event.

The sequence of operation may be influenced by the vehicle design. For example, some manufacturers design vehicles so that the key cannot be taken out of the ignition without first placing the vehicle in gear. The combination of subtasks can vary and when drivers are asked in what order the subtasks are performed they may not be able to recall immediately what they do. The plan may be to complete 1-2-3-4-5 to park the vehicle so that it remains stationary, but some subtasks may be omitted or completed in a different order.

The potential factors that could contribute to vehicle rollaway are considered in a fault tree analysis (Figure 1.3) to enable exploration of areas for further investigation and data analysis. As the research progressed, the fault tree was developed and formed a structure to explore and discuss the data collated in relation to the mechanical, driver and organisational components of the parking brake system.

If the action of parking a vehicle so that it remains stationary is incomplete and the parking brake’s holding capability is compromised, the risk of the vehicle failing to remain stationary is increased. Figure 1.3 illustrates the complexity of a control action that is regarded as relatively simple and demonstrates the task components which may contribute to an unsuccessful outcome. Considering the task in a fault tree analysis format provides the basis for a review of related literature and exploration of the potential factors associated with failure of the parked unattended vehicle remaining stationary or vehicle rollaway.

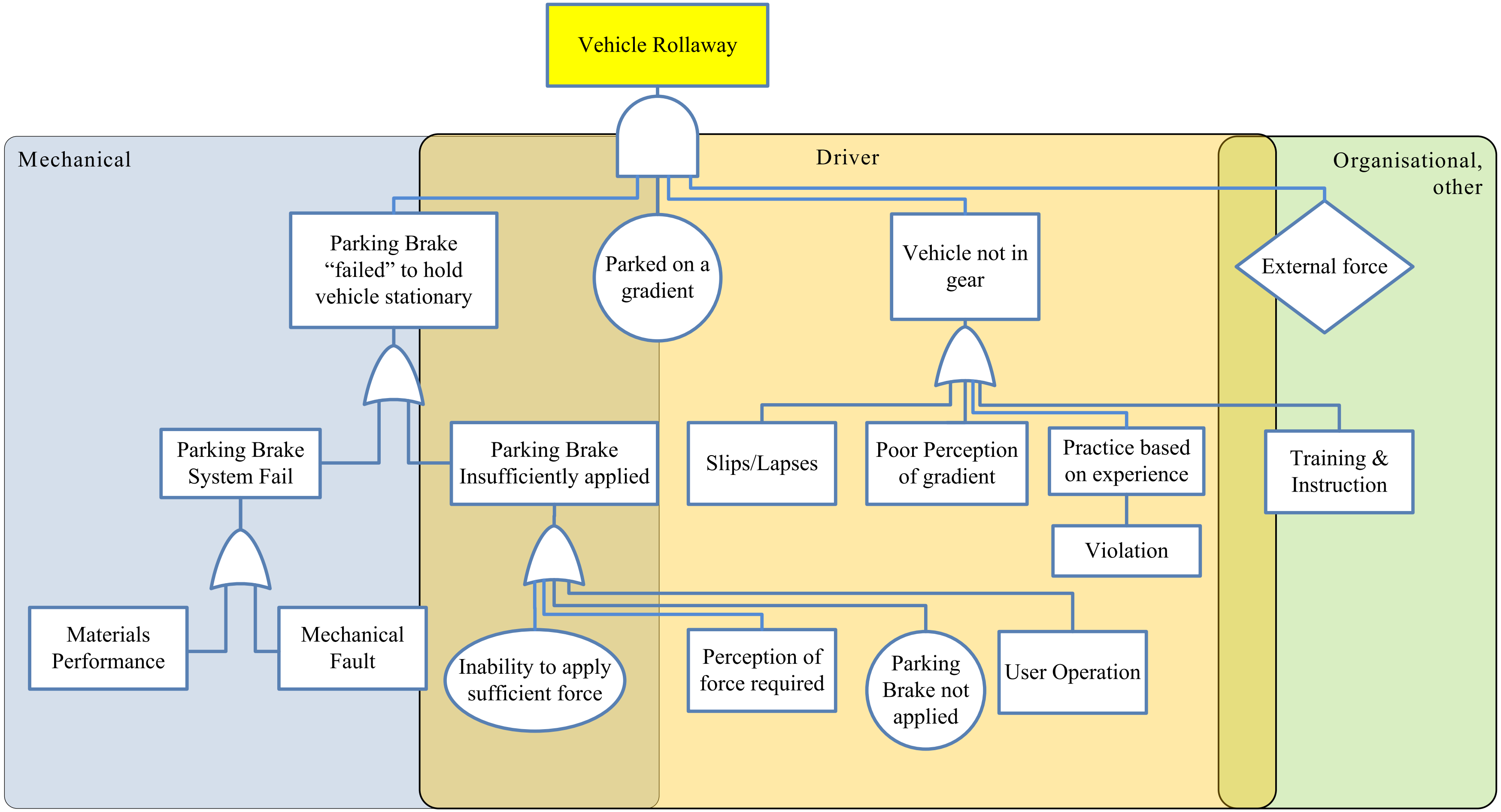



*Figure 1.3 Fault tree analysis for vehicle rollaway*

## 1.4 Aim and Scope of the Research

### 1.4.1 Aim and objectives

The aim of this project was to explore the ergonomic and human factors associated with operation of the parking brake system and to identify potential contributory factors for the parked unattended vehicle failing to remain stationary.

A summary of the objectives and research questions are listed below and will be discussed in more detail within the methodology of each study.

The objectives of the study were to:

- Determine the extent of the perceived issue of parking brake system failure or vehicle rollaway
- Examine the nature of the task of operating the parking brake system
- Investigate the relevant ergonomic factors - physical, cognitive, organisational, environmental
- Explore current practice i.e. parking behaviour and operation of the system
- Explore training and instruction delivered in the UK
- Explore driver experiences and perception of the parking brake system
- Establish any demographic indices in relation to parking brake miss-application or failure
- Explore driver interaction with vehicle controls
- Determine the factors that influence how the parking brake is applied
- Consider implications for future design and driver interaction.

## 1.5 Structure of the Thesis

### Chapter One: Introduction and Background to Research

This chapter provides an introduction to the research with background information to support the aim and objectives of the project. The potential components that could contribute to a vehicle failing to remain stationary are illustrated.

### Chapter Two: Defining the Problem

This chapter summarises the exploration of data bases and discussions with subject matter experts to determine the extent of vehicle rollaway incidents in the UK.

### Chapter Three: Literature Review

A literature review of published material relevant to the ergonomics of parking brake application and vehicle rollaway is presented. It provides an overview of the potential organisational, mechanical, physical and cognitive factors associated with the task of parking a vehicle in order to remain stationary when unattended.

### Chapter Four: Review of Exploratory Methods

A literature review of the exploratory methods considered applicable to addressing the research objectives and questions.

### Chapter Five: Exploring Driver Interaction

This chapter reports an online survey conducted to explore driver interaction with the parking brake system in relation to experience and current practice.

### Chapter Six: Observation of Practice

Parking practice was observed in five car parks in different geographical regions of the UK. The results were explored in relation to parking practice, distribution of parking brake systems and geographical location.

### Chapter Seven: Training and Instruction

A survey of training and instruction delivered by Approved Driving Instructors is presented and reviewed in relation to recommended parking brake application and practice. Standards for learner drivers are reviewed and discussed with the UK Driving Standards Agency.

### Chapter Eight: Driver Interaction and Application of Force

This chapter presents the observational studies using a static assessment rig and a "real life" study using the driver's own vehicle to explore their interaction with the parking brake system and their parking practice.

### Chapter Nine: Mechanical and System Considerations

The performance of rear brake discs and drums is reviewed when conducting a parking task before and after driving a set route.

### Chapter Ten: Discussion

This chapter discusses the results and theories generated during the research project. The results of the empirical studies are discussed in relation to the factors contributing to vehicle rollaway and to suggest remedial actions.

### Chapter Eleven: Conclusions and Recommendations

The conclusions drawn from the overall findings and recommendations for further research are presented in this chapter.

The structure of the thesis is illustrated in Figure 1.4.

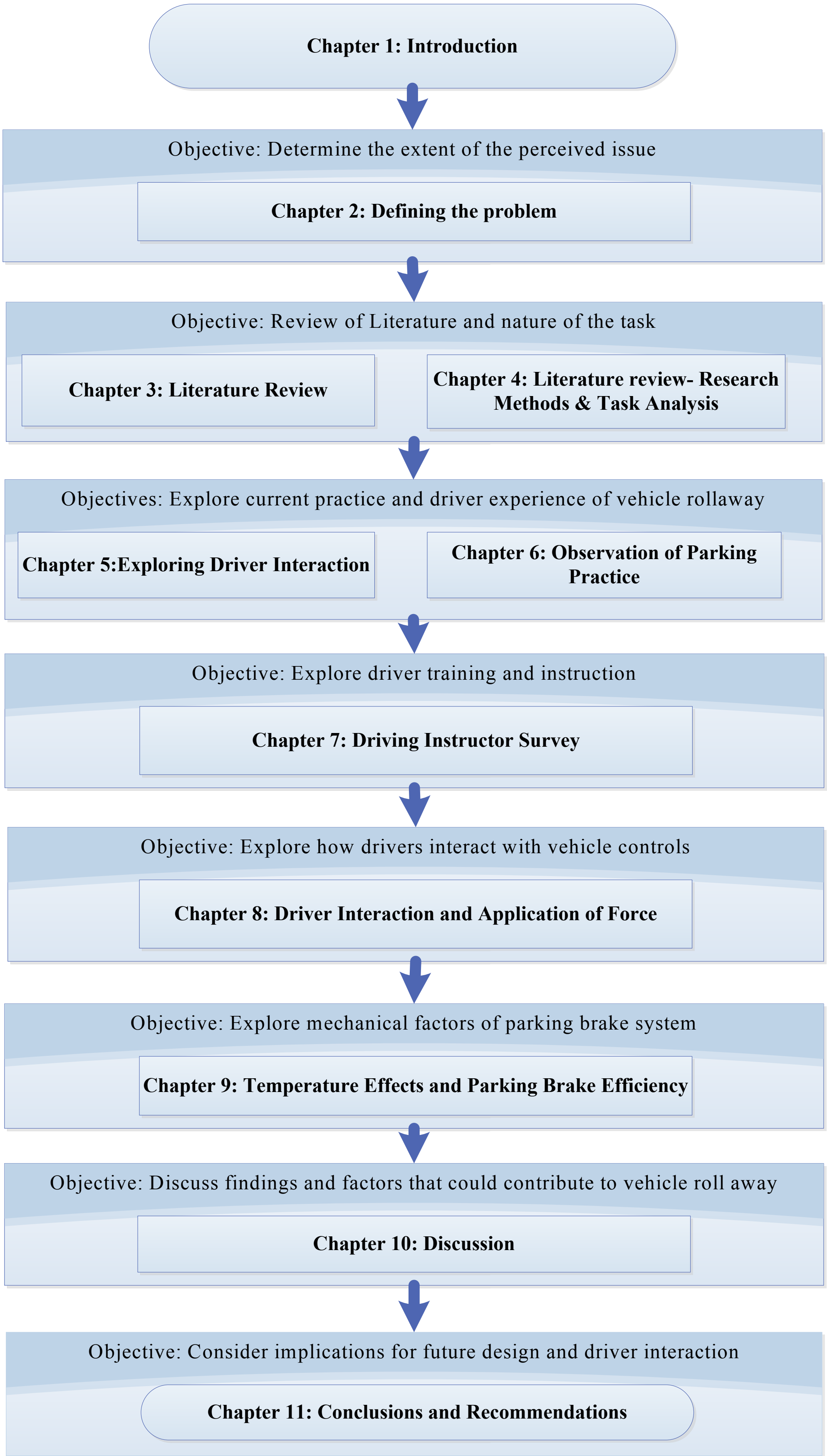



*Figure 1.4 Structure of thesis*

## 1.6 Chapter Summary

This PhD thesis explores the factors associated with vehicle rollaway from an ergonomics perspective and explores how the driver interacts with the parking brake system. This area of exploration reflects that:

- few studies have been conducted in relation to the performance of the parking brake system and vehicle rollaway in passenger vehicles
- previous studies related to parking brake effectiveness tend to be experimental and laboratory based and focus on the mechanical components of the system.
- there is insufficient data relating to vehicle rollaway events making it difficult to determine the contributory factors.

An anthology of real life studies provide results, discussion areas and conclusions that contribute to original knowledge of the factors associated with vehicle rollaway and identify further areas for exploration.

It is proposed that the findings will have implications for regulatory bodies, manufacturers, incident reporting authorities, those responsible for training and instruction as well as the drivers themselves. The implications are likely to include:

- review of data recording procedures to reflect the contributory factors of vehicle rollaway in a consistent manner
- increased education and awareness of drivers and driving instructors of the risk of vehicle rollaway and risk reduction practices
- encouraging manufacturers to 'design out' the problem.

# Chapter 2: Defining the Problem

## 2.1 Introduction

Vehicle rollaway is a generic term used to describe failure of the parking brake system (McKinlay, 2007). However, related incidents in the UK are subject to the problems of differential reporting. The data recorded may be dependent on the recording system employed and reporting of the incident is dependent on its nature, location, and the level of severity of damage or disruption incurred. Incidents occurring on the public highway will only be recorded through the police recording system, STATS19 (Department for Transport (DfT), 2004a; DfT, 2011), if an injury has occurred and incidents occurring on private property may go unreported.

This chapter presents the information retrieved from Police databases via freedom of information requests; communication with motor insurance bodies; a search of media reports; details of vehicle recalls and correspondence with subject matter experts to determine the extent of failed parking brake applications/vehicle rollaway incidents within the UK and the potential contributory factors.

## 2.2 Exploring the Accident Data

STATS19 is the primary source of data that records road accident casualties in the UK. The data are collected to an agreed national standard by local police forces and are collated and analysed by local authorities e.g. Transport Scotland and the Department for Transport (DfT). The data are used nationally to monitor trends, inform policy and to identify areas for action (Scottish Executive, 2004, pp.171-184; DfT, 2011a; Smith et al., 2015). Instructions for completing the STATS19 report and a detailed explanation of the information collected by a Police Officer when an injury road accident has been reported to them is contained in the STATS20 manual for the use of police forces, local authorities and their agents (DfT, 2004; DfT, 2011a).

STATS19 records data where an injury or death has occurred on the public highway, or road, and is reported to the police within 30 days of the incident. A casualty can be recorded as a seriously or slightly injured. Seriously injured will include an injury requiring hospital admission, or any of the following: fractures, concussion, internal injuries, crushings, non-friction burns, severe cuts and lacerations, severe general shock requiring medical treatment.

Within the recording system (see Appendix A.1), Accident, Vehicle and Casualty records mainly record objective details and will include failures and manoeuvres that immediately led to the accident. The contributory factors (causes for the failures and manoeuvres) are largely subjective and depend on the skill and experience of the investigating officer to reconstruct the events which led directly to the accident.

There are five main categories of contributory factors each of which has a number of coded factors or variables: (see Appendix A.1)

1. Road environment - 9 factor codes
2. Vehicle defect - 6 factor codes
3. Driver/rider only - 47 factor codes in total
    - injudicious action - 10 factor codes
    - error or reaction - 10 factor codes
    - impairment or distraction -10 factor codes
    - behaviour or inexperience - 7 factor codes
    - vison affected by - 10 factor codes
4. Pedestrian only - 10 factor codes
5. Special codes - 4 factor codes

The reporting officer can select up to six factor codes from the grid and identify whether each factor is very likely or possible. The system allows for more than one factor to be allocated to the same road user and for the same factor to be allocated to multiple road users for the incident being recorded. The factors recorded are the reporting officer's opinion and may not reflect the results of further investigation. "Parking/hand brake fail" is not one of the causative factors when recording a road traffic collision (England and Wales), therefore the results are dependent on the police officer making a note of that fact. A copy of the form MG NRSF introduced from the beginning of 2005 to collect the STATS19 data can be seen in Appendix A.

Comparison of STATS19 data with Hospital Episode Statistics indicated that although fatalities were reported according to the STATS19 requirement, there was significant under-reporting of non-fatal injuries (DfT, 2011c) and not all vehicle related injuries may be reported to the police.

## 2.3 Freedom of Information (FOI) Requests

### 2.3.1 Introduction

The Freedom of Information Act (FOIA) 2000, enables access to data held by public authorities. One previous request to VOSA for information related to parking brake failure was in relation to failure of electronic parking brakes on a vehicle with manual transmission (Ambrose, 2009). The request was refused under section 44 of the FOI which indicates certain conditions under which information can be exempt from disclosure (Information Commissioning Office (ICO), 2006). No further requests were found associated with lever operated parking brakes.

### 2.3.2 Freedom of information request to UK police constabularies

A Freedom of Information Request was made in February 2011 using the "What Do They Know" website (*http://www.whatdotheyknow.com*) to six of the 51 Police forces across the UK: Avon and Somerset, Devon and Cornwall, Grampian, Northern, South Wales and South Yorkshire Police Constabularies (Noble Ergonomics, 2011). The request asked each constabulary to provide data over a 36 month period in response to the following questions:

- In the last 3 years how many incidents have involved rollaway vehicles?
- In how many of the above was parking/ hand brake failure cited as a potential factor?
- How many incidents resulting in serious injury or fatality have cited hand brake or parking brake as a potential factor?
- What was the manufacturer, model and age of the vehicle involved?
- What was the age and gender of the driver involved?

Where it was considered by the corresponding freedom of information officer that the request was outside the economical boundaries, direct communication was made electronically and/or by telephone communication and the request was amended to cover a 12 month period. All data were received by May 2011.

### 2.3.3 FOI responses

In response to the Freedom of Information (FOI) request, data were extracted from STATS19 and Operational Information System (OIS) reports by four of the six Police Constabularies contacted. Only one constabulary was able to provide the data as initially requested (Appendix A.2), the others were able to provide data following an amended request. Two constabularies refused due to economic limitations and all constabularies indicated that retrieving data citing parking or handbrake as a causative factor is difficult as it was dependent on how it was categorised by the reporting officer and whether any additional notes were documented.

The number of recorded incidents by the four Police Constabularies who responded ranged from one to an average of 11 in a 12 month period (see Table 2.1). The responses indicated an annual average of three serious injury related incidents per region.

*Table 2.1 Incidents recorded in OIS/STATS19 reports*

| Constabulary | Months (Time period) | Incidents | No Injury | Injury | Fatality |
|---|---|---|---|---|---|
| **Northern** | 36 (Jan 2008-Dec 2010) | 32 | 30 | 1 | 1 |
| **Grampian** | 12 (Jan- Dec 2010) | 3 | 0 | 3 | 0 |
| **Devon & Cornwall** | 12 (Jan-Dec 2010) | 4 | 0 | 4 | 0 |
| **Avon & Somerset** | 12 (Jan-Dec 2010) | 1 | 0 | 1 | 0 |

## 2.4 Access to Motor Insurance Databases

Requests for data on claims related to parking brake failure or rollaway of vehicles were made in writing and by telephone communication to Thatcham, Automobile Association (AA), Churchill, Norwich Union, Motor Insurance Bureau (MIB), Association of British Insurers (ABI) and Aviva. These organisations reported that they do not hold such data and Aviva responded stating that such claims would be recorded as “own damage” (Watson, 2012).

## 2.5 Media Reports

### 2.5.1 Introduction

Media reports for incidents in the UK were collected by accessing on line news sites (BBC News Channel, Daily Mail online) for the period from July 2008 to August 2012. Key words such as parking brake or hand brake failure and vehicle rollaway were used to conduct the search. Following the initial search a monthly search was conducted using Google News and a Google alert was created to monitor the internet for any related content.

### 2.5.2 Media reports

Subjective search reports are summarised in Table 2.2. Insufficient application of the parking brake ('hand brake') was listed as a contributory factor and eight cases stated that the vehicle was not parked in gear. Twelve of the 26 listed cases resulted in pedestrian fatality.

*Table 2.2 Vehicle rollaway incidents reported in the media (July 2008 - August 2012)*

| Date | Location | Outcome | Reported Factor |
|---|---|---|---|
| **July 2008** (Scotsman, 2008) | Highlands of Scotland | Elderly pedestrian fatally injured | Handbrake not fully applied, vehicle not in gear, 5% gradient |
| **Aug 2008** | Aberdeenshire | Driver of vehicle fatally injured | Handbrake not fully applied, engine running |
| **August 2008** | Devon | Pedestrian injured and hospitalised when vehicle rolled over tent. | Handbrake not fully applied vehicle not in gear |
| **August 2008** | Devon | Vehicle damage after rolling down steep slope | Handbrake not fully applied, not in gear |
| **September 2008** | Devon | Vehicle damage. Injury prevented by driver action | "Brakes failed" |
| **October 2008** | Yorkshire | Driver of vehicle fatally injured | Handbrake not applied |
| **November 2008** | Jersey | Driver of vehicle fatally injured | Handbrake not fully applied |
| **December 2008** | Cheshire | Train de-railed by vehicle rolling onto track | Handbrake not applied |
| **December 2008** | Isle of Man | Driver fatally injured | Handbrake partially applied, engine running |
| **April 2009** | London | 2 Pedestrians fatally injured | Handbrake not applied |

| Date | Location | Outcome | Reported Factor |
|---|---|---|---|
| **August 2009** | Wales | Vehicle damage - injury prevented by actions of bystander | Handbrake failure recorded, vehicle not in gear |
| **August 2009** | Wales | Vehicle rolled over cliff – injury avoided by passenger (child) jumping clear | Handbrake knocked by passenger, vehicle not in gear |
| **October 2009** | Kent | Pedestrian (child) fatally injured | Handbrake not fully applied, car not in gear |
| **March 2010** | Dublin | Driver fatally injured | Not reported |
| **September 2010** | Cumbria | Vehicle rolled into sea – no injury | Handbrake not fully applied |
| **December 2010** | Northampton | Driver fatally Injured | Handbrake not applied – Goods vehicle fitted with warning but not heard over loud music. |
| **February 2011** | Devon | Car plunged onto railway line. No injury but travel disruption. | Electronic parking brake failure |
| **March 2011** | Lancashire | Passenger trapped, no injury | Handbrake not applied |
| **September 2011** | Birmingham | Injury to pedestrian (child) | Handbrake failure, vehicle not in gear |
| **September 2011** | Hertfordshire | Pedestrian fatally injured | Handbrake not fully applied, vehicle not in gear |
| **September 2011** | Wales | Pedestrian (child) fatally injured | As disc brakes cooled, handbrake did not hold on steep slope, vehicle not parked in gear |
| **September 2011** | France | British actress - driver on holiday – injury avoided | Handbrake not applied. Vehicle parked on slope |
| **October 2011** | Devon | Driver of vehicle fatally injured | Not reported |
| **February 2012** | Valencia | British footballer injured foot | Handbrake not applied |
| **April 2012** | Yorkshire | Teenager trapped under vehicle | Handbrake failure reported, vehicle not in gear |
| **August 2012** | Yorkshire | Teenager stops rollaway vehicle with toddler inside | Handbrake not applied/released. Vehicle not in gear. |

One case was related to failure of an electronic parking brake system and although there was no injury, it caused disruption to rail services (BBC Devon, 2011).

Further information was available for three of the cases listed either by direct correspondence or by access to reports published online. In one case the procurator fiscal concluded that the parking brake being insufficiently applied when the vehicle was parked on a 5% gradient was as a result of human error (Laing, 2011). In another case the coroner concluded that the vehicle rollaway was as a result of the brakes cooling and the vehicle not being parked in gear (Hassell, 2011; Thomas and Patterson, 2013).

After a vehicle rolled onto the railway track resulting in a train derailment and injury to the train driver, an extensive report by the Railway Accident Investigation Board (RAIB) focused on environmental preventive measures. Barriers were erected to prevent vehicles rolling onto the track from a nearby carpark (RAIB, 2009).

Without access to the incident reports, the contributory factors for the cases listed in Table 2.2 remain unconfirmed but the issue whether vehicles are parked in gear is an area for further exploration.

## 2.6 UK Vehicle and Operator Service Agency (VOSA) Recalls

### 2.6.1 Introduction

From 3 April 2003 to 31 March 2014 VOSA was an executive agency, sponsored by the Department for Transport and was the public body for the management of safety recalls. Allegations of potentially unsafe vehicle components were passed to the manufacturer as they would have the relevant technical specifications, original road safety test results, equipment and facilities to conduct any contemporaneous investigation. VOSA’s role was to ensure the automotive manufacturers consider such matters in a reasonable way and that they respond to any concerns in an appropriate manner (VOSA, 2011; DVSA, 2014). Since April 2014 when VOSA merged with the Driving Standards Agency (DSA) to form the Driver and Vehicle Standards Agency (DVSA), a serious defect that affects the safety of the vehicle, one of its parts, or an accessory, can be reported to the DVSA. The issue will then be investigated with the manufacturer to identify the action to be taken (DVSA, 2014).

### 2.6.2 Recalls related to parking brake

A search was conducted using the VOSA Vehicle Recalls search criteria for the period January 2008 to December 2011 by entering the free text ‘parking brake’ or ‘hand brake’ (*http://www.DfT.gov.uk/vosa/apps/recalls/searches/search.asp*).

Twenty nine recalls relating to private light good/passenger (PLG) vehicles affecting vehicle models from 11 different manufacturers were listed (see Table 2.3). The reported reasons for recall were: parking brake may fail or was not effective (20), performance affected (5), inadvertent application (1), fire in engine bay resulted in parking brake failure (1), EPB malfunction (2).

The investigations resulting from the recall of Honda Civics and Vauxhall Vectras and Sigmas in 2008 concluded that the vehicle rollaway was related to the driver operation of the parking brake system. Four of the recalls were related to the pawl and ratchet design.

*Table 2.3 Private Light Goods/Passenger vehicle recalls (VOSA, 2011)*

| Recall Date | Manufacturer | Model | Fault Reported |
|---|---|---|---|
| 04/08 | Honda | Civic | 'If handbrake is applied with release button depressed, handbrake may not latch sufficiently to hold vehicle on a slope' |
| 04/08 | Vauxhall | Vectra C & Signum | Handbrake may partially release - 'provided the handbrake is applied correctly without depressing the release button, the handbrake is perfectly safe' |
| 09/08 | Honda | Civic | Excessive travel of parking brake lever. Parking brake performance affected |
| 11/08 | Citroen | C4 Picasso | Parking brake may be ineffective |
| 11/08 | Honda | Jazz | Handbrake could become inoperative – handbrake lever ratchet may not latch into position |
| 12/08 | Nissan | X93 Primaster | Possible failure of parking brake - primary handbrake cable end - piece crimping may not conform so the handbrake cable may become detached. |
| 12/08 | Vauxhall | Vivaro | Possible failure of parking brake |
| 01/09 | Chrysler UK Ltd | Dodge Nitro, Jeep Cherokee | Park brake may not be effective |
| 03/09 | Mercedes Benz | Vito and Viano | Parking brake may fail |
| 03/09 | Mercedes Benz | Sprinter | Possible engine bay fire and parking brake failure |
| 04/09 | Mercedes Benz | Sprinter | Parking brake may not be effective |
| 04/09 | VW | Crafter | Handbrake may not fully apply |
| 05/09 | Mercedes Benz | Sprinter | Parking brake may fail |
| 10/09 | Citroen | C2/C3 | Parking brake may fail |

| Recall Date | Manufacturer | Model | Fault Reported |
|---|---|---|---|
| 10/09 | Honda | Civic | 'the handbrake ratchet tooth dimensions are incorrect resulting in a mismatch and incorrect engagement between pawl and ratchet teeth. Consequently, the handbrake lever may disengage' |
| 12/09 | Land rover | Defender | Parking brake may become ineffective |
| 05/10 | Renault | Scenic 11 | Unexpected application of parking brake |
| 06/10 | Vauxhall | Corsa | Handbrake my fail |
| 10/10 | Peugeot | 405 | Parking brake may fail |
| 11/10 | Citroen | C5 | Parking brake may fail |
| 12/10 | Renault | Traffic 11 | Handbrake may fail |
| 01/11 | Nissan | Primaster | Handbrake may fail |
| 03/11 | Vauxhall | Vivaro | Handbrake may fail |
| 03/11 | LT1 | TX4 | Handbrake may fail |
| 04/11 | Landrover | Defender | Parking brake efficiency affected |
| 04/11 | Citroen | C4 Picasso | Electric parking brake may malfunction |
| 05/11 | Sirus/ VW | Caddy Life | Handbrake may be inadvertently applied |
| 07/11 | Citroen | C3 and DS3 | Parking brake may not apply fully |
| 09/11 | Vauxhall | Corsa D | Handbrake may fail |

## 2.7 Information from Subject Matter Experts

### 2.7.1 Introduction

A Subject Matter Expert (SME) is defined as an individual who, by virtue of position, education, training, or experience, is expected to have greater-than-normal expertise or insight relative to a particular technical or operational discipline, system, or process. Subject Matter Experts (SMEs) were identified within MIRA Ltd., Department for Transport (DfT), Transport Research Laboratory (TRL), Vehicle Safety Branch of Vehicle Operator Service Agency (VOSA) and Traffic Accident Investigators to explore:

- 'What is the extent of failed parking brake applications in the UK ?'
- 'What are the potential contributory factors?'
- 'What force is required to hold the vehicle stationary, how is this tested?'

Initial communication with the relevant organisation, or SME directly, was via e-mail with follow up by e-mail, telephone or face to face meeting.

### 2.7.2 Outcome

Discussions with subject matter experts (SMEs) exploring 'what are the potential contributory factors to failed parking brake application?' and 'what force is required to hold the vehicle stationary?' established that vehicle parking brakes are tested in accordance with UNECE Regulation 13-H although some manufacturers may have their own industrial tests. These experts also advised on areas to consider such as 'brake fade' and the effects of brakes cooling after parking.

The Vehicle Safety Branch (VSB) of VOSA reported 152 investigations concerning rollaway incidents in a 5 year period from January 2006-December 2010 (Ryder, 2013a).

A potential contributory factor to parking brake release was highlighted where a change in ratchet design could result in the pawl slipping off the ratchet if applied with the release button pushed in (Ryder, 2013).

In addition, 22 reports related to electronic parking brakes were submitted in 2010-2012 (Ryder, 2013b, VSB, 2013).

Communication with a local Traffic Accident Investigator and Police vehicle examiner described a case where the investigation concluded that the parking brake lever was insufficiently applied at 2 out of 6 notches to hold on a 10% gradient (Richards, 2013).

## 2.8 Workplace Incidents

Incidents involving work vehicles are reportable to the Health and Safety Executive (HSE) under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) (HSE, 2008). Entries extracted from the HSE, RIDDOR data base indicated that 67 incidents related to parking brake application were reported in a 12 month period from 2009-2010; of these, 36 were related to the handbrake not being applied and the vehicle rolling resulting in one fatality and 15 major injury cases.

Harley and Cheyne (2005) reported failed application of the parking brake on slopes to be a causal factor in work-related vehicles overturning and drivers being crushed or run over by their own vehicle. In agriculture one in 8 (12%) of farm tractors are thought to have defective hand brakes (HSE, 2009a) and in the service industry 36% of the fatalities associated with being struck by moving vehicles were related to parking brake application (HSE, 2004).

## 2.9 Driveway Injuries

In the United States, a commissioned report for NHTSA's (National Highway Traffic Safety Administration) National Centre for Statistics and Analysis (NCSA), data extracted from the national electronic injury surveillance database identified 12 cases where injuries were sustained as a result of vehicle rollaway during a 12 month period in 1994-1995. Based on this, it was estimated that 590 people were treated for vehicle rollaway injuries across the United States in the same year. Related literature indicated that vehicle rollaway and affiliated driveway injuries tended to be associated with pedestrians, predominantly children, being struck by the driver failing to see them or when a child (or adult) had shifted a parked vehicle out of gear (Partrick et al., 1998; Nadler et al., 2001).

A formal agreement was made that from September 2006, vehicles manufactured in the US with automatic transmission should be fitted with a Brake Transmission Safety Interlock (BTSI). This mechanism prevents the vehicle being taken out of park without the foot brake being engaged. Full compliance with Federal Motor Vehicle Safety Standard (FMVSS) 102 was mandatory from September 2010 (Code of Federal Regulations, 2005a; NHTSA, 2006; NHTSA, 2011).

Despite these measures, unattended vehicle rollaway fatalities increased in a 4 year period from 46 (7%) of pedestrian fatalities in 2008 to 144 (21%) of the 2011 figures (NHTSA, 2014). However, no reference is made to vehicle rollaway associated with failure of the parking brake system or to vehicles with manual transmission.

In the UK, the Royal Society for the Prevention of Accidents (ROSPA) launched a Driveway Safety Campaign in 2012 after highlighting that 18 children had been fatally injured in driveway incidents in the previous 5 years; three of these had resulted from the parking brake being accidentally released (ROSPA, 2012). The campaign includes detailed advice about parking in gear (PING) and turning the wheels when parking on a slope

## 2.10 Chapter Summary

The data collected following a vehicle rollaway incident is dependent on the reporting mechanism. The apparent lack of a consistent approach to recording data using STATS19 (Smith et al., 2015) combined with non-specific data recorded in relation to vehicle rollaway and parking/hand brake failure make it difficult to fully determine the extent of vehicle rollaway incidents.

Up to 10 incidents have been recorded on police databases in a 12 month period with 12 out of 24 cases reported in the media resulting in fatality. However, the number of near miss events that did not result in serious injury or excessive damage is unknown. It is recognised that a considerable proportion of all non-injury accidents are not reported and based on 2012 data, it is estimated that 52,000 serious and 308,000 slight accidents do not appear in the UK police data (DfT, 2013, p.40). These figures may or may not include data relating to vehicle rollaway or parking brake failure incidents and therefore further investigation involving feedback from drivers was considered.

Considering the safety pyramids of Heinrich and Bird (Bird, Germain and Clark, 2003), major injuries are rare events and there is expected to be a large variation between the most serious incident and the minor or near miss incident (Willbanks, 2013). In general, Bird estimated that for each major incident, there were 10 reported minor injuries, 30 incidents of property damage and 600 incidents or near misses where there was no property damage or injury (Bird, Germain and Clark, 2003; Nichol, 2012; Wilbanks, 2013). In reference to these figures in the three year period 2008-2011 there were potentially 7,200 near miss incidents related to parking brake system failure.

The VOSA recalls indicated that the majority of the parking/hand brake related recalls were associated with a mechanical issue. However 8% of the listed recalls affecting around 300,000 vehicles in 2008 were associated with the driver interaction and operation of the system itself.

Although the data recorded for vehicle rollaway and parking brake system failure on police accident databases is limited, there is sufficient information available to support the exploration of the factors associated with vehicle rollaway commencing with a literature review followed by the empirical studies.

# Chapter 3: Literature Review

## 3.1 Introduction and Aims

Exploring the factors associated with vehicle rollaway, from a human factors perspective, requires an understanding of the task demands in relation to driver interaction with the organisational, physical and cognitive components at each interface level of the parking brake system. The associated or causative factors of system failure can be constructed through a review of existing knowledge and employing human factors methods in analysis of the task. Factors associated with automotive incidents are established to be those relating to the transport infrastructure, vehicle design, individual (driver) differences and organisational factors such as training. These may also be the key protective components against system failure (Dekker, 2006) and this approach was applicable to exploring the literature in relation to factors associated with vehicle rollaway.

Although the problem of vehicle rollaway has been explored from a mechanical perspective (McKinlay et al., 2004; McKinlay 2007; Rozaini et al., 2013) there remains little published materials on the subject particularly in relation to driver interaction and the relevant ergonomics and human factors associated with parking brake system application.

The aim of the literature review was to review and evaluate the extent to which literature and previous research can provide information related to ‘vehicle rollaway’ and the human factors associated with operating the parking brake system.

The objectives were to explore the current state of literature in relation to:

- Ergonomics and Human Factors related to operating the parking brake system
- Function and operation of the Parking brake system
- Relevant regulatory controls
- Current design features of lever operated parking brakes
- The human factor failures (human error) which could lead to failed parking brake application
- Previous work in relation to stationary vehicle safety

## 3.2 Literature Search

The initial literature search was conducted using Google Scholar, Meta-lib, Loughborough Library Catalogue plus, ProQuest in addition to information available on various road safety related websites. Key search terms employed were vehicle rollaway, parking/hand brake incidents, parking/hand brake application, parking brake legislation, human factors/ergonomics of driving, systems approach to road safety, driver training and instruction, driver distraction, human error and driving. The literature was then grouped into reporting of incidents; systems approach; regulatory controls and standards; parking brake design and mechanical factors; individual factors; human error and driver training and instruction.

## 3.3 A Systems Approach to Road Safety

### 3.3.1 Systems theory

Systems theory focusses on systems as a whole. It recognises that "some properties of a system can only be treated in their entirety, taking into account all facets relating the social to the technical aspects. These system properties derive from the relationships between the parts of systems: how the parts interact and fit together" (Leveson, 2002). In human factors terms, the system represents the physical, cognitive and organisational components that people, or the driver, interacts with (Carayon, 2012; Marras and Hancock, 2013). As in health care, the focus on the design of systems is to ensure they fit the requirements, capabilities and limitations presented in the human (IEA, 2004). Leveson (2002) and Hollnagel (2004) refer to accidents being an 'emergent phenomenon' where emergence is considered to be a result of components no longer being independent but interact and influence each other (Skyttner, 2005).

Due to their complexity, these interactions may not be foreseen (Hollnagel, 2004). Leveson (2002) indicated that systems theory is the basis for systems engineering and despite the diversity of components, whether individual or specialised, each system is seen as an integrated whole. As such, a focus on improving or optimisation of individual or sub-systems may not improve the overall system performance and could be detrimental to long term safety measures.

In line with Reason's Swiss Cheese theory (Reason, 1990), accidents will occur if variability in performance of components and the complexity of interactions is not controlled and barriers introduced. The human tendency to be inconsistent in perceptual and cognitive functions, and impaired ability to adjust performance to conditions at that time, are important sources of variability necessary for system development and for operators and system users to learn (Hollnagel, 2004). In the systems approach, accidents, or unwanted events, occur when component interactions violate the constraints or barriers. These violations could be through external factors, component failures and/or dysfunctional interactions between system components. Control is imposed on several levels from operational to organisational (Leveson, 2002).

Considering a task or situation using a systems framework enables exploration in an organised manner of how the components and subsystems interact (Leveson, 2002; Dul et al., 2012).

### 3.3.2 Systems theory and road safety

Although references to systems theory and road safety is a developing area, Larsson, Dekker and Tingvall (2010), concluded that a systems approach could overcome some of the limitations where the more complex nature of multiple factors interacting and resulting in an accident, or crash (Peden et al., 2004), is acknowledged.

A hierarchical model of socio-technical control which emphasises constraints and control processes at interfaces between the different levels could control the processes at lower levels. In road safety these control processes are mainly between the regulatory bodies and the operating process (Larsson, Dekker and Tingvall, 2010).

The Haddon matrix (Figure 3.1), developed in 1970 by William Haddon, is often seen as a model for an integrated systems approach to road safety and is commonly used to approach safety analysis at a site in a systematic fashion. The Matrix is a two-dimensional model which applies basic principles of public health to motor vehicle-related injuries. The first dimension is the phase of injury divided into pre-crash, crash, and post-crash. The second dimension is the four factors of injury:

vehicle/equipment, human, physical environment, and socioeconomic (Peden et al., 2004; Federal Highway Administration (FWHA), 2011)

| | | Factors | | |
|---|---|---|---|---|
| **Phase** | | **Human** | **Vehicles & Equipment** | **Environment** |
| Pre-crash | Crash Prevention | Information<br>Attitudes<br>Impairment<br>Police enforcement | Roadworthiness<br>Lighting<br>Braking<br>Handling<br>Speed management | Road design and layout<br>Speed limits<br>Pedestrian facilities |
| Crash | Injury prevention during crash | Use of restraints<br>Impairment | Occupant restraints<br>Other safety devices<br>Crash-protective design | Crash-protective roadside object |
| Post-crash | Life sustaining | First aid skill<br>Access to medics | Ease of access<br>Fire risk | Rescue facilities |

*Figure 3.1 The Haddon matrix*

However, there may be complex interactions that the matrix cannot account for and although it cannot be seen as a systems theory approach, it is useful for implying the significance of working with both loss reduction and crash prevention and the significance of working with all elements of the system to identify causes and preventative measures.

Larsson, Dekker and Tingvall, (2010) describe two approaches to road safety:

1. The road-user approach where human error is the main focus as the cause of the accident and therefore the driver is responsible when an event occurs. Countermeasures have been directed at the performance of the road user through regulation and surveillance of behaviour, education and information.
2. The Vision Zero approach, developed in Sweden in the late 1990s, where the responsibility for road safety is shared by the road-user, professional users, administrators and designers of the road transport system.

The Vision Zero approach is based on four elements: ethics, responsibility, a philosophy of safety and mechanisms for change (Peden et al., 2004; WHO, 2004).

A model of safe road traffic within the framework describes the way a number of factors interact to achieve safe road traffic and serves as a basis for developing countermeasures.

Responsibility for road safety is shared in the following way:

- The designers are responsible for the level of safety within the road transport system by way of its design, operation and use
- The road users are responsible for complying with the system designer rules for using the road transport system
- The system designers are responsible for identifying and implementing further actions when injuries occur or road users fail to obey the rules through lack of knowledge, ability or violation.

The Vision Zero approach, being more holistic and systemic may be closer to a systems theory based safety approach (Larsson, Dekker and Tingvall, 2010).

## 3.4 The Parking Brake System

### 3.4.1 The function of the parking brake system

The vehicle parking brake system may be foot, lever or electronically operated. Its function is to hold the vehicle stationary on the flat roadway and "whether on an up or down gradient even in the absence of the driver" (Brooks and Barton, 2001; UNECE, 2008, p.11).

*Figure 3.2 Lever operated parking brake*

*PB foot pedal* *PB release*

*Figure 3.3 Foot operated parking brake*

The mechanical parking brake system generally controls the rear brakes of a vehicle through a series of steel cables that are connected to either a hand lever, such as in Figure 3.2 or a foot pedal (Figure 3.3). Some manufacturers fit the parking brake to the front wheels e.g. Citroen, or the propeller shaft e.g. Landrover).

The system is fully mechanical and could be employed to bypass the hydraulic system to slow the vehicle down should there be total brake failure and as such it may be referred to as the emergency braking system.

This thesis focuses on the floor mounted lever operated parking brake system and explores the potential factors that could lead to failure of the vehicle remaining stationary when parked unattended.

### 3.4.2 Lever operated Parking Brake (PB) system

The manually operated lever parking brake, or handbrake, employs a simple ratchet and pawl mechanism which allows motion in one direction but locks it in the other. A toothed wheel, a pawl and a lever are all that is required and as such is a simple design, considered to be of relatively low cost, reliable with the ability to carry a large force in relation to its size. It must be capable of holding a laden vehicle stationary on a 20% up or down gradient with an operating force applied to the lever not exceeding 400N (UNECE, 2008). However, this system holds the potential for problems with wear, control and stability due to its impacting mechanism and requires the driver to effect considerable bio-mechanical effort.

### 3.4.3 Rear brake type

The parking brake system is a secondary system applied independently of the service brakes and may utilise a drum or disc design on the rear wheels.

On a vehicle fitted with *drum brakes,* the wheel cylinder is bypassed and the brakes are controlled by the cable pulling on a lever mounted in the rear brake which is connected directly to the brake shoes and pushes them against the drum to produce a frictional force as illustrated in Figure 3.4 (Halderman, 2009).

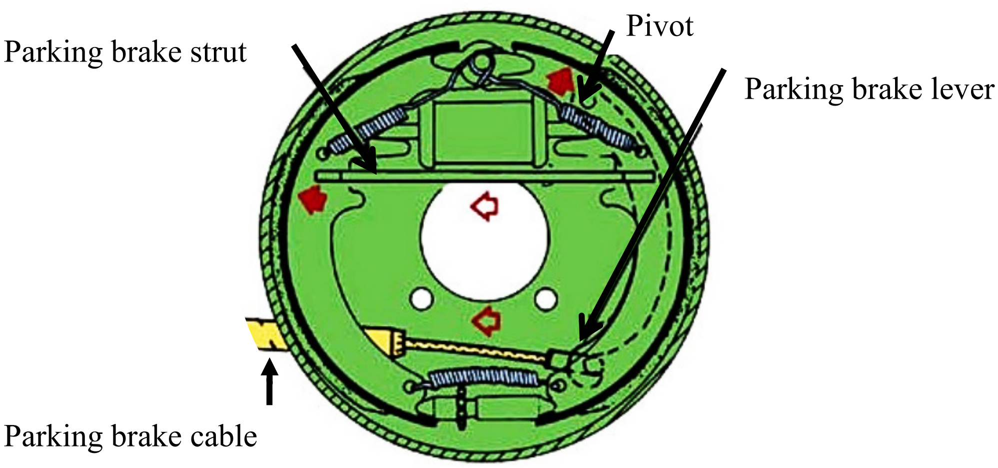



*Figure 3.4* *The parking brake cable pulls on the parking brake lever to force the brake shoe onto the drum. (Halderman, 1996; 2009)*

The drum design is considered to be ideal as a parking brake due to its higher brake factor in relation to the friction coefficient (Limpert, 1999).

Parking brake systems employing *disc brakes* on the rear wheels are more complicated and there are two main designs:

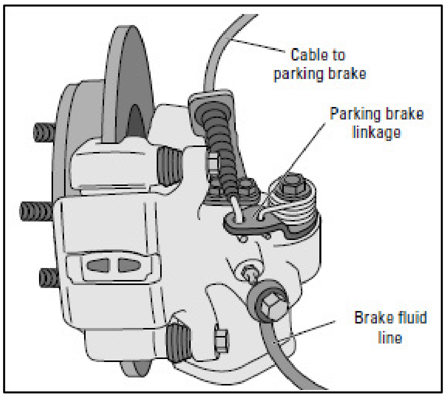



*Figure 3.5* *Rear brake disc assembly (Halderman, 2009)*

1. The rear wheel caliper that applies the hydraulic brakes is used and a lever attached to a mechanical corkscrew device inside the caliper piston is added. When the operating lever is pulled by the parking brake cable the corkscrew device pushes the piston against the pads (bypassing the hydraulic system), to hold the vehicle (Figure 3.5).

2. A complete mechanical drum brake unit mounted inside the rear rotor. The parking brake cable pulls on a lever that is connected to the brake shoes to activate the brakes.

When sufficient torque is applied through the mechanical system to the disc or drum, the resulting friction holds the vehicle stationary and a red parking light is illuminated on the instrument panel. The warning lamp warns the driver that the parking brake is applied (whether or not sufficiently) to prevent damage or overheating should the vehicle be driven with the parking brake applied.

### 3.4.4 Temperature effects

Modern braking systems work by converting kinetic energy into heat energy and by their nature, the sliding systems such as disc brakes can potentially generate a significant amount of heat. The heat generated can create temperature distributions in the foundation brake which can affect the friction and wear of the friction material and the contact components, ultimately affecting the brake performance (Day, 2014).

Disc brakes utilise hydraulic actuation systems and friction materials that are capable of withstanding higher pressures and less susceptible to brake fade i.e. loss of braking power in dynamic braking (Kinkaid, O'Reilly and Papadopoulos, 2003). However when employed in a parking brake system, as disc brakes cool towards their ambient temperature the disc material contracts and when the contact force is no longer sufficient to counteract the resultant force from the weight of the vehicle, the vehicle rolls (McKinlay et al., 2004; McKinlay, 2007).

The disc brake assembly expands when the brake temperature increases. The contact area where the friction forces are active is far smaller than in drum brakes and as a result, the temperatures in the contact area have the potential to be higher than that recorded in drum brakes (McKinlay, 2007). As the system cools and returns to ambient temperature the discs and pads contract with a potential loss in braking force and holding capability.

Drum brakes operate using a moment arm, and therefore require a smaller actuation force than disc brakes. In drum brakes, the drum diameter increases as the temperature increases but cooling has little or no reduction in the friction coefficient

(McKinlay, 2007). Rozaini et al. (2013) studied the performance of rear drum brakes and developed an experimental model to assess the performance of the parking brake system. The drum surfaces were heated to 200°C and allowed to cool over a period of 60 minutes. The study concluded that as the temperature drops over time the parking brake torque reduces as well.

The studies of Rozaini et al. (2013) and McKinlay (2007) were of an experimental design which focused on the mechanical factors associated with vehicle rollaway. Although on-vehicle testing was employed to compare the laboratory based results, these did not employ drivers in their own vehicles to conduct any 'real life' studies.

### 3.4.5 Hand lever Parking Brake operation

The lever operated parking brake is applied by the driver operating the system components, which includes the lever and linkage, to activate a braking force (Halderman, 1996, pp.23-24). The parking brake lever gives the driver a mechanical advantage by increasing the mechanical leverage. The force can be multiplied by arranging the lever inputs and outputs in relation to their pivot points. The arrangement of levers, cables, and linkages that make up the lever operated parking brake system is similar on all vehicles as illustrated in the example in Figure 3.6.

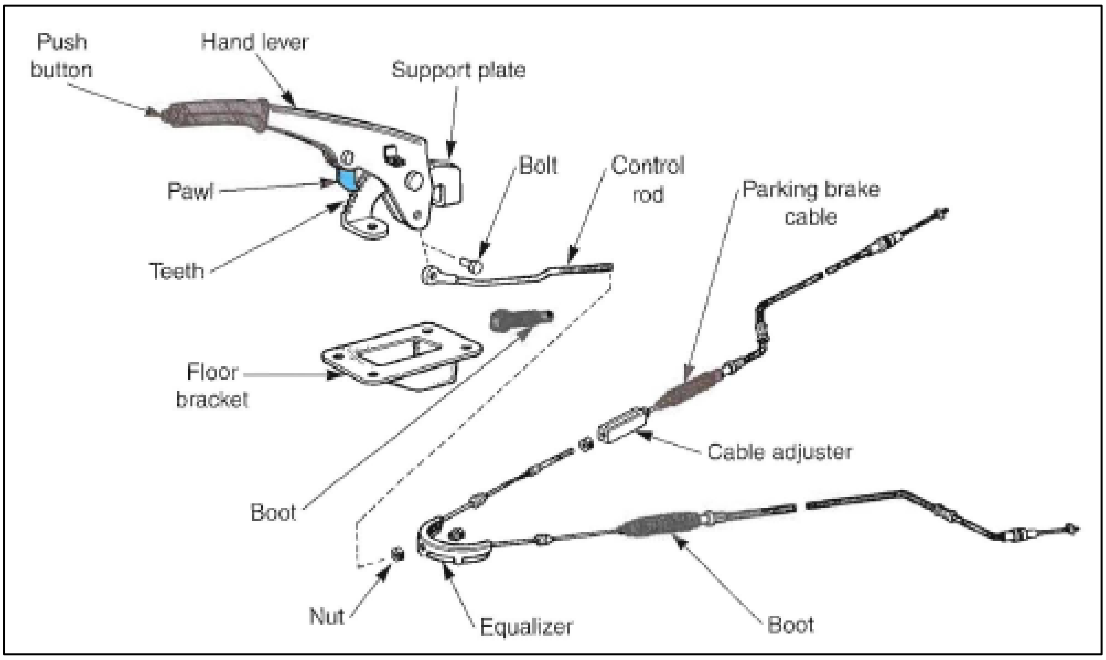



*Figure 3.6 Floor mounted, hand operated, lever assembly (Halderman, 1996)*

One end of the lever is connected directly to the brake cable while the other end forms the handgrip, with a release press button at the end (Figure 3.6, 3.7). The lever is pivoted on a ratchet bracket. When the driver pulls the lever arm up, the spring-loaded pawl slides over the ratchet teeth creating maximum tension on the cable. At the point when the lever is released the pawl should rest between the ratchet teeth.

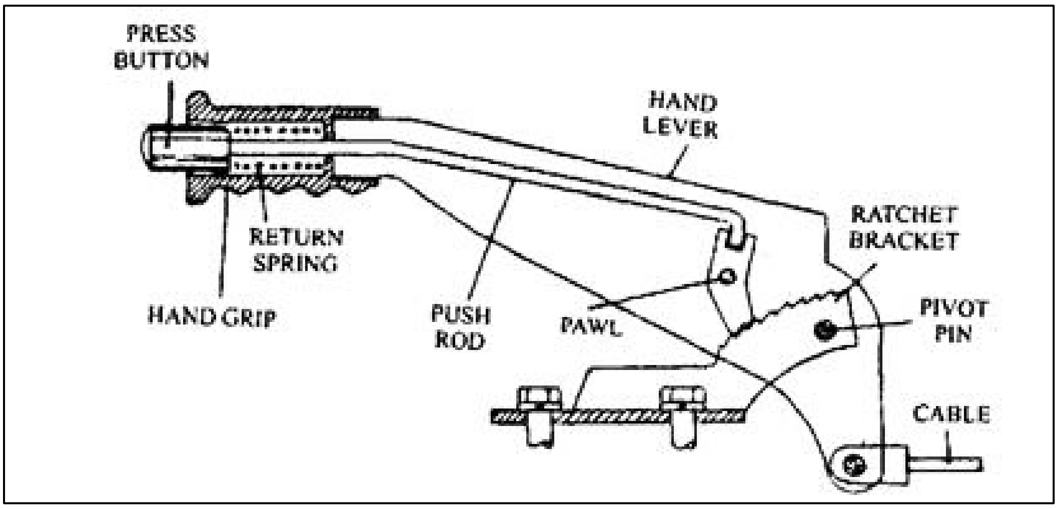



*Figure 3.7 Parking brake lever (Crankshaft publishing, 2013)*

In a right hand drive vehicle, the application of the mechanical handbrake is expected to be a single handed operation performed by the left upper limb, the non-dominant hand for around 90% of the population (McManus, 2009). The lever is grasped, using a power grip, (Figure 3.8) and pulled upwards with or without the release button being depressed, dependent on driver practice and manufacturer's instructions.

*Figure 3.8 Operating the parking brake lever*

The lever may be lifted an additional distance without the button being depressed so that the action on the ratchet is audible. When sufficient pressure is applied through the hydraulic system to the disc or drum, the resulting friction holds the vehicle stationary and a red parking light is illuminated on the instrument panel. The warning lamp warns the driver that the parking brake is applied (whether or not sufficiently) to prevent damage or overheating should the vehicle be driven with the parking brake applied (Birch, 1995; Day, 2014, p.193)

To release the parking brake, the driver grasps the lever, can pull upwards to relax the tension on the pawl, then presses in the release button with his/her thumb, so that the pawl teeth are rotated clear of the ratchet teeth. The lever can then be returned to the released position and the parking indicator light will extinguish.


*Figure 3.9 Sticker sent to Vauxhall owners*

Following a recall of vehicles due to rollaway, Honda and Vauxhall instructed drivers not to push the release button in when pulling the lever up (VOSA, 2011, AA recalls). In 2007, Vauxhall sent a warning sticker (see Figure 3.9) to 279,000 Vectra and Signum owners as an interim measure (Which, 2007) for vehicles manufactured after 2003.

An investigation conducted by the Vehicle Safety Branch (VSB) of VOSA into failure of the mechanical lever operated parking brake focused on the operation of the ratchet and pawl system (see Figure 3.10).

*Figure 3.10 Parking brake lever ratchet and pawl*

The outcome of depressing the release button was compared to not depressing the release button when applying the parking brake. This was based on a change of design of the ratchet where profiling of the saw tooth could mean that as the lever was pulled up with the button depressed the tooth of the pawl could rest on the tooth of the ratchet and then slip or drop off into the gap below. Testing was conducted on 59 vehicles at the dealerships of 8 different manufacturers to explore whether the parking brake could be released easily if the ratchet and pawl mechanism was set tooth on tooth. Parking brake release or 'drop off' occurred in 13 (22%) of the vehicles tested where it was considered that the parking brake was not applied as per manufacturer's recommendations (Ryder, 2013a).

### 3.4.6 Electromechanical Parking Brakes (EPB)

Although it is not within the scope of this study to include exploration of electro-mechanical parking brake systems, acknowledgement and some understanding of their operation is obligatory. The continued development and design of passenger vehicles in a competitive market may be the driving force behind the development of electronic parking brake systems. It would appear that in some cases this may be a space saving measure in others the minimal operator force required is considered to be a valuable feature for those with impaired upper limb strength (Leiter, 2002).

The EPB system may be operated by a switch or button that is activated by a fingertip and may be released automatically when the footbrake is released and the accelerator pedal is depressed, or may require driver action to press to release. The car should be held securely parked when the two geared electric motors on the rear disc brakes operating the parking brake are engaged. An additional extended feature of the EPB considered helpful for convenience and additional safety is the Auto Hold function. This stops the car from rolling away when stationary or setting off. It is operated through the anti-lock braking system (ABS) and the electronic stability programme (ESP) hydraulic unit and when the car is braked to a stop the Auto Hold retains the braking pressure last applied. Any rolling is detected by the ABS wheel sensors which results in an automatic increase in the braking force to bring the car to a stop. The pressure is reduced again by releasing the clutch (for manual gearboxes) or pressing the accelerator pedal (Day, 2014 p.418).

The basic concept for EPB may be the same but as systems develop there appears to be variance across manufacturers in relation to the operating concept and functions of the installed system. TRW automotive anticipated growth in uptake of its electronic parking brake (EPB) technology and proposed that one in five European vehicles would be fitted with EPB as standard by 2015 (Challen, 2011). In 2011, only one out of the 10 most popular vehicles sold in the UK was fitted with EPB. By the end of 2015 this increased to 3 of the 10 most popular vehicles sold were with EPB as standard representing 26% of the total number of vehicles sold. The top two vehicles sold were fitted with lever operated parking brakes as standard (SMMT, 2015).

## 3.5 Legislation and Testing of Parking Brake Systems

### 3.5.1 Braking legislation

Prior to January 1976 legislation related to the requirements of the passenger vehicle parking brake did not exist. The introduction of Federal Motor Vehicle Standards (FMVSS) 105-75 required the motor industry to review the parking brake systems in use and identify any remedial action required to comply with the regulations. The review identified potential mechanical improvements but also resulted in lower effort being required to operate the parking brake (Cross, 1976).

Since September 2000, passenger vehicles manufactured in the USA must meet the requirements of FMVSS standard 135 (FMVSS 571.135) "light vehicle braking systems" (Code of Federal Regulations (CFR), 2005). The vehicle must hold on a 20% gradient for 5 minutes in both directions with a maximum effort of 500N (112.4lbs) for foot controls and 400N (89.9lbs) for hand controls (e-CFR, 2005). All vehicles must be equipped with a parking brake indicator light.

The testing procedure, which includes a test initial brake temperature (IBT) of 100°C, and instructions on how vehicles should be tested are outlined in sub part B of FMVSS 135 (see Appendix B.2) (NHTSA, 2005).

The European Brake Directives and ECE Regulations (71/320/EEC as amended and UN ECE Regulations 13.10 and 13-H) legislate the minimum standards for the performance of systems and components that combine to stop the movement of cars and commercial vehicles in a controlled manner requiring tests to be conducted by the technical service. ECE regulation 13-H specifies that the parking brake must be capable of holding a vehicle at gross weight on a 20% gradient with a maximum force of 40daN (400N) applied at the hand lever, if manually operated, or 50daN (500N) applied to the pedal, if foot operated, for 5 minutes facing up and down the gradient. The parking brake must also be capable of decelerating a vehicle from an initial speed of 30km per hour at a rate of at least 1.5m/s$^2$. Braking systems that are controlled electronically require a further assessment (Day, 2014, pp. 259-302). ECE RH-13 does not specify an initial brake temperature and despite research of archived 1970s records, the UNECE were unable to provide any reference as to why the value of 400N stated above was adopted (UNECE, 2012).

### 3.5.2 Industrial testing

Some vehicle manufactures have developed their own self-certificating tests to ensure that their vehicles satisfy the current ECE regulations:

- Ford developed a test where the vehicle is parked on a 30% gradient and a force of 400N is applied to the lever operated parking brake. The vehicle passes the test if it remains stationary (Curry, 2013).
- Jaguar conduct static hold tests on 4 different gradients (16%, 20%, 25% and 33%). The parking brake is applied sufficiently so that the vehicle remains stationary for one minute on the 16%, 20% and 25% gradients and for 5 minutes

on the 33% gradient. The force required to operate the lever and the lever travel is recorded (Curry, 2013).

- Federal Mogul developed a test that considers the brake temperature and different gradients called the Federal Mogul 20 minute Hot Hill Hold test (McKinlay, 2007). The test requires the vehicle to be parked on gradients of 30%, 16% and 12% with the disc at an initial temperature of 50°C, 100°C, 200°C and 300°C. The test requires the driver to apply the parking brake until the vehicle is held on the gradient without the use of the foot brake. The parking brake is applied again until the next available notch on the ratchet mechanism is engaged. The brake is then allowed to cool for 20 minutes. During this time the driver of the vehicle estimates the magnitude of any movement of the vehicle. If the vehicle moves more than 1m it is deemed to fail the test. Table 3.1 shows a summary of the above test requirements.

*Table 3.1 Summary of test requirements*

| Test | Gradient | Initial Brake Temperature | Performance Requirement |
|---|---|---|---|
| FMVSS 135 | 20% | 65-100°C | Hold vehicle stationary >5 minutes |
| ECE R13-H | 20% | - | Hold vehicle stationary for 5 minutes |
| Ford | 30% | ≤95°C | Hold vehicle stationary |
| Federal Mogul | 12%,16%, 30% | 50°C, 100°C, 200°C, 300°C | Hold vehicle stationary for 20 minutes |
| JLR | 16%, 20%, 25% | <80°C | Hold vehicle stationary for 1 minute |
| | 33% | | Hold vehicle stationary for 5 minutes |

### 3.5.3 Parking brake control and efficiency –Ministry of Transport (MOT)

In accordance with Sections 45 to 48 of the Road Traffic Act 1988, passenger vehicles aged 3 years and over require a Ministry of Transport (MOT) test certificate which indicates the vehicle complies with the key road worthiness and environmental requirements in the Road Vehicle Construction and Use Regulations 1986 and the Road Vehicle Lighting Regulations 1989 as amended.

During the test the parking brake is checked to ensure there is a reserve of travel and that it will prevent at least two wheels from turning. The effectiveness of the pawl mechanism is checked by applying the parking brake slowly, without operating the pawl mechanism, and listening for definite and regular clicks as the pawl moves over the ratchet teeth. There are nine areas in which the parking brake may fail the test or be rejected. The failure descriptions are listed in Table 3.2 (VOSA, 2012). (Section 6a reflects the testing procedure used by VSB when conducting investigations as described in section 3.4.6).

*Table 3.2 MOT failure descriptions (VOSA, 2012)*

| Reasons for rejection (failure of MOT) |
|---|
| 1. The vehicle does not have a parking brake designed to prevent: at least two wheels from turning; with a three-wheeled vehicle, at least one wheel from turning. |
| 2. For vehicles first used on or after 1 January 1968 the parking brake is not capable of being maintained in operation by direct mechanical action only. |
| 3. The brake lever or control is: a. missing b. insecure c. defective or located so that it cannot be satisfactorily operated. |
| 4. a. Side play in the brake lever pivot to the extent that the pawl may inadvertently disengage<br>b. the lever or pawl mechanism pivots and their associated mountings are insecure or a locking or retaining device is insecure or |
| 5. The pawl spring is not pushing the pawl positively into the ratchet teeth or the ratchet has broken, or excessively worn teeth. |
| 6. a. When knocked, the lever is not held in the 'on' position<br>b. when the brake is fully applied there is no possibility of further travel of the lever because the lever is at the end of its working travel on the ratchet, or fouling adjacent parts of the vehicle<br>c. the lever is impeded in its travel. |
| 7. Electronic parking brake warning indicates a malfunction. Note: An EPB malfunction may alternatively be indicated by a message on the dashboard. |
| 8. A parking brake lever or control inappropriately repaired or modified. |
| 9. Deliberate modification which significantly reduces the original strength, excessive corrosion, severe distortion, a fracture or an inadequate repair of a load bearing member or its supporting structure or supporting panelling within 30cm of the parking brake mechanism or associated mounting(s), that is, within a 'prescribed area', |

The required braking performance or minimal braking efficiency is 16% which equates to a vehicle holding on a 1:6.25 gradient and must be tested on a properly calibrated and maintained slow-speed roller- brake tester designated as acceptable for the statutory tests. The wheels on which the parking brake operates, e.g. the rear wheels, are positioned on the rollers and both sets are run together forwards to align the vehicle. With one set of rollers revolving at a time, the manually operated parking brake is gradually applied, keeping the 'hold-on' button or trigger in the disengaged position the whole time, until maximum effort is achieved, or until the wheel locks and slips on the rollers. The reading at which maximum braking effort is achieved and whether 'lock-up' occurs is recorded and the parking brake is released.

The parking brake percentage efficiency is calculated by dividing the total brake effort achieved when the parking brake is applied by the vehicle weight and then multiplying the result by 100.

That is: $\frac{total\ brake\ effort}{vehicle\ weight} \times 100 = \%\ efficiency$

Where using rollers is not possible, a properly calibrated and maintained decelerometer or a plate brake tester may be used. In some cases, such as motorhomes where the parking brake operates through the prop shaft, the parking brake may be tested on a 16% gradient. In these cases the vehicle is reversed onto the incline and will fail if the vehicle fails to remain stationary.

If the tester identifies a potential mechanical impairment in the system but the efficiency test is of 16% or more then it cannot be failed. However, good practice would be an advisory note to the customer (Ryder, 2013).

### 3.5.4 Maintenance testing

Halderman (2009) instructs that parking brake problems can be diagnosed by using the 'click' test where the parking brake is applied and the number of 'clicks' are counted. He indicates that most manufacturers recommend a minimum of 3-4 'clicks' and a maximum of 8 - 10 'clicks' when applying the parking brake. If this number is exceeded the rear brakes are likely to be worn or the parking brake cable requires adjustment. Although this technique does not involve any scientific indices, it would appear to provide a quick practical test.

## 3.6 Ergonomics Design Considerations

### 3.6.1 Introduction

Investigating the cause of the system or equipment failure and the circumstances which could lead to its failure requires recognition of the interfaces involved in operating the system. This, along with materials performance, mechanical defects and human error, includes exploring the system or equipment design features (Jones, Scott and Taylor, 2001).

Systems should be so designed to develop a balance between performance and wellbeing (Marras and Hancock, 2014) and the ergonomic design of systems and equipment will consider the physical interaction between the human and the interface and employ knowledge from occupational biomechanics considering anthropometry, effort and force required to operate the system.

### 3.6.2 Anthropometry

Anthropometry deals with the measurement of size, shape, mass and inertial properties of the human body (Chaffin, Andersson and Martin, 2006a). Statistical data collated from empirical measurements of various physical human dimensions can be referenced to direct an improved 'fit' and user interaction. The product engineer or designer can refer to the relevant data or tables (Pheasant, 1988) to match the human requirements which is fundamental for developing biomechanical models for predicting human reach, force and space requirements (Chaffin, Andersson and Martin 2006a,).

When applying anthropometric data directly there are two areas to satisfy: is the body envelope of the human sufficient? is one single measurement for the design relevant? (Seidi and Bubb, 2006). Reference to tables may be sufficient for simple designs but the development of two-dimensional templates makes anthropometric data more available to the designer. However their use does require knowledge of what they represent in terms of demographics of the driver (Porter and Porter, 2001). The Society of Automotive Engineers (SAE) template (Figure 3.11) is a 2D template contained within the SAE standard SAE J826a especially developed for use in the motor industry. It is extremely important in the industry for design, authorisation and evaluation purposes.

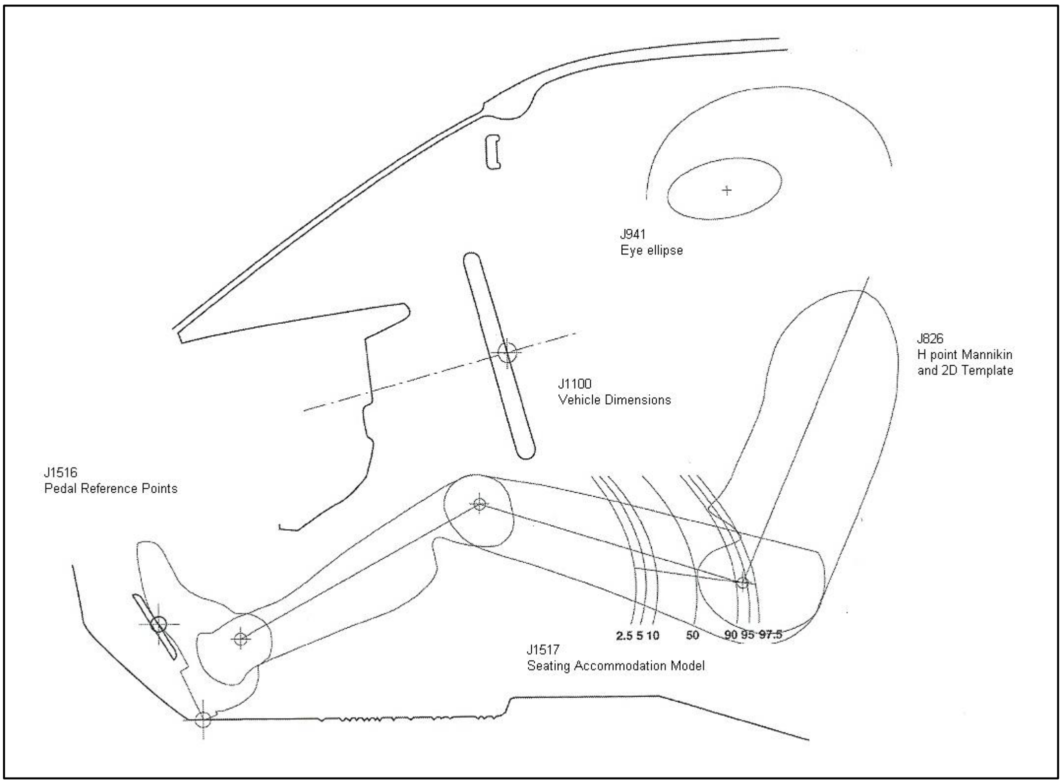



*Figure 3.11 SAE template (Roe, 1993; Seidi and Bubb, 2006)*

Further developments employ 3D digital human modelling and manikins. The RAMSIS manikin was developed for vehicle design and is used by more than 75% of car manufacturers (Seidi and Bubb, 2006)

The H-point manikin has 50$^{th}$ percentile male weight and body contour but is used with 95$^{th}$ percentile male legs. The H-point is intrinsic to the seat and simulates the pivot centre of the trunk and thigh thus providing a landmark to reflect the driver's position in the seat. The seating reference point (SgRP, SAE J1100) is a specific H-point near the back of the seat travel path which can be used as a landmark depicting the rearmost normal driving design position. The location of primary vehicle controls, such as the parking brake can be considered within the adult grip reach envelope (Pheasant, 1988) and in relation to the H- point and seating reference point.

Standards for Human Factors and Ergonomics are mainly developed by the International Organization for Standardisation (ISO) and the European committee for standardisation (CEN). Subcommittees address different aspects with TC159/SC3 focussing on anthropometry and biomechanics (Sherehiy, Rodrick and Karwowski, 2006). The standards for transportation considered to be the most relevant to parking brake application are ISO 3958:1996 Passenger cars – Driver hand-control reach; ISO 4040:2001. Road Vehicles – Location of hand controls, indicators and tell-tales in motor vehicles; ISO 6549 -1999 Procedure for H and R point determination; ISO/TR 9511:1991. Road vehicles –Driver hand-control reach- in vehicle checking procedure.

### 3.6.3 Operating posture

The driver's posture may be influenced by the position of task points, the reach required, clearance offered, the line of vision, the necessity to perform manipulative tasks in a supported seating position. Consideration should be given to the number of movements using the same muscles and whether the task is static or dynamic. The configuration of the skeletal framework, represented by the relative positions of the joints of the body, is thought to be the fundamental basis of posture (Haslegrave, 1994). The adopted posture may be dependent on the position of the eyes and head for vision, the arms for reaching and the muscle length or leverage required for the application of force. To maintain mechanical efficiency and avoid the adverse effects of altered body mechanics, the centre of gravity of each body segment must be centred over its supporting base. Excessive deviation from the anatomical position places loading on the musculoskeletal system and should therefore be avoided.

The following general principles of design layout (Corlett, 1990) are considered relevant to parking brake operation:

- The task should be done in a forward facing upright posture for most or all of the task, without the need for twisting or turning.
- The posture of the head, trunk and upper limbs should be in the mid-range of movement.
- Muscular force must be exerted by the largest appropriate muscle groups in line with the direction of the limb(s) concerned.
- Tasks should be performed as far as possible with the hands/arms below the level of the heart.
- The visual task points should be clearly seen with the head and trunk upright or the head slightly inclined forwards.

The location of the primary vehicle controls in relation to the seated position is likely to be a major determining factor in the driver's posture. Limb deviation will not only have localised effects but the whole body may accommodate and adopt awkward compensatory postures in an attempt to gain greatest mechanical efficiency of one particular set of muscles. The orientation of the *hand* will dictate the posture of the arm/forearm. The supinated hand is normally adducted and held close to the trunk. In contrast, a task which requires the hand to be pronated will induce a more abducted and elevated arm. This interdependence between hand orientation and arm postures is therefore important in the application to the design of hand-tool configurations and machine controls. (Chaffin, 1984; Parker, 1992; Milerad, 1994).

Limb postures which are considered to be less efficient are those:

- which allow gravity to act about a joint creating or increasing the joint moments and thus increasing the load on the soft tissues.
- which dictate a change in the musculoskeletal alignment and therefore place more stress on the supporting tissues and may reduce their tolerance.

The parking brake mechanism should be operational from the driver's seat and is considered to be a one handed activity. However, some drivers may require additional force to apply or release the handbrake and as such two hands could be employed with compensatory movements occurring at the trunk. Reed et al. (2000) concluded that during dynamic driving tasks, trunk posture remains relatively unchanged and that adaptations to the layout of the primary driving task points is through changes in limb posture. However, the study was conducted with the left hand remaining on the steering wheel and the driver posture was evaluated in relation to changes in seat and or steering wheel position. It is unclear whether the primary driving tasks included parking brake application.

The ability to depress the button and grasp the lever may be determined by the configuration of the wrist and the posture of the seated driver's upper limb. Kang and Duffy (2011) found that which hand was used (i.e. dominance), the grip posture and duration of the grip along with the level of force required, had a significant impact on the co-ordination of the grip force. The results indicated that when considering hand operated devices more attention should be given to these factors than the anthropometric data and gender. Wang et al. (2011) found that the maximal hand effort on the manually operated parking brake (handbrake) depended on the position of the lever and the demographics of the subjects. In this study, the parking brake lever was operated with the right hand and the study revealed a large variation in muscle capacity between males and particularly the shorter females. Maximum force was found to be exerted when the parking brake lever was positioned below the level of the seat and behind the front edge and at the furthest point from the shoulder with the elbow almost fully extended.

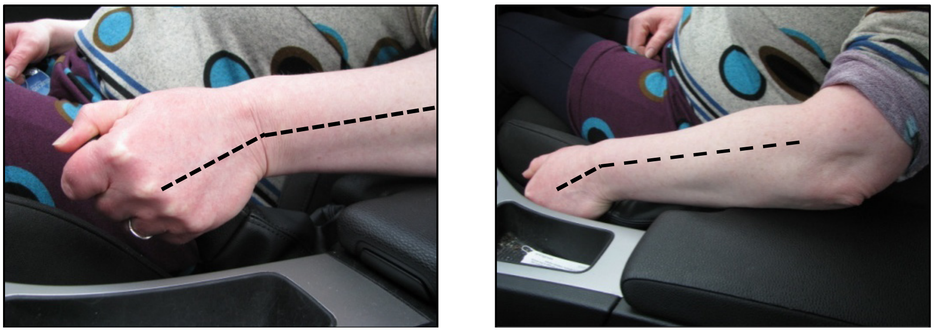


*Figure 3.12 Operating posture for 50$^{th}$ percentile female in BMW 3 series*

Figure 3.12 illustrates the upper limb posture of a 50$^{th}$ percentile female driver (standing height 1626mm) operating the lever hand brake of a 3 series BMW. As the parking brake lever is released from the applied position, the wrist is extended and deviated from midline. To pull the lever up the wrist is again deviated and the upper arm is abducted away from the body due to the central storage area.

The operation of the conventional hand operated lever parking brake requires thumb tip pressure to depress a button on the lever to release the ratchet mechanism, regardless of whether or not it is depressed to engage the system. In this action the distal interphalangeal joint is flexed and the thumb is actively adducted against resistance. Thumb tip pressures are complex and are dependent on the alignment and torque acting at the thumb joints (Pearlman, Road and Valero-Cuevas, 2004). In a wrist neutral position the force that can be applied is greater when there is a smaller angle between the thumb and index finger (Park et al., 2009).

### 3.6.4 Force required

For the upper limbs, the hand grasp employed to operate a tool or lever will affect the muscular effort required to apply force to that object. For example, a pinch grip requires approximately five times higher tendon and joint loads than a power grip and should therefore be avoided where force must be applied. The posture of the joints will also affect the force required with maximal power being gained in the near neutral position. Any deviation from this will require more effort and place more strain on the proximal, stabilising joints. The size of the object to be grasped and the coefficient of friction offered by the grip influences the effort required to manipulate the object and the resulting applied force (Hagberg, 1981). Individual factors such as hand dominance may also play a part where at maximum effort the dominant hand may exert 10% more force than the non-dominant hand (Li and Yu, 2011).

Operation of the lever parking brake requires concentric contraction (muscle shortening against resistance and eccentric contraction (muscle lengthening against resistance). Muscle strength, measured in terms of maximum voluntary exertion levels, depends on muscle length and as the muscle contracts and shortens, strength reduces and is therefore weakest at its fully contracted length. For example, with the arm by the side and the elbow flexed at 90°, prediction of the elbow flexion strength, based on both shoulder and elbow angles is 42-111N for the adult male and 16-41N for the adult female. At 70°, the predicted strength is 31-67N and 9-39N respectively (Schanne, 1972 as cited in Chaffin, 1984).

It is considered that the force required to apply the lever parking brake could be a limiting factor in some driver groups. To perform the function efficiently the task should be within the normal demands of the driver population.

Kember and Staddon, (1987) explored the force required to operate primary controls and documented that the force required to operate the parking brake on a 16% gradient ranged from 11.2N to 250N for five different manufacturers.

Pettigrew, (1981) indicated that after testing three different vehicles on a 30% slope a range of effort from 244-328N was required to hold the vehicle stationary.

As part of an ergonomic evaluation of the Elswick Envoy, Fernie, (1983) tested five stages of operating the lever parking brake with the following results: set parking brake: 173N; pull back on lever to release brake: 116N; release parking brake (button depressed) while pulling back on the lever: 78N; without pulling back on the lever: 135N. However, this vehicle was designed for the disabled driver and therefore had atypical controls, not representative of standard vehicles or the magnitude of force required to operate their controls.

Wang et al. (2011), concluded that the maximum effort applied to the lever operated parking brake depended strongly on the subject group and the hand lever configuration. The maximum effort for the ‘short female’ was almost less than half that of two male groups. The predicted force for the right upper limb with a parking brake lever positioned at 100mm along the x axis and 350mm on the y axis was recorded as 55.4N for the smaller female and 110.9N for the average height male (Wang et al., 2011).

In the study by Wang et al. (2011), the parking brake lever was positioned on the right hand side of the driver and so employed the right upper limb to operate. The maximum effort observed was where the parking brake lever was positioned furthest away from the shoulder and the minimum force was recorded at a point closest to the shoulder.

McKinlay (2007) conducted in-vehicle tests where an experienced driver drove and parked 2 vehicles (Jaguar on gradients of 8%, 16.6% and 25%. The results indicated that the amount of excess applied force that was required to move the parking brake lever from the ‘just hold’ to the ‘park’ condition had an influence on the likelihood of rollaway occurring. McKinlay concluded that the higher the amount of excess force that was applied, the less likely the vehicle was to roll away as the excess stored load could compensate for the load lost due to the thermal contractions of the brake components.

A more recent study by Rozainia et al. (2013), using an experimental layout concluded that the minimum force required to hold the vehicle fitted with drum brakes stationary on a 7% gradient was 60N and on a 14% gradient was 120N and on a 20% gradient was 180N when facing down the gradient and 58N, 110N and 160N respectively when facing up the gradient. From the results of the experimental study it was concluded that that the minimum force to hold the vehicle stationary on a 20%

or 11 degree slope with four 70Kg passengers was 220N with the vehicle facing down the gradient and 200N when the vehicle was facing up the gradient. Unlike the study by McKinlay (2007) where the performance of disc brakes and various pad materials were used, drum brakes were tested in this laboratory based rig with no driver interaction or driving performance.

### 3.6.5 Handle and lever design

The lever should enable the driver to transfer sufficient force through the braking system in a comfortable and efficient manner. The floor mounted parking brake lever commands a power grip accompanied by a thumb tip pressure. The design of the lever should maintain a near neutral wrist position. Force is applied more effectively when it is applied perpendicular to the axis of the cylindrical lever so that the hand and lever interact in compression rather than shear (Pheasant, 1988).

The grip diameter for handles should be between 30 - 50mm (Pheasant, 1988) but an upper limit of 40mm is recommended so that the smallest user can have a full hand grasp for pulling (Currie and Southall, 2002). Handle length should not be less than 77mm (small female handbreadth across knuckles) with an ideal length of 95mm to fit a large male hand and allow the effort to be spread across the largest area.

Circular handles are likely to be more comfortable but may provide less leverage than rectangular or polyhedral shaped levers. Finger shaping of handles should be avoided. The surface of the lever handle should have a high friction coefficient, so that the hand does not slip. The type of lever selected should also be related to the type of grasp that will be used (Pheasant, 1988; Mital, Subramanian and Pennathur, 2008).

Palm thickness of the grasped hand should be taken into account to allow clearance between the lever and any surrounding ‘furnishings’. This should allow for the hand thickness of the 95$^{th}$ percentile male wearing a thin glove and should be 50mm to allow for the thumb plus up to 25mm adjustment for gloves. If the hand has to be inserted into the handle a rectangle of 110mm x 45mm should be allowed (Pheasant, 1988).

### 3.6.6 Lever operated Parking Brake design (passenger vehicles)

*Figure 3.13 1928 Bugatti*

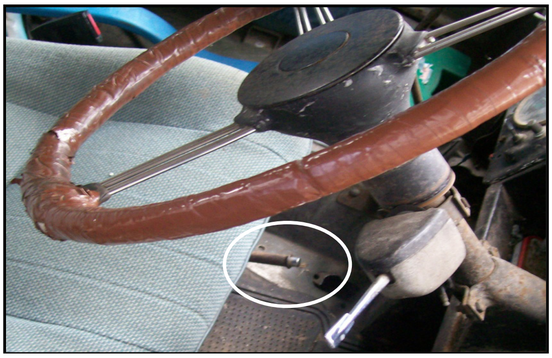


*Figure 3.14 1958 Series II Land Rover*

The position, diameter and grip of the parking brake hand lever has developed (see Figure 3.13 and 3.14.) but until recent years the design of the lever positioned between the front seats has remained relatively unaltered. Figure 3.15 to 3.20 give examples of variation in the parking brake lever in 2011 vehicles.

*Figure 3.15 Ford S Max*

*Figure 3.16 Ford Focus*

*Figure 3.17 Peugeot 207*

*Figure 3.18 Mazda RX-8*

*Figure 3.19 Vauxhall Corsa*

*Figure 3.20 BMW Mini*

Initial observations indicate that most parking brake levers offer a friction grip that does not depress when grasped. Ford suffered a recall on Mondeo due to the use of a 'soft feel' lever grip which could tend to interfere with the release button movement. The result was a loss of 1 or 2 notches on parking brake application and hence an increased risk of rollaway (Curry, 2011; VOSA, 2011).

## 3.7 Human Error

### 3.7.1 Introduction

Reason (1990) defines human error as "a generic term to encompass all those occasions in which a planned sequence of physical or mental activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency" (Reason, 1990, p.9).

Many human errors result from limitations in human cognitive, sensory and motor processes (Sharit, 2006) as illustrated in Wickens (2004) model of human information processing. Information received through the body's receptors is stored and is available (all be it briefly) for further processing. Information selected for further processing at this stage forms the perception process. Information is compared with that stored in the long term memory and may result in a response or further processing using the working memory, or short term memory store. Working memory activities include evaluating, planning, decision making and conceptualising which largely depends on information stored in the long term memory. Practise or rehearsal of information in the working memory enables it to be embedded into the long term memory (Wickens, 1992; Wickens et al., 2004; Sharit, 2006).

The processing resources require attention, but when attention is focused on one resource it may affect another e.g. a driver from USA who normally drives a left hand drive vehicle with automatic transmission hires a vehicle with manual transmission in the UK. The focus of attention is on the perceptual processing of driving on the opposite side of the road from what the driver is familiar with which may affect operation of the controls such as in gear changes which may also be an unfamiliar task (Sharit, 2006).

Much of the information and knowledge a person has about a topic or concept is organised and stored as schemas and mental models. Norman (1988) refers to memory units as schemas which are triggered if conditions satisfy. When people interact with systems, equipment or technology they form beliefs or their own 'fact file'. The models generated provide some indication of the understanding that guides peoples' behaviour and actions. The successful application of a task requires the matching or association of mental models and the presenting situation. However, mental models can be incomplete and may be driven by 'a rule of thumb' approach rather than a detailed knowledge of the system. Information from repeated exposure and 'rehearsal' of activities will be stored in the long term memory and will contribute to the formation of these mental models. Any new information such as that gained from exposure to a new system will be stored in the short term or working memory which is more likely to be disrupted by other activities or distractions.

### 3.7.2 Error types

*Slips* are the most common error type (Reason, 1990; Salmon, Regan and Johnston, 2005) and refer to the correct action carried out incorrectly although the intention was correct, e.g. pressing the accelerator instead of the brake when intending to stop (Schmidt, 1989; Young and Salmon, 2012).

*Lapses* occur when an individual unintentionally fails to perform an action i.e. the action is omitted or not carried out (e.g. forgetting to lock the car) (Young and Salmon, 2012). Slips and lapses are executional failures and are likely to be the result of inattention or over attention (e.g. conducting checks at the wrong point in a task).

A *mistake*, either rule based or knowledge based, is a planning failure where the action is completed correctly but is inappropriate, e.g. accelerating towards a red light. Mistakes are likely to be the result of the wrong application of a good procedure or the application of a bad procedure (Reason, 1990; Reason et al. 1990).

A behaviour that deviates from accepted standards, procedures and rules such as legislation is categorised as a *violation* whether deliberate, e.g. exceeding the speed limit, or unintentional e.g. exceeding the speed limit when not aware of what the limit is (Reason, 1990, Parker et al., 1995).

### 3.7.3 Human error models

Models of human error that have been developed provide insight into the psychological and organisational factors that can contribute to incidents and unwanted events (Drew, 2012). Errors may be dependent on skill, experience and knowledge of the current situation and Rasmussen (1986) identified three levels of cognitive control i.e. skill based, rule based and knowledge based behaviour (Stanton and Salmon, 2009).

Skill based behaviour is largely automatic and tends to be related to routine tasks and relies on stored patterns of information from highly practiced tasks. Errors at the skill level are more likely to be linked to variations in force, space or time co-ordination such as untimely interruptions (Sharit, 2006; Reason, 1990). Interruptions are a common reason for error (Norman, 2013).

Tasks that may require recall of actions or responses stored in memory are rule based and this process is applicable when finding solutions to familiar problems (Wierwille et al., 2002). Errors at the rule-based performance level are likely to result in applying the wrong rule or the incorrect recall of procedures because the situation has been misclassified (Wierwille et al., 2002; Reason, 1990).

Knowledge based behaviour relates to tasks that are unfamiliar and require attention and conscious effort (Drew, 2012; Stanton and Salmon, 2009). Errors at the knowledge based level are related to individual limitations and incorrect or incomplete knowledge. (Reason, 1990). With increased expertise, knowledge based errors decrease but skill-based errors may increase (Sharit, 2006).

The generic error modelling system (GEMS) is an extension of the skill, rule and knowledge (SRK) approach (Rasmussen, 1986; Reason, 1990) and identifies three stages of processing (planning, storage and execution) and three levels of control (automatic, mixed and effortful) related to the cognitive effort required (Wierwille et al., 2002; Salmon, Regan and Johnston, 2005; Stanton and Salmon, 2009). The GEMS presents an integrated picture of the error mechanisms at all three levels of performance and splits them into the areas preceding the detection of a problem (skill based) and those after detection (rule based and knowledge based) as can be seen in Figure 3.21. The GEMS model conveys how switching between different information processing occurs.

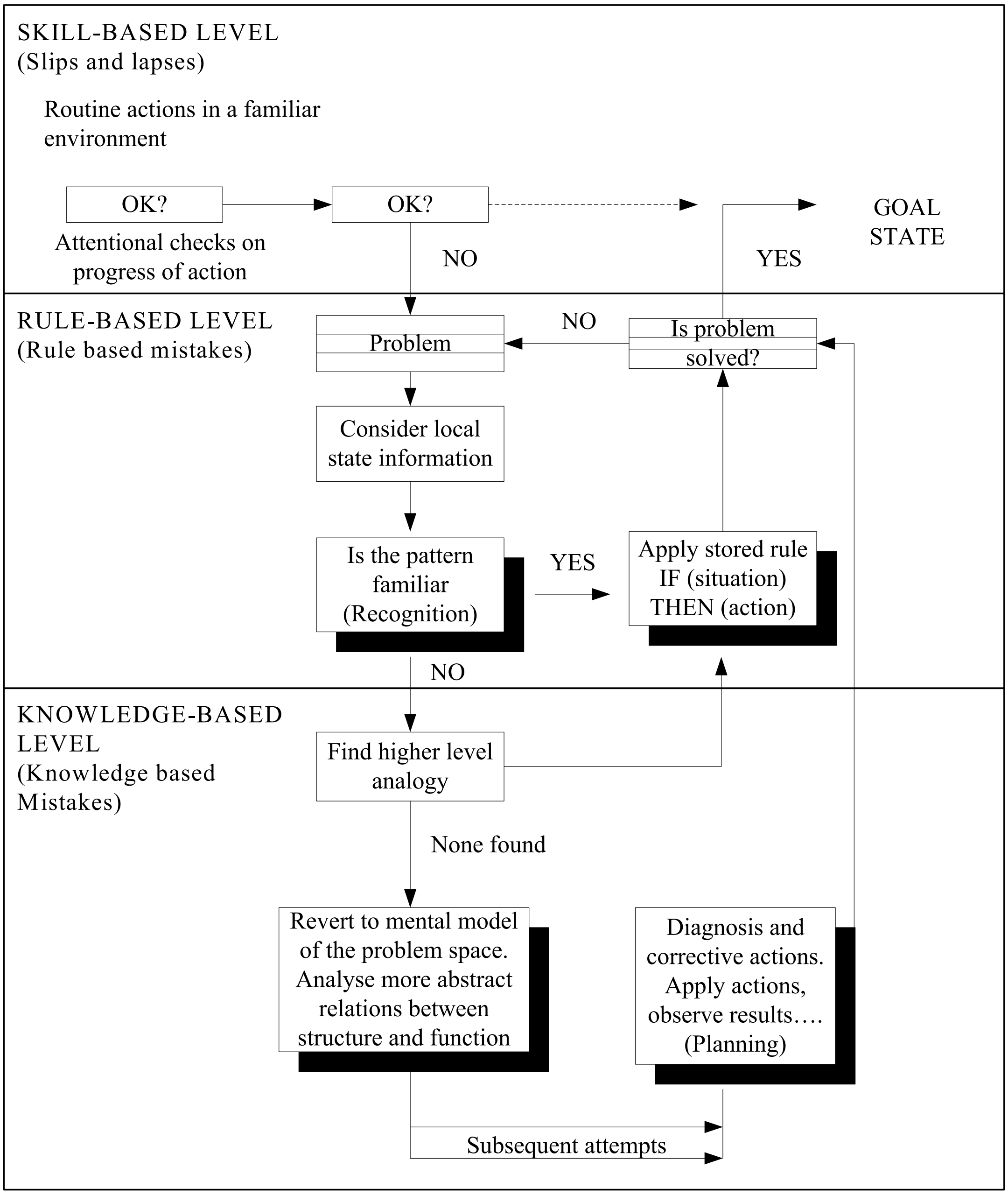



*Figure 3.21 Generic Error Modelling System and related errors (Reason, 1990; Wierwille et al., 2002; Salmon, Regan and Johnston, 2005).*

At the skill level, the cognitive function is mainly one of monitoring. Consistent practise develops automatic component processes (Schneider et al. 1984) and over time a degree of automaticity develops and the process becomes fast, parallel, fairly effortless and not limited by short term memory. This also leads to reduced error, increased performance rate and a reduction in variability of the task. However, Dismukes (2010) highlights the vulnerability of automatic processing when conscious supervision of the task is prevented.

If a problem is detected the rule based processes come into action. The stored rules reflect the state (i.e. IF), the diagnosis (THEN) and remedial action required to complete the task. IF symptoms are X, THEN the cause of the problem is Y. This can then be stored as a rule that IF the cause of the problem is Y, THEN do Z. If the problem is resolved, the human will return to the skill based level, if not resolved further information will be required and the individual may proceed to the knowledge based level. At this level a match of the unfamiliar situation with any rules available at rule based level is explored. If diagnosis is successful the processing will revert back to rule based level. If no suitable analogy is available further input and knowledge is required. (Reason, 1990; Wierwille et al., 2002).

Norman (1988) described seven stages of action divided into the processes of execution and evaluation (Salmon et al. 2010; Norman, 2013, pp.40-44) and the error types that can occur at the different stages is illustrated in Figure 3.22.

| **Execution** | | **GOALS** | **Evaluation** | |
|---|---|---|---|---|
| **Action Stage** | **Error type** | ↓ ↑ | **Action Stage** | **Error type** |
| Intention to act/planning | Mistakes & violations | | Evaluation | Mistakes & violations |
| Action sequence | Lapses | | Interpretation | Mistakes & violations |
| Execution | Slips | | Perception | |

*Figure 3.22 Error types that can occur at different stages*

### 3.7.4 Unsafe acts and incident causation

An unsafe act is defined as an error or violation that is committed in the presence of a potential hazard and could cause injury or damage, and can be caused by either an active or latent failure (Reason, 1990; Reason, 2008, pp.92-102).

Active failures are actions or inactions of operators (or drivers) that are thought to directly cause an accident. The consequences of the actions are felt immediately. Latent failures stem from errors committed as a result of organisation policy or management (Wierwille et al., 2002). Unsafe acts can be intentional or unintentional. Intended actions are those that are planned and conducted as planned. Unintentional actions are those where actions are executed but not as planned and are related to memory or attentional failures (see Figure 3.23).

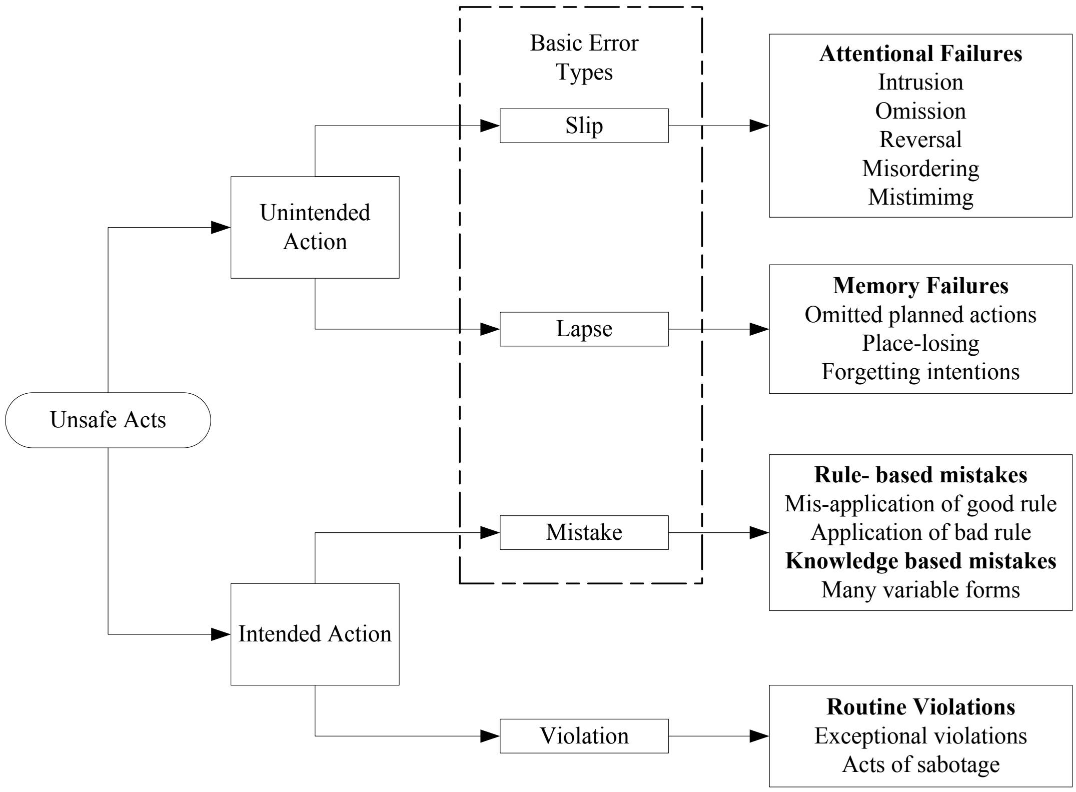



*Figure 3.23 Unsafe acts taxonomy (Reason, 1990)*

## 3.8 Driver Error

### 3.8.1 Introduction

Two theoretical perspectives in human error are recognised a) the person approach, b) the system approach (Reason, 1990) which Dekker (2002; 2006) refers to as the old and new view respectively and each model may give rise to differing procedures for error management (Reason, 2000). The 'person' approach focuses on errors that may result from psychological processes such as forgetfulness, inattention, poor motivation, carelessness and negligence (Reason, 1990; Dekker, 2002; 2006). Safety improvement programmes for the person approach will include automation, training, discipline and developing procedures (Salmon, Regan and Johnston, 2005). The systems approach treats error as a systems failure and so the 'human error' is not considered as the primary cause but a consequence of latent failures in the process and requires all the systemic elements to be considered such as the equipment or vehicle, other road users, the driver and the environment (Reason, 1990, Salmon, Regan and Johnston, 2005, Stanton and Salmon, 2009). Error is then the result of an imbalance between the driving task demands and the human mental and physical capabilities (Sharit, 2006).

### 3.8.2 Driver error and incident causation

Some form of driver error is reported to be a causal factor in as much as 75% (Wierwille et al., 2002) to over 90% of vehicle crashes (Peden et al., 2004; Harley et al. 2008). Human error or Human functional failures (HFF) in vehicle driving tasks are considered to be the result of malfunctions in the driving system related to its components (driver, vehicle and environment) and their impaired or defective interactions (Harley and Cheyne, 2005).

Four primary groups of incident causation have been identified as seen in Table 3.3 (Wierwille et al., 2002; Stanton and Salmon, 2009). These are:

1. Human conditions and states - factors that affect the driver's ability to process information and perform the driving task safely.
2. Human direct causes - human acts or failures that occur immediately before the incident.
3. Environmental factors relate to factors which are outside of the vehicle or the driver and may needlessly or dramatically increase the risk of an incident.
4. Vehicle factors are those where faults or weaknesses with the vehicle may increase the risk of an incident.

*Table 3.3 Overview of driver error and incident causation (adapted from Wierwille et al., 2002).*

| **1. Human Conditions and States** | | |
|---|---|---|
| 1.1 Physical/Physiological | 1.2 Mental/Emotional | 1.3 Experience/Exposure |
| • Alcohol impairment<br>• Other drug impairment<br>• Reduced vision<br>• Critical non-performance | • Emotionally upset<br>• Pressure or strain<br>• In hurry | • Driver inexperience<br>• Vehicle unfamiliarity<br>• Road over –familiarity<br>• Road/area unfamiliarity |
| **2. Human Direct Causes** | | |
| 2.1 Recognition Errors | 2.2 Decision Errors | 2.3 Performance Errors |
| • Failure to observe<br>• Inattention<br>• Internal distraction<br>• External distraction<br>• Improper lookout<br>• Delay in recognition for other or unknown reasons | • Misjudgement<br>• False assumption<br>• Improper manoeuvre<br>• Improper driving technique or practice<br>• Defensive driving technique<br>• Tailgating<br>• Excessive acceleration<br>• Pedestrian ran into traffic | • Panic or freezing<br>• Inadequate directional control |
| **3. Environmental Factors** | | |
| 3.1 Highway related | 3.2 Ambient conditions | |
| • Control hindrance<br>• Inadequate signs and goals<br>• View obstructions<br>• Maintenance problems | • Slick roads<br>• Special/transient hazards<br>• Ambient vision limitations<br>• Rapid weather change | |
| **4. Vehicle factors** | | |
| • Tyre and wheel problems<br>• Brake problems<br>• Engine system problems | • Vision obscured<br>• Vehicle lighting problems<br>• Total steering failure | |

A study of parking lot crashes identified environment characteristics where the driver’s vision was obstructed to be a contributory factor and that there was a higher percentage of property only damage (Siddiqui, Abdel-Aty and Anjuman, 2012) but the research did not refer to rollaway of unoccupied vehicles.

A survey of 1000 UK drivers conducted by an independent vehicle supply firm indicated that 20% of drivers who reported a parking ‘prang’ cited passenger distraction as a factor, 17% reported that the passenger had blocked their view, 11% indicated they felt pressurised by other drivers and 7% reported they were distracted by their mobile phone (Hull, 2016). No reference was made to parked unattended vehicles.

Most crashes have more than one contributing factor with a possible overabundance of combinations. Wierwille et al. 2002 developed a framework or taxonomy of contributing factors affecting driving performance as seen in Figure 3.24.

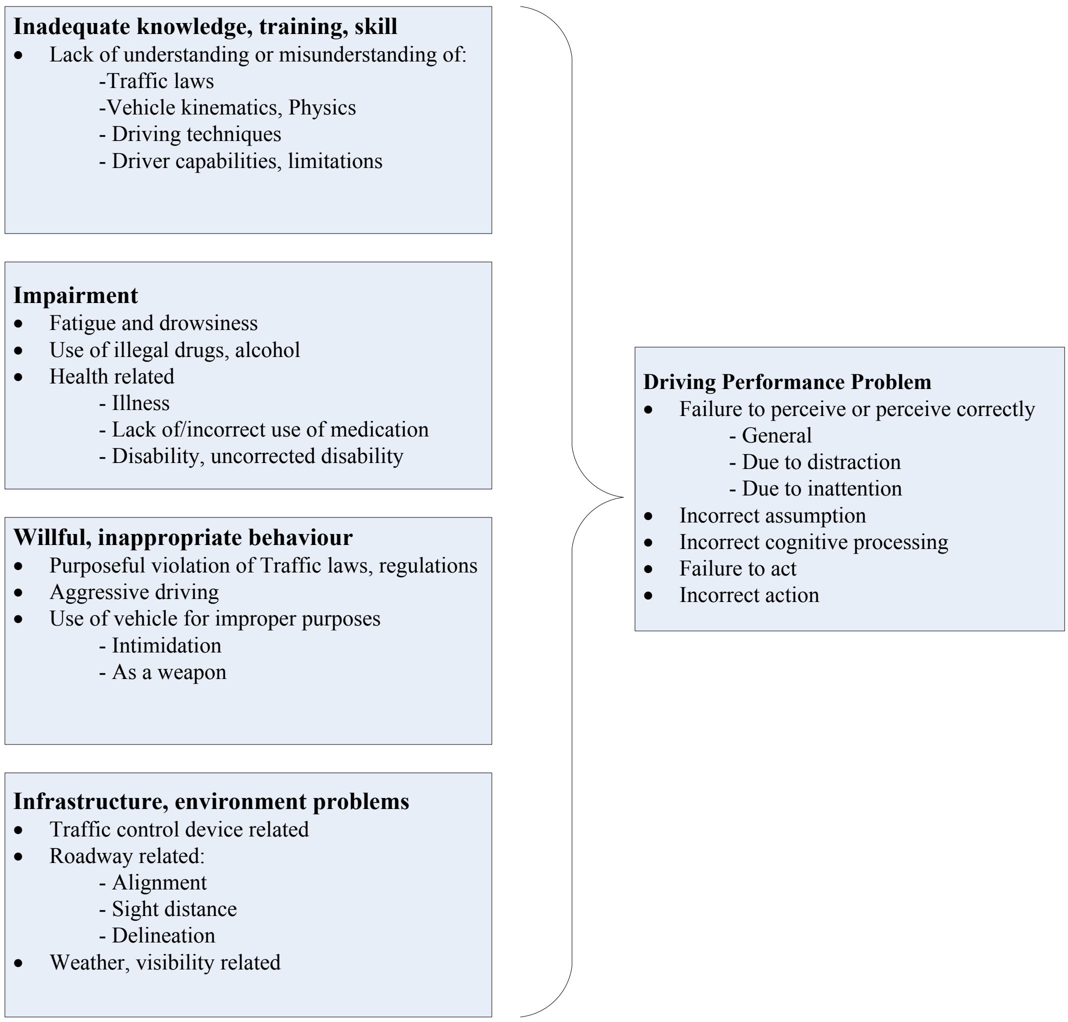



*Figure 3.24 Taxonomy of contributing factors (Wierwille et al., 2002)*

### 3.8.3 Decision making

The decisions made by the driver on when and how to apply the parking brake may be though recall of stored information (memory) or via the mental models formed. In breaking down the task into its components there are stages where decisions are made possibly subconsciously. That is why it is important that we understand why humans make errors and the theories and models based on cognitive and organisational ergonomics (Reason, 1990; Rasmussen, 1994, Wickens, et al., 2004). Mental Models represent the understanding and beliefs that individuals hold about a particular task or subject (Johnson-Laird, 1983; Norman, 2013). When people interact with systems, equipment or technology they form beliefs or their own ‘fact file’. The models generated provide some indication of the understanding that guides people’s behaviour and actions even though these mental models can be incomplete and lack detailed knowledge of the system.

Information from repeated exposure and ‘rehearsal’ of activities will be stored in the long term memory and will contribute to the formation of these mental models. Any new information such as that gained from exposure to a new system will be stored in the short term or working memory which is more likely to be disrupted by other activities or distractions. Any introduction of new technology e.g. EPB, must consider that individuals may need to develop a new mental model process (Wickens, et al., 2004; Wickens, et al., 2008; Norman, 2013).

Routine actions may present a greater potential for error along the constructed stages and could result in an omission error (failing to apply the parking brake) or perhaps an exchange error if the driver drives two different vehicles with two different parking brake systems. The initial task analysis demonstrates the potential points along the decision making process where slips or lapses leading to error could occur.

### 3.8.4 Attention and distraction

Driver distraction occurs when a driver fails to devote sufficient attention to the driving task at a critical moment because their attention is diverted towards another activity (Young and Salmon, 2012).

Posner and Petersen (1990) suggest the 3 major functions of attention are:

- to orient to sensory stimuli such as visual location
- engage in executive control – such as selecting the appropriate response
- remain alert

Groeger (2000) refers to seven aspects of attention that are deployed during driving tasks. These are sustaining, concentrating, suppressing, switching, sharing, setting and preparing. When considering the attention demands of driving tasks, apparently routine operations may directly prime stored knowledge or the developed schemata and the related activities are implicit and automatic. However, unfamiliar situations will require controlled explicit functioning to select the desired action. Through the 'Supervisory Attentional System', sensory input activates a network of neurons and specific schemata may be selected or the effects of other schemata may be suppressed to enable the appropriate action.

The driver may have one specific goal, such as parking the vehicle, and is consistently engaged in achieving that aim so may refer to or activate the 'schemata' based on how this task was done in the past. Any discrepancies or alterations may affect the feedback as to how well the task is completed. Even though the driver is 'programmed' to this pre-ordained activity he/she must still remain vigilant or sustain preparedness (Groeger, 2000) to respond to a relatively rare event. To concentrate the efforts, the driver must maximise activation of the current schema and the supervisory system must continually trigger the targets for detecting stimuli or initiate other actions that may be required.

Schemata that are irrelevant to the task may be suppressed to allow the primary task to be conducted effectively and in some situations sharing across schemata can occur. The tasks may be unrelated but able to continue simultaneously at a lower activated level than if just one task were conducted. Within the primary task, switching between schemata can occur but the successful switch requires the activation of the less activated task to be augmented. The driver must also be prepared for a forthcoming action and when the trigger or stimuli occurs, be ready to respond safely and efficiently. Should that action be taken prematurely it could be subject to a loss of place or anticipatory error (Reason, 1984).

Distractions can be visual, cognitive or physical and is thought to be a contributory factor in up to 23% of crashes and near misses (Young and Salmon, 2012). Driver distraction may contribute to errors through a variety of ways but activities that require a considerable level of visual-physical resources such as operating media systems or responding to passengers are associated with a higher crash risk than activities that are largely cognitive e.g. viewing the surrounding scenery (Young and Salmon, 2012).

Literature indicates the quantity of research that has been conducted exploring the effects of mobile phone use while driving (National Safety Council, 2012) but the emphasis has been on dynamic driving tasks rather than static driving tasks such as securing a vehicle so that it remains stationary. Young and Salmon (2012) concluded on review of the literature, that although distraction plays a part in error causation, distraction has not been linked to error types and advocate a systems based approach to distraction-related error research.

Harley et al. (2008) reported an association with rollaway vehicles in the USA and slips and lapses when conducting gear shifting tasks in vehicles with automatic transmission. Recognising gear shifting to be an automatic task, they hypothesised that distraction could interrupt the automated sequence and result in gear shift errors. The results indicated that drivers relied on biomechanical feedback when the gearshift lever reached the end of its travel to determine the end of the movement and the task and typically applied more force than required to reach 'park'. However gearshift errors when the driver either shifted into unintended gears or forgot to shift into park occurred when drivers were hurried or distracted with 3 out of 65 drivers exiting the vehicle when the vehicle was not in park. The study focused on automatic gear shift transmission employing 'park' to secure the vehicle and did not include parking brake application (Harley et al., 2008).

## 3.9 Error Management

### 3.9.1 Introduction

Dekker (2002) describes the shifting role of human error in accident investigation over the last two decades. With the old models of accident investigation, a person approach was taken to identify contributing factors. This approach focused on the unsafe acts of the people immediately involved with an adverse event. It was a deficiency or lack of action on the part of the individuals involved that lead directly to an accident occurring. In the new approach to accident investigation and prevention advocated by Dekker (2002) and the World Health Organisation (Peden et al., 2004) a systems or organisational approach should be taken. The goal of this approach is to identify the deficiencies within the system rather than simply 'blaming' the individual involved in the incident. It is within this over-arching systems approach to accident investigation that root causes are identified.

## 3.10 Defence Mechanisms

In the systems approach, human error is seen as a consequence of latent conditions within the system and it is a combination of error causing conditions and operator or driver error that result in incidents and accidents (Salmon, Regan and Johnston, 2005). Latent conditions are present in all systems and tend to be related to regulators, manufacturers, designers and organisational structures Active errors, or unsafe acts are those errors committed by the operator that have an immediate impact on safety (Salmon, Regan and Johnston, 2005; Salmon et al., 2010).

Reason (1990) 'Swiss Cheese Model' is well known and illustrates defence layers at different levels within a system (see Figure 3.25). Defences can include legislation, training, equipment design, equipment checks and 'holes' or weaknesses in the defences created by latent conditions and active errors can result in an accident when the 'holes' line up.

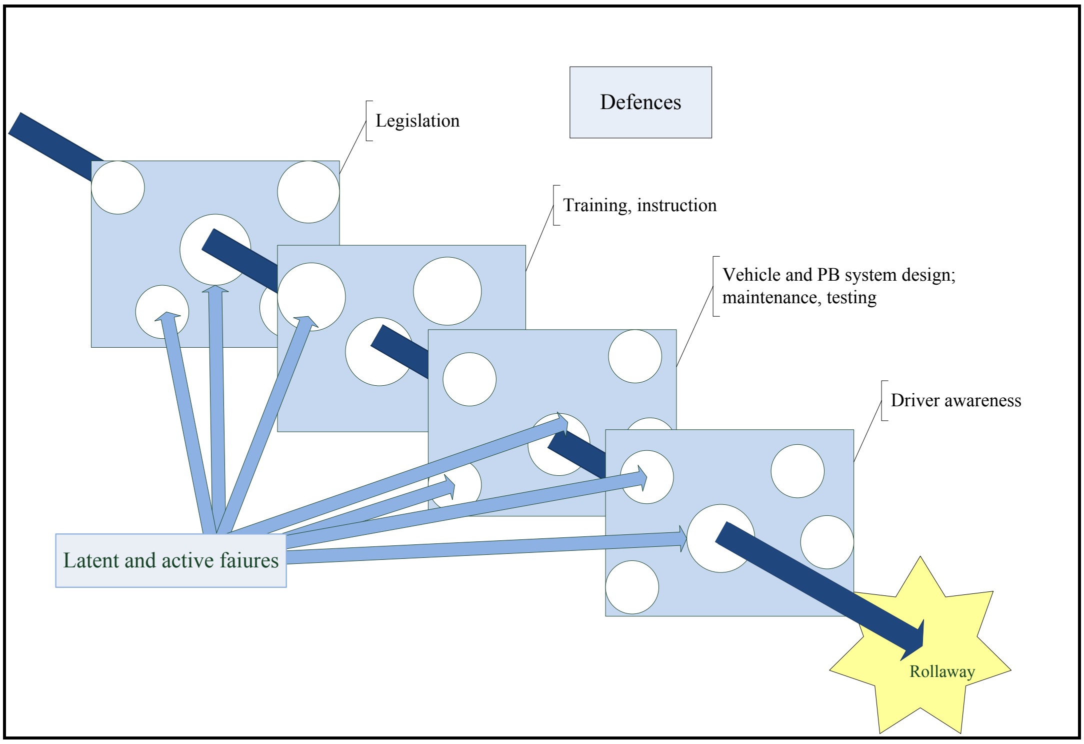



*Figure 3.25 Swiss cheese model in relation to the parking brake system adapted from Reason, (1990), Reason, (2008) and Salmon et al. (2010).*

## 3.11 UK Legislation, Highway Code and Driving Standards

### 3.11.1 Legislation

The Road Traffic Act 1988 section 42, Breach of Other Construction and Use Requirements, states that subject to sections 41(2), 43 and 44, a person who

"(a) contravenes or fails to comply with any construction or use requirement under section 41 of this Act, or

(b) uses on a road a motor vehicle or trailer which does not comply with such a requirement, or causes or permits a motor vehicle or trailer to be so used, is guilty of an offence." *http://www.legislation.gov.uk/ukpga/1988/52/section/42*

Section 107 of the Road Vehicles (Construction and Use) Regulations 1986, leaving motor vehicles unattended states:

"no person shall leave, or cause or permit to be left, on a road a motor vehicle which is not attended by a person licensed to drive it unless the engine is stopped and any parking brake with which the vehicle is required to be equipped is effectively set"

### 3.11.2 Highway Code and driving standards

Rule 239 of the Highway Code states "you *must* apply the handbrake before leaving the vehicle". When parking on a hill the vehicle *should* be parked close to the kerb and the handbrake applied firmly (Highway Code sections 238-252). In this situation, if the vehicle is facing upwards a forward gear should be selected and the front wheels should be turned away from the kerb. When the vehicle is facing downward, the driver should select reverse gear and turn the wheels towards the kerb. It may be an offence under the Road Vehicle (Construction and Use) Regulations and the Road Traffic Act 1988 not to do so.

Rule 2 of the 2011 DSA Driving Standard (Appendix D.3) indicated that for a driver to meet the performance standard 2.1.4: "park the vehicle safely and responsibly" they must be able to "use the parking brake to hold the vehicle; if appropriate, select a gear to hold the vehicle safely when parked; ensure that vehicles fitted with automatic transmission are left with the lever in the Park position". "How and when to set the position of the steering wheels of the vehicle when parked on a gradient" is listed as one of the knowledge and understanding requirements (DSA, 2011).

However, what is a gradient or a hill may be dependent on the driver's perception of such. Witt and Profitt (2007) explored individual's perception of a slant and found that an estimation of the gradient was more accurate when an action was required e.g. walking on the slant than when it was estimated visually. Bressan, Garlaschelli and Barracano (2003) using models representing 1.5% and 3% inclines reported an under estimation of the perceived angle of an incline when the horizontal plane is shifted towards the surface referenced eye level or direction of eye level parallel to the ground. They concluded that the perceived slope is dependent on the height of the visible horizon. Several investigators have shown that a visual array that is not aligned with gravity can alter the apparent orientations or locations of targets that are viewed against it (Cohen, Ebenholtz and Linder, 1995). This may be the case in illusions where the incline is not in the direction perceived such as in antigravity hills otherwise known as 'electric braes' or 'magnetic hills' (Ross, 1974; Bressan, Garlaschelu and Barracano, 2003).

## 3.12 Driver Training and Instruction

In the UK drivers have to pass a two part driving test to gain their license to drive unsupervised and this is likely to follow a period of formal instruction and, particularly in younger drivers, practice may be influenced by parents and siblings (Lahatte and Le Pape, 2008; Sherman et al., 2004). Learning to drive is more than just learning how to perform one task but how to conduct multiple inter-related tasks. Performance may improve with practise but also requires experience of different driving scenarios. Lahatte and Le Pape (2008) indicated that the influence from family members reduced as young drivers developed their own risk management processes and driver identity. Although not specifically about vehicle controls and not conducted with UK drivers, Sherman et al. (2004) concluded that teen driving safety was increased when parents actively communicated about driving practice (Sherman et al., 2004).

Learning theorists identify three domains for learning – psychomotor, cognitive and affective (Reece and Walker, 2007). The psychomotor domain is predominantly associated with physical skills which require practice; the cognitive domain involves knowledge and requires developed thought processes and the affective domain deals with factors such as attitude towards risk and compliance with regulations.

Within the psychomotor domain, there will be a cognitive and affective aspect (Reece and Walker, 2007) and it is considered that there are 3 stages to the ability to transfer skills from learning into practice – cognitive, associative (or fixative) and autonomous (Groeger, 2000; Kent, 2006; Reece and Walker, 2007).

The cognitive stage requires knowledge on how to execute the skill, procedures involved, knowing what to look out for e.g. hazard awareness and relies on memory of previous instruction and experience. This stage is usually dependent on teacher, or instructor, demonstration (Reece and Walker, 2007).

The associative or fixative stage involves the learner developing correct behavioural patterns and practising the skills to remove errors and responding to performance feedback.

The autonomous stage is where speed, rhythm and fluency should increase as the skill becomes more automatic (Reece and Walker, 2007).

As the driver progresses through these stages so their actions become more automatic and the effects of distractions likely to reduce. However, it is possible that despite an individual reaching the level of automaticity other cognitive factors such as an increase in mental workload may divert the driver's focus of attention and lead to lapses or slips. Wulf, McNevin and Shea (2001) proposed that when learners developing motor skills focus on the external outcome rather than the actions or movements required to complete the task a higher degree of automaticity was achieved. Their research is predominantly associated with sports performance but some parallels can be drawn with motor skill development in other areas.

Practise is fundamental to acquiring skill but requires more than just repetition of the same activity. Competent driving requires the ability to transfer skills that have been developed through instruction into unique circumstances not previously encountered. Concentrated instruction and practise may enable an individual to acquire skills rapidly but it could result in less durable retention and transfer of these skills beyond the situations encountered during training (Hall and West, 1996; Groeger and Banks, 2007).

As such the basic driving tasks must be integrated even though constantly changing along the route. Tasks such as parking a vehicle may be sporadic but will still employ operational, tactical and strategic considerations for safe practice. That is where control is exercised, safe interactions with the environment and other road users is considered and a higher level of reasoning and decision making is activated (Salvucci, 2006).

In years 2010 and 2011, 0.8% of failed UK driving tests were related to parking brake control and in the 12 month period of April 2009 to March 2010, 6.1% of successful passes demonstrated minor parking brake control faults (DfT, 2012; DSA, 2012).

English (2011) concluded that in the US, despite the development of strategic highway safety programmes, the requirement for continued driver education was missing. Although public education and information campaigns are more effective when they accompany laws which are enforced, they can improve knowledge and increase compliance (Peden et al., 2004). For example, the ‘Clunk Click’ media campaign that accompanied the introduction of mandatory seat belt use in the UK contributed to a high level of compliance with the legislation (Broughton, 1984; Gwilliam, 2009).

## 3.13 Operator Instruction (Owner Manuals and Driver Instruction)

Materials which assist users in their interactions with systems can be referred to as ‘facilitators’ (Laux and Mayer, 1993). The information presented can contain operating instructions and warnings. If users believe that what they are doing is hazardous i.e. requires a warning, they are more likely to comply with safety instructions. However the effort required and their own beliefs and attitude may be the determining factors rather than knowledge.

Mehlenbacher, Wogalter and Laughery (2002) surveyed 380 drivers of whom 58.9% reported referring to the owner manual but only 52.7% of those had read the manual otherwise. The study found that age was a dividing factor for referring to the manual but the amount read varied very little across the age groups. The results indicated that people preferred hard copy owner manuals than electronic versions. Attaching warning and safety information directly to the vehicle may be a consideration for safety critical information (Mehlenbacher, Wogalter and Laughery, 2002).

To aid compliance, any instructions must be comprehensive and easily understood. Information should be clearly defined into general procedural and critical. If a warning is required the appropriate signal word should be used with attention to the ergonomic principles in relation to design of warnings (Wogalter, 2006).

User manuals carry a reputation for being difficult to follow and find information quickly. Therefore organised manuals with clear well defined and labelled graphics are likely to be more acceptable. Manufacturers should monitor information sources and consider the ‘facilitator’ as a means of communicating information. If there is a change in vehicle operation, the manual must be updated. Adult learners can be impatient when trying to access information, they may ‘skip around’ trying to find information in a manual and they are discouraged by large bulky manuals. Although aimed at software users, Smart, Whiting and DeTienne, (2001), found that adult learners and inexperienced users preferred printed copies of trouble shooting lists rather than accessing the information online.

Discussion on how to apply the lever operated parking brake and whether or not to depress the release button when pulling the lever up has been raised on instructor/learner forums (2passforum.co.uk; Driver Training Today, 2012; Diary of an ADI, 2012; Driving Instructor.tv, 2013). Instructor manuals indicate that learner drivers may be instructed to push in the release button of the lever when applying the parking brake (McArdle, Wood and Morton, 2015) but some manufacturers e.g. Vauxhall and Ford have issued specific advice to their owners not to depress the button when pulling the parking brake lever up. A review of 2011 owner manuals available online for the 10 most popular vehicles purchased in 2010 indicates that the lever operated parking brake may have varying terminology and the instruction is not to push the button in when pulling the lever up or reference to the release button is only made when releasing the parking brake. Only one of the top ten vehicles was fitted with an EPB as standard. The most popular fleet vehicles for 2010 were the Vauxhall Astra and the Ford Focus (SMMT, 2011).

The top ten vehicles purchased in 2010 with the parking brake reference and operating instructions contained within the owner manual for the corresponding 2011 models are listed in Table *3.4*.

*Table 3.4 Most popular vehicles purchased in 2010 (SMMT, 2011) with lever parking brake operating instructions for corresponding 2011 models.*

| Manufacturer | Model (purchased) | Parking Brake Reference | Operating Instructions in Owners Handbook |
|---|---|---|---|
| Ford | Fiesta (103,013) | Parking brake | Pull the parking brake lever up smartly to its fullest extent. Do not press the release button while pulling the lever up. To release the parking brake, press the brake pedal firmly, pull the lever up slightly, depress the release button and push the lever down. |
| Ford | Focus (77,804) | Parking brake (Some previous models had EPB) | |
| Vauxhall | Astra (80,646) | Parking brake EPB on SE model only | Always apply parking brake firmly without operating the release button, and apply as firmly as possible on a downhill or uphill slope. To release the parking brake, pull the lever up slightly, press the release button and fully lower the lever. To reduce the operating forces of the parking brake, depress the foot brake at the same time. |
| Vauxhall | Corsa (77,398) | Parking brake | |
| VW | Golf (58,116) | Handbrake | Pull the lever for the handbrake up firmly. To release: lift the handbrake up slightly and press the lock button .With the lock button pressed, guide the handbrake lever down. |
| VW | Polo (45,517) | Handbrake | |
| Peugeot | 207 (42,185) | Parking brake | Pull the parking brake lever fully up to immobilise your vehicle. To release: pull the parking brake lever gently, press the release button then lower to the lever gently. |
| BMW | 3Series (42,020) | Parking brake | Applying: the lever automatically engages after being pulled up. Releasing: raise lever slightly, press the button and guide the lever down. |
| BMW | Mini (41,883) | Parking brake | Applying: the lever locks in position automatically Releasing: pull slightly upwards, press the button and lower lever. |
| Nissan | Quashquai (39,048) | Handbrake lever | To apply: pull the lever up To release: pull the lever up slightly, push the button and lower completely. |

Outside of the top ten, a 2011 Volvo manual provided clear step by step instructions reflecting the requirements of the Highway Code and included instructions to press firmly on the brake pedal when applying and releasing the 'handbrake'.

Initial communication with driver instructors suggested the caveat for learner instruction was "refer to the owner's manual". Drivers who drive several makes and models of cars may not be aware of the manufacturer recommendations and hire companies may only supply basic instructions and not the owner manuals with the rental vehicles.

Where technology is introduced, such as systems employing EPB, further instruction may be required. Habits, practices and mental models may have developed which makes it more difficult to interact with the new systems. Other methods of instruction could be effective such as 'auditory facilitators' where the driver could listen to the information through the medium of their choice.

## 3.14 Alerts and Prompts

Visual and auditory alerts or prompts can be used to alert the driver to a failed or hazardous activity. For example, when the driver fails to engage their seatbelt or tries to drive away when the parking brake is still engaged. Auditory alarm systems are available in the commercial and workplace transport sector to alert the driver that the parking brake is not engaged as he opens the door to exit the vehicle (Pownall, 2011). It is reported that the incidents associated with work vehicle rollaway has reduced following installation of these systems alongside implementation of other safety measures as advised by the Health and Safety Executive, (HSE, 2011; HSE, 2013) but no supporting research material was available.

In an analysis of Australian mining incidents skill-based errors associated with the use of tools and equipment were observed with one of the more common examples involving parking of vehicles. Drivers were instructed that when parking either a heavy or light vehicle on site, the engine must be shut off, the parking brake applied, and the wheels turned correctly before exiting the cab. It was identified that drivers often exited the cab without completing one of these tasks. One possible intervention to prevent these types of errors was considered to be the installation of auditory or visual warnings to remind operators of the steps that need to be completed (Patterson and Shappell, 2010).

Alerts should only be employed when all other safety measures have been used in order to prevent the action being alerted about. An associated alert philosophy should specify the design and characteristics of alerts, their implementation, and when and how they are used. Consideration should be given to the level of response required of an operator and only higher priority alerts should require a response (Wogalter, 2006)

## 3.15 Human Error and Design

Norman (2013) states that the two most important characteristics of good design are:

- Discoverability – the actions that are possible and where and how to perform them can be figured out
- Understanding – understanding how the product is to be used and what different controls and settings mean (Norman, 2013 pp.1-36)

Manuals or instruction may be required for discoverability and understanding of complex devices but should be unnecessary for simple things (Norman, 2013). Interaction with a product (or system) requires discoverability and Norman (2013) explains six fundamental psychological concepts to achieve this.

1. Affordances – affordance refers to the relationship between a physical object and a human and determines how the object could be used e.g. a chair affords or is for sitting; a flat metal plate mounted on a door would afford pushing; a lever affords pulling and a button affords pushing. When there is no need for instructions these are perceived affordances
2. Signifiers- a signifier is any indicator that communicates how something should be used or interaction required e.g. the word push on a door or an illuminated symbol on a control.
3. Constraints – constraints can result from limitations in knowledge of a particular operation e.g. starting a car that is unfamiliar to the driver and requires it to be parked in reverse before the key can be removed. They can also be functions in a system to prevent failure or an inappropriate action e.g. the driver must be in

possession of a key to start the car. Interlocks are forms of constraints e.g. preventing the vehicle automatic transmission being taken out of Park unless the brake pedal is depressed.

4. Mapping – refers to the relationship between the elements of two sets of things. The relationship between a control and the result is easier to learn if there is comprehendible mapping between the controls, actions and intended result. Related controls should be grouped together and the control should be close to the item being controlled (proximity of use).
5. Feedback – communicates the results of an action and must be immediate but also must be appropriate and not excessive so that it becomes annoying.
6. Conceptual Models – are the conceptual, or mental, models that are in people's minds which represent their understanding of how something works. Different people may hold different mental models for the same system. Conceptual models may be inferred from the system or product, passed on from person to person or come from instruction manuals but are usually developed from the experience of interacting with the equipment, product or system.

Advances in technology can make life easier by providing more functions and reducing any manual action. However added complexities may require more effort to learn and increase the level of frustration.

## 3.16 Maintenance and Testing

MOT testing and driver checks were presented in section 2.5.3. However, potential failure of the system may not be detected by these checks (Ryder, 2013).

## 3.17 Driver Demographics

### 3.17.1 Age and gender

In 2011, 79% of males and 65% of females had a full driving licence and while car driver trips and distance travelled by women had increased over the previous 10 years, men were still reported to drive nearly twice as many miles per year (DfT, 2012).

Lancaster and Ward (2002) indicated that although male drivers were more likely to be involved in a larger number and more serious accidents female drivers appeared more likely to be involved in incidents resulting from perceptual error. It is unclear whether the gender difference is as apparent when the amount of time spent driving and the annual mileage is increased as there is then an increased exposure to the risk.

The number of older drivers has increased over the last 40 or so years with more than 2 million drivers in the UK aged over 70 and this was expected to rise to 4.5 million by 2015 (Horberry and Inwood, 2010). Inattention errors increase with age and older drivers are more likely to be involved in collisions associated with higher levels of error and lapses of attention (Reason, 1990; Parker et al 2000). Cognitive failures such as unintended acceleration incidents are more likely in the older driver (Schmidt, 1993; Herriots, 2005; Clark et al., 2009). Although level of experience through driving more frequently and for longer periods of time can compensate, it is recognised that a reduction in response and reaction time, reduced mobility, flexibility and strength can affect the performance of driving tasks in the older driver. Peak muscle forces are reduced and could be almost half that exerted as a younger driver (Stelmach, 1993) making manipulative tasks more difficult.

### 3.17.2 Driver behaviour

Individuals who display a low level of conscientiousness may be careless or impulsive and may lack respect for regulatory bodies which may result in deliberate violations. Other driver behaviour characteristics such as neurosis and distractibility may make the driver more anxious and fatigued and an increased likelihood of effort may be exhibited. Poor driving behaviour in female drivers in the 18-33 and 45-50 year group has been related to stress with contributory factors such as feeling rushed increased work hours and shift work (Dobson et al., 1999). Minor accidents have been associated with higher general levels of stress (Lancaster and Ward, 2002). Lawton and Parker (1998) indicated some links with personality type and errors. For example those considered to display neurosis may demonstrate a lack of attention to the task, may be more anxious or fatigued and therefore possess an increased likelihood of error.

### 3.17.3 Capability and disability

Operating the lever parking brake requires the driver to be able to grip the lever, apply sufficient force to pull the lever up and the ability to apply thumb tip pressure to release the parking brake lever.

Short term conditions such as musculoskeletal injury may impair the driver's capability to operate the lever operated parking brake in their normal way and can result in a temporary alteration in the method of application. Where a long term condition or age is the contributory factor adaptations to the parking brake lever or a change of vehicle may be required. An assessment can be conducted by a driving adviser (a specially trained driving instructor) and if appropriate an occupational therapist. The assessment identifies any physical limitations which could affect the ability to operate the standard controls of a vehicle, and possible adaptations required. (Spence, 2011).

For example, the driver's expectation of being unable to depress the button to release the parking brake lever may limit the full engagement of the parking brake on application or cause the driver to use the other hand or both hands to operate the lever. The hand lever can be adjusted to remove the thumb tip pressure and reduce the overall upper limb force required. This is a subjective assessment based on a Yes/No response unlike the footbrake where the maximum constant force is measured electronically (Spence, 2011).

## 3.18 Summary

The literature review has highlighted there is little previous research on vehicle rollaway and what is available in the open literature is focused on performance of the mechanical components of the parking brake system. There is evidence supportive of a systems approach to explore the factors associated with vehicle rollaway as per the systems theory to road safety described by Larsson et al. (2010).

The research in this thesis will employ human factors methods to explore organisational, mechanical/vehicle and driver related factors that may contribute to vehicle rollaway.

# Chapter 4: Literature Review of Methods and Task Analysis

## 4.1 Introduction

The literature indicates that there is a substantive amount of information available on error within systems and that system based approaches to road safety is a developing area. Regardless of training and experience, drivers continue to make errors while performing driving tasks which impacts on system safety (Salmon, Regan and Johnston, 2005). Reason (2005) refers to error prevention, containment and management programmes which can employ a variety of methods to identify related factors. Techniques employed in error management and identifying contributory factors to incidents or failure are intended to explore the different components of the system i.e. the organisational and regulatory features, the equipment and parking brake system itself, the task and the individual (Reason, 2005).

To identify the factors associated with parking brake system failure and vehicle rollaway, collection of specific information and data needs to be in relation to:

- the nature of the errors
- the tasks and equipment involved
- the factors contributing to and causing them
- the consequences (Salmon, Regan and Johnston, 2005)

Task analysis techniques describe and represent the activity or event. Data collection methods collect specific data regarding the activity or event (Stanton et al., 2013, pp. 21-44). The task analysis and data collection techniques described in the following sections are a sample of the many methods available and were selected as considered appropriate for exploring the factors associated with passenger vehicle rollaway.

## 4.2 Incident and Accident Data Analysis

Access to relevant databases can provide supporting evidence and information regarding the extent and nature of incidents relating to the research area. Archived data complement surveys in that they represent information collected over a period of time and can therefore highlight any pattern of change. However, it is unlikely that the data were collected for ergonomic purposes and may not answer particular research questions (Drury, 1990, pp. 89-100).

## 4.3 Task Analysis

Task analysis methods describe the activity being performed and can be defined as what the operator or driver is required to do in order to achieve the acceptable outcome (Kirwan, 1990; Stammers, Carey and Astley,1990; Stanton et al., 2005 pp. 46-76; Stanton et al., 2013 pp. 39-68). The initial or gross task analysis provides a general description of the task being conducted (O'Brien and Malone, 2002).

The information for the more detailed task analysis is derived from observation, structured and unstructured interviews, analysis of operating procedure, incident investigation data, structured walk-throughs or talk-throughs and relevant documentation (Stammers and Shephard, 1995). Task description can then be used to input to other analysis methods such as human error identification techniques.

Detailed information about a particular task can be gathered by using Task Decomposition (Stanton et al., 2005, pp. 46-76). This method describes the task and then uses specific task related information to break down or decompose the task into task specific statements. The categories used to decompose the task are selected by the researcher, as the analysis requires, and could include any of the following:

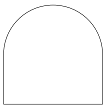
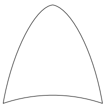
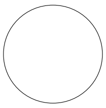
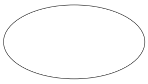
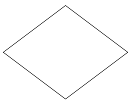
- Description
- Subtask
- Cues initiating action
- Controls used
- Information
- Training/skills
- Decisions
- Typical Errors
- Response
- Criterion of acceptable performance
- Feedback

This method provides a flexible approach with the potential to explore all aspects and provide a comprehensive analysis of the task. Although it enables a more detailed exploration, it can be very time consuming and labour extensive (Stanton et al., 2013, p.56)

## 4.4 Fault Tree Analysis

Fault tree analysis graphically demonstrates failure scenarios (Salmon, Regan and Johnston, 2005). The fault trees define system failure events and portray the possible contributory factors in terms of equipment and human error (Stanton et al., 2013). The main failure event is placed at the top of the tree and the contributory events are placed below. The pathways interconnect contributory events and conditions using a set of standard logic symbols as in Table 4.1. AND and OR gates link events in the failure or incident sequence. Events linked with an AND gate must occur together for the failure event above the gate to occur. Events linked with an OR gate occur independently (Nemeth, 2004 pp.224-229; Stanton et al., 2013 pp. 136-140).

*Table 4.1 Fault tree symbols*

| Symbol | | |
|---|---|---|
|  | Event | Failure event is placed at top of the tree and the contributing events are placed below. |
|  | AND gate | An AND gate is used when multiple contributory factors are involved and occur together |
|  | OR gate | An OR gate is used when there are multiple contributory factors or events but they do not occur together |
|  | Basic event | A basic initiating or failure event |
|  | Conditional event | Event is conditional on something else |
|  | Undeveloped event | An event which is no further developed or explored e.g. external force when vehicle is pushed |

The process for constructing a fault tree starts with defining the failure event followed by determining the causes of the failure event. These include factors that may influence the driver's perception of the task (Marras and Hancock, 2014) such as:

- physical environment – e.g. visual conditions, auditory environment, tactile and haptic information, gradient of the surface
- physical demands – the force, perceived effort and manipulation required
- cognitive demands – mental processes, decision making, multi-tasking, memory, problem solving and perception of the demands e.g. perception of force required
- psychosocial – other personal factors that my influence driver behaviour

For vehicle rollaway, the causative factors determined from the databases and literature review are summarised in a cause and effect diagram (Nemeth, 2004) in Figure 4.1.

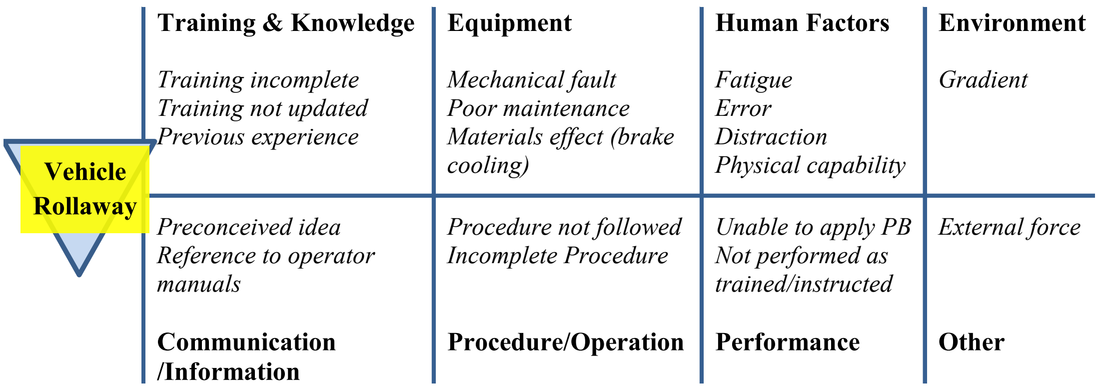



*Figure 4.1 Cause and effect diagram for vehicle rollaway*

The contributory causes can be grouped into mechanical, driver and environmental or organisational factors (Salmon, Regan and Johnston, 2005). Each contributory cause is then classified as either an AND or OR event. Determining the causes and classification thereof will continue until both the initial and associated causes have been explored (Stanton et al., 2013) using the data collection methods that follow (see Figure 4.2).

As indicated by Hollnagel (2014) the Fault Tree method provides a systematic way of analysing how a specific undesired outcome might happen in order to identify or develop preventative measures. It can be an effective method to demonstrate how causes or basic events in the fault tree interact to cause the top failure event (Zhang, Kecojevic and Komijenovic, 2014). In that way, fault trees have the advantage that they can be used predictively and retrospectively (Stanton et al., 2013, p.140; Hollnagel, 2014, p.57). The fault tree developed to explore vehicle rollaway can be seen in Figure 4.3.

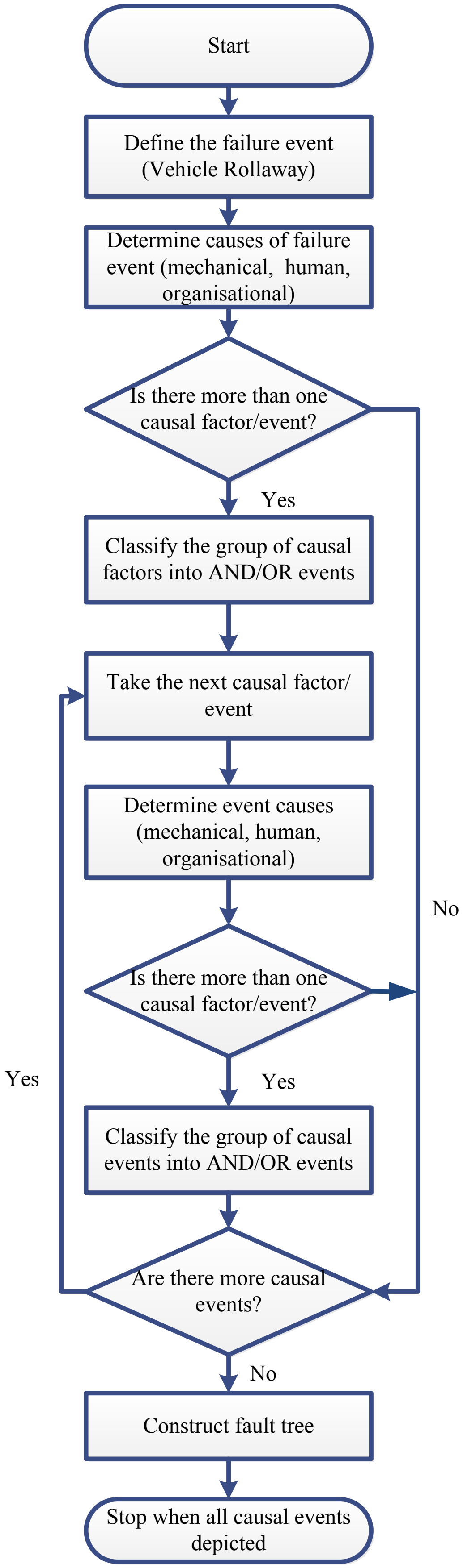



*Figure 4.2 Flow chart for constructing a fault tree (Stanton, et al., 2013)*

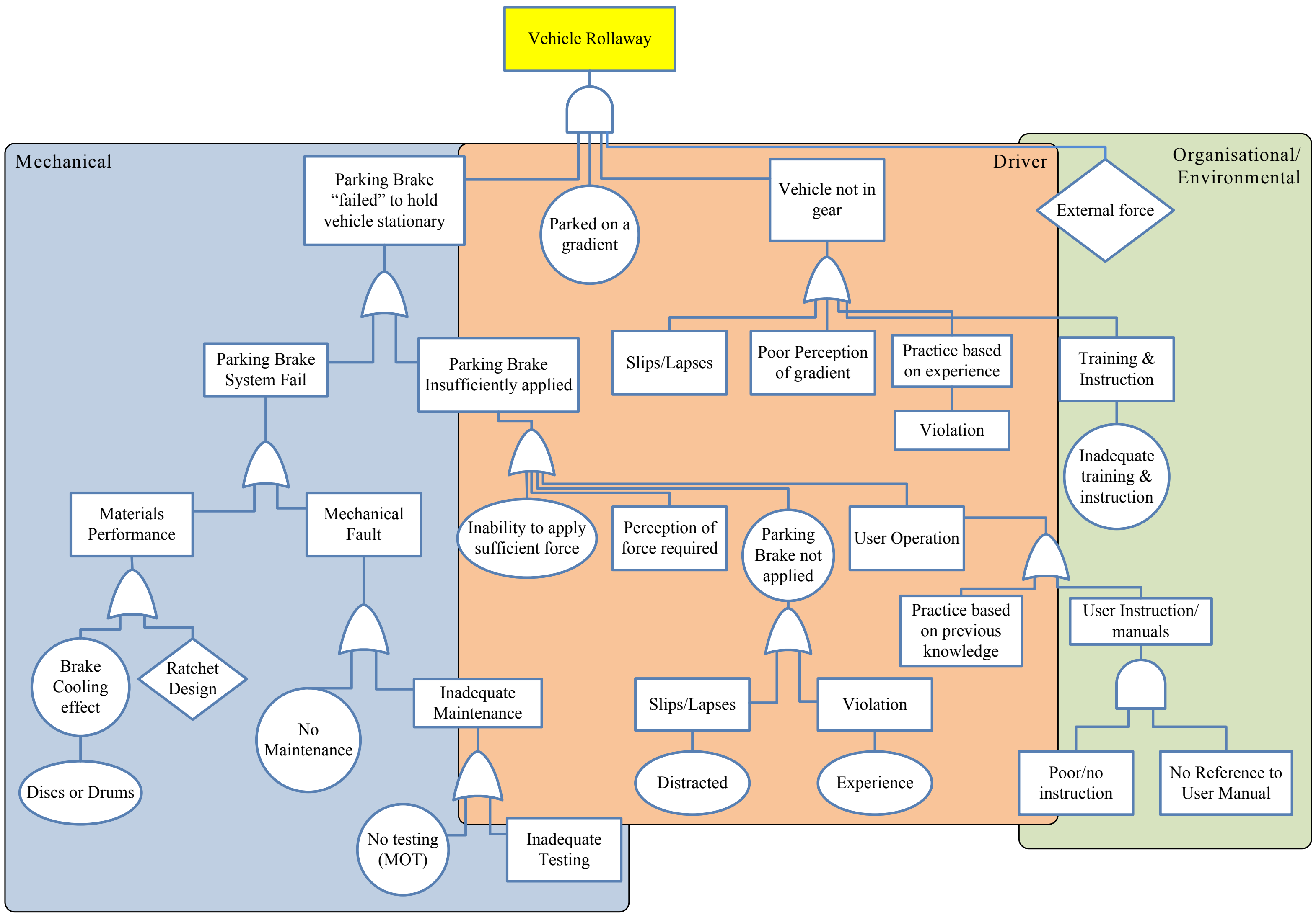



*Figure 4.3 Fault tree- coloured sections illustrate grouping of mechanical, driver and organisational/environmental factors*

## 4.5 Interviews and Focus Groups

Interviews are a flexible way of gathering large quantities of information in relation to the area being explored (Sinclair, 1990; Stanton et al., 2013, pp.12). The interviews can be structured, semi-structured or unstructured. The semi-structured interview has the advantage of following a pre-determined set of questions but can use further questions to probe for relevant information. The data gathered reflects the participant's practice and personal experience and is therefore very powerful. However the quality of the data is dependent on the skill and experience of the interviewer and the ability of the participant to respond. The responses may need to be collated into common themes for data analysis but the response data in numerical form can be analysed statistically.

*Focus Groups* or group discussions can be an efficient way of gathering information from small groups of people who have experience in the area being researched instead of interviewing them one to one. The researcher acts as a moderator and introduces the topic and then facilitates the discussion. Group dynamics help to focus on the key areas and it can become relatively easy to assess any consistency in shared views, experiences and opinions (Robson, 2011, pp.293-300. The sessions should be recorded (with the consent of the participants) for ease of transcription and later analysis. Internet focus groups have the advantage of being able to reach a wider group of people but the interaction with individuals gained within a room is sacrificed (Krueger and Casey, 2009).

## 4.6 Questionnaires and Surveys

Questionnaires are a flexible method to collect large amounts of specific data from a population sample (Oppenheim, 1992; Fink, 2006; Fowler, 2009). The introduction to the questionnaire should provide sufficient information for the participant to understand who is conducting the survey and why it is being conducted but should not bias the responses. Multiple choice type questions can be used to collate data about the participants and the information gathering section will contain questions related to the study objectives (Sinclair, 1995; Stanton et al, 2013, p.20-27).

The responses can be used to direct investigation of specific aspects of the subject being explored. For self-completion questionnaires, open ended questions should be kept to a minimum to avoid spending a lot of time on analysis (Robson, 2011, 235-274). Questions can be included from other validated questionnaire tools such as the Driver Behaviour Questionnaire (DBQ) (Wickens, Toplak and Weisenthal, 2008) and Borg's Rating of Perceived Exertion (RPE) scale (Borg, 1998) as well as tailored questions specific to the subject area.

The Manchester Driver Behaviour Questionnaire (DBQ) is a 50 item questionnaire designed to explore the following classes of aberrant driver behaviour: slips, lapses, mistakes, unintended violations and deliberate violations (Salmon et al. 2010; Reason et al., 1990). It originally used a five point Likert-type response scale although a six point scale has been used (af Wåhlberg, Dorn, and Kline, 2011).

Internet based surveys for data collection offer the potential for an increased sample size and diversity (Robson, 2011, pp. 378-384). The relative low cost, ease of access, monitoring and data analysis make them a more attractive option and less time consuming than manually collated surveys (Eboli and Mazulla, 2011; Bryman, 2012). Participants can be recruited by e-mail invitation and through access to discussion and social networking groups. Completing self-administered questionnaires online may be more efficient than completing paper questionnaires and returning them by post but paper copies should be made available to individuals who do not have internet access or do not feel sufficiently computer literate. Electronic questionnaires have similar potential areas for bias and variability errors as manually collated questionnaires such as securing a representative sample and authenticity of response (Robson, 2011). As found by Eboli and Mazulla (2011), the responses given on an online survey may not reflect those that would be given in face to face interviews.

## 4.7 Rating Methods

Rating scales can be used to collect subjective data where the subject during observations or the respondent to a survey rates the attribute or property of the entity to be scaled A simple rating scale uses anchor points at either end of a 100mm line with regular intervals along the line that can also be labelled. The Likert method typically employs a 5 point scale, e.g. 1 to 5 and the respondent indicates their opinion on the scale. In semantic differential techniques, the end points of the scales are given anchors which are single word adjectives and opposites e.g. poor – excellent. The rating is then made according to these scales (Sinclair, 1990).

### 4.7.1 Subjective rating of perceived exertion

Subjective rating is a cost effective method of obtaining perceived force exertion from a population and if incorporated into a survey does not require face to face contact. Borg's concept of perceived exertion (Borg, 1998) and ratings of perceived exertion (RPE) scale has been used widely in the assessment of physical tasks and supplements other evaluation methods (Li andYu, 2011).

Borg's rating of perceived exertion is based on the theory that there is a relationship between the intensity of the physical effort and the perceived exertion. The scale steps are constructed so that the ratings from 6 to 20 are linearly related to the heart rate divided by 10.

## Borg's Rating of Perceived Exertion (RPE) Scale

| | |
|---|---|
| 6 | No exertion at all |
| 7 | |
| 8 | Very light |
| 9 | |
| 10 | |
| 11 | Light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard (Heavy) |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Extremely hard |
| 20 | Maximal exertion |

Pulling up the parking brake lever is not a particularly dynamic task and the scale may not be relevant in relation to the individual's heart rate, but can provide useful information regarding the perceived effort required (Corlett, 1990, p.545).

The rating of perceived exertion (RPE) provides an individual's subjective measure of the perceived exertion or effort required which is considered to correlate with the hand force applied (Li and Yu, 2011). It does not provide an objective measure and previous experience and motivation of the individual may affect the rating indicated. However, using this method as a self-reporting tool can be a useful filter and indicator of potential risk factors.

## 4.8 Measurement of Force Application

### 4.8.1 Direct measurement

Load cells or force transducers attached to handles capture force signals and can be used to demonstrate muscular effort in pulling tasks. An electrical voltage is produced that is proportional to the force applied and the trace can be displayed on an oscilloscope using data acquisition software (Chaffin, Andersson and Martin, 2006c; Caldwell, et al., 2014).

The procedure for testing of vehicle lever operated parking brakes involves attaching a handbrake load cell to the lever. A force of 400N is then applied manually by the tester and the vehicle is expected to remain stationary (UNECE, 2008; Southall and Curry, 2011). The design of the F319/F268 handbrake load cell is reported to enable the "typical unevenly distributed force applied by the human hand to be measured with good repeatability and minimum error in a sense normal to the lever axis". Its double shear web design and rigid low profile finger grip combine to maintain the same precision of measurement along the entire finger grip length. A 'dorsal fin' in the moulding ensures that the hand clamping forces are not measured in addition to the handbrake pull force (Novatech, 2008).

### 4.8.2 Indirect measurement

Forceful hand exertions may be measured indirectly using a dynamometer or a strain gauge (Li andYu, 2011). That is the individual grips the dynamometer with the same effort that he/she perceives the task requires. In the methods that follow grip strength was measured but only as an indication of the strength of the left upper limb.

## 4.9 Driving Simulator or Static Assessment Rig (SAR)

Driving simulators provide a safe environment to conduct research and evaluate driver behaviour. A static assessment rig (SAR) consists of a rig based on a modified vehicle body connected to a PC or laptop. SARs are used within UK Driving Assessment centres to assess an individual's physical and cognitive functions prior to assessment on the open road and to assess their requirement for adaptations to vehicle controls (Bowens, 2004; Horberry, Inwood and Walter, 2007; Horberry and Inwood, 2010; Spence, 2011).

Meister (1990) describes simulation as a physical representation of reality. The rig provides an environment where a standardised layout can be used with multiple drivers and a variety of observation techniques employed. The use of the rig in addition to collating anthropometric data and interactions with perceived situations can serve as a pilot for observations in driver's own vehicles. It allows for the use of measuring and technical equipment to be evaluated in test scenarios where environmental factors are controlled.

## 4.10 Observational Studies

Observations in 'real life' research enables data to be gathered regarding the physical, and verbal, aspects of a task scenario (Stanton et al., 2013, pp.28-33). Participants may recall what is required in a process but direct observation of the activity confirms or adds to the narrative providing a more detailed account or analysis. Observation allows the researcher to establish the components of a task and explore how the individual interacts with and relates to equipment, environment and organisational features.

Carsten, Kircher and Jamson (2013), reported that real world driving studies have face validity in that they focus on driving in a natural environment. However, conducting observations in the 'real world' rather than in a laboratory can have disadvantages which should be considered in relation to the benefits of this method.

In naturalistic driving studies vehicles are fully instrumented and data is collected over a prolonged period of time. On road studies use drivers' own vehicles in a controlled situation to explore the task and associated research question. Although the observer is in the vehicle and able to view activities, their presence may affect the normal behaviour of the individual being observed (Carsten, Kircher and Jamson, 2013). In real life research uncontrollable elements such as the weather can affect the programme and cause delays. Variables are controlled as far as possible to ensure reproducibility, but unforeseen situations may result in change along the way. As such, conducting observations can be very time consuming but can be very creditable. (Nemeth, 2004; Robson, 2011).

## 4.11 Sampling Strategies

Various sampling techniques are used in qualitative and quantitative research studies with samples categorised as probability or non-probability, depending on the sampling method selected (Robson, 2011, pp.270-277; Bryman, 2012, p.187).

A probability sample is one that has been selected using random selection from a population list and is more likely to be representative of the target population. This includes cluster sampling where groupings of the units of the population are sampled (Bryman, 2012, p.193). A non-probability sample is one that has been selected using non-random selection methods (Bryman, 2012, pp.183-207) such as quota, purposive, judgemental convenience and snowball sampling. These tend to be used in smaller scale studies where there is no sampling frame or resources are limited and a probability sample would not be feasible (Robson, 2011).

Even when probability sampling has been employed, sampling errors can occur where an error in the findings are due to a difference in the sample and the related population. Non-sampling errors can arise from deficiencies in the sampling approach, poor response or from the problems associated with research tools and data processing (Bryman, 2012, p.187).

## 4.12 Summary of Methods

The strengths and weaknesses of methods of exploration are summarised in Table 4.2.

*Table 4.2 Strengths and weaknesses of methods*

| Method | Strengths | Weaknesses |
|---|---|---|
| Incident Data | Related to real incidents | Only injury incidents will be recorded (STATS19)<br>Depth of data dependent on subjective recording<br>May not be economically viable to conduct search |
| Interviews | Flexible technique<br>Interviewer can direct analysis but can use information (e.g. from SME's) to explore other sources<br>Gain information from personal experience and knowledge<br>Participants enjoy experience<br>Relates to 'Real Life Activity' | Subjective information<br>Time consuming<br>Dependent on skill of interviewer and interaction with interviewee<br>Subject to bias –interviewee may wish to 'please' or has strong opinions |
| Focus Groups | Efficient way of collecting data from several people<br>Group dynamics help focus and 'weed out' extreme views<br>Participants enjoy experience<br>Low cost<br>Improved contributions from people who would not wish to or be able to participate in other methods | Limited number of questions<br>Researcher requires skill in facilitating and managing any conflict within the group<br>Confidentiality can be a problem<br>Care required not to generalise the results |
| Questionnaires (Internet) | Flexible technique<br>Easy to use<br>Able to collate large amounts of information across user groups<br>Responses can direct further analysis<br>Low Cost<br>Speed of data collection | Subject to bias from sample strategy, structure of questions and data analysis<br>Poor sampling frames<br>May lack uniform presentation<br>Internet access required |
| Task Analysis | Flexible approach<br>Comprehensive analysis<br>Detailed description of task | Time consuming<br>Labour intensive |
| Fault Tree | Graphically represent possible failure events and possible causes | Diagrams can become large and complicated |

| Method | Strengths | Weaknesses |
|---|---|---|
| Observation | Observe current practice<br>Observe driver interaction with controls<br>Can be used to collate specific information including decision making<br>Data used to input to task analysis<br>Able to interview participant on personal experience | Logistically demanding<br>Performance may be affected by observer presence |
| Vehicles parked in car parks | Ability to gain specific information in large numbers and across several geographical locations | Reliant on observer experience<br>Could be subject to bias from researcher expectation |
| Static Assessment Rig | Control over environment | |
| 'On road' study | Relates to real life activity<br>Able to observe driver interaction with their own vehicle | Focuses on one task<br>Difficult to recruit participants<br>Does not capture driver behaviour over a period of time |

## 4.13 Chapter Summary

A wide range of mechanical, procedural and cognitive factors that could play a part in parking brake system failure were determined from the data available and the literature review. These causative factors or events were used to construct a fault tree analysis and became the framework to direct the research into the topology of vehicle rollaway. The data collection methods reviewed will be described further in relation to the relevant studies developed to explore the causative factors.

In view of the limited literature available specific to vehicle rollaway, exploration of the task in reference to general vehicle ergonomics and application of system failure methodology provides an evidence base for the empirical studies which follow.

# Chapter 5: Exploring Driver Interaction

## 5.1 Introduction

Literature suggests that driver characteristics such as age, gender, physical capability and behaviour may affect the way that driving tasks are conducted (Schmidt, 1993; Herriots, 2005; Parker et al., 2007). For other than the learner driver, applying the parking brake can be considered to be a skill based task, but errors and failure in satisfactory completion of the overall task i.e. maintaining the vehicle stationary, could be the result of skill based (slips and lapses), rule or knowledge based mistakes (Reason, 1990, pp. 53-96; Reason et al., 1990).

Figure 5.1 illustrates the potential areas of human failure when the driver interacts with the parking brake system. It focuses on the driver related factors that could contribute to vehicle rollaway.

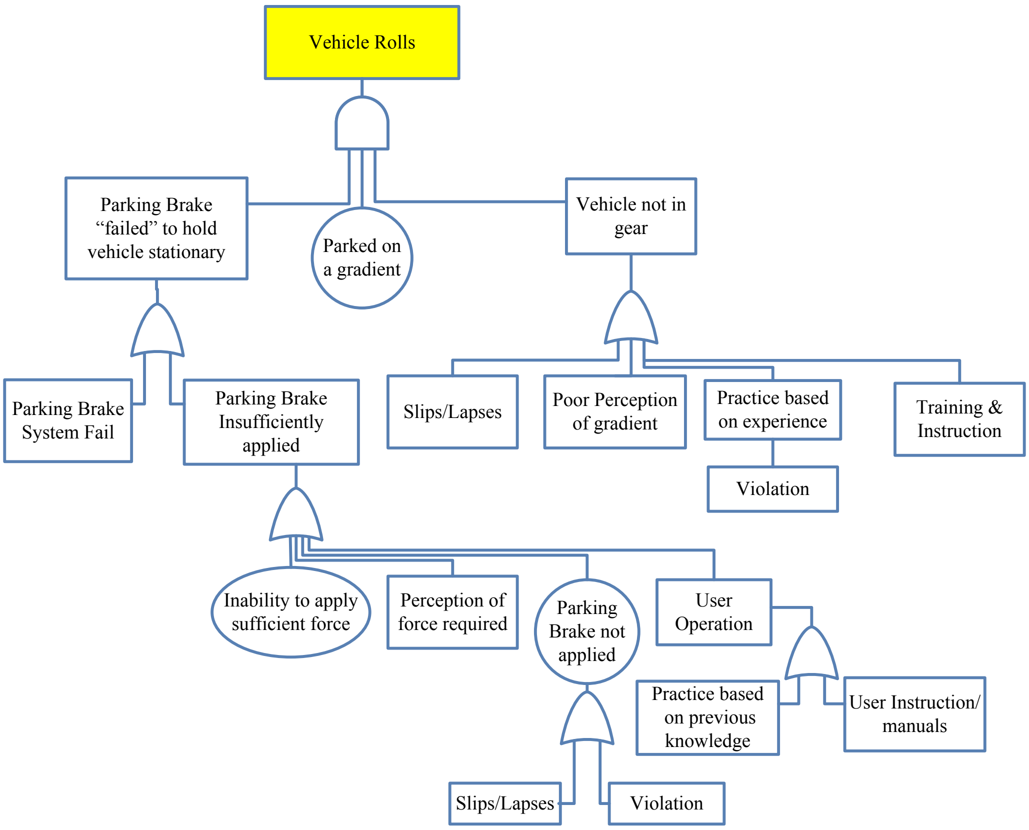



*Figure 5.1 Potential driver related factors in vehicle rollaway*

To explore the potential contributory factors to vehicle rollaway, from a driver perspective an online survey was designed to address the following questions:

- What is the driver's perception and experience of the parking brake system? (e.g. effort required, vehicle rollaway)
- How do drivers park their unattended vehicle?
- Why do drivers park their unattended vehicle in the way they do?
- Are there any individual characteristics such as driver behaviour that relate to vehicle rollaway or mis-application of the parking brake? (e.g. lapses, violations)

## 5.2 Methods

### 5.2.1 Survey development and distribution

The online survey was developed using Thesis Tools (*www.thesistools.com*) and the questionnaire focus areas were based on findings from the literature review and incident reports. The survey asked drivers to provide information about themselves, their vehicles, operation of the parking brake system, their normal parking practice and any experience of vehicle rollaway (see Figure 5.2).

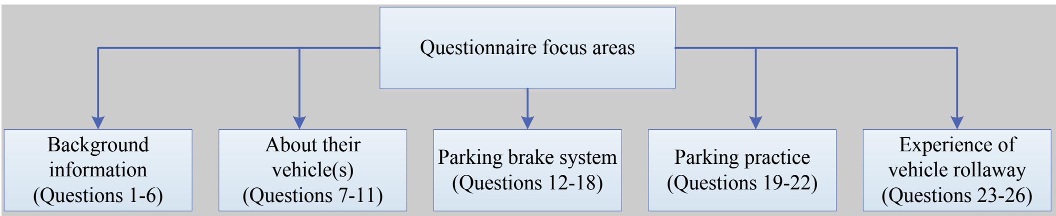



*Figure 5.2 Questionnaire focus areas*

The self-administered questionnaire contained 26 questions of both open and closed design and a final section allowing respondents to add comments.

Questions 1-6 obtained background information about the participants including age, gender, hand dominance, driving experience and weekly driving frequency and distance. Also incorporated was a section from the Manchester Driver Behaviour Questionnaire (Af Wåhlberg, Dorn, and Kline, 2011) which focuses on slips and lapses.

Questions 7-11 asked respondents to identify the make, model, age and transmission type of up to three vehicles they drove regularly

Questions 12-18 asked about the type of parking brake system employed, and whether the respondent knew how to operate it with or without instruction. The perceived effort that the respondent considered was required to operate the parking brake was recorded in reference to a perceived exertion scale (Borg, 1998) see Figure 5.3.

| | Level of Exertion |
|---|---|
| 6 | No exertion at all |
| 7 | Extremely light |
| 8 | |
| 9 | Very light |
| 10 | |
| 11 | Light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard (heavy) |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Extremely hard |
| 20 | Maximal exertion |

*Figure 5.3 Borg rating of perceived exertion scale (Borg, 1998)*

Questions 19-22, participants were requested to indicate their normal parking practice overnight and through the day, and why they considered they parked in the way they reported.

Questions 23-26, respondents were asked to recall any incidents where their vehicle had rolled away or when the parking brake was not applied and the associated circumstances.

Thesis tools was selected as the data collection tool as it was easily accessible, competitively priced and a survey link could be e-mailed to contacts and other organisations. The software collates and summarises the data and the data can be exported to Excel.

## 5.3 Pilot Study

A pilot study was conducted on the online questionnaire survey to:

- Check the structure and wording of the questionnaire
- Check the clarity and ease of completion of the questions
- Ensure responses were as anticipated
- Evaluate the time taken to complete the survey
- Develop a strategy for data analysis

### 5.3.1 Participants

The survey was piloted with a convenience sample of drivers who would not be participating in the final survey. Ten participants took part in the pilot study: three ergonomists, three university lecturers, three health care staff and one business manager.

### 5.3.2 Amendments

Some minor re-structuring and typographical amendments were made to some of the questions to improve clarity and flow. Other specific changes were:

- Addition of 'less than 5 miles' as an indicator of short journeys in question 4
- Addition of 'don't know' as a choice to answer question 12 - *how is the parking brake applied in your vehicle?*

The pilot study demonstrated that the responses were as anticipated and the average time to complete the questionnaire was 10 minutes (range 7-13 minutes). A printed copy of the final questionnaire is in Appendix C.

## 5.4 Data Collection - Survey

Agreement was obtained from various organisations to distribute the link to the online questionnaire (*http://www.thesistools.com/web/?id=210987*). The link was distributed electronically to staff of St Luke's Hospice, Plymouth; another local health care organisation; Plymouth University of the Third Age (U3A); co-ordinators of park in gear awareness groups (Royal Society for Prevention of Accidents (ROSPA) and Park in Gear (PING) campaign); professional networks and social media sites for the Institute of Advanced Motorists (IAM), Vauxhall and Volkswagen user groups, Automobile Association (AA) Driving Instructors and the Institute of Traffic Accident Investigators). This was predominantly a convenience sample but snowball sampling was also used to increase the online responses.

### 5.4.1 Data collection and analysis

The responses were collated in a Microsoft Excel spreadsheet. Descriptive analysis was conducted using Microsoft Excel 2010 and data were transferred to IBM Statistics SPSS versions 19 and 22 for statistical analysis. Responses to open ended questions were collected into trends and coded accordingly.

### 5.4.2 Participants

A total of 186 drivers, 107 (57.5%) male and 79 (42.5%) female, responded to the online survey. The age range of the respondents was 20 to 80 years with a mean age of 49.75 (SD 13.8) years. The majority of drivers were aged between 37 and 68 years and 89.2% of respondents reported over 10 years driving experience. The respondents ranged in weight from 44Kg to 139Kg; in height from 1290mm to 1980mm and 17 (9.1%) of the respondents reported they were left hand dominant. Eight (4.3%) respondents passed their driving test outside of the UK and 17 (9.1%) reported regularly driving a left hand drive vehicle. The environment that all the drivers experienced regularly was reasonably evenly spread across motorway (29.3%), rural (26.7%) and urban (30.8%) categories with least responses to city driving (14.2%).

## 5.5 Results

### 5.5.1 Vehicles and Parking Brake systems

Thirty different manufacturers were reported to be the maker of the respondent's main vehicle (vehicle 1). The most reported manufacturers were Ford (29, 15.6%), Volkswagen (20, 10.8%) and Vauxhall (19, 10.2%). Driving a second vehicle (vehicle 2) was indicated by 87 (46.8%) of the respondents and 23 (12.4%) respondents indicated driving a 3rd vehicle (vehicle 3).

Manual transmission in their main vehicle (vehicle 1) was reported by 142 (76.3%) respondents. A hand lever operated parking brake was reported to be employed in 151 (81.2%) of the main vehicle cases with 22 (11.8%) electronic (EPB), nine (4.8%) foot activated, and four (2.1%) reported to be automatic parking brakes in the remainder. Of the second vehicle cases (vehicle 2), 68 (78.1%) were fitted with lever operated parking brakes, 10 (11.5%) with EPB and four (4.6% %) with a foot activated parking brake. A hand lever operated parking brake was employed in 18 (78.3%) of the vehicle 3 reports with one (4.3%) EPB and one (4.3%) foot activated parking brake (see Table *5.1*).

*Table 5.1 Vehicle characteristics*

| | Transmission | | Parking Brake Type | | | |
|---|---|---|---|---|---|---|
| | **Manual** | **Automatic** | **Hand Lever** | **EPB** | **Foot** | **Auto/Blank** |
| Vehicle 1 (n=186) | 142 | 44 | 151 | 22 | 9 | 4 |
| Vehicle 2 (n=87) | 66 | 21 | 68 | 10 | 4 | 5 |
| Vehicle 3 (n=23) | 20 | 3 | 18 | 1 | 1 | 2 |

### 5.5.2 Operating the Parking Brake system

One hundred and forty (75.3%) of the drivers indicated they knew how the parking brake system worked without instruction, (25 respondents reported that they worked out how the system worked), 16 reported requesting advice from the manufacturer, 16 indicated they had referred to the vehicle handbook, three required instruction after consulting the owner manual.

### 5.5.3 Applying the lever operated parking brake

Thirty (19.9%) of the 151 respondents with a lever operated parking brake reported that they pulled the hand lever up without pushing the button in, 121 (80.1%) reported pulling the handbrake up while pushing the button in and one driver reported pushing the button in and pulling up using two hands.

### 5.5.4 Perceived effort required for lever operated parking brake system

Almost 20% (19.8%) of respondents (15 male and 15 female) aged 27 to 73 years (mean 49.8, SD 15.13) indicated the perceived level of exertion to operate the parking brake lever of their main vehicle to be somewhat hard (rating 13). Nine (13.2%) of the vehicle 2 respondents and two (11.1%) of the vehicle 3 respondents also rated the parking brake system to be somewhat hard to operate. For their main vehicle (vehicle 1) two drivers rated the effort as 14, one driver reported it to be 15, one driver reported it to be 16 and two drivers reported the operation to require maximum effort (20) (Borg, 1998). Only one driver reported being unable to apply sufficient force to hold the vehicle stationary.

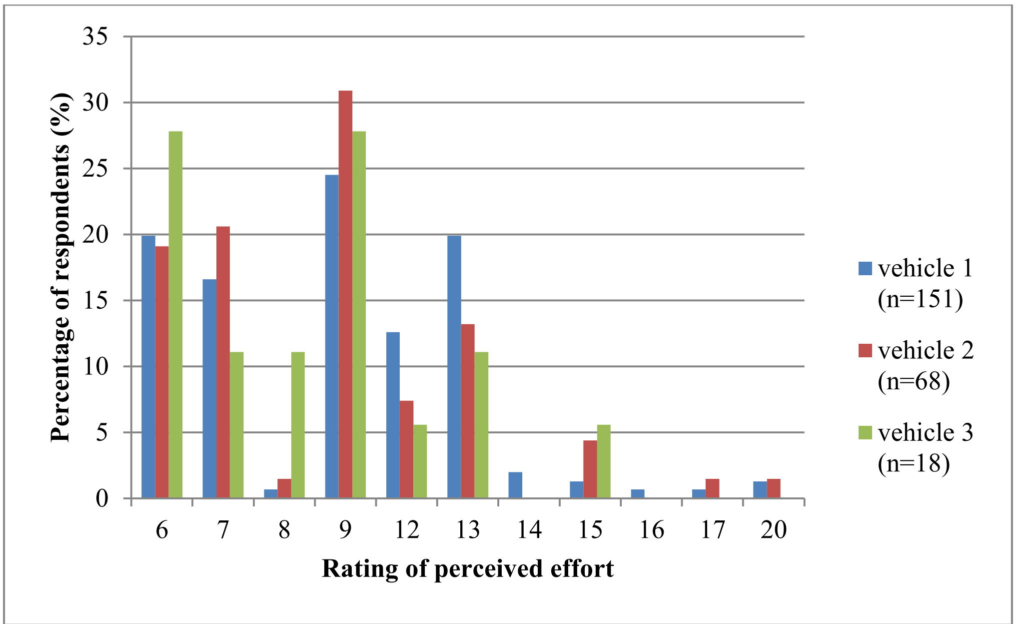



*Figure 5.4 Rating of perceived effort for each of respondents' vehicles*

Thirty (19.9%) of respondents reported vehicle 1, 13 (19.9%) reported vehicle 2 and five (27.8%) reported vehicle 3 to require no exertion at all (rating 6) to operate the parking brake lever. Twenty five (16.6%), 14 (20.6%) and two (11.1%) rated the perceived effort as 7 for vehicle 1, 2 and 3 respectively. Thirty seven (24.5%), 21 (30.9%) and five (27.8%) rated the perceived effort to be very light (9) for vehicles 1, 2 and 3 respectively (see Figure 5.4). The mean rate of perceived effort for vehicle 1 was 10.5 i.e. less than light and the median was 13 (somewhat hard).

The perceived ratings of effort required to operate the lever operated parking brake system in the respondents' main vehicle (vehicle 1) were used to explore differences in gender and age. Using 'somewhat hard' (rating 13) as the dividing marker, the perceived effort ratings were categorised into two groups: less than 13 (n=114) and 13 and more (n=37).

Initially, the responses for age were categorised into two groups: less than 60 years and 60 years and over to reflect the defined age of the older driver (Herriots, 2005). The responses within these categories were unevenly distributed hence the median age (51) of the respondents was used to determine categories more representative of the sample and reflective of the age at which there is likely to be a reduction in muscle strength (Chaffin, Anderson and Martin, 2006b). These categories were 50 years and under and 51 years and over. The results for the comparisons of perceived effort in relation to age and gender can be seen in Table *5.2*.

*Table 5.2 Rating of perceived effort in relation to gender and age of respondent*

| | **Rating of Perceived Effort** | |
|---|---|---|
| | <13 | 13+ |
| Male (n=77) | 58 (75.3%) | 19 (24.7%) |
| Female (n=74) | 56 (75.7%) | 18 (24.3%) |
| <60 years (n=106) | 79 (74.5%) | 27 (25.5%) |
| 60 + years (n=44) | 35 (79.5%) | 9 (20.5%) |
| <51 years (n=73) | 49 (67.2%) | 24 (32.8%) |
| 51+ years (n=78) | 65 (83.3%) | 13 (16.7%) |

The results indicated there was no significant difference between the gender groups in the rated level of perceived effort (Chi square test, (N= 151, 1 df), p = 0.84). Around 75% of both male and female groups rated the level of perceived exertion to be less than 13 ('somewhat hard'). For the respondents aged 60 years and over, 5% fewer rated the perceived effort as being 13 or more than those aged less than 60. The percentage of drivers aged less than 51 years who reported a rating of 13 or more was almost that for the group aged 51 or more. A Chi square test of independence indicated a significant relationship between these categories (Chi square p- value (N=151, 1 df.) = 0.0059, $p < 0.05$).

### 5.5.5 Parking practice

Respondents were asked to report how they would park their vehicle in a car park or on a slope to leave it unattended. The results for the 184 drivers who responded to this question are presented in Figure 5.5.

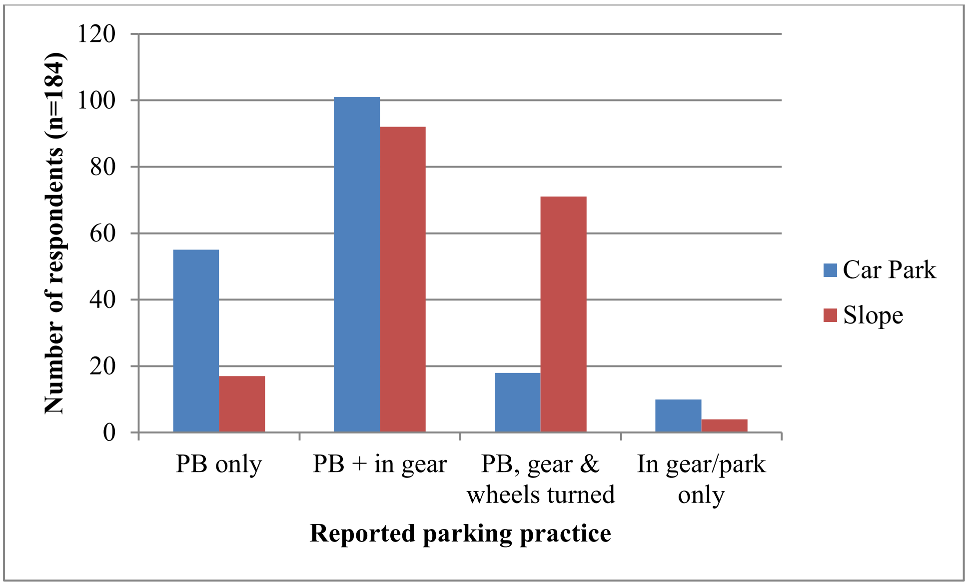



*Figure 5.5 Reported parking practice in a car park and on a slope (n=184)*

When parking in a car park, 101 (55%) of the respondents reported that they would apply the parking brake and park in gear with 41 (41%) indicating past experience as an influencing factor.

When parking on a slope, 92 (50%) respondents reported that they would apply the parking brake and park in gear with 46 (50%) indicating 'past experience' as an influencing factor (see Table 5.3).

In addition to applying the parking brake and selecting a gear when parking in a car park, 18 (10%) drivers indicated they turned the wheels and 71 (39%) drivers reported this to be their practice when parking on a slope (see Table 5.3).

The results for the respondents who reported they parked in gear in a car park or on a slope and the reasons for their practice are presented in Figure 5.6.

*Table 5.3 Reasons reported for parking practice in a car park and on a slope*

| | Car Park | | On Slope |
|---|---|---|---|
| **Parking Practice** | **Number** | **Reasons reported** | **Number** |
| PB only | 25 (45.5%) | How Instructed | 5 (29.4%) |
| | 4 (7.3%) | Overnight Parking | 0 |
| | 23 (41.8%) | Past Experience | 11 (64.7%) |
| | 3 (5.5%) | Other | 1 (5.9%) |
| **Total** | **55** | | **17** |
| PB+ park in gear/park | 34 (33.7%) | How Instructed | 23 (25%) |
| | 5 (4.9%) | Overnight Parking | 4 (4.3%) |
| | 41 (40.6%) | Past Experience | 46 (50%) |
| | 21 (20.8%) | Other | 19 (20.7%) |
| **Total** | **101** | | **92** |
| PB+ park in gear/park + turn wheels | 3 (16.7%) | How Instructed | 24 (33.8%) |
| | 1 (5.6%) | Overnight Parking | 1 (1.4%) |
| | 9 (50%) | Past Experience | 32 (45%) |
| | 5 (27.8%) | Other | 14 (19.7%) |
| **Total** | **18** | | **71** |
| Park in gear/park only | 1 (10%) | How Instructed | 0 |
| | 2 (20%) | Overnight Parking | 0 |
| | 3 (30%) | Past Experience | 3 (75%) |
| | 4 (40%) | Other | 1 (25%) |
| **Total** | **10** | | **4** |

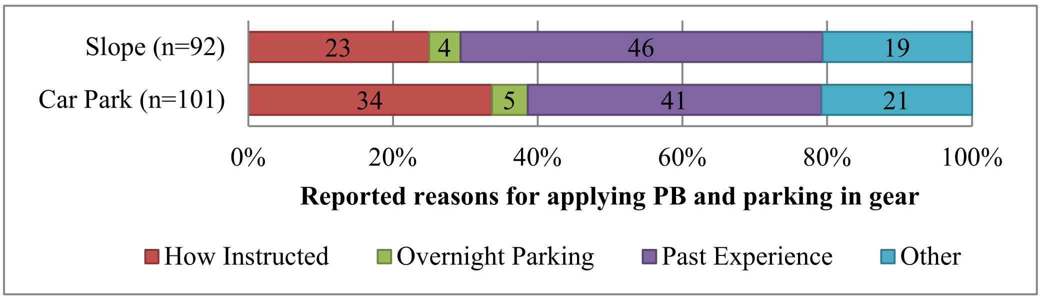



*Figure 5.6 Comparison of results for parking in gear on a slope (n=92) and in a car park (n=101)*

Statistical analysis indicated there was no significant difference in reported reasons for parking practice between slope and car park (Chi square test, p= 0.1376, 3df). However when the results for parking in gear were explored, the results suggested that 'past experience' had a significant influence on practice (Pearson Chi Square Phi = .190, 3 df, p=0.021, p<0.05).

Other reasons for reported parking practice were recorded for 33 respondents parking in a car park and 36 respondents parking on a slope (Table 5.4).

*Table 5.4 'Other' reasons for parking practice reported*

| 'Other' reasons provided | Parking in a car park (n=33) | Parking on a slope (n=36) |
|---|---|---|
| Additional training | 3 (9%) | 6 (16.7%) |
| Mechanical knowledge | 5 (15.1%) | 1 (2.7%) |
| Safety | 8 (24.2%) | 12 (3.3%) |
| Vehicle design | 3 (9%) | 3 (8.3%) |
| PING campaign/media | 3 (9%) | 7 (19.4%) |
| Advised by others e.g. family | 8 (24.2%) | 7 (19.4%) |
| Prevent stalling or PB sticking | 3 (9%) | 0 (0%) |

Safety (24.2%), advice by others (24.2%) and mechanical/engineering knowledge (15.1%) appear to be the other influencing factors when parking in a car park.

Awareness of the PING campaign (19.4%), advice from others (19.4%) and additional training (16.7%) appear to be the other main factors influencing reported parking practice when parking on a slope.

### 5.5.6 Comparison of parking practice for Electronic Parking Brake (EPB) with mechanically operated systems

Eighteen (81.8%) of 22 respondents whose main vehicle was fitted with EPB reported they would park in gear in a car park. Of the 160 respondents whose main vehicle was fitted with a lever or foot operated parking brake, 83 (52%) reported they parked in gear in a car park.

Eleven (61.1%) of the 18 drivers with EPB systems and 38% of the 83 drivers with mechanical parking brake systems who parked in gear in a car park, related their practice to past experience. Four (22.2%) of the EPB respondents and 26 (31%) of the mechanically operated parking brake respondents relating their practice to how they were instructed.

Ten (45.5%) of the respondents with vehicles employing EPB reported they would park in gear on a slope with a further eight (36.4%) respondents indicating they would park in gear and turn the wheels. Eighty (50%) of 160 respondents with vehicles employing mechanically operated systems indicated they would park in gear on a slope with 63 (39.4%) respondents reporting they would also turn the wheels.

The results suggest that a greater percentage of respondents with EPB systems report parking in gear on the flat than those with mechanical systems but there was little difference for parking on a slope.

### 5.5.7 Parking practice in relation to overnight parking

Out of 184 respondents to the question 'do you normally park on the flat or on a slope overnight?', 115 (62.5%) drivers indicated they would routinely park on the flat overnight, 61 (33.2%) drivers indicated they would routinely park on a slope overnight and eight (4.4%) indicated they could park on both.

The results for the 176 respondents who indicated whether they parked on a slope or on the flat overnight were categorised into two groups representing their routine. The results were then compared with the reported parking practice when parking their vehicle to leave it unattended in a car park or on a slope and are shown in Figure 5.7.

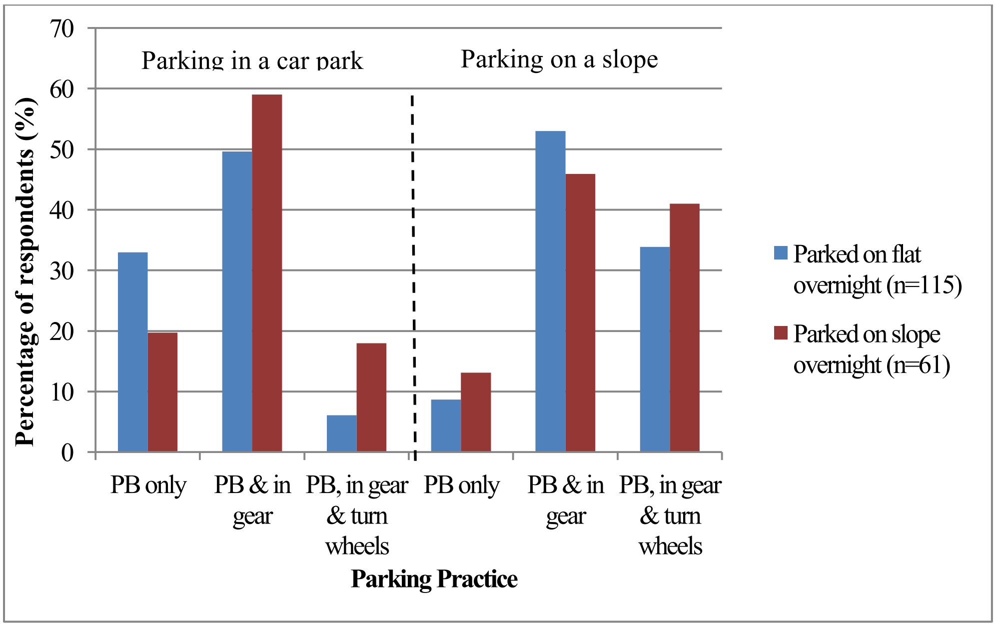



*Figure 5.7 Reported parking practice in relation to overnight parking routine (n=176)*

When ***parking in a car park***, 49.6% of drivers who parked on the flat overnight and 59% of drivers who parked on a slope overnight indicated that they would apply the parking brake and leave the vehicle in gear. Of the drivers who parked on the flat overnight, 33% would park with only the parking brake applied compared to 19.7% of drivers who parked on a slope overnight.

When ***parking on a slope***, 53% of respondents who parked on the flat overnight and 45.9% of respondents who parked on a slope overnight reported they would apply the parking brake and park in gear when parking on a slope (Figure 5.7). In addition to parking in gear, 33.9% of drivers who parked on the flat overnight and 41% of drivers who reported they parked on a slope overnight also turned the wheels.

### 5.5.8 Parking practice across groups of respondents

The responses to why drivers parked their vehicle in a car park as they reported were categorised into 4 groups to represent background of the drivers (Figure 5.8):

- Health Care (HC) n=33
- Professional Drivers (IAM) n=84
- Drivers aware of Park in Gear (PING) campaign n=49
- Others- non-professional driver forums n=15

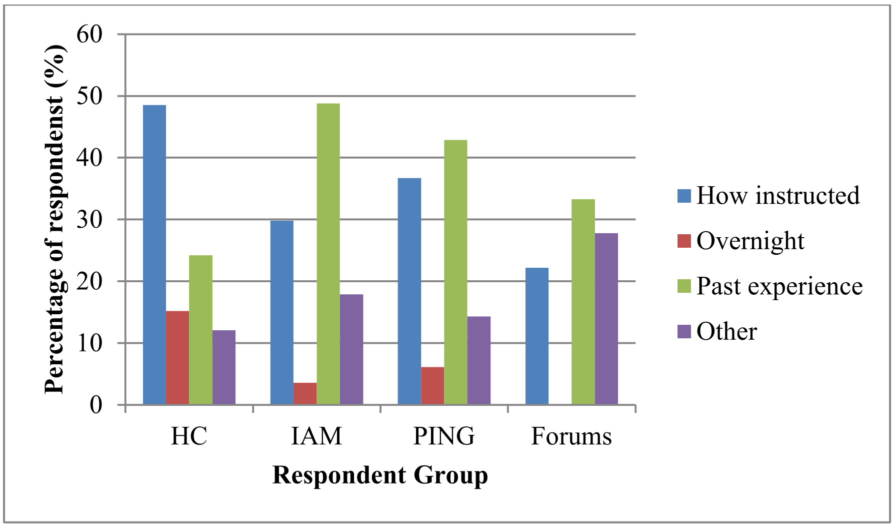



*Figure 5.8 Reasons for reported parking practice in a car park in relation to respondent group*

Almost 50% (48.5%) of Health Care staff and 36.7% of the PING group cited how instructed as a reason for their parking practice. Past experience was the primary reason reported for parking practice in all but the Health Care group – IAM (48.8%), PING (42.9%) and Forums (33.3%).

### 5.5.9 Experience of vehicle rollaway

Twenty two (11.8%) respondents, 15 male and 7 female, aged between 25 and 68 years, (mean 50, SD 13.8) reported that their current vehicle had rolled away. Thirteen (59%) of the 22 respondents indicated this had occurred within the previous two years. Sixteen (72.7%) of the 22 reports related to their main vehicle (vehicle 1) and 6 (27.3%) reports related to another vehicle they would drive (vehicle 2).

In five (22.7%) cases the parking brake had not been applied, with three (13.6%) respondents reporting 'forgot' or distracted as the reason. Eleven (50%) of the respondents reported the rollaway to be mechanical or system related, including two (18.2%) cases where the vehicle was fitted with an EPB. Three (13.6%) cases were reported to be related to insufficient application of the parking brake (see Table 5.2) and no reason was given for three (13.6%) cases.

Three respondents indicated they had not parked in gear and one respondent reported the vehicle had 'jumped' out of gear and rolled. Reported cases where the parking brake was applied and a rollaway occurred, cited vehicles from a range of manufacturers: four Fords (Fiesta and Focus), six Vauxhalls (Corsa, Astra and Safira models); two Volkswagens (Passat and Polo models) and one Hyundai ix20).

*Table 5.5 Vehicle rollaway and reasons reported*

| | Reasons reported for vehicle rollaway | | | |
|---|---|---|---|---|
| Vehicle rollaway | Parking brake not applied | Mechanical/ system failure | Insufficient application of parking brake | No reason |
| Vehicle 1 (n=16) | 3 | 9 | 2 | 2 |
| Vehicle 2 (n=6) | 2 | 2 | 1 | 1 |

### 5.5.10 Slips and lapses

Drivers were asked to indicate the frequency they displayed 8 different driving related behaviours in a section taken from the Manchester Driving Behaviour Questionnaire (Af Wåhlberg, Dorn, and Kline, 2011**).** The results of the responses to the driver behaviour statements were compared with the results for experience of vehicle rollaway. The results for the reported ratings of 'occasional', 'quite often' and 'nearly all the time' were grouped and compared between respondents who had reported experience of a vehicle rollaway within the last two years (n=13) and respondents who had not indicated experience of a vehicle rollaway (n=172) , see Table *5.6*.

*Table 5.6 Vehicle rollaway in relation to reported driver behaviour*

| | Roll (n=13) | No Roll (n=172) | Total |
|---|---|---|---|
| Hit something when reversing | 0 | 9 (5.2%) | 9 |
| Intending to go to A find yourself going to B | 2 (15.4%) | 12 (7%) | 14 |
| Wrong lane before roundabout or junction | 7(53.8%) | 56 (32.5%) | 63 |
| Switch wrong thing on | 2 (15.4%) | 27 (15.7%) | 29 |
| Drive away in 3rd gear | 4 (30.7%) | 16 (9.3%) | 20 |
| Forget where you park your car | 4 (30.7%) | 41 (23.8%) | 45 |
| Misread signs and exit on wrong road | 3 (23.1%) | 26 (15.1%) | 29 |
| Realise no clear recollection of road | 5 (38.5%) | 39 (22.7%) | 44 |

The results indicate that drivers who reported a vehicle rollaway also had a greater response rate to finding themselves in the wrong lane before a roundabout or junction, attempting to drive away in third gear, forgetting where they parked their car and realising they had no clear collection of the road they had just travelled on.

Ten drivers reported returning to their vehicle to find the parking brake had not been applied but only one of these had experienced a vehicle rollaway. Five of the 10 respondents indicated they would always park in gear in a car park and 7 respondents indicated they would park in gear on a slope with a further two indicating they would park in gear and turn the wheels.

## 5.6 Chapter Summary

An online survey was developed to explore driver interaction with the parking brake system to which 186 drivers from across the UK responded.

Most of the drivers surveyed (81%) indicated that the parking brake system in their main vehicle was lever operated. The majority of drivers (75.5%) rated the perceived exertion required to operate this system to be less than 13 (somewhat hard) on the Borg perceived rate of exertion scale.

Contrary to manufacturer's instructions, 80% reported pushing the release button in when pulling the lever up.

Around half (55%) of respondents reported they would apply the parking brake and park in gear when parking in a car park. When parking on a slope, 50% of respondents reported they would park in gear with a further 39% indicating they would also turn the wheels.

The results indicated that 'past experience' had a greater influence on parking practice than 'how instructed'. Drivers who parked their vehicle on the flat overnight appeared more likely to **only** apply the parking brake when parking in a car park than drivers who parked on a slope overnight.

A greater percentage (81.8%) of drivers whose main vehicle was fitted with an EPB indicated they would park in gear in a car park than those whose vehicle was fitted with a mechanically operated parking brake (31%).

Almost 12% (11.8%) of respondents reported that they had returned to their parked, unattended vehicle to find it had rolled away. Half of these respondents indicated that the vehicle rollaway was mechanical or system related while 13.6% reported 'forgot' or being distracted as the reason.

# Chapter 6: 'Real Life' Parking Practice

## 6.1 Introduction

The online driver survey explored reported parking practice and factors that may influence the way in which drivers would park their cars to leave them unattended on an incline or in a car park. Around half (55%) of the drivers reported they would park in gear when parking in a car park indicating 'how instructed' and 'past experience' as the main influencing factors. However, it is recognised that there are discrepancies between what people say and what they do (Robson, 2011, p.316) and further exploration of 'real life' parking practice was required to determine current practice in the UK.

This chapter presents the findings of observations conducted in five public access car parks in different geographical areas across the UK (Figure 6.1) to explore the question *'how are unattended vehicles parked?'*

The aim of the study was to observe which controls were engaged when the unattended vehicle was parked and supplement data collected in relation to common practice.

## 6.2 Methods

### 6.2.1 Selection of test areas

Results from the online survey indicated that the terrain drivers parked on overnight may influence their parking practice in other locations such as car parks. In relation to this, despite the surrounding topography, car parks typically are relatively flat areas (Hill et al., 2005, pp. 6-25). Car park provision has similar demands across acute NHS hospital sites and it was considered that the users of NHS car parks would be comparable across the UK (Department of Health, 2009). An estimated average of 4,000 vehicles access each acute hospital car park on a daily basis. Over 1,000 of these are likely to belong to staff, the remainder belonging to patients and visitors (Keilthy, 2003).

A convenience sample of NHS district hospital car parks were selected as study sites representative of regions of varying topography across the UK. The population sample was likely to represent a cross section of drivers in terms of age, experience and capability, include regular users, such as staff, and occasional or irregular users such as patients and visitors who would be respectively familiar or unfamiliar with the environment. Five NHS Hospital car parks served as study areas and observations were conducted between June and October 2012 in the areas located in Figure 6.1.


*Figure 6.1 Location of car parks in relation to topography*

### 6.2.2 Procedure

Facilities Managers and/or Security Managers of five NHS Trusts across the UK were contacted by telephone and by email to seek permission to conduct observations within the hospital car parks. Details of any ‘rollaway’ incidents were requested and noted accordingly.

The observations were conducted mid-week between 0900 and 1700 by two investigators, both experienced drivers with experience of driving multiple vehicles on a regular basis. Security personnel were made aware of the observers’ presence on site and were able to support the observers should any concerns by members of the public be raised.

The observers wore high visibility vests and worked together to record make, model and age of vehicle; whether the vehicle was manual or automatic; parking brake type; whether the parking brake was engaged; and whether the vehicle was left in gear (manual) or park (automatic). If there was any doubt as to the control position the observers collaborated to reach a decision and if unable to do so the vehicle was excluded. Any notable observations such as design of parking brake were recorded. The gradient and surface material of the car parks was noted along with the weather conditions.

### 6.2.3 Reliability testing (pilot)

Ten vehicles were selected in a local health care car park and each observer independently recorded their observations. Observations were conducted through the driver or passenger window of the locked vehicle and indications such as a crease in the gear stick gaiter and position of the gear stick in relation to its housing or other parts of the vehicle were used to assist the assessment. The observer records were checked against each other and against the actual position of the controls by entering the pilot vehicles. Each observer’s result correlated 100% with the actual position of the controls (Kappa =1; Geertzen, 2012) and therefore the procedure was considered to have sufficient inter observer consistency for observational purposes.

### 6.2.4 Materials

*Figure 6.2 Measuring the gradient*

Data were recorded using a simple table in paper format and transcribed into Excel for analysis. The gradients of areas within the car parks were calculated by positioning a 1000 mm ruler spirit level along the *run* and measuring the *rise* from the end of the level to the carpark surface (Figure 6.2).

Gradient % = rise/run x 100. A Canon Power Shoot SX100 was used to take photographs of the locations.

## 6.3 Car Parks

### 6.3.1 Car park 1 (Plymouth)

The area around Plymouth and across the South West peninsula can be described as undulating, reaching a height of 506m above sea level in some areas. Derriford Hospital is situated on the outskirts of Plymouth at the edge of Dartmoor. The pay and display visitor car parks (Figure 6.3) had a tarred surface with incline ranging from 6-9%. The staff car park (Figure 6.4) had a gravel surface with tarmacked access routes and an incline range of 9-11%. The staff car park operated on a swipe card and pay on exit system.

**Incidents**

Incidents were not recorded but staff recalled three rollaway incidents in the 8 week period prior to the observations commencing.

*Figure 6.3 Visitors Car park*

*Figure 6.4 Overflow/ staff car parking areas*

### 6.3.2 Car park 2 (Cambridge)

The Cambridgeshire Fens is the lowest area in the UK devoid of high hills or mountains. Addenbrooke’s hospital is a large teaching hospital situated on the southern side of the city of Cambridge. It was recognised to be a busy site with an estimated 8,000 car movements daily and parking provision for around 3,000 vehicles.

There were two management arrangements for the car parks. The pay on exit multi-storey (Figure 6.4), with 1050 spaces available, was operated by a national operator. It had seven levels with an 18% incline access ramp between the levels. The levels themselves had a gradient range of 2-6% incorporating a camber. The outside car park (Figure 6.5) was managed and operated by NHS employed staff. The access slope was 18% and the car park had a gradient range of 2 - 4.5%.

**Incidents**

Staff in the multi-storey car park reported that they occasionally had to push a car back into its space and choc the wheels. These incidents were not recorded as no damage had incurred, however t incidents where damage had occurred were recorded for the preceding 12 months. The staff reported that they felt vibration in the car park was a contributory factor particularly at busy times.

In the outside car park staff recalled one incident within the preceding six months where a vehicle had rolled the length of the car park, down a bank, across the road and into a hedge without causing any damage to other road users.

*Figure 6.5 Multi storey car park*

*Figure 6.6 Outside car park*

### 6.3.3 Car park 3 (Inverness)

Inverness lies within the Highlands of Scotland surrounded by some of the highest mountains in the UK. Raigmore Hospital is located on the outskirts of Inverness close to the main A9 route through the Highlands. The main car park with around 1,000 spaces for visitors and staff was managed by the NHS trust. The main area was tarred throughout with an incline range of 0- 2%. The surface of the smaller area mainly used by staff was a combination of gravel and tarmac with a gradient range of 2-6% (Figure 6.7).

*Figure 6.7 Car park with gradient range 2-6%*

## Incidents

Although the facilities manager reported knowledge of vehicle rollaway incidents, no figures were available as these had not been recorded.

### 6.3.4 Car park 4 (Birmingham)

The car park was split into visitor (Figure 6.8) and staff areas (Figure 6.9) and was managed by the NHS. Both operated on an exit barrier system with the visitor car park requiring payment on foot before returning to vehicle. The walk ways and access routes were tarred and the parking spaces were tarred or gravel. The gradient of the car parks ranged from 0-14%

*Figure 6.8 Staff and visitor parking*

*Figure 6.9 Staff parking area*

### 6.3.5 Car park 5 (Gloucester)

The fifth car park was a multi-storey type with four levels and managed by a national car park franchise. There were 1,000 spaces available occupied by both staff and visitor vehicles. In some areas of the car park the surface sloped in the same direction as the vehicles were parked (Figure 6.10 and 6.11).

*Figure 6.10* Outside parking area

*Figure 6.11 Indoor parking area*

*Figure 6.12 Indoor parking area*

In other areas there was a moderately steep incline (9% gradient) perpendicular to the car park spaces (Figure 6.12).

The gradient range for the parking bay areas was 0-9%.

**Incidents**

In the 18 months following the car park opening in October 2010, there had been 5 recalled incidents of vehicles rolling resulting in minor property damage. In 2 of the incidents, it was reported that the driver forgot to apply the parking brake.

## 6.4 Results

### 6.4.1 Vehicles observed

Observations were conducted on 1,996 vehicles with an overall mean of 6.7 years post registration as indicated by the registration plate (Plymouth 7.7 (SD 3.9); Cambridge 6.1 (SD 3.9); Inverness 5.5 (SD 3.5); Birmingham 6.9 (SD 3.5); Gloucester 7.3 (SD 3.9)). Of the 1,996 vehicles observed, 1,790 (89.7%) were fitted with lever operated parking brakes (HB); 142 (7.1%) were fitted with EPB and 24 (1.2%) employed a foot operated parking brake system (see Table *6.1*).

*Table 6.1 Observation of Parking Brake Systems and status of controls*

| | Car Park Location | | | | | |
|---|---|---|---|---|---|---|
| | **Plymouth** | **Cambridge** | **Inverness** | **Birmingham** | **Gloucester** | **Totals** |
| Gradient range (parking bay area) | 9-10% | 5-6.5% | 0-6% | 0-14% | 0-8% | |
| Number of vehicles | 363 | 540 | 265 | 315 | 513 | 1996 |
| Automatic transmission | 31 | 94 | 18 | 24 | 39 | 206 |
| **Lever operated PB (HB)** | **344 (94.8%)** | **453 (83.9%)** | **236 (89.1%)** | **280 (88.9%)** | **477 (92.9%)** | **1790 (89.7%)** |
| Manual transmission + HB | 317 | 400 | 228 | 265 | 446 | 1656 |
| Automatic transmission + HB | 27 | 53 | 8 | 15 | 31 | 134 |
| HB not applied | 13 | 16 | 6 | 3 | 7 | 45 (2.5%) |
| HB not applied, in gear | 11 | 8 | 6 | 2 | 5 | 32 |
| HB not applied, in park | 2 | 8 | 0 | 1 | 2 | 13 |
| HB applied not in gear | 128 | 284 | 129 | 176 | 308 | 1021 (61.7%) |
| **HB applied, in gear** | **163 (51.4%)** | **92 (23%)** | **93 (40.8%)** | **84 (31.7%)** | **126 (28.3%)** | **558 (33.7%)** |
| **EPB (total)** | **14** | **69** | **20** | **16** | **23** | **142 (7.1%)** |
| EPB with manual transmission | 10 | 36 | 14 | 10 | 17 | 87 |
| **EPB, in gear** | **5 (50%)** | **15 (41.67%)** | **8 (57.14%)** | **6 (60%)** | **5 (29.4%)** | **39 (44.8%)** |
| EPB not in gear | 5 | 21 | 6 | 4 | 12 | 48 |
| Foot operated PB (FB) | 0 | 6 | 6 | 9 | 3 | 24 |
| Vehicles excluded | 5 | 12 | 3 | 10 | 10 | 40 |

In vehicles fitted with a lever operated parking brake, 1,656 (92.5%) had a manual transmission and 134 (7.5%) had an automatic transmission. In vehicles fitted with EPB, 87 (61.3%) had a manual transmission. Forty (2%) vehicles were excluded from analysis due to difficulty determining the status of the controls. Reasons for exclusion were: controls obscured by personal belongings, design of controls, vehicle was occupied.

Three further questions were applied to explore the data collated in Table *6.1*:

*'What percentage of manual transmission vehicles fitted with a hand lever operated parking brake are left in gear?'*

*'What percentage of manual transmission vehicles fitted with an electronically operated parking brake (EPB) are left in gear?*

*'Is there any association between car park location and parking practice?'*

### 6.4.2 Observed practice

**Lever operated parking brake**

A total of 558 (33.7%) of the 1,656 vehicles with manual transmission and a lever operated parking brake were parked in gear. For individual car parks these figures were 51.4% in Plymouth, 23% in Cambridge, 40.8% in Inverness, 31.7% in Birmingham and 28.3% in Gloucester (see Figure 6.13.)

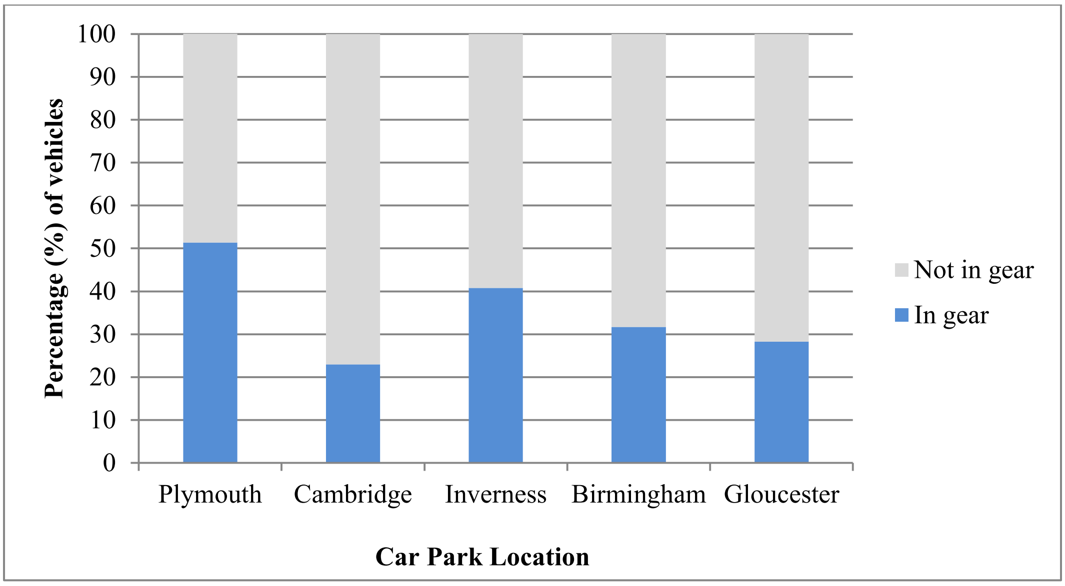



*Figure 6.13 Comparison of vehicles with lever operated parking brakes and whether parked in gear*

Of the 1656 vehicles observed with manual transmission and lever operated parking brake, 1021 (61.7%) were not parked in gear. A binomial statistical test indicated that the proportion of vehicles not parked in gear 0.66 was greater than the expected test proportion of 0.5 (2 tailed, $p < 0.01$).

Descriptive statistical analysis identified a possible relationship between car park location and parking practice. Further analysis indicated a very weak association with parking in gear and car park geographical location (Lambda = 0.033, assym std error 0.14, approx. p=0.022). These results suggest that vehicles with a lever operated parking brake were less likely to be parked in gear in the region with least undulating topography (Cambridge) than other areas.

The lever operated parking brake (HB) was not applied in 13 (3.8%) of the vehicles in Plymouth, 16 (3.5%) in Cambridge; 6 (2.5%) in Inverness, 3 (1.1%) in Birmingham and 7 (1.6%) in Gloucester. However in all cases the vehicle was left in gear or in park.

**Electronic Parking Brake**

Across the five observed car parks, of the 87 vehicles with manual transmission and EPB, 39 (44.8%) were parked in gear: five (50%) in Plymouth, 15 (41.7%) in Cambridge, eight (57.1%) in Inverness, six (60%) in Birmingham and five (29.4%) in Gloucester. The results for both systems across the five locations are compared in Figure 6.14.

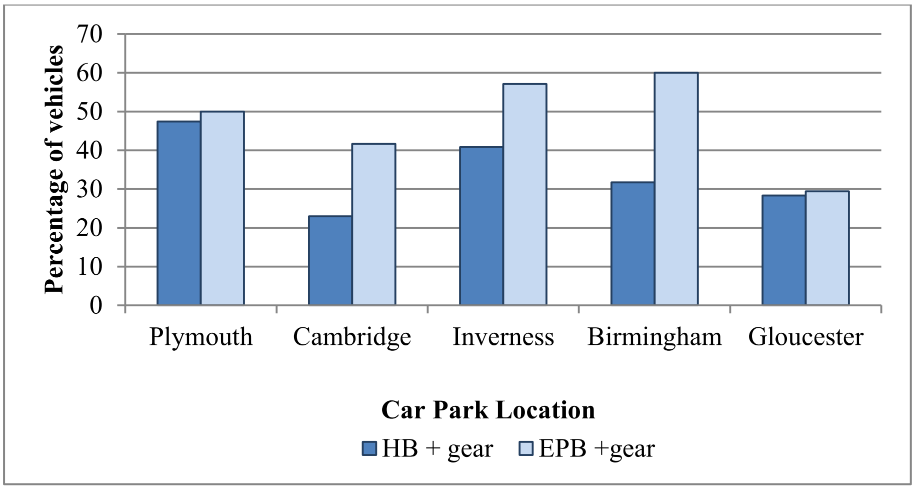



*Figure 6.14 The percentage of vehicles with lever operated parking brakes (HB) and vehicles with electronic parking brakes (EPB) parked in gear across the car park sites.*

The percentage of vehicles parked in gear and fitted with EPB appears to be greater than the percentage of vehicles parked in gear with lever operated parking brakes (Wilcoxon signed ranks test, Z= -2.023, p=0.043).

In 2009, TRW automotive holdings estimated that by 2015 one in five cars would be manufactured with EPB (Challen, 2010). To reflect the mid-point timescale for this prediction, and the period post registration that MOT testing is not required, the data for vehicles registered 2009 - 2012 (i.e. less than three years old at the time of observation) were explored. The relative percentage of vehicles that were fitted with an EPB system was calculated and the results are seen in Table 6.2.

The percentage of vehicles fitted with EPB fell below the 20% proportion in four of the five car parks. Although only 26% of the vehicles observed in Cambridge were less than three years old, the percentage of vehicles fitted with EPB (21.47%) may reflect the population of higher end vehicles such as Audi. This requires further exploration outside the scope of this study.

*Table 6.2 Vehicles Registered 2009-2012*

| Location | Vehicles Registered 2009-2012 (N=456) | Most Observed Manufacturer | Vehicles Fitted with EPB | Make of vehicle observed with EPB |
|---|---|---|---|---|
| Plymouth | 69 (19%) | Ford | 7 (10.14%) | Mercedes, Audi, Vauxhall, BMW |
| Cambridge | 139 (25.74%) | BMW | 30 (21.58%) | 11 different manufacturers VW & Audi most frequent |
| Inverness | 86 (32.34%) | Vauxhall | 15 (17.44%) | Most frequent Volvo and Vauxhall |
| Birmingham | 68 (21.45%) | Vauxhall | 6 (8.81%) | VW, Vauxhall, Audi |
| Gloucester | 94 (18.32%) | Ford | 12 (12.77%) | 6 manufacturers, most frequent VW, Audi |

### 6.4.3 Other observations (push button start vehicles)

BMW vehicles were equipped with push button ignition as standard since 2005 (Clark, 2009) and in 2009 it was agreed that all vehicles manufactured in the EU fitted with push button start would have a secondary feature where the clutch or brake had to be engaged when starting the vehicle (ROSPA, 2011). An assumption then was that these vehicles would be more likely to be parked in gear and that requiring the depression of the clutch to enable starting would be consistent with this change in driver practice. From the results, data were extracted for BMW vehicles registered from 2005 onwards. Vehicles with private number plates were excluded as the year of manufacture could not be established.

A total of 57 BMWs registered from 2005 onwards with manual transmission were observed with 26 (44.1%) being parked in gear; 23 vehicles were registered from 2009 with six (26.1%) being parked in gear. The results for each car park can be seen in Table *6.3*.

*Table 6.3 Push button start (BMW) vehicles*

| Location | 2005-2012 | Manual transmission | Parked in gear | 2009-2012 | Parked in gear |
|---|---|---|---|---|---|
| Plymouth | 13 | 12 | 9 | 3 | 1 |
| Cambridge | 21 | 16 | 5 | 11 | 2 |
| Inverness | 10 | 8 | 7 | 2 | 2 |
| Birmingham | 9 | 9 | 5 | 4 | 1 |
| Gloucester | 13 | 12 | 0 | 3 | 0 |
| Total | 59 | 57 | 26 | 23 | 6 |

Despite the requirement to engage the clutch to start the vehicle, less than 30% of vehicles less than three years old were parked in gear compared to the number of vehicles fitted with EPB.

## 6.5 Chapter Summary

Out of almost 2000 parked, unattended vehicles observed in five NHS car parks across the UK in 2012, 90% were fitted with a lever operated parking brake.

The average age, years post registration, of the vehicles observed was 6.7 years.

The results indicated that across the UK, 34% of vehicles observed with manual transmission and lever operated parking brake were parked in gear in a public car park. In comparison, 45% of vehicles fitted with EPB were parked in gear.

Exploration of the data indicated a weak association with parking in gear and car park geographical location. A greater percentage of the vehicles were parked in gear in the car parks in regions of surrounding elevated terrain (Inverness and Plymouth) with Cambridge (flattest region) having the lowest percentage of vehicles parked in gear. However, the observations were unable to confirm that all vehicles observed were registered in the locality.

An average 15% of vehicles less than 3 years old were fitted with EPB. The percentage of vehicles parked in gear was greater in vehicles with EPB than those with lever operated parking brakes in four of the five car parks ($P<0.05$).

Despite developed secondary safety features in vehicles with push button ignition systems and manual transmission which require the driver to depress the clutch to start the engine, only 44% were parked in gear.

# Chapter 7: Driver Instruction and Training

## 7.1 Introduction

Competent driving requires the ability to transfer skills that have been developed through instruction into independent practice (Hall and West, 1996; Groeger and Banks, 2007). The knowledge of the procedures involved, the associated hazards and how to complete the task is usually dependent on the instructor (Reece and Walker, 2007) and the instruction provided.

In the UK, it is reported that 98% of learner drivers receive professional tuition (DfT, 2002). From January to December 2012, more than 9,600 Driving Instructor registrations were approved with an average of 181 new Approved Driving Instructors (ADIs) registering per month (*https://www.gov.uk/government/statistical-data-sets/ins01-numbers-of-approved-driving-instructors*). The coloured boxes in Figure 7.1 illustrates how instruction may be a contributory factor to vehicle rollaway within the fault tree analysis and justifies it as an area of exploration.

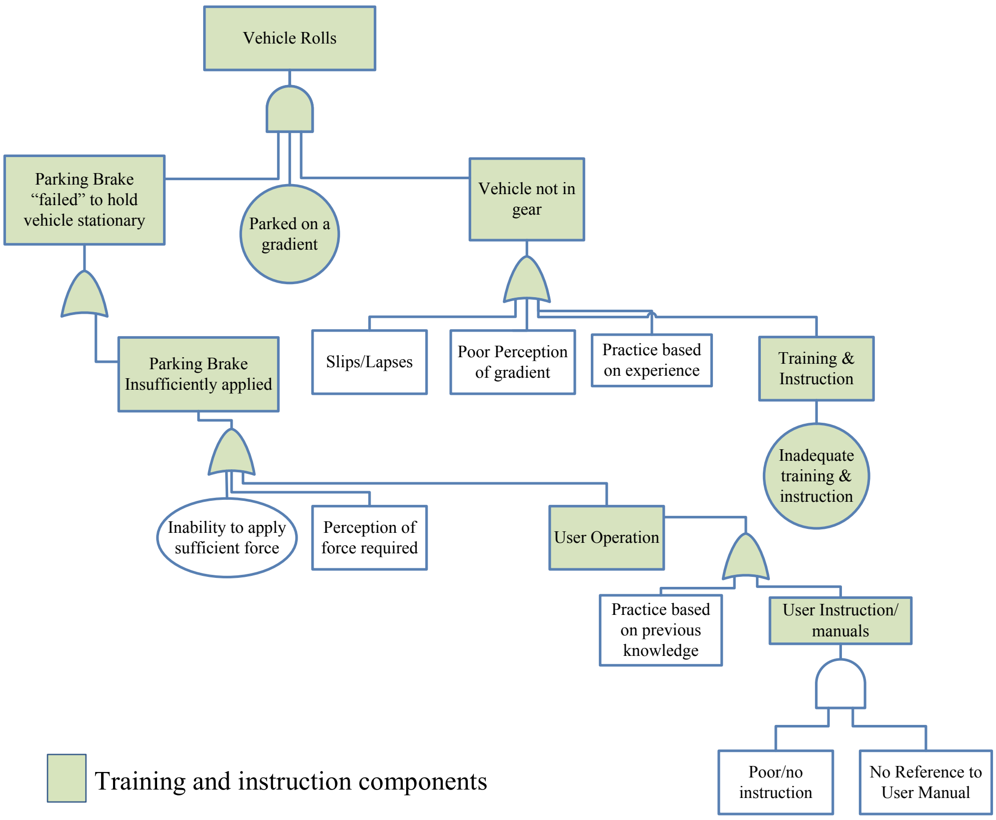



*Figure 7.1 Training and instruction in the fault tree analysis*

This chapter presents the results of a questionnaire survey which targeted Approved Driving Instructors (ADIs) within the UK to explore:

- the instruction provided in relation to applying the lever operated parking brake
- the instruction provided in parking the vehicle so it remains stationary when left unattended
- the ADI experience of vehicle rollaway

## 7.2 Methodology

### 7.2.1 Survey design

A questionnaire survey for ADIs was constructed using Survey Monkey, an online competitively priced data collection tool. This enabled a survey link (*https://www.surveymonkey.com/s/BLF56LW*), to be communicated by e-mail to contacts and organisations, and data to be exported to Excel and SPSS. Baseline data were collected such as age, gender, driving instruction experience and geographical location. The remainder of the questions focused on methods of application of the lever operated parking brake and instruction on how to park an unattended vehicle based on information available in the literature and regulatory guidance.

The self-administered questionnaire was divided into four sections and contained 16 questions of both open and closed design with a final section allowing respondents to add relevant comments (see Figure 7.2).

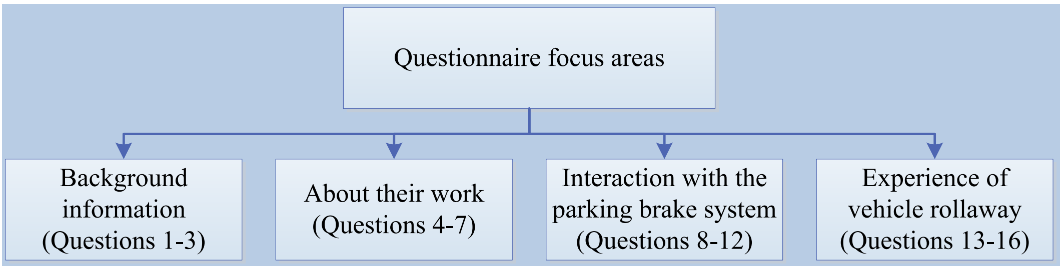



*Figure 7.2 Questionnaire focus areas*

Questions 1-3 obtained background information about the participants including age, gender and experience as a driving instructor.

Questions 4-7 explored their work situation and how they became aware of any new information

Questions 8-12 asked respondents to indicate:

- How pupils were instructed to operate the manually operated parking brake
- How pupils were instructed to park a vehicle to leave it unattended
- Whether pupils experienced difficulty operating the manually operated parking brake
- Whether learning to drive a vehicle fitted with EPB presented any difficulty

Questions 13-16 required the respondent to provide information about their own and that of their pupils' experience of vehicle rollaway.

## 7.3 Pilot Study

A pilot study was conducted to:

- Check the wording and structure of the questionnaire
- Check the clarity and ease of completion of the questions
- Ensure responses reflected information requested
- Evaluate the time taken to complete the survey

### 7.3.1 Participants

Twenty four Approved Driving Instructors (ADIs) who attended a local Approved Driving Instructor (ADI) Federation meeting served as a convenience sample to pilot the questionnaire. Twenty (83.3%) of the respondents (17 male, 3 female) were aged between 40 and 69. Twenty two (91.7%) were self-employed, with five of these belonging to a franchise. Meeting attendees were asked to complete and return a printed copy of the survey with most participants being able to do so within 10 minutes. An open facilitated discussion followed which further supported the questions raised in relation to driving instruction as a contributory factor to vehicle rollaway.

Four ADIs who would not be participating in the final survey completed the questionnaire online in an average time of 9 minutes.

### 7.3.2 Pilot study outcome

In addition to minor typographical corrections, question 5 *'please indicate the nearest town/city to where you live'* was added to explore any regional variations in the instruction provided. 'DSA bulletins' was added as a selection choice to question 7 following feedback from the pilot group indicating this to be a key source for updated information. The pilot study demonstrated that the responses were as anticipated and that the questionnaire could be completed within 10 minutes. A printed copy of the final questionnaire can be found in Appendix D.1.

Almost 70% (67%) of the pilot study respondents indicated they would instruct pupils to push the release button in when pulling up the lever operated parking brake. Fifty one percent indicated they would instruct pupils to park in gear and turn the wheels when parked on a 20% incline.

## 7.4 Data Collection - Online Survey

### 7.4.1 Distribution of survey

Distribution of the survey to the Approved Driving Instructor National Joint Council (ADINJC) membership was agreed with the ADINJC chairman. The uniform resource locator (URL) link was communicated by newsletter with a follow up email to all members by the ADINJC Liaison Officer inviting members to complete the survey online. This was a convenience sample with snowball sampling to increase the response rate. Data collection was conducted over a six week period and completed on 06/06/13.

### 7.4.2 Data collection and analysis

Data from the questionnaire were analysed using Microsoft Excel and IBM statistics software SPSS versions 21 and 22. Data were extracted to gain an understanding of current driving instruction practice and explore any variations within participant responses and from information available in the literature. Statistical methods used to analyse the data were those considered appropriate for ordinal and nominal data.

## 7.5 Online Survey Results

### 7.5.1 Sample distribution

The online survey received a response from 146 ADI's from across the UK. The average time recorded by the software to complete the questionnaire was 9 minutes with 7.5% of participants taking more than 15 minutes to complete.

Thirty six female and 107 male ADI's responded (3 blank responses) with 71.3% (n= 102) aged between 40 and 59 years and 70.6% (n=101) with less than 11 years driving instruction experience as recorded in Table *7.1* and 7.2. A total of 133 (93%) of the respondents reported they were self- employed including 35 (24.5%) who indicated they belonged to a franchise.

*Table 7.1 Age groups and response distribution (n=143)*

| Age | Female | Male | Count | Percent |
|---|---|---|---|---|
| 21-29 | 1 | 1 | 2 | 1.4% |
| 30-39 | 4 | 2 | 6 | 4.2% |
| 40-49 | 13 | 25 | 38 | 26.8% |
| 50-59 | 16 | 48 | 64 | 45.1% |
| 60-69 | 2 | 26 | 28 | 19.7% |
| 70 or older | 0 | 5 | 5 | 3.5% |

*Table 7.2 ADI experience and response distribution (n=143)*

| ADI experience | Female | Male | Count | Percent |
|---|---|---|---|---|
| 0-5 years | 10 | 37 | 47 | 32.9% |
| 6-10 years | 16 | 38 | 54 | 37.8% |
| 11- 15 years | 8 | 12 | 20 | 14.0% |
| 16-20 years | 1 | 3 | 4 | 2.8% |
| 20+ years | 1 | 17 | 18 | 12.6% |

The majority of ADIs reported they were made aware of any new information through the internet, professional newsletters or Driving Standards Agency (DSA) bulletins (see Table 7.3).

*Table 7.3 How are you made aware of new information?*

| Answer Options | Response count | Response Percent |
|---|---|---|
| Conferences | 43 | 30.7% |
| Local/regional meetings | 68 | 48.6% |
| Internet | 125 | 89.3% |
| Professional Newsletters | 109 | 77.9% |
| DSA bulletins | 121 | 86.4% |
| *answered question n= 140* | | *100%* |

### 7.5.2 Applying the lever operated parking brake

*Q.9 How do you teach your pupils to operate a manually operated parking brake?*

Eighty eight (68.2%) of the 129 ADIs who responded to this question reported they would instruct pupils to push the button in and pull on the lever 'all of the time'; 8 (6.2%) indicated they would teach pupils to push the button in, pull the lever up and then pull the lever up a further '1-2 clicks', 'all of the time'; 14 (10.9%) reported they would always instruct pupils to pull up without pushing the button in and 19 (14.7%) indicated they would always advise the pupil to refer to the operating manual. The results are illustrated in Figure 7.3 and tabulated in Table D1.3 of Appendix D.2. The results indicate that a significantly higher number of ADIs instruct learners to push the release button in when pulling up the lever operated parking brake (Chi square 3.22342E-17 (N=129, 3df); $p<0.001$).

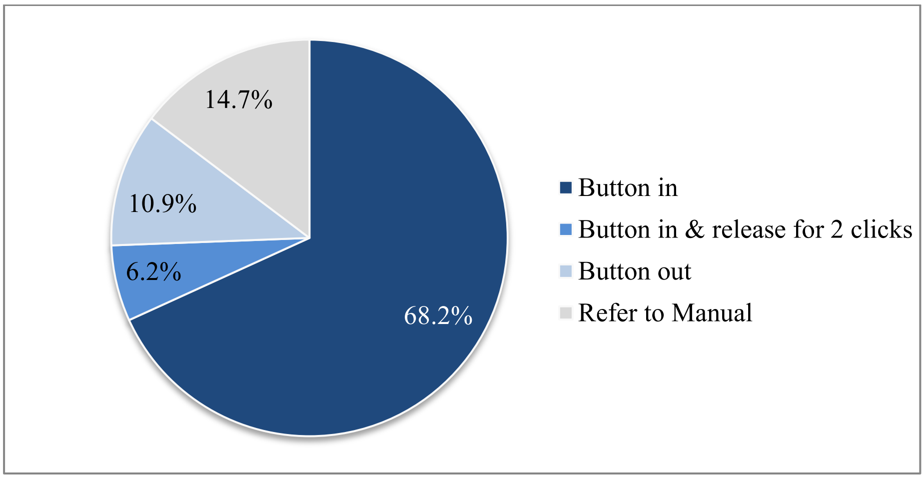



*Figure 7.3 How do you teach your pupils to operate the manual parking brake? 'all of the time'.*

Forty (31%) respondents indicated they would ‘never’ teach learners to pull the lever up without pushing the button in and 25 (19.4%) respondents indicated they would ‘never’ advise learners to refer to the operating manual.

### 7.5.3 Parking the vehicle to leave it unattended

*Q10 How do you teach pupils to park their vehicle as if to leave it?*

The question asked respondents to indicate what gradient they would instruct learners to park with parking brake only, parking brake and in gear (or park) and parking brake, in gear and turn the wheels. The results are seen in Table 7.4.

*Table 7.4 Responses to how pupils are instructed to park (n=131)*

| | Gradient | | | | | | |
|---|---|---|---|---|---|---|---|
| **Parking practice instructed** | **Flat** | **5%** | **10%** | **15%** | **20%** | **Response Count** | **Blank** |
| Parking brake only | 104 | 8 | 3 | 2 | 0 | 117 | 29 |
| Parking brake and in gear | 20 | 33 | 29 | 8 | 12 | 102 | 44 |
| Parking brake, in gear and turn wheels | 4 | 8 | 34 | 24 | 36 | 106 | 40 |
| Total | 128 | 49 | 66 | 34 | 48 | | |

From the 128 ADIs who indicated their parking instruction on the flat, 104 (80.6%) reported they would instruct pupils to only apply the parking brake when parking on the flat to leave the vehicle unattended. Twenty (15.6%) indicated they would instruct learners to apply the parking brake and park in gear or park, and 4 (3%) respondents indicated their instruction would be to park in gear and turn the wheels when parking on the flat.

For parking on a 5% gradient, eight (16.3%) ADI’s reported that they would instruct learners to apply the parking brake only, 33(67.3%) would instruct to park in gear and eight (16.3%) would instruct to park in gear and turn the wheels.

When parking on a 10% gradient, three ADIs reported they would instruct learners to apply the parking brake only, 29 would instruct to apply the parking brake and park in gear, and 33 would instruct to also turn the wheels.

When parking on a 15% gradient, two ADIs reported they would instruct learners to apply the parking brake only, eight would instruct to park in gear and 23 would instruct to also turn the wheels.

For parking on a 20% gradient or more 12 respondents indicated they would instruct apply the parking brake and park in gear, 36 would instruct to also turn the wheels.

A total of 100 (77.9%) responses were recorded for instructing learners to apply the parking brake, select a gear and turn the wheels when parking on a gradients of 5%, 10%. 15% and 20%. One ADI reported "there are no hills in the area so may not mention it". Figure 7.4. illustrates how the responses of reported practice was distributed across the gradients and the relative percentage for each gradient.

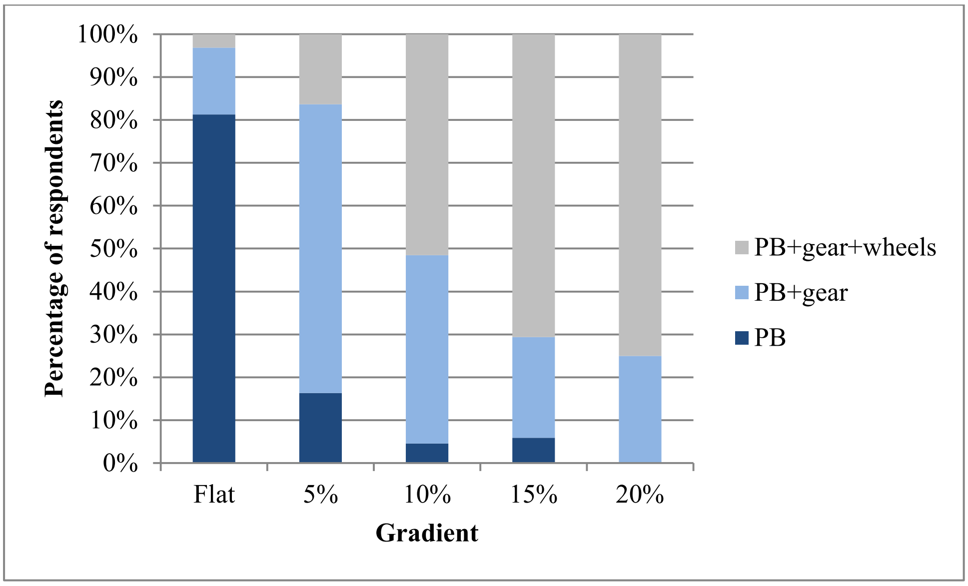



*Figure 7.4 How do you teach your pupils to park their vehicle as if to leave it? (n=131)*

The descriptive statistics indicate that as the gradient increases an increasing number of respondents instruct learners to park in gear. The majority (80%) of ADIs reported that they instruct learners to park in gear on gradients of 5% or more. Almost 90% (89%) instruct pupils to also turn the wheels on gradients of 10% or more. Nearly 90% of respondents indicated they would instruct learners to apply the parking brake only ($p<0.05$; one sample binomial test) when parking on the flat with a further 11% giving this instruction for parking on gradients of 5%, 10% and 15%.

### 7.5.4 Regional instruction - to park in gear

The data from individual responses to "please indicate the nearest town or city to where you work" were collated and categorised into 11 different regions of the UK. The results were explored for any differences in instruction to park in gear across the regions represented. Figure 7.5 illustrates regional responses in relation to instruction to park in gear for different gradients.

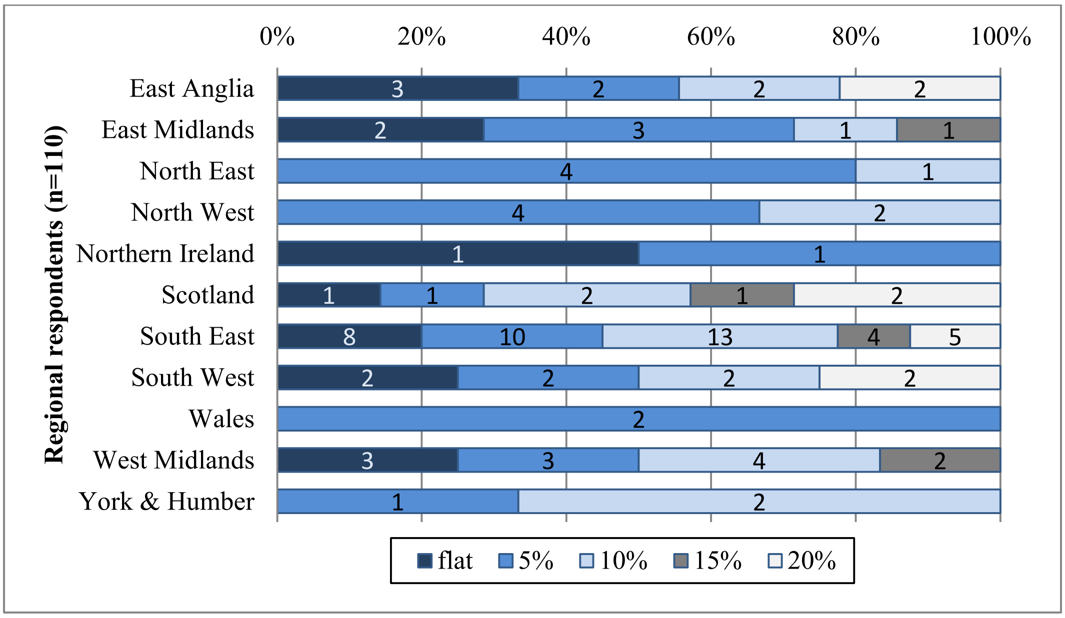



*Figure 7.5 Regional responses for instruction to park in gear (n=110)*

Although the sample size is small and the individual regional response counts are low, there appears to be some regional variation in parking in gear instruction in relation to the gradient.

ADIs in seven (63.6%) of the 11 regions (East Anglia, East Midlands. Northern Ireland, Scotland, South East, South West and West Midlands) reported they would instruct pupils to park in gear on the flat. The greatest percentage of responses to instructing pupils to park in gear on a 5% gradient was recorded for ADIs in the East Midlands, North East, North West and Wales. The results indicate that a greater percentage of ADIs in Scotland, South East, West Midlands and York and Humberside, Two thirds (67%) of the responses from York and Humberside would instruct learners to park in gear on a 10% gradient.

### 7.5.5 Regional instruction - park in gear and turn the wheels

The results of the full survey indicated that instruction for parking on the 10% gradient was the modal point with the percentage of ADIs who instructed pupils to park in gear (28%) and those who instructed to park in gear and turn the wheels (32%) almost the same. The results for parking in gear and turning the wheels when parked on a 10% gradient were used to explore any further regional differences and are illustrated in Figure 7.6

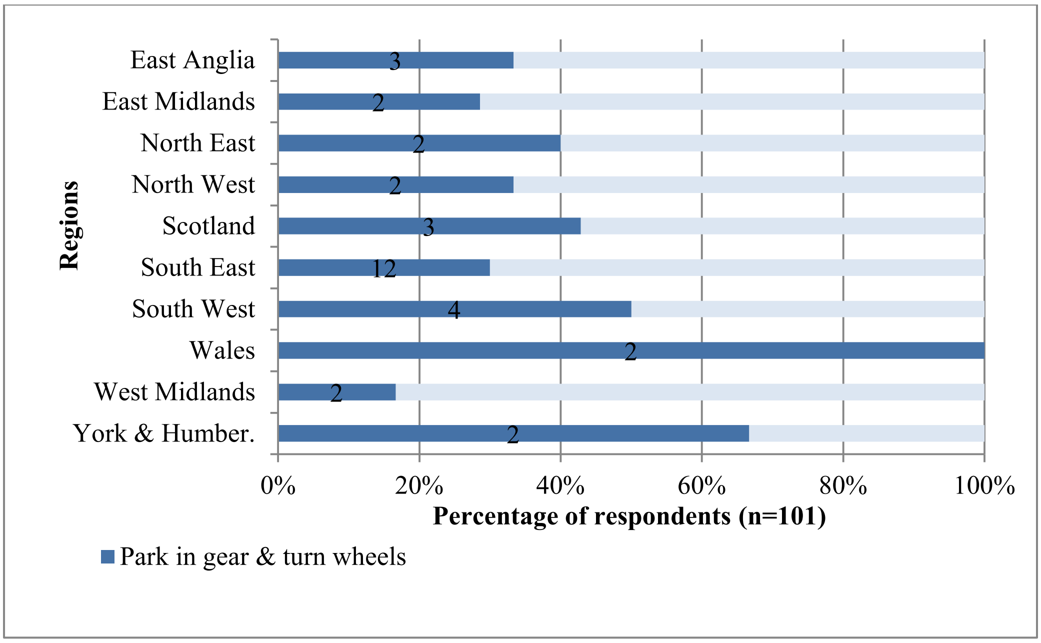



*Figure 7.6 Percentage of ADIs per region who reported instructing to park in gear and turn the wheels on a 10% gradient*

Results from North East, Scotland, South West, Wales and York and Humberside indicated that a higher percentage of ADIs in these regions would instruct learners to park in gear on a 10% gradient suggesting there may be a regional influence.

### 7.5.6 Instruction in relation to experience

The data were explored for any variation in instruction for parking the vehicle to leave it unattended in relation to ADI experience.

Seventy percent of respondents in each of the instruction experience groups 0-5, 6-10 and over 15 years, reported they instructed pupils to apply only the parking brake when parked on the flat.

For each category experience group, less than 15% would instruct learners to park in gear on the flat (See Figure 7.7).

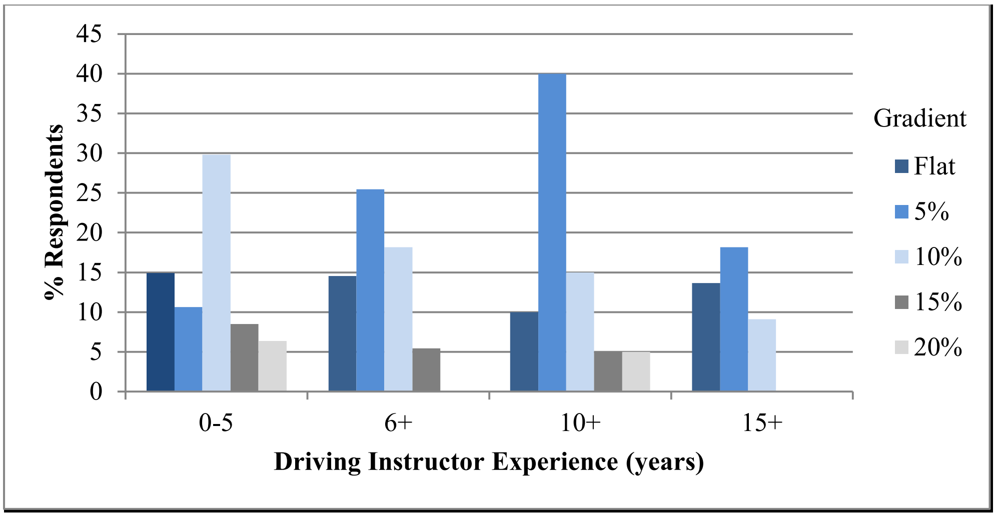



*Figure 7.7 Parking in gear instruction across instructor experience groups*

Twenty five percent of the ADIs with 6-10 years' experience and 40% of ADIs with 11 to 15 years' experience reported they would instruct learners to park in gear on a 5% gradient. Thirty percent of ADIs with 5 or less years' experience reported they would instruct learners to park in gear on a 10% gradient.

The results show that ADI's of 5 or less years' experience tend to instruct pupils to park in gear when on a 10% incline, whereas ADI's of 6 or more years' experience would instruct pupils to park in gear on a 5% incline (Pearsons Chi square, p=0.04)

### 7.5.7 Reported difficulty applying sufficient force

Around 55% respondents reported that learner drivers demonstrate difficulty applying sufficient force to operate the parking brake effectively. Three ADI's suggested that the location of the parking brake in relation to the driver could be a contributory factor and one ADI reported that it was "less of a problem if the button on the lever was not pushed in" when applying the parking brake.

### 7.5.8 Electronic Parking Brake (EPB)

Since 01 November 2010 electronic parking brakes (EPB) can be used in driving tests (DSA, 2012). However 94% (121) of 129 ADI's reported only 0-5% of their pupils drive vehicles fitted with EPB.

Around 80% of respondents considered that learning to drive a vehicle fitted with EPB would present difficulty in the following areas illustrated in Figure 7.8.

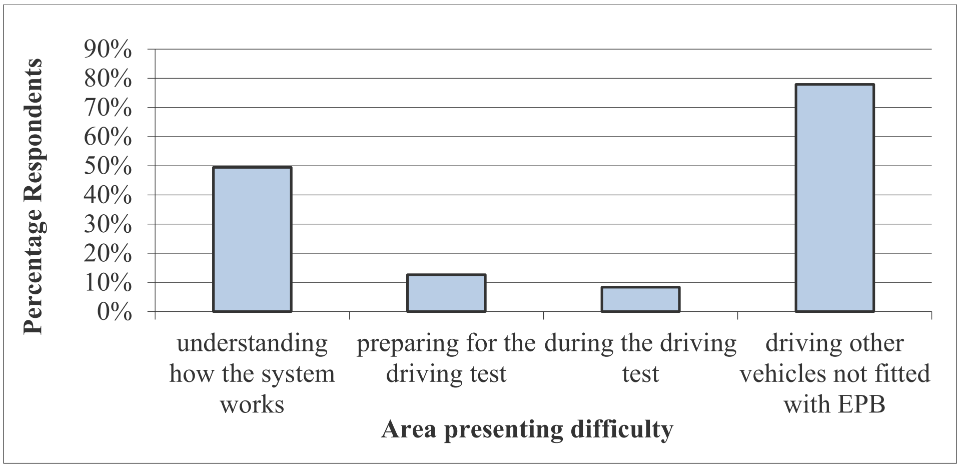



*Figure 7.8 ADI responses (n=95) for areas presenting difficulty learning to drive a vehicle fitted with EPB*

Forty seven (50%) respondents reported that the difficulty would be understanding how the system works, 12 (13%) thought it would be preparing for the driving test and 74 (78%) ADIs reported they considered the difficulty would be driving other vehicles not fitted with EPB.

Eighteen respondents reported no experience with EPB, 6 ADIs reported they did not consider there would be a problem if training was provided and one ADI reported that they thought EPB could not be used in a driving test.

### 7.5.9 Experience of rollaway

*Q14 Have you ever experienced your unattended vehicle rolling?*

Seventeen (13.3%) of the 128 ADIs who responded to this question indicated that they had experienced such an event in their own vehicle.

The circumstances recalled were allocated to 3 categories: environment, mechanical and human to reflect the primary groups of incident causation (Wierville et al, 2002; Stanton et al., 2009). A fourth category 'unknown' related to responses where circumstances were unspecified (see Table 7.5).

Seven (41.2%) of the 17 respondents reported vehicle or mechanical issues to be a contributory factor, including 3 reports of the parking brake to be poor or faulty. Two of the reported rollaways involved vehicles fitted with an electronic parking brake. Five (29.4%) responses were categorised as human (driver) related including 3 reports of the parking brake not being applied or was insufficiently applied and 2 reports of not parking the vehicle in gear.

*Table 7.5 Circumstances of reported vehicle rollaway*

| Factor category | Circumstances Recalled | Number (n=17) | Percentage (%) |
|---|---|---|---|
| Environment | Steep Incline | 1 | 17.6 |
| | Weather | 2 | |
| Vehicle/mechanical | Faulty/poor parking brake | 3 | 41.2 |
| | Brakes cooled (time delay) | 2 | |
| | Electronic Parking Brake | 2 | |
| Human | Vehicle not in gear | 2 | 29.4 |
| | Parking Brake not applied | 3 | |
| Unknown | Unspecified circumstances | 2 | 11.8 |

Six (35.3%) ADI's reported that their car had rolled on an incline of 10% or less or on a garage forecourt and only one ADI reported an incident involving a steep incline.

For the majority of reported rollaways (71.5%) there was no damage or injury, with 21.4% resulting in minor property damage and 7.1% resulting in major property damage as illustrated in Figure 7.9.

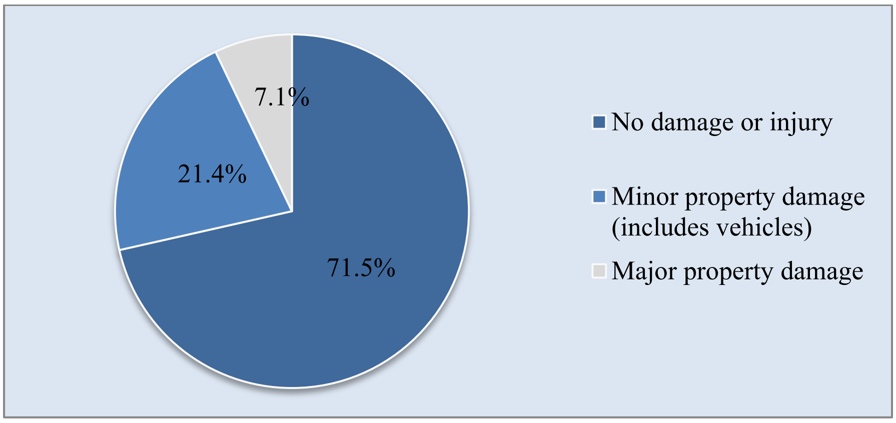



*Figure 7.9 Outcome of vehicle rollaway*

Using the nearest city indicated by the respondents, the results were segregated into the regional distribution as seen in Figure 7.10. to explore whether there were any regional differences.

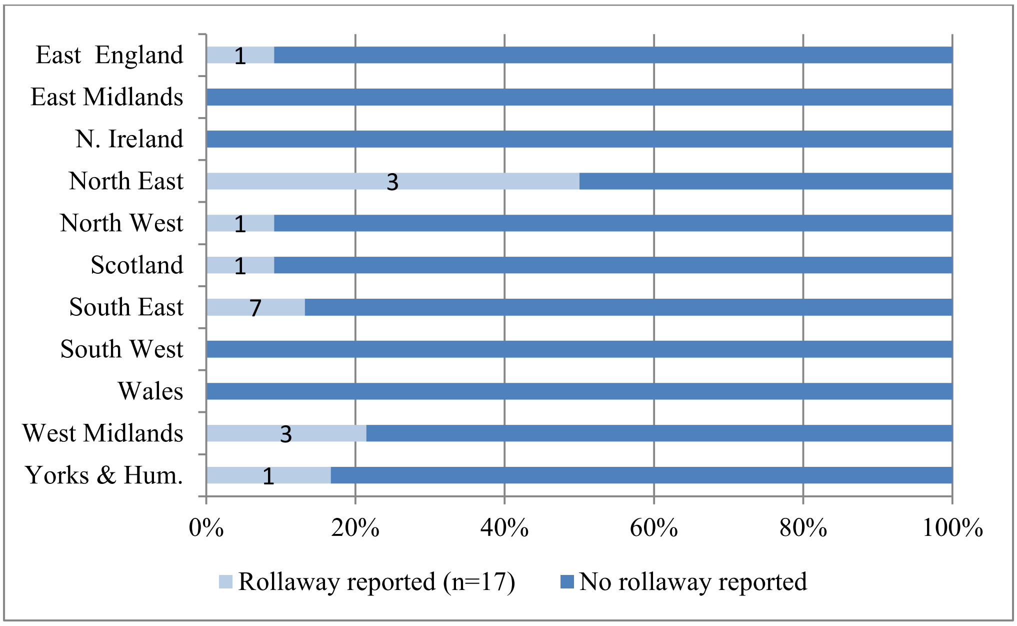



*Figure 7.10 Reported rollaway by respondents per region.*

Seven (13%) of the 53 ADI's based in the South East, 3 (21%) of the 14 ADI's in the West Midlands and 3 (50%) of the 6 ADI's in the North East reported a rollaway experience.

### 7.5.10 Driving instruction in relation to rollaway experience

From the results of the ADI's who reported a vehicle rollaway (n=17), 14 (88%) reported instructing pupils to park with parking brake only on the flat and 3 reported they would instruct pupils to park in gear on the flat. Six respondents reported they would instruct pupils to park in gear on a 5% incline, 5 on a 10%, 2 on 15% and 1 on 20%. The results for parking in gear for the no rollaway group and the rollaway group are compared in Table 7.6.

*Table 7.6 Parking in gear instruction for rollaway and no rollaway respondents*

| | Instruction to apply parking brake and select gear | | | |
|---|---|---|---|---|
| | Rollaway experience reported (n=17) | | No rollaway experience reported (n=111) | |
| **Gradient** | **Count** | **Percentage** | **Count** | **Percentage** |
| Flat | 3 | 17.6 | 17 | 16 |
| 5% | 6 | 35.3 | 26 | 24 |
| 10% | 5 | 29.4 | 22 | 20 |
| 15% | 2 | 11.8 | 06 | 06 |
| 20% | 1 | 5.9 | 11 | 10 |
| Other/ missing | 0 | 0 | 29 | 26 |

The results seem to indicate that a greater proportion of ADIs with rollaway experience instruct their learner drivers to park in gear on gradients of 15% or less than the ADIs with no rollaway experience There appears to be a weak association (Lambda 0.059, p=0.012) with experience of vehicle rollaway and instructing to park in gear but this requires further exploration with a larger sample size.

## 7.6 Chapter Summary

The results indicate that driver instruction may not reflect manufacturers' operating instructions for a lever operated parking brake.

A significant number of ADIs reported that they instruct learners to apply only the parking brake when parking on the flat. However, instruction on how to park on a "hill", as stated in Rule 252 of the Highway Code, may be dependent on the perception of the incline or gradient and therefore subject to individual interpretation.

Respondents to the online survey indicated that 75% ADIs would instruct learners to apply the parking brake and select a gear when parking on a 20% gradient and 25% would instruct learners to also turn the wheels. There was minimal difference in instruction to park in gear and park in gear and turn the wheels at the 10% gradient.

Some regional variation in practice was also observed but the sample size is insufficient to draw any conclusive correlation with regional trends.

Despite the recommendations in the Highway Code and the Driving Standards Agency directives, it would appear that learner drivers may not be instructed to apply the parking brake and turn the wheels when parked on an incline. Even at 15% incline some pupils may be instructed to apply the parking brake only.

ADIs who reported a rollaway indicated they would instruct learners to park in gear at lesser gradients than those who had not experienced a rollaway.

Contributory causes for rollaway were identified as almost 50% vehicle or mechanical and 30% human.

# Chapter 8: Driver Interaction and Application of Force

## 8.1 Introduction

Insufficient application of the lever operated parking brake has been cited as a causative factor for vehicle rollaway in the media reports, accident investigations and by drivers surveyed within this research project. In addition, in two (8%) of the listed vehicle recalls, affecting over 400,000 vehicles, investigators associated the potential for failure of the manually operated parking brake with driver interaction with the system (VOSA, 2011).

This chapter presents the results of observational studies conducted to explore the interaction of the driver with the parking brake system when applying the parking brake to hold the vehicle stationary. It focuses on the coloured areas of the fault tree in Figure 8.1 particularly the orange sections which indicate driver related factors.

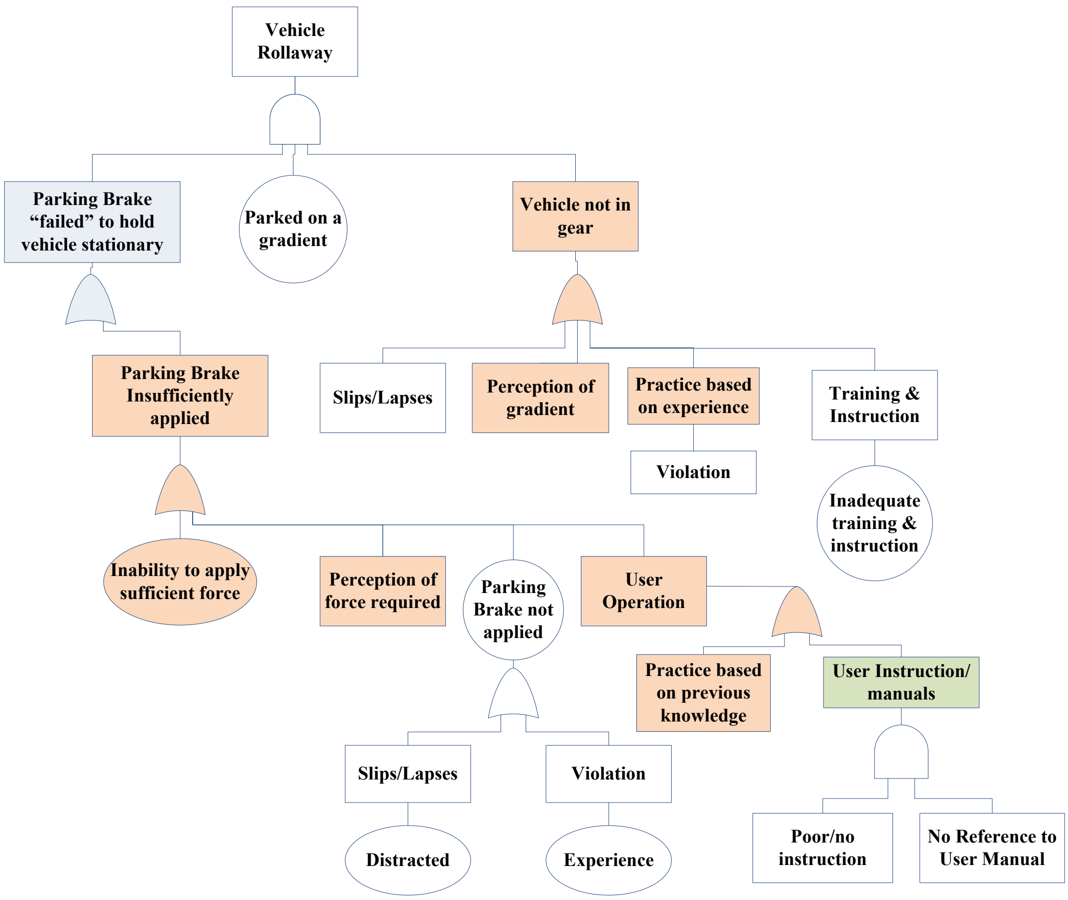



*Figure 8.1 Fault tree analysis for vehicle rollaway with areas to be explored highlighted*

The "apply system" referred to by Halderman, is the parking brake system component operated by the driver and includes the lever and linkage required to activate a braking force (Halderman, 1996 pp. 23-24). Regulation 13-H "Braking for Passenger Cars" requires that the manually operated parking brake must hold the vehicle stationary on a slope of 20% with a maximum applied force of 400N (UNECE, 2008). Halderman (1996) states that the lever mechanism is designed to apply the required force on the parking brake using normal driver effort but doesn't specify any expected magnitude of the force applied. Chateauroux and Wang (2012) found that the maximum force when tightening the parking brake was 233N for young males and that the force producing capabilities were higher when the parking lever brake had a low and backward configuration. Rozaini et al. (2013) using a parking brake model, concluded that the system would hold the vehicle stationary on a 20% gradient with less than 200N applied to the lever. However these studies were laboratory based and did not explore driver interaction with drivers' own vehicles.

To explore the driver interaction with the parking brake system in real life, a study was piloted and developed to explore the force that the driver applied to the parking brake lever, their confidence in the holding capability of the parking brake system and their current practice in relation to the relevant legislation and manufacturer's recommendations. Information gained from a semi-structured interview was collated and analysed for any trends in practice.

## 8.2 Pilot Study –Testing on Static Assessment Rig

### 8.2.1 Methodology

A pilot observational study was conducted using a static driver assessment rig (SAR) to observe and evaluate the interaction of individual drivers with a lever operated parking brake in a controlled environment.

The objective of the pilot study was to explore the following research questions and collect the respective data:

*"How do drivers interact with the vehicle controls?"*

- What force do individuals apply to pull the parking brake lever up?

- What is the position of the parking brake lever in relation to the preferred sitting position?
- How does the interaction with the geometric layout affect the force applied and posture adopted?
- How does operation of the parking brake lever compare to manufacturer's instructions?
- What is the driver's perception and experience of the parking brake system? (e.g. effort, usability, vehicle rollaway)

### 8.2.2 Ethical clearance

As the research was to involve human participants, an application for ethical approval was made to Loughborough University Ethical Advisory Sub-Committee .

The participant information sheet, consent form, health screening questionnaire and assessment documentation developed to aid data collection were submitted with the application. Approval was granted subject to conditions in January 2012 (see Appendix E.1).

### 8.2.3 Participants

Twenty seven participants (18 female, 9 male) aged 21-59 years (mean= 27, SD =10.03) were recruited from the staff of the Cornwall Disability Assessment Centre and from the medical students on clinical placement. All participants were licensed drivers with varying levels of driving experience and had undergone simulated driving practice in the static assessment rig prior to testing Volunteers who did not hold a driving license or indicated they had existing health issues which could be affected by their participation were excluded. The sessions were timetabled weekly to accommodate the students. The study objectives were explained to each participant and written consent obtained. Observations were conducted with participants wearing indoor clothing and comfortable driving shoes.

### 8.2.4 Test environment

An established static driver assessment rig (SAR) within the Cornwall Mobility Centre in Truro was deployed for assessment purposes (see Figure 8.2). There were 10 mobility centres in the UK with a SAR allowing an Approved Driving Instructor

(ADI) to assess individual driving abilities without actually being on a public road (Spence, 2011). The rig resembled an Alpha Romeo 156 with an automatic transmission and was instrumented to enable the ADI to assess reaction times and hazard perception in response to randomly lit lights during a simulated drive. It was also used to test modifications which may be required for people with physical disabilities (Hornberry and Inwood, 2010). The SAR was selected due to its accessibility, financial restraints of the project and the ability to recruit participants who would not be participating in the final studies.

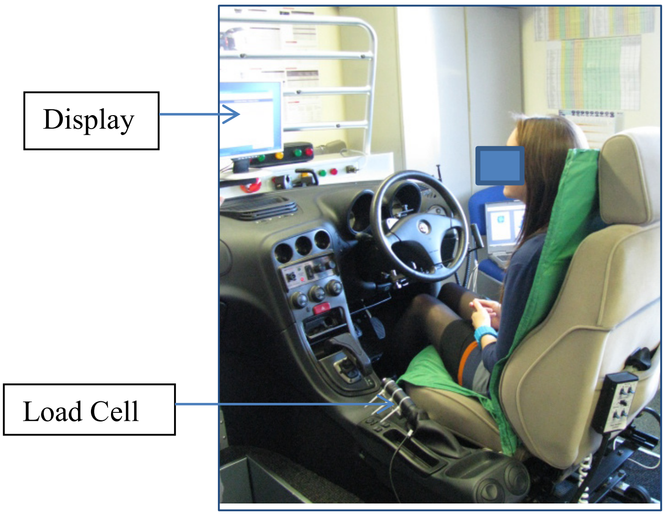



*Figure 8.2 Static assessment rig layout*

### 8.2.5 Data collection

**Anthropometry**

Pre- test measurements: in addition to standing height, 18 static anthropometric measurements in sitting were recorded for participants. Body height, eye height, shoulder height, shoulder to shoulder breadth, upper arm length, lower arm length, elbow height, elbow to elbow breadth, grip length, hand length, hand thickness, thumb length, body depth, thigh clearance, hip breadth, buttock to popliteal length, knee height.

Body landmarks were recorded in relation to the hip to mid grip point of parking brake lever- A (anterior distance) and hip to parking brake lever B (lateral distance) (see Figure 8.3).

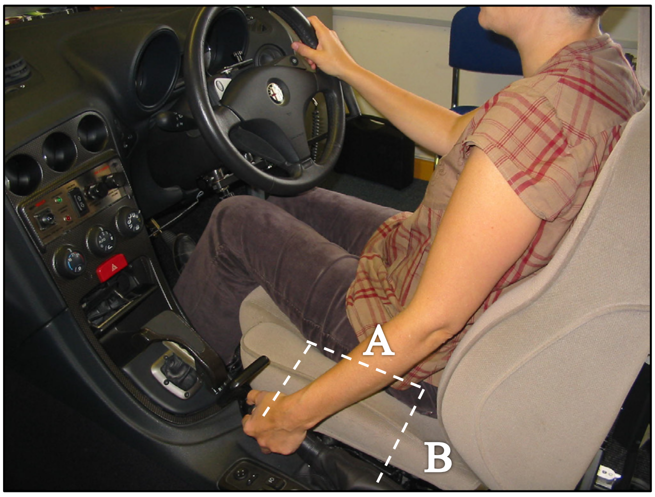



*Figure 8.3 Recording of body landmark positions in relation to parking brake lever*

Measurements were recorded using a flexible steel tape measure. This method was selected instead of using an anthropometer as some measurements would be difficult to collect with an anthropometer. May, Lomas and Gale (1999) indicated a high correlation between the two methods particularly for shoulder height when employed by individuals experienced in recording body measurements. In addition it was considered to be a more flexible method which was transferable to later field studies.

**Force applied to Parking Brake lever**

*Figure 8.4 Load cell fixed to parking brake lever*

A Novatech F268-Z0979 handbrake load cell, used in industrial testing within the UK based Motor Industry Research Association (MIRA), was fixed to the parking brake lever with plastic tie wraps and the ends trimmed to avoid injury to the participant (Figure 8.4).

In the initial testing set up, the force applied to the lever and load cell was recorded using a Novatech TR100 portable data acquisition monitor. However, this only momentarily displayed the peak force applied and manual recording of such was required at that moment. This was not considered to be an efficient or reliable combination for data collection Consultation with electronics engineers led to the development of custom made data acquisition hardware powered by two cell batteries (Figure 8.5, 8.6, 8.7) connected to Fosc-21 Oscilloscope software loaded on a Toshiba Portege laptop. This enabled a visible trace of the force applied to be viewed on screen and recorded for later data analysis. Calibration of the testing combination was performed by positioning a known weight (10Kg) on the load cell and confirming the equivalent load (100N) was recorded on the trace. The results presented are in relation to the data collated using the F268-Z0979 load cell and custom built data acquisition hardware.

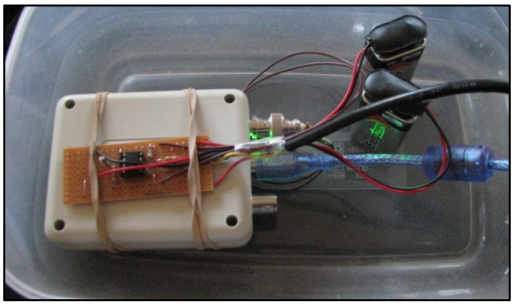


*Figure 8.5 Data acquisition raw materials*

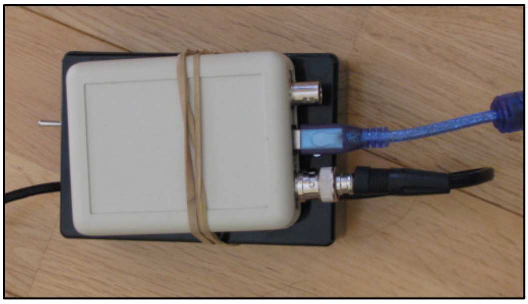


*Figure 8.6 Final version in casing*

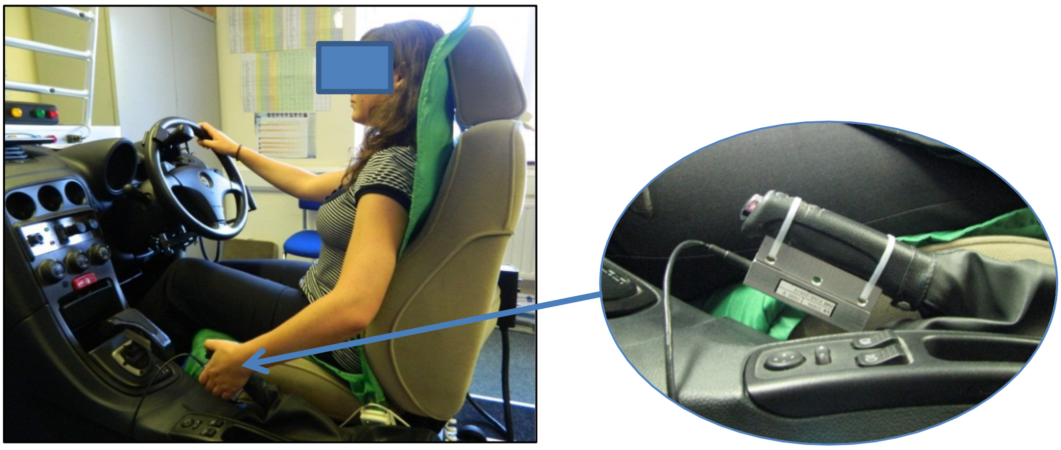


*Figure 8.7 Load cell attached to parking brake lever*

**Recording of images**

Still images and video footage were recorded using a Canon powershot SX100 camera mounted on a bar behind the participant. These images were used to view postural changes and the manual operation of the parking brake lever.

**Data analysis**

Data were transcribed and collated into Excel and initially analysed using descriptive statistics.

### 8.2.6 Procedure

Participants were instructed to adjust the seat to their preferred driving position. When the participant indicated achievement of a comfortable driving position, the body landmark locations were recorded and measurements in relation to parking brake lever position noted.

Six static road scenes (three driving on a road and three parking situations) presented on a Toshiba Portege laptop were displayed in front of the driver as a visual cue to the driver to either park or drive. The driver was instructed that when a parking cue was displayed (Figure 8.8) they were to stop and park as if they were leaving the vehicle.


*Figure 8.8 Parking cues: car park, hill, supermarket*

When a picture of a driving scene was displayed the driver was instructed to release the parking brake and continue to drive. Each cue was displayed for 20 seconds and in the following order: drive scene, car park symbol, drive scene, parking on a hill, drive scene, parking in a supermarket car park. The drivers were presented with the cues once only and were not informed in which order they would be presented.

The parking brake was returned to the ‘off’ position at the end of each participant’s test by the researcher. Following the test procedure drivers were given a short interview reflecting the assessment scenarios, how it compared with their normal practice and to recall any incidents or difficulties they had experienced with applying the parking brake

### 8.2.7 Results

**Driver experience and practice**

Three drivers had experienced a vehicle rollaway and reported they would always park in gear. Only one driver reported that they would not normally push the button in and the same driver would not normally park in gear even on a hill.

**Force applied**

The mean force recorded in response to visual cues for parking in the car park, parking on a hill and parking at the supermarket were 100.8N (SD=70.23); 145.8N (SD= 67.28) and 94.5N (SD= 49.83) respectively. The results indicated that drivers applied an increased force to the parking brake lever when an increase in gradient was perceived.

Previous research indicated that the individual's sitting shoulder height and the position of the parking brake lever in relation to the individual's hip influenced the force required to pull up the parking brake lever (Wang et al., 2011; Chateauroux and Wang, 2012), therefore these measurements were used for analyses of force applied.

The force recorded in relation to shoulder height is illustrated in Figure 8.9.

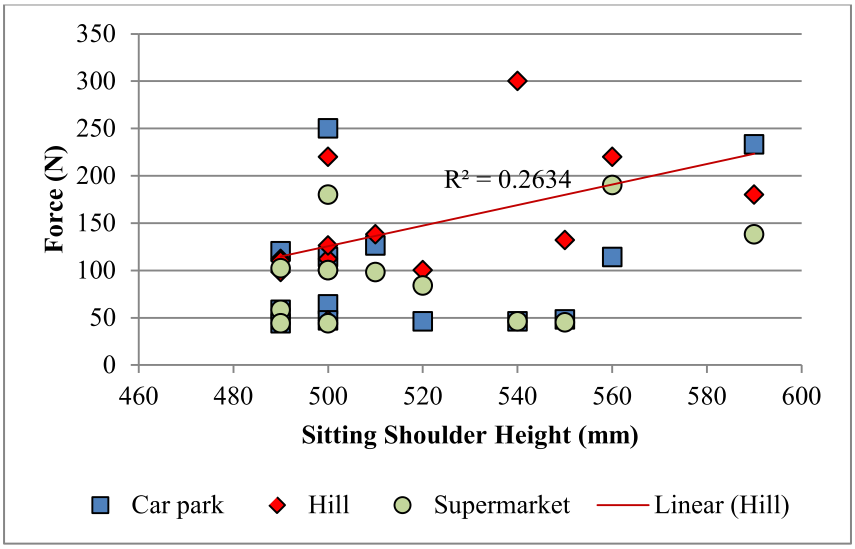



*Figure 8.9 Force applied to parking brake lever in relation to sitting shoulder height for each visual parking cue*

The force recorded in relation to the forwards distance from the hip to the parking brake grip can be seen in Figure 8.10.

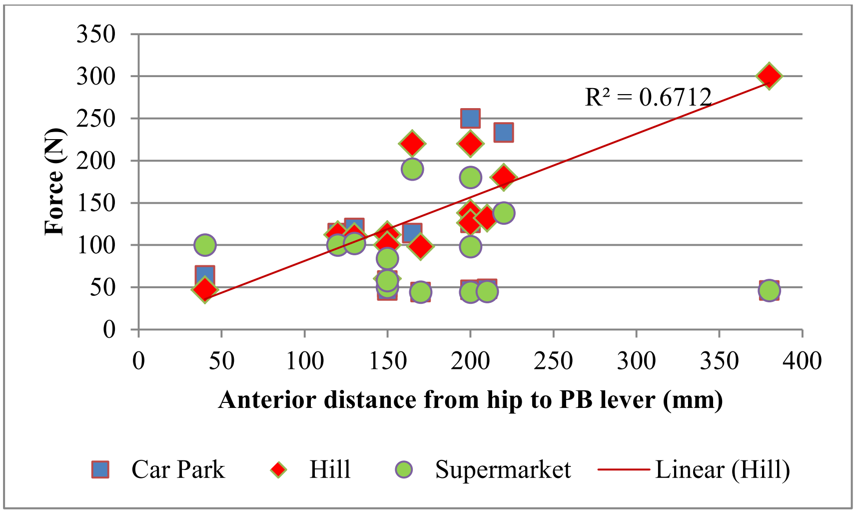



*Figure 8.10 Force applied to parking brake lever in relation to anterior distance of hip to hand grip of lever for each visual parking cue*

The results indicate a positive relationship ($R^2$= 0.6712) between the anterior distance from the hip to the mid-point of the grip on the parking brake lever (measurement A, Figure 8.10).

## 8.3 Observation of Driver Interaction with New Vehicle Models

To explore variances in design and layout across manufacturers and evaluate the driver interaction with the parking brake on currently marketed vehicles, it was planned that selected individuals (5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile males and females) to represent the adult population would be observed in three 2012 car models available from a local dealership. Unfortunately on the arranged date for testing, only four female drivers were available to take part in the pilot study and no further dates could be arranged. Despite the limited number of participants, the results from the observations provided valuable insights for further study developments.

### 8.3.1 Methodology

**Participants**

Four female drivers participated in the study aged 26, 40, 55 and 60 years with a sitting shoulder height of 470mm, 590mm, 520mm and 540mm respectively. These measurements related to the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile British female (Pheasant, 1988, p.85).

**Vehicles**

Three 2012 registered demonstrator vehicles parked on the forecourt of a local dealership were supplied for testing: Ford Fiesta, Peugeot 207, Peugeot 308.

**Data collection**

Still and video images were recorded using a Canon Power Shoot SX100.

The force applied to the parking brake lever was recorded with a Novatech F268 handbrake load cell connected through custom made data acquisition hardware to Focus Oscilloscope software

**Procedure**

Participants, after reading the information sheet and being given the opportunity to ask questions, completed a health screening questionnaire and a consent form. They were provided with a controls evaluation form to complete for each vehicle.

**Test Scenario**

Participants were instructed to adjust the seat to their preferred driving position. When the participant had achieved a comfortable driving position the body landmark locations were recorded and measurements of seat position and seat to parking brake lever distance noted.

The driver was instructed to position his/her feet over the clutch and brake and depress the clutch and brake fully. They were then instructed to release the parking brake and apply it as if they were parking where the car was positioned. They were then asked to repeat the process but to park as if they were leaving the car unattended on a hill.

### 8.3.2 Results

**Force applied to Parking Brake lever**

The force each driver applied to the lever when applying the parking brake and releasing the parking brake was recorded when the driver was cued to park on the flat (e.g. car park) and park on a hill. Figure 8.11 and 8.12. illustrates the forces recorded in the 2012 Fiesta for the tallest and smallest participants.

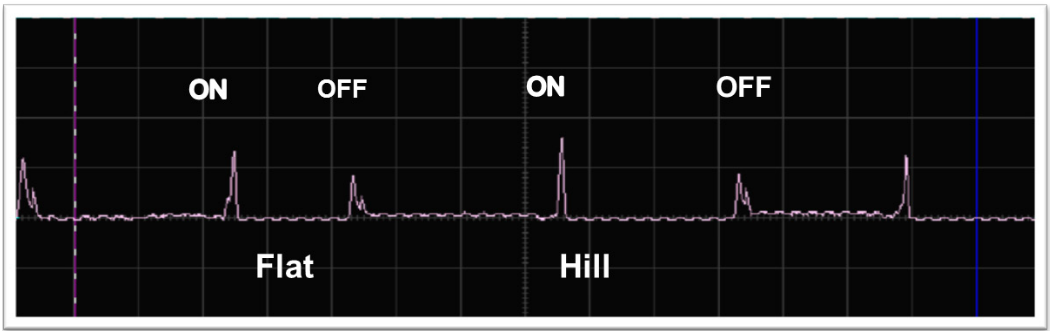



*Figure 8.11 Force application by 5th percentile female in 2012 Fiesta*

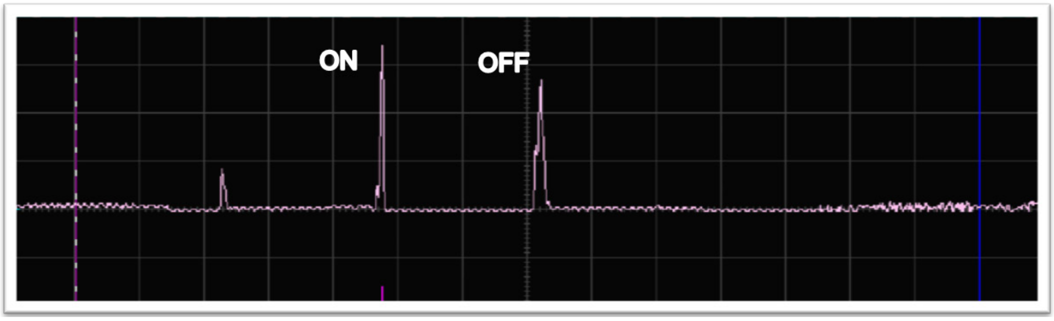



*Figure 8.12 Force application by 95th percentile female in 2012 Fiesta*

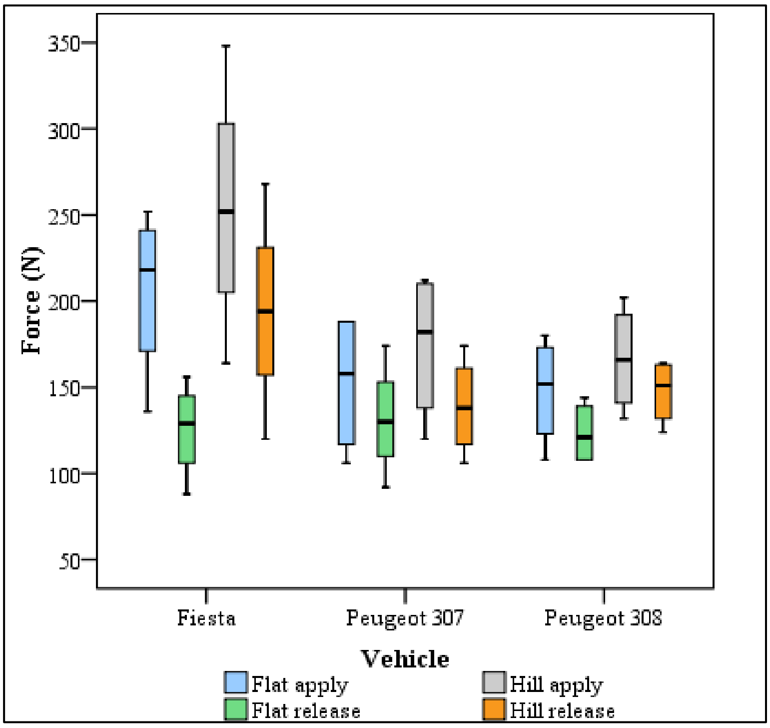



*Figure 8.13 Force applied to parking brake lever in each vehicle by four drivers*

Figure 8.13 illustrates the distribution of force applied to the parking brake lever by the four participants for each vehicle. The mean forces recorded for each vehicle are presented in Table 8.1. A greater mean force was recorded for pulling the parking brake lever up (on) in the Fiesta than in the other two vehicles.

The force recorded when the driver perceived to be parking on a hill was greater than parking on the flat for all three vehicles. In all three vehicles the force recorded to release the parking brake (off) was less than the force recorded to apply it and there was little difference across the three vehicles when releasing the parking brake on the 'flat scenario'. The 5% female applied the least force in all tasks but she was also the youngest and least experienced driver which could affect performance.

*Table 8.1 Force applied to each vehicle by four drivers*

| Vehicle | | Force (N) applied on Flat | Force (N) applied on hill | Force (N) to release on flat | Force (N) to release on hill |
|---|---|---|---|---|---|
| Fiesta | Mean | 206 | 254 | 125.5 | 194 |
| | Std. Dev. | 50.3 | 75.3 | 28.4 | 60.4 |
| | Minimum | 136 | 164 | 88 | 120 |
| | Maximum | 252 | 348 | 156 | 268 |
| Peugeot 307 | Mean | 152.5 | 174 | 131.5 | 139 |
| | Std. Dev. | 41.96 | 44.1 | 33.6 | 28.96 |
| | Minimum | 106 | 120 | 92 | 106 |
| | Maximum | 188 | 212 | 174 | 174 |
| Peugeot 308 | Mean | 148 | 166.5 | 123.5 | 147.5 |
| | Std. Dev. | 31.9 | 31.4 | 18.4 | 19.1 |
| | Minimum | 108 | 132 | 108 | 124 |
| | Maximum | 180 | 202 | 144 | 164 |

It can be seen that even with four drivers observed, there is a variance in the force applied to the parking brake lever when applying the parking brake.

**Operation of controls**

Three of the four drivers reported the parking brake of the Peugeot 207 to be difficult to operate due to insufficient hand clearance and poor design while the driver with the smallest hands reported it to be very good.

Although difficult to make any association with anthropometry of the driver and the force applied, Figure 8.14 to 8.17 illustrates the posture configurations for the smallest and tallest driver observed in a 2012 Fiesta.

**Parking brake off position** | **Parking brake on position**

*Figure 8.14 5th percentile female*

*Figure 8.15 5th percentile female*

*Figure 8.16 95th percentile female*

*Figure 8.17 95th percentile female*

The upper limb of the smaller driver is flexed at the elbow with the upper arm abducted and the shoulder elevated. Whereas the upper limb of the taller driver is extended at the elbow and flexed forwards at the shoulder with no abduction or shoulder elevation. While the posture of the driver limbs may or may not affect the mechanical advantage on the parking brake lever, the pilot studies indicated it did not affect the ability to apply sufficient force to the parking brake. Therefore while it may be a factor to consider if the driver was experiencing musculoskeletal discomfort detailed postural analysis is not included in this study exploring vehicle rollaway.

## 8.4 Section Summary

The studies served as effective pilots for later studies using on the road vehicles and enabled the evaluation of equipment and procedures to be employed.

On the SAR, the combination of the force transducer and data acquisition equipment was developed and tested for the adequacy of recording the force applied to the parking brake lever. Although some concern was considered as to whether the presence of the transducer would alter the driver's hand grip it did not affect the ability to apply the force required to pull the lever up and the forces recorded were within the range recorded by Chateauroux and Wang (2012) and less than 400N.

The recorded force applied to the parking brake lever on both the SAR and on the static test vehicles indicated that a greater force was applied when the driver perceived an increased gradient.

The results of the pilot studies indicated that the force which the driver applied to the parking brake lever may not be directly related to driver anthropometry. In reflection of this and consideration of workable recording arrangements, the number of anthropometric measurements was modified for the following studies.

Responses in relation to experience of the parking brake system indicated that recruited participants should have a minimum of one year's driving experience and that the question base of the semi-structured interview should be modified to reflect their level of confidence in the system.

In view of the logistical arrangements for recruiting participants and the application of the research tools in a restricted time period, it was realised that using vehicles supplied for test purposes was not feasible. It was anticipated that the limited access to the vehicles would limit the data collated and would not reflect real life driver interaction with the vehicle. This supported the proposed method of observing drivers in their own vehicles to study the interaction with the parking brake system.

## 8.5 Testing on a Gradient with Drivers' Own Vehicles

To explore driver interaction with the parking brake system in a 'real life' setting, an observational study was developed where drivers were requested to park their own vehicle on a 20% gradient as if to leave it unattended. The aim was this was to reflect the requirements of ECE Regulation 13-H.

During the course of this research, a review of incident reports and driver feedback indicated that vehicle rollaway could occur on gradients of less than 20%. In addition, the results of the driver and driving instructor surveys reflected a variation in practice when parking on lesser gradients. Industrial testing and previous research (McKinlay, 2007; Rozaini et al., 2013) also related to performance of the system on various gradients therefore the study was extended to include testing on a 3-4% (<5%) and a 10% gradient.

The following questions were generated:

- How do drivers park their vehicle on a gradient to leave it unattended e.g. was the vehicle parked in gear?
- What is the driver's level of confidence in the parking brake system?
- What force do drivers apply to the parking brake lever to hold the vehicle stationary?
- How does driver practice compare with manufacturer instructions?

## 8.6 Methodology

### 8.6.1 Study rationale

The pilot studies aided development of the methods to be employed to observe interaction of the driver with the parking brake system. To provide real world representation it was decided to conduct an observational study using drivers with their own vehicles. Considering the potential difficulties in recruitment of participants, the study was designed so that data collection was conducted within 30 minutes.

### 8.6.2 Ethical clearance

A request to amend the original ethical clearance application to include participants driving their own vehicles was approved on 06 June 2012 by the Loughborough University Ethical Advisory committee. A detailed participant information sheet (Appendix E.2) was provided for participants to read and inform them of the details of the study. An informed consent form was signed by each participant agreeing to take part in the study which indicated their level of consent (Appendix E.2).

### 8.6.3 Test environments

Three areas were selected as suitable test environments and the relevant risk assessments were conducted (Appendix E). Testing was conducted on a 20% gradient (A) and a 3-4% (<5%) gradient (B) at St Luke's Hospice (SLH) in Plymouth (Figure 8.18A and 8.18B.) Two vehicles had rolled away on the latter area in the previous 12 months resulting in damage. Testing on a 10% slope (C) was conducted within a car park on the Loughborough University (LU) campus (Figure 8.18C)


*Figure 8.18  A) 20% gradient B) <5% gradient C) 10% gradient*

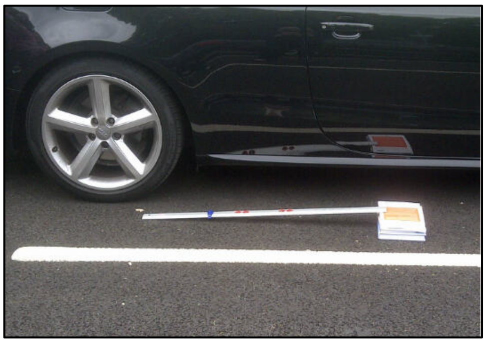


*Figure 8.19  Measuring the gradient*

The gradient percentage was calculated using a 1000mm ruler with integral spirit level along the *run* and measuring the *rise* from the end of the ruler to the road surface (see figure 8.19. Gradient % = rise/run x 100

### 8.6.4 Participants

Fifty six participants with more than one year's driving experience were recruited through the St Luke's Hospice staff email system, the South West Regional Ergonomics Group, the Plymouth University of the Third Age group and Loughborough Design School staff and postgraduate email group.

Twenty seven female and 16 male (2 left hand dominant) drivers aged between 19 and 70 years (mean=47.7, SD=13.9) with an average driving experience of 25 years (SD= 12.6) participated in the gradient study in Plymouth. Ten male and 3 female drivers aged between 23 and 65 years (mean 41.43, SD=12.86) with an average driving experience of 23 years (SD=12.03) participated in the study at Loughborough.

### 8.6.5 Data collection

Data collection methods included semi-structured interviews and observation of practice. The documentation used can be seen in Appendix E.2.

**Demographic information**

Participants provided background information on their age, gender, years of driving experience, annual mileage, where they parked their vehicle overnight, the make and model of vehicle and whether they had experienced a vehicle rollaway.

**Self rated confidence**

Participants were asked to rate the vehicle controls on a scale of 1 to 5 (poor to excellent) and their level of confidence in the parking brake system holding capability on a scale of 1 to 5 (not at all confident to extremely confident).

**Operation of vehicle controls**

Participants were asked to recall in what order they operated the vehicle controls when parking on the flat and on an incline. The researcher observed whether the participant had selected a gear when parked.

**Anthropometric data and grip strength**

Anthropometric measurements using a flexible steel tape measure of sitting shoulder height and hip position in relation to the parking brake lever were recorded to explore the geometric layout. Hand grip force was tested using a TK-1201 grip dynamometer.

**Measurement of force applied to parking brake lever**

The Novatech F268 load cell was applied to the parking brake lever and connected through custom made data acquisition hardware to Focus Oscilloscope software on a Toshiba Portege laptop.

### 8.6.6 Data analysis

Data were collated using Microsoft Excel and transferred to SPSS v21 for further analysis.

### 8.6.7 Procedure

Drivers were directed to area A (<5% gradient), B (20% gradient) or C (10% gradient) and asked to park their cars facing downwards. The procedure was explained with reference to the information sheet provided (see Appendix E) and consent to proceed gained.

The vertical position of the parking brake lever was measured in relation to the base as a benchmark to determine whether the same position was reached on application prior to the load cell being fitted. The Novatech F268 load cell was applied to the parking brake lever. The drivers were then requested to switch on the engine and with the footbrake depressed, release and re-apply the parking brake as they normally would to hold the vehicle stationary and then release the footbrake. If there was a difference in travel height, the driver was requested to repeat the process once only.

## 8.7 Results

### 8.7.1 Experience of vehicle rollaway

Sixteen (28.6%) of the 56 participating drivers reported an experience of a vehicle rollaway. As to why, 7 (43.8%) indicated that they were distracted, in a rush or forgot to apply the parking brake, 8 (50%) indicated they forgot to park in gear when they normally would and one driver indicated the parking brake required adjustment.

### 8.7.2 Parking practice (see Table 8.2)

Twenty six (46.4%) of the 56 drivers selected a gear when the vehicle was parked on the flat (<5% gradient). Nine (69.2%) of the 13 drivers observed on the 10% gradient parked in gear with 6 (66.7%) of these selecting reverse and 1 selecting1$^{st}$ gear. Thirty three (76.7%) of the 43 drivers observed on the 20% gradient selected a gear when parked facing downwards. Eight (24.2%) of these drivers selected 1$^{st}$ gear and 25 (75.8%) selected reverse.

*Table 8.2 Observed parking practice*

| Gradient | Park in Gear | 1$^{st}$ gear | Reverse | Park (Automatic) |
|---|---|---|---|---|
| Flat (n=56) | 26 (46.4%) | - | - | - |
| 10% (n=13) | 9 (69.2%) | 1 (11%) | 6 (66.7%) | 2 |
| 20% (n=43) | 33 (76.7%) | 8 (24.2%) | 25 (75.8%) | |

### 8.7.3 Operation of controls

Twenty six drivers who parked in gear were asked to recall the order in which they operated the controls to park on the flat and on an incline (see Table 8.3)

*Table 8.3 Order of operating vehicle controls when parking*

| | Flat (n=23) | | Incline (n=26) | |
|---|---|---|---|---|
| Order of selecting gear | Number | Percent | Number | Percent |
| Before Parking Brake | 4 | (17.4%) | 8 | (30.8%) |
| After Parking Brake | 19 | (82.6%) | 18 | (69.2%) |
| Before engine switched off | 14 | (60.9%) | 18 | (69.2%) |
| After engine switched off | 9 | (39.1%) | 8 | (30.8%) |

When parking on the flat 82.6% of drivers indicated they would select a gear after applying the parking brake and 60.9% indicated they would select a gear before switching the engine off. When parking on an incline, 69.2% indicated they would select a gear after applying the parking brake and before switching the engine off.

From the results, over 60 to 70% of drivers indicated that they selected a gear before switching the engine off whether parking on the flat or on an incline. It would appear that a larger proportion of drivers select a gear after operating the parking brake lever when parking on the flat than on an incline.

Although this is a small sample size, the results imply that there is individual variation in the order of operating the controls when parking a vehicle.

**Parking brake lever operation**

Only two drivers were observed not pushing the release button in when pulling the parking brake lever up and confirmed this to be their normal practice.

The owner manuals for the presenting vehicles were reviewed during the assessment or accessed online. Those reviewed made either no reference to the 'release button' on applying the parking brake or included 'do not push button in' instruction (see Appendix E.6).

### 8.7.4 Level of confidence in the Parking Brake system

Forty (78.6%) of the 56 participants rated their level of confidence (LOC) parking on an incline to be 4 or 5 indicating they were very confident conducting this task. Around 45% rated their level of confidence as a 5 (extremely confident) that their vehicle would remain stationary. Drivers indicated they may be less confident when parking on a gradient with the parking brake only applied with 43% participants rating their level of confidence (LOC) for this task as a 4. Eighteen drivers (33%) rated their level of confidence as 2 or 3 that the parking brake alone would hold the vehicle stationary.

Fifty two (93%) of participants rated their level of confidence as 4 or 5 that they could apply sufficient force to the parking brake lever to hold the vehicle stationary. Around half (52%) reported being extremely confident they could release the parking brake after somebody else had applied it. The results are illustrated as percentages in Figure 8.20.

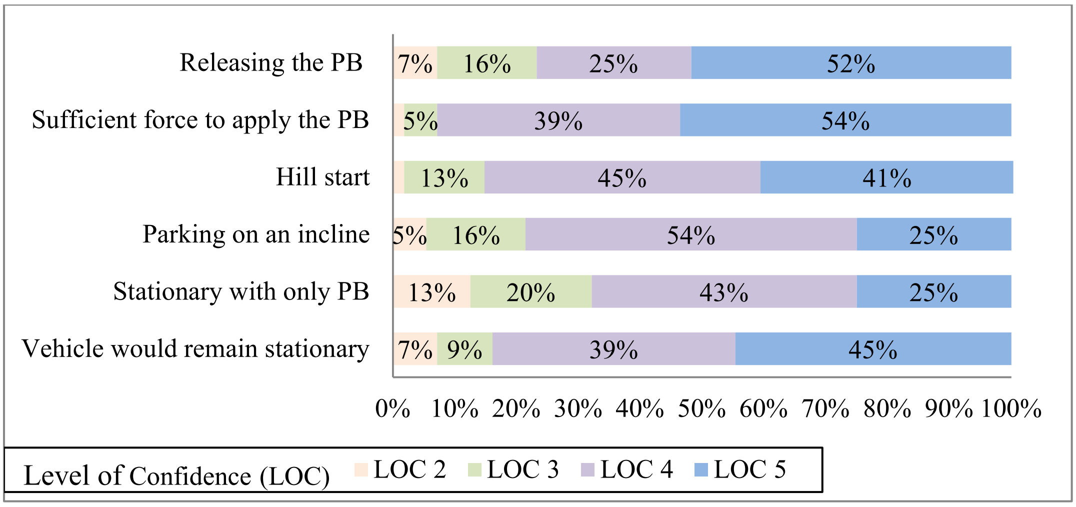



*Figure 8.20 Reported level of confidence in relation to parking task (n=56)*

### 8.7.5 Level of confidence in relation to parking practice

The data were explored to consider any relationship between the driver's confidence in the parking brake system and their normal parking practice. The results for the level of confidence reported by 42 drivers who indicated their regular overnight parking environment are tabulated in Table 8.4.

*Table 8.4 Level of confidence in relation to overnight parking (n=42)*

| Level of confidence | | Overnight Parking Gradient | | | Total |
|---|---|---|---|---|---|
| | | Flat | moderate | steep | |
| Vehicle remain stationary | 2 | 3 | 1 | 0 | 4 |
| | 3 | 4 | 1 | 0 | 5 |
| | 4 | 5 | 10 | 2 | 17 |
| | 5 | 8 | 7 | 1 | 16 |
| Total | | 20 | 19 | 3 | 42 |
| Hold with PB only | 2 | 2 | 3 | 1 | 6 |
| | 3 | 5 | 3 | 1 | 9 |
| | 4 | 9 | 9 | 0 | 18 |
| | 5 | 4 | 4 | 1 | 9 |
| Total | | 20 | 19 | 3 | 42 |
| Parking on an incline | 2 | 2 | 1 | 0 | 3 |
| | 3 | 3 | 2 | 1 | 6 |
| | 4 | 9 | 13 | 1 | 23 |
| | 5 | 6 | 3 | 1 | 10 |
| Total | | 20 | 19 | 3 | 42 |

Twenty (90.9%) of the 22 drivers who parked on a moderate or steep gradient overnight and 13 (68.4%) of the 20 drivers who parked on the flat overnight rated their level of confidence that the vehicle would remain stationary as a 4 or 5.

Fifteen (63.6%) of the drivers who parked on a moderate or steep incline overnight and 13 (65%) of the drivers who parked on the flat overnight rated their level of confidence to be a 4 or 5 that the vehicle would hold with only the parking brake applied.

Eighteen (81.8%) of the drivers who parked on a moderate or steep incline overnight and 15 (75%) of the drivers who parked on the flat overnight rated their confidence for parking on an incline as 4 or 5.

**Level of confidence in relation to parking in gear**

Twenty four (72.7%) of the 33 drivers who parked in gear on the 20% gradient rated their level of confidence (LOC) to be 4 or 5 that their vehicle would remain stationary. Seventeen of the drivers (51.9%) who parked in gear on the 20% gradient rated their level of confidence as a 4 or 5 that the vehicle would hold with the parking brake only applied. Nine (47.3%) of the 19 drivers who parked in gear on the flat rated their level of confidence as 4 or 5 that the vehicle would remain stationary with only the parking brake applied. Eighteen (60%) of the 30 drivers who did not park in gear on the flat reported a level of confidence as 4 or 5 that the vehicle would remain stationary on an incline with only the PB applied (see Table *8.5*).

The results were categorised for further analysis: LOC A (rating 2 or 3); LOC B (rating 4 or 5) and can be seen in Table *8.6*. Statistical analysis (Chi square, Fischer's exact test p=0.038) suggests that for drivers who would normally park in gear on the flat, an additional degree of confidence in the vehicle remaining stationary is provided by parking in gear.

*Table 8.5 Level of confidence (LOC) reported for vehicle remaining stationary with PB only applied in relation to parking practice*

| | | Park in gear on flat | | Total |
|---|---|---|---|---|
| | | No | Yes | |
| PB only | LOC A | 5(21.7%) | 10 (52.6%) | 15 (35.7%) |
| | LOC B | 18(78.3%) | 9 (47.4%) | 27 (64.3%) |
| | Total | 23 | 19 | 42 |

### 8.7.6 Application of force on the 20% gradient

The recorded force that the driver applied to the parking brake when parking on the 20% gradient ranged from min 152N to max 436N (mean 252.5N, SD=68.61). Three drivers (6.98%) exerted a force of more than 400N. The male driver who recorded the maximum force reported that he never parks in gear and has not experienced a rollaway. However, he stated that his wife cannot release the parking brake when he has applied it. The female driver recording the least force reported that she always parks in gear because "sometimes the handbrake doesn't hold".

Figure 8.21 illustrates how two drivers who drive the same vehicle operate the parking brake lever. This suggests that drivers may adapt individual methods of operation to overcome individual physical limitations of applying sufficient force

*Figure 8.21 Operation of parking brake lever for two drivers in the same vehicle*

**Peak force applied in relation to anthropometry**

The data were explored to consider any relationship between the force applied to the parking brake lever and anthropometry.

The mean of the force recorded on the 20% gradient in relation to shoulder height was calculated and compared with the mean force recorded for shoulder height on the static assessment rig (SAR) when the visual cue 'hill' was viewed (see Figure 8.22). The mean difference between the force recorded on the SAR and the force recorded on the 20% gradient was 89.9N (SD=55.1N). The $R^2$ values indicate a weak association between anthropometry and the force applied to the PB lever.

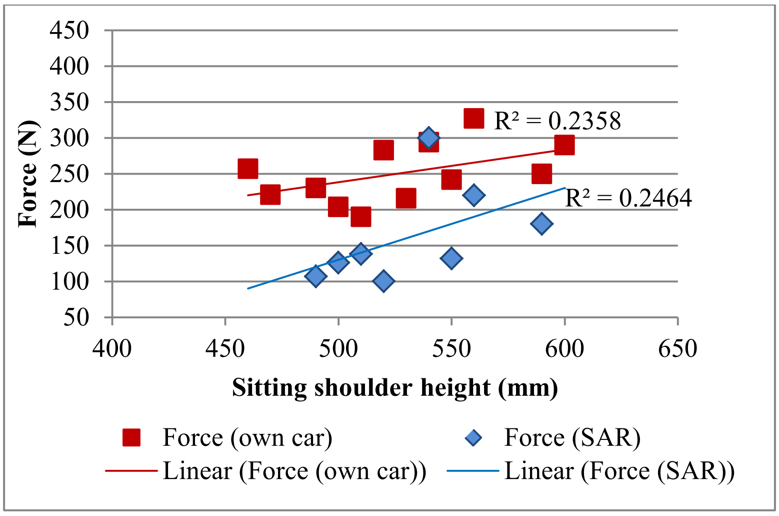



*Figure 8.22 Comparison of peak force applied to PB lever on SAR and on 20% incline*

The mean force recorded in relation to forwards distance from hip to PB lever was compared for results on the 20% gradient and the SAR (see Figure 8.23)

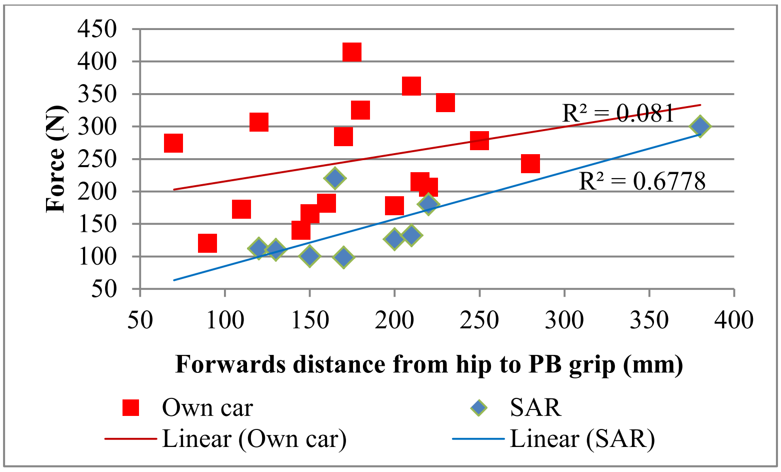



*Figure 8.23 Comparison of force applied to PB lever in relation to forwards distance from hip to PB lever*

Despite an apparent trend between anthropometry and force applied on the SAR ($R^2$=0.678), this was not apparent using own vehicles and is considered with caution due to the sample sizes.

**Force applied to the parking brake lever in relation to hand grip**

The peak force recorded when pulling the parking brake lever up was compared with the grip force recorded using the dynamometer. The results are tabulated in Table 8.6 and illustrated in Figure 8.24.

*Table 8.6 Hand grip force and PB lever force for drivers observed parking on 20% gradient*

| | Handgrip force (N) (n=35) | PB lever force (N) (n=41) |
|---|---|---|
| Minimum | 150 | 152 |
| Maximum | 550 | 436 |
| Mean | 296.9 | 252.2 |
| Std. deviation | 105.85 | 68.61 |

The recorded force applied at the parking brake (PB) lever appears to correlate with the recorded hand grip force beyond the 0.05 significance level where Pearson's moment correlation coefficient R, is .6, the coefficient of determination $R^2$ is .360 and the slope of the regression line is .412.

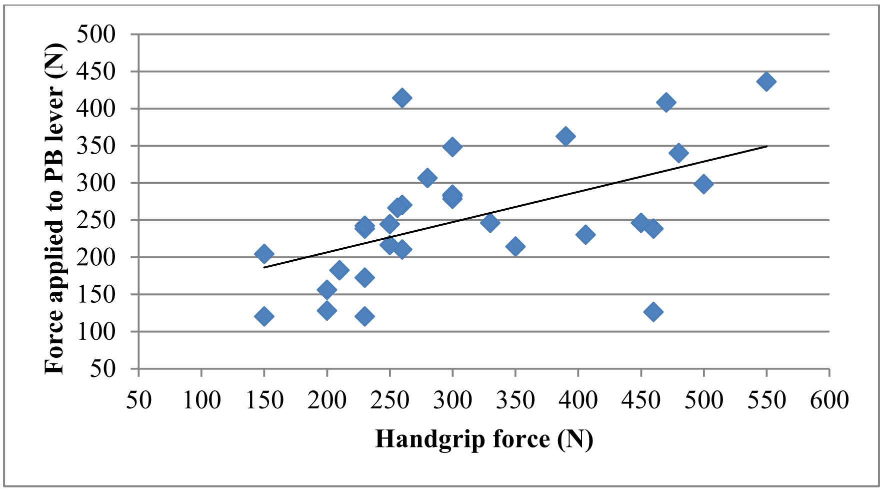



*Figure 8.24 Scatterplot of handgrip force and force applied to parking brake lever (n=41)*

### 8.7.7 Force applied to parking brake lever in relation to level of confidence in the system

The results for the peak forces recorded by 35 drivers on the 20% gradient were compared with the reported level of confidence in the parking brake system as seen in Table 8.7.

*Table 8.7 Force applied to PB lever in relation to level of confidence in system*

| **Force Applied in N** | **Level of Confidence** | | | |
|---|---|---|---|---|
| | **2** | **3** | **4** | **5** |
| Vehicle would remain stationary | | | | |
| Mean | 256 | 201 | 260 | 249 |
| Median | 270 | 204 | 240 | 246 |
| Std deviation | 35.2 | 66.1 | 93.5 | 84.1 |
| Vehicle would hold with PB only applied | | | | |
| Mean | 224 | 239.3 | 273.6 | 222.9 |
| Median | 216 | 238 | 255 | 210 |
| Std. deviation | 41.9 | 94.3 | 82.8 | 88.6 |

Figure 8.25 illustrates the results collated for level of confidence that the vehicle would remain stationary, and Figure 8.26 illustrates results for level of confidence that the vehicle would hold with the parking brake only applied.

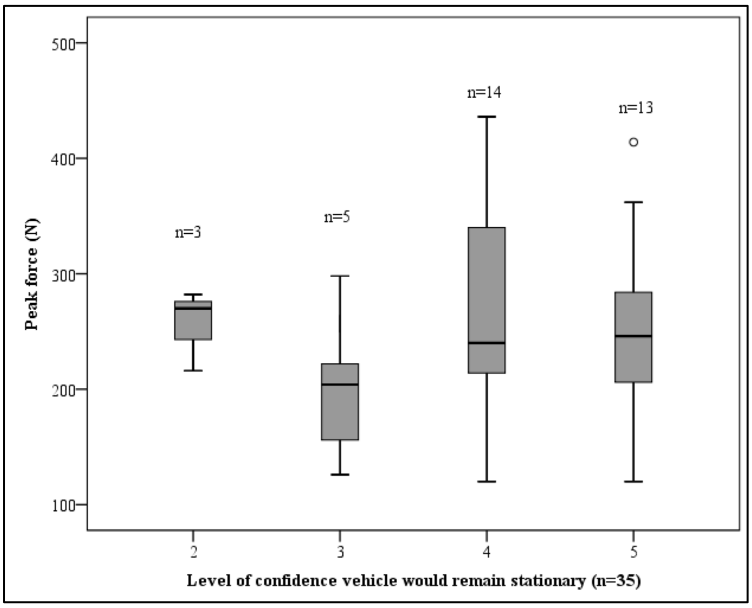



*Figure 8.25 Peak force recorded in relation to level of confidence that vehicle would remain stationary.*

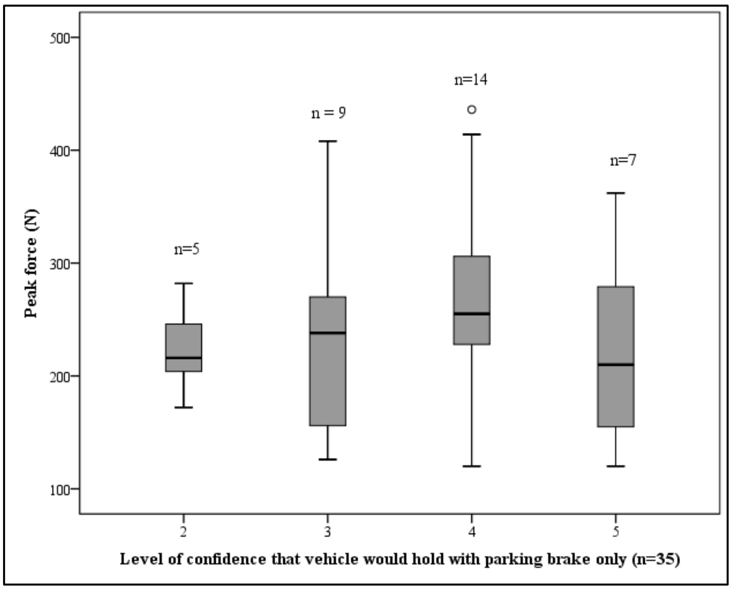



*Figure 8.26 Peak force recorded in relation to reported level of confidence that vehicle would hold with PB only applied.*

Figure 8.26 suggests that although there is a distribution of the force applied in relation to the level of confidence, there is little difference in the median force applied to the parking brake lever. The results do not indicate any significant correlation between the level of confidence in the system and the force applied.

### 8.7.8 Force applied in relation to operation of the parking brake lever

The above force applications were recorded when the release button was depressed and the parking brake lever was pulled up in one action. However, if the PB lever is pulled up without engaging the release button, allowing the pawl to move over each ratchet, the force applied may increase with each ratchet position until the point where the vehicle holds. Figure 8.27 illustrates the force trace recorded for a Peugeot 406 fitted with drum brakes parking on a 20% gradient.

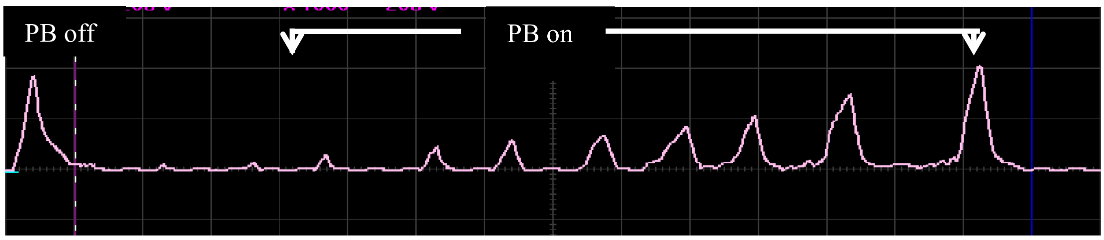



*Figure 8.27 Force applied when the parking brake lever is pulled up ratchet by ratchet (20% gradient)*

As the study progressed, media reports, personal communication and anecdotal evidence indicated that vehicle rollaway incidents are not limited to what may be perceived as steep inclines but could occur on relatively low gradients. In addition, manufacturer owner manuals and subject matter experts indicated that the release button of the lever operated parking brake should not be depressed when applying the parking brake.

Therefore the results of parking on the 5% and 10% gradients were used to explore:

> *How does the force applied to the PB lever when it is pulled up with the button depressed compare with the force applied when the button is not engaged?*

Pulling the PB lever up without depressing the release button may or may not be the driver's current practice, therefore further instruction was required and the peak force at the ratchet point where the parking brake system held the vehicle stationary was recorded.

**Parking on a <5% gradient**

The mean peak force recorded for pulling the PB lever up with the button depressed (n=18) was 186.83N (min 102N, max 290N, SD=54.86) and the mean peak force for pulling the PB lever ratchet by ratchet (n=17) was 117.3N (min 61N, max 192N, SD=35.12). Due to a technical fault, data were missing for force application to the PB lever when operated ratchet by ratchet for a vehicle with rear disc brakes so this case was excluded from further analysis.

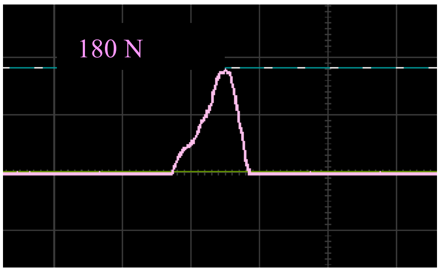
**Parking on a 10% Gradient**

The mean peak force for pulling the PB lever up with the release button depressed (n=10) was 228N (min 162N, max 292N, SD=49.2). The mean peak force recorded when the button was not depressed (n=10) was 169.2N (min 118N, max 236N, SD= 42.4).

The data used for analysis in this chapter reflects the recorded force applied to the PB lever when the rear brakes were at ambient temperature. The effects of brake temperature change will be discussed in chapter 9.

Figure 8.28 illustrates an example of the trace recorded when the PB was applied by pulling the lever up in one movement with the release button depressed. Figure 8.29

illustrates the trace when it was applied ratchet by ratchet without depressing the release button for the same driver-vehicle combination.



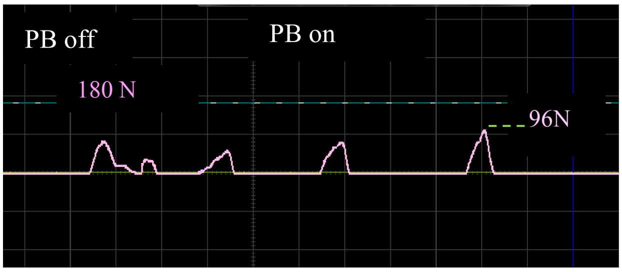




*Figure 8.28 PB applied no ratchet* *Figure 8.29 PB applied by ratchet*

The results indicate a significant difference ($p<0.05$) between the peak force applied using the non ratchet method and the ratchet method where using a paired samples T-test t=10.38, 26 df, p=0.000. ( t=9.674, p=0.000 for the <5% gradient and t=4.882, p=0.001 for the 10% gradient).

**Force applied in relation to gender**

The results were explored for any difference in the force applied to the parking brake lever in relation to gender (see Figure 8.30 and Table 8.8).

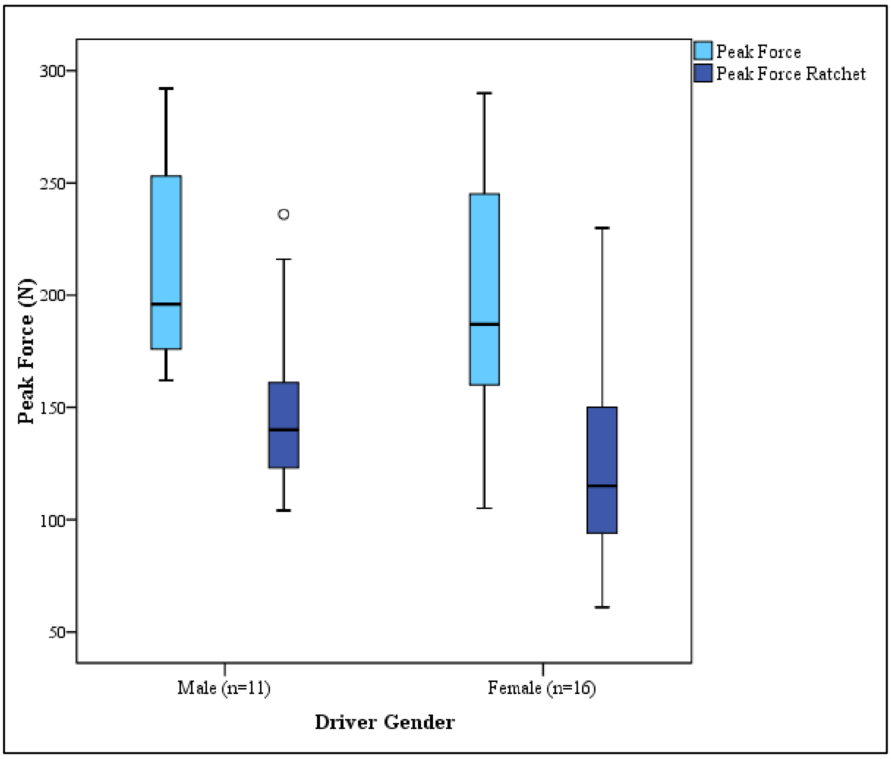



*Figure 8.30 Force applied to PB lever in relation to gender and operation*

*Table 8.8 Force applied in relation to gender of driver*

| Force applied to PB lever | | Gender of Driver | |
|---|---|---|---|
| | | Male | Female |
| | **<5% gradient** | **(n=4)** | **(n=13)** |
| Peak Force (N) (non ratchet) | Mean | 188 | 193 |
| | Min | 166 | 105 |
| | Max | 230 | 290 |
| | SD | 28.98 | 58.42 |
| Peak force (N) (ratchet) | Mean | 116 | 117.7 |
| | Min | 104 | 61 |
| | Max | 132 | 192 |
| | SD | 11.662 | 40.121 |
| | **10% gradient** | **(n=7)** | **(n=3)** |
| Peak Force (N) (non ratchet) | Mean | 232 | 219.33 |
| | Min | 162 | 168 |
| | Max | 292 | 264 |
| | SD | 52.85 | 48.35 |
| Peak force (N) (ratchet) | Mean | 171 | 164.67 |
| | Min | 134 | 118 |
| | Max | 236 | 230 |
| | SD | 39.41 | 58.29 |

The sample size in the <5% group and the 10% group was not evenly distributed and the results were grouped together for statistical analysis.

Figure 8.30 illustrates the results for the force applied to the parking brake lever when pulling up with the button in (peak force) and for pulling up with the button not depressed (peak force ratchet).

For the <5% and the 10% gradients there is no significant difference (Mann Whitney U test) in the mean of the force applied to the parking brake by male and female drivers regardless of whether the application is by ratchet or non ratchet method. However, for both genders, the median force applied to the parking brake lever and pulling up with the button depressed was greater than the median force recorded when the button is not depressed and the lever is pulled up ratchet by ratchet ($p<0.001$, Wilcoxon, signed rank test).

**Force applied in relation to rear brake type**

It was considered whether there was any difference in the force applied to the PB lever in relation to rear brake type within the parking brake system and the results are compared in Figure 8.31. The peak force for ratchet application indicates the force recorded when the parking brake lever reaches the ratchet position at which the vehicle remains stationary when parked.

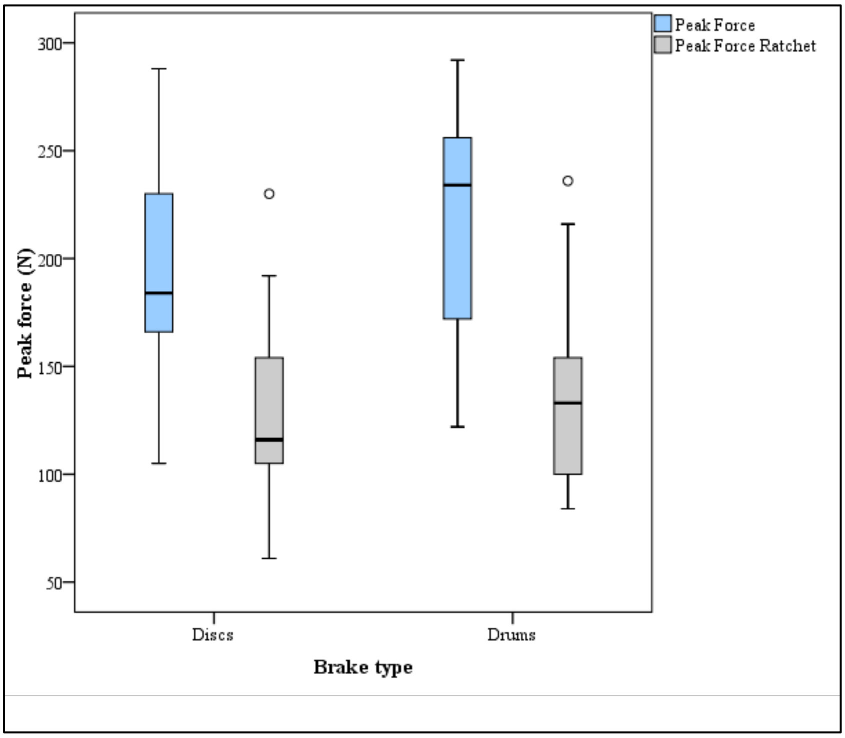



*Figure 8.31    Comparison of force recorded in relation to brake type*

The mean peak force recorded was slightly greater for drum brakes than disc brakes for both the <5% and 10% gradients (see Table 8.9).

It would appear that for the non- ratchet application, the median value of the peak force applied to the PB lever is 46N greater for drum brakes than disc brakes on the 10% gradient. However, the overall results indicate that there is no significant difference in the force applied to the parking brake lever in relation to brake type at ambient temperature.

*Table 8.9 Mean peak forces recorded on <5% and 10% gradient*

| **Force applied to PB Lever** | | **Brake Type** | |
|---|---|---|---|
| | | **Discs** | **Discs** |
| | **<5% Gradient** | **(n=8)** | **(n=9)** |
| Peak Force (N) (non ratchet) | Mean | 180.9 | 201.6 |
| | Min | 105 | 122 |
| | Max | 244 | 290 |
| | Median | 182 | 188 |
| | Std. deviation | 43.5 | 59.7 |
| Peak Force (N) (ratchet) | Mean | 113.8 | 120.4 |
| | Min | 61 | 84 |
| | Max | 192 | 190 |
| | Median | 109 | 114 |
| | Std. deviation | 36.2 | 36 |
| | **10% Gradient** | **(n=5)** | **(n=5)** |
| Peak Force (N) (non ratchet) | Mean | 215.6 | 240.8 |
| | Min | 162 | 180 |
| | Max | 288 | 292 |
| | Median | 196 | 242 |
| | Std. deviation | 57.2 | 42.1 |
| Peak Force (N) (ratchet) | Mean | 167.6 | 170.8 |
| | Min | 140 | 118 |
| | Max | 230 | 236 |
| | Median | 154 | 150 |
| | Std. deviation | 36.4 | 52.1 |

## 8.8 Section Summary

Almost 30% of participants had experienced a vehicle rollaway with 43.8% indicating they were distracted, forgot or in a rush and didn't apply the parking brake sufficiently.

Almost 50% of participants parked their vehicle in gear on the flat and 76% selected a gear when parking on the 20% gradient. However contrary to guidance in the UK Highway Code, Driving standards, and manufacturer's operating manuals, only 76%

of these selected the appropriate gear for facing down the gradient i.e. reverse gear, the others selected first gear.

Contrary to manufacturer’s operating instructions over 95% of participants pushed the release button in when pulling up on the parking brake lever.

The observed mean force applied to the parking brake lever was less than 400N. The force applied to the parking brake lever correlated to the driver’s hand grip force but was not related to gender or anthropometric dimensions such as shoulder height. The force applied to the parking brake lever using drivers’ own vehicles was greater than that recorded on the static assessment rig.

The peak force applied when the parking brake lever was pulled up with the release button pushed in was greater than when the parking brake lever was pulled up without pushing the button in.

The mean force applied to the parking brake lever appeared to be irrespective of the rear brake type utilised in the parking brake system.

# Chapter 9: Mechanical and System Considerations

## 9.1 Introduction

Although the parking brake system is expected to hold the vehicle stationary on a gradient for an unspecified period of time, the performance required by European legislation is that the system has the capability of holding a vehicle for 5 minutes on a 20% gradient (UNECE, 2008; UNECE, 2014; Day, 2014). But, reports of vehicle rollaway collated within this research, indicated that a vehicle may fail to remain stationary after a period of 5 minutes has lapsed and on gradients of less than 20%.

Previous engineering related studies concluded that brake cooling was a contributory factor to vehicle rollaway (McKinlay et al., 2004; McKinlay, 2007; Rozaini et al., 2013). The study presented in chapter nine investigates whether the brake type (discs or drums) and the effects of brake cooling affects the ability of the parking brake system to hold the vehicle stationary as represented by the blue areas in Figure 9.1. It is then considered how the results may impact on driver interaction with the system.

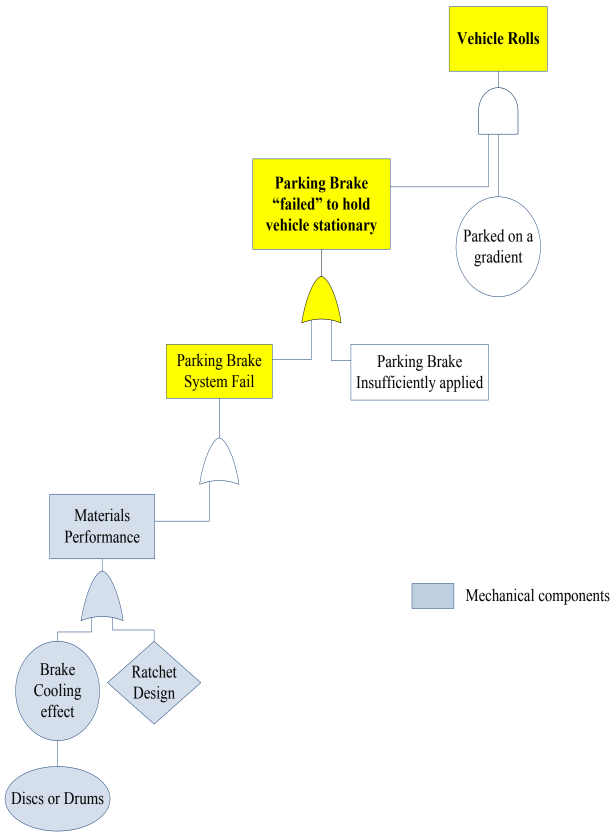



*Figure 9.1 Section of the fault tree analysis exploring parking brake system fail*

In most passenger vehicles, the parking brake system operates through the rear wheel brakes. Drum brakes are widely employed as parking brakes but disc brakes are increasingly being used particularly on higher performance cars (Day, 2014). The problem with disc brakes is that as the rear brakes cool towards their ambient temperature, the pad and disc contract and the contact of the friction surface reduces. When the contact force becomes insufficient to counteract the resultant force from the weight of the vehicle, the vehicle rolls away (McKinlay, 2007).

To explore the generated theory that brake cooling is a potential factor for vehicle rollaway, a real life study was developed to test the holding capability of the vehicle parking brake system on three gradients (20%, 10% and <5%) using privately owned passenger vehicles. The aim of the research by using vehicles routinely driven on the public highway was to provide new data to contribute to the related field of knowledge. It was hypothesised that if the parking brake lever was applied to the lowest position required to hold the vehicle stationary and, as may or may not be driver practice, the vehicle was not parked in gear would the vehicle remain stationary over a period of time?

Data were collated to explore the following research questions:

*If driver practice is to park the unattended vehicle in neutral and pull the parking brake lever up to its lowest position to hold the vehicle on the gradient, would the vehicle remain stationary as the brake temperature returns to ambient?*

*Is there a difference in how the rear brake type within the parking brake system performs as the brakes cool?*

## 9.2 Methodology

### 9.2.1 Study rationale

Privately owned vehicles, driven by their owners or authorised drivers were tested on three gradients before and after driving a predetermined route. The study methods and sample size was defined by:

- Recruitment of large enough sample of vehicles and drivers to enable statistical analysis
- practical limitations of time restraints, access to test gradients, weather conditions

### 9.2.2 Participants

Drivers who participated in part one of the incline study described in chapter eight, exploring driver interaction with the parking brake system, were invited to participate in the second part requiring a further 30-40 minutes of their time.

The advantage of testing with the same drivers who had participated in the static study was that they knew the general aim of the research and were familiar with the equipment and the investigator.

### 9.2.3 Test environments

The tests were conducted on the gradients used in the previous study presented in chapter eight. These were a 20% gradient (to reflect the requirements of RH-13) and a 3-4% (<5%) gradient within the grounds of St Luke's Hospice, Plymouth. Permission was granted by Senior Management to use the gradients for test purposes and a risk assessment was completed (Appendix E). Testing on a 10% gradient was conducted on Loughborough University Campus with permission from the Security and Facilities staff to use a parking space as a test area. The lower gradients reflected the findings of previous chapters where it may or may not be normal practice to park in gear on lesser gradients.

### 9.2.4 Test routes

To increase the temperature in the rear brakes under near normal driving conditions from ambient, the vehicles were driven on a pre-determined route, used by public transport and other road users, within an urban area in Plymouth or on the University campus and public roads in Loughborough.

Although drivers may use their brakes in different ways, both routes were planned to include three types of braking associated with thermal performance:

- single application e.g. when stopping at a junction
- repeated application e.g. for speed humps
- continuous application e.g. going downhill

(Day, 2014 p.217).

The predetermined route for testing on the <5% and 20% gradients in Plymouth was a 3 mile route within an urban and residential area along a main bus route comprising down- hill sections with bends, mini roundabouts, a pedestrian crossing, a school and several speed humps (see Figure 9.2 to 9.4).

*Figure 9.2 Approach to speed hump followed by mini roundabout*

*Figure 9.3 Approaching school patrol area*

*Figure 9.4 Downhill section with left hand bend approaching entrance to test area*

The route for testing on the 10% gradient was 2.7 miles mainly within the Loughborough University campus. It included junctions, speed humps, a pedestrian crossing and one 20% gradient descent where drivers were encouraged to depress the footbrake pedal for the length of the incline so as to sufficiently increase the temperature in the brakes.

### 9.2.5 Data collection

**Rear brake temperature**

Temperature at the rear brakes was recorded using an infra-red hand held pyrometer (see Figure 9.5). The use of thermocouples within the brake linings was not within the scope of this study and as pyrometer data has been shown to match thermocouple data (Schultz and Babinchak, 1998) it was considered to be appropriate to use this method to record and compare temperatures of the brake surfaces. For disc brakes, the temperature on the exposed disc surface was recorded and for drum brakes the reading was taken from the outer surface of the drums.

*Figure 9.5 Recording rear brake temperature with an infrared pyrometer*

**Ratchet position**

Manufacturer's owner manuals instruct drivers not to press the release button when pulling the parking brake lever up (see Appendix E.6). Halderman (1996), referred to using the number of 'clicks' as a maintenance test when applying the parking brake. It was therefore deemed appropriate, although not providing data in SI units, to gauge the ratchet position by recording the number of audible 'clicks' as the pawl moved over the ratchets.

*Figure 9.6 Measurement of parking brake lever height*

The parking brake lever height when applied was measured in mm using a standard tape measure from the central housing to the mid contact point of the parking brake lever (see Figure 9.6).

**Force application**

The force applied by the driver to the parking brake lever was recorded via a Novatech F268 handbrake load cell fixed to the parking brake lever and connected through custom made data acquisition hardware to Focus Oscilloscope software installed on a Toshiba Portege laptop.

**Vehicle roll**

Plastic wheel chocks were positioned 500mm in front of the rear wheels (see Figure 9.7). Chocks with a scaled surface was considered for ease of positioning but when the vehicle rolled forwards, it was difficult to gain sufficient traction to reverse back from the chocks to remove them. A roll was recorded when the rear wheels made contact with the chocks or movement was such that the driver pressed the foot pedal.

*Figure 9.7 Position of chocks*

### 9.2.6 Data analysis

Data were summarised using Microsoft Excel and transferred to IBM SPSS version 21 for further analysis.

## 9.3 Test Procedure

### 9.3.1 Timescale and conditions

Testing was conducted between Spring 2013 and Spring 2014 as weather conditions, access to test areas and availability of vehicles allowed. Testing was conducted in dry conditions and each test was conducted with the vehicle facing down the gradient only. This was an outcome of the risk assessment which identified that if a vehicle facing up the gradient rolled with the passenger door open, the investigator could be injured.

### 9.3.2 Procedure (see Appendix E)

Volunteers were given an appointment to attend and were directed to the testing area. The procedure was explained to the driver and consent to participate completed. Drivers were then instructed to park in the test area with the vehicle facing down the gradient. Where drivers participated in testing on more than one gradient, this was done in no particular order).

With the engine switched off, the load cell was applied to the parking brake lever. When the load cell was secured and the driver was comfortable with the grip and procedure, the engine was switched on. With the car in neutral, the driver was instructed to apply the parking brake in his/her normal way. The driver was then asked to release the parking brake with the foot brake depressed and re-apply the parking brake by pulling the lever up ratchet by ratchet, releasing pressure off the foot brake at each level and repeating the process until reaching the ratchet position where the vehicle remained stationary with no audible signs of strain e.g creaking.

The engine was then switched off and the driver remained in the vehicle for safety, ready to re-apply the foot brake and/or handbrake if the vehicle rolled. Chocks were positioned 500mm in front of the rear wheels and the temperature of the rear brakes was recorded. The investigator checked for roll at 5 minute intervals up to 15 minutes or until the vehicle rolled and recorded the final temperature of the rear brakes.

Once complete, the driver was advised of the route to be taken. The chocks were removed and the investigator sat in the front passenger seat, instructed the driver to start the engine when ready to proceed and provided directions of the route to be taken.

On completion of the route, the driver was requested to park the vehicle facing down the test gradient and the test procedure was repeated as above. The temperature was recorded at three 5 minute intervals or until the vehicle rolled. The final temperature recorded would then be that taken immediately following the roll.

## 9.4 Results

### 9.4.1 Vehicles

A total of 53 tests were conducted on right hand drive passenger vehicles registered between 1999 and 2013 (Table 9.1.) from 16 different manufacturers (see Appendix E.5). The average age of the vehicle was 6 years (SD 4.2). Vehicles were unladen apart from the driver and personal contents.

Nine (50%) of the 18 vehicles tested on the <5% gradient were fitted with rear disc brakes and 9 (50%) with drums. Seven (58%) of the 12 vehicles tested on the 10% gradient were fitted with rear disc brakes and 5 (42%) with drums. Ten (43.5%) of the 23 vehicles tested on the 20% gradient were fitted with rear disc brakes and 13(56.5%) with drums.

*Table 9.1 Characteristics of vehicles tested*

| Gradient | No. of Vehicles (N=53) | Rear Brake Type | | Year of Registration | 2010 onwards | EPB/Foot Operated PB |
|---|---|---|---|---|---|---|
| | | Discs | Drums | | | |
| <5% | 18 | 9 | 9 | 2001-2013 | 6 | 0 |
| 10% | 12 | 7 | 5 | 2001-2013 | 2 | 2 |
| 20% | 23 | 10 | 13 | 1999-2013 | 9 | 1 |

Six (66.7%) of the vehicles tested on the <5% gradient; two (16.7%) of the vehicles tested on the 10% gradient and 9 (39.1%) of the vehicles tested on the 20% gradient were less than three years old and did not require an MOT.

The three vehicles not fitted with a lever operated parking brake were included in 'rear brake type' and stopping temperature analysis but were excluded from the results related to lever parking brake operation.

### 9.4.2 Rear brake temperatures

Figure 9.8 illustrates the temperature recorded at the nearside (n/s) rear brake before and after driving on the set route for each gradient.

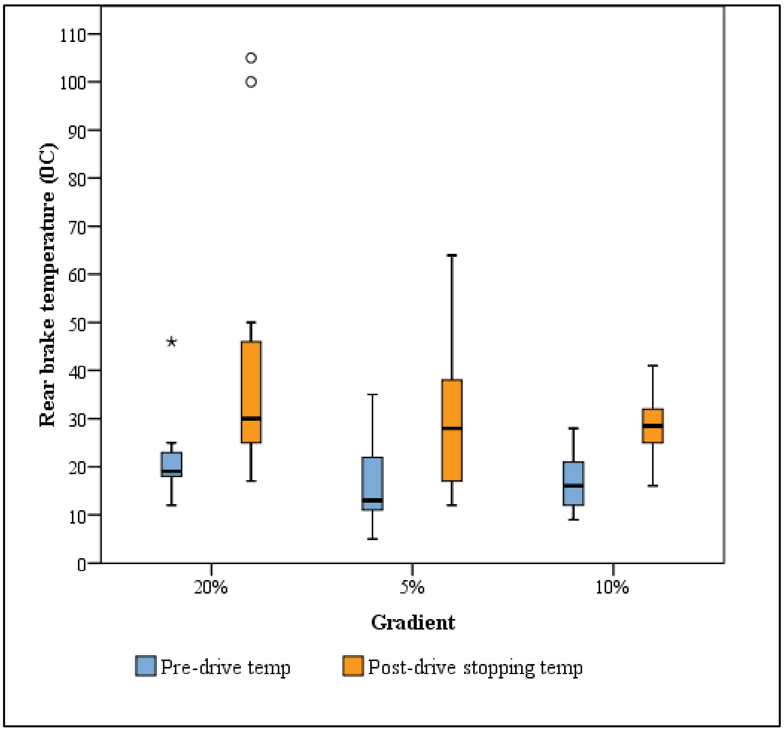



*Figure 9.8 Temperature change in rear brakes pre and post driving on predetermined route*

A relatively small change in temperature from ambient was recorded with a mean rise in temperature of 7.9°C (SD 4.9). The mean post drive temperature across all 3 gradients was 34.5°C (SD 18.7). The max temperature (105°C) was recorded for a heavily loaded vehicle on the 20% gradient which was excluded from further testing.

*Table 9.2    Temperature recorded at rear brake pre and post driving test route*

| | Gradient | N | Mean (°C) | SD | Min | Max | Sig |
|---|---|---|---|---|---|---|---|
| Pre-drive temp | 20% | 23 | 30.7 | 17.0 | 15.0 | 98.0 | 0.145 |
| | 5% | 16 | 22.9 | 12.0 | 11.0 | 58.0 | |
| | 10% | 12 | 23.4 | 4.4 | 14.0 | 29.0 | |
| | Total | 51 | 26.6 | 13.8 | 11.0 | 98.0 | |
| Post-drive temp | 20% | 23 | 39.4 | 23.2 | 17.0 | 105.0 | 0.219 |
| | 5% | 18 | 32.4 | 16.8 | 12.0 | 64.0 | |
| | 10% | 12 | 28.4 | 7.1 | 16.0 | 41.0 | |
| | Total | 53 | 34.5 | 18.7 | 12.0 | 105.0 | |

**Temperature differences of disc and drum brakes**

The collective results for both rear brake types were explored and indicated that for the disc brakes (n=26) the overall mean stopping temperature recorded was 43°C (SD 20.7°C) and for the drum brakes (n=27) the overall mean stopping temperature recorded was 26.3°C (SD 12.2).

The disc brakes appeared to demonstrate a higher mean stopping temperature than drums and the differences were further explored across the 3 test gradients. The mean temperatures, rounded to one decimal place, recorded for each brake type and each gradient can be seen in Table 9.3 and illustrated in Figure 9.9.

*Table 9.3    Stopping temperature ($T_1$) recorded at nearside rear brake*

| Rear brake type | Gradient | N | Mean Temperature (°C) | SD | Median |
|---|---|---|---|---|---|
| Drums | 20% | 13 | 28.5 | 12.7 | 26 |
| | 5% | 9 | 25.3 | 14.6 | 20 |
| | 10% | 5 | 22.4 | 5.2 | 24 |
| Discs | 20% | 10 | 53.5 | 26.7 | 45.5 |
| | 5% | 9 | 39.4 | 16.5 | 37 |
| | 10% | 7 | 32.7 | 4.7 | 31 |
| Total | 20% | 23 | 39.4 | 23.2 | 30 |
| | 5% | 18 | 32.4 | 16.8 | 28.5 |
| | 10% | 12 | 28.4 | 7.1 | 29 |

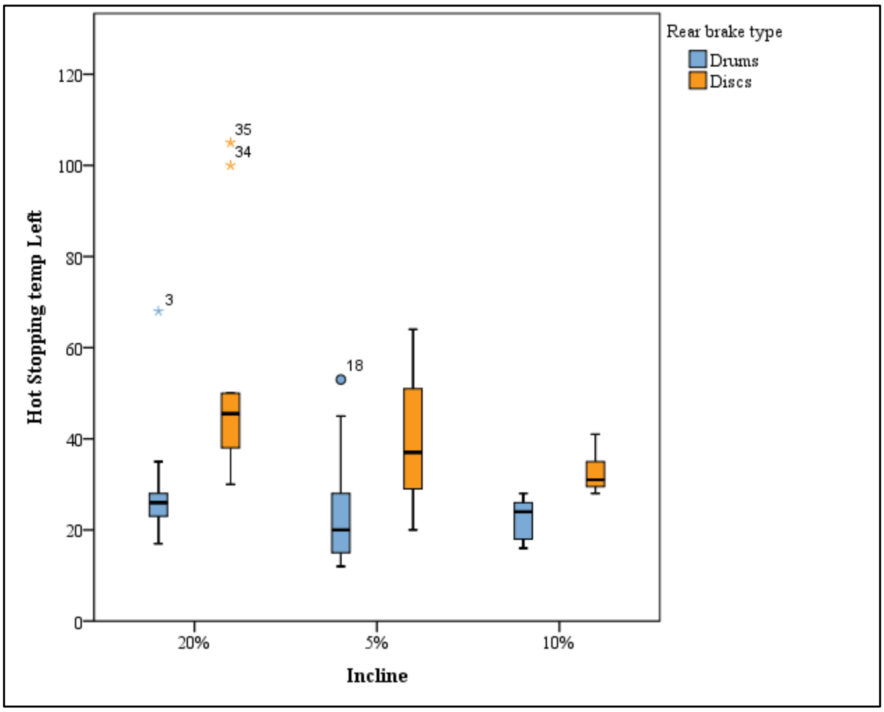



*Figure 9.9 Stopping temperature recorded at rear nearside brake*

The mean temperatures for each brake type were compared using a one way ANOVA test (Table 9.4). This indicated a significant difference between temperatures of disc and drum brakes on initially stopping (p=0.001) after driving a predetermined route and 5 minutes after stopping (p=0.039) but no significant difference after 10 minutes.

*Table 9.4 Comparison of mean brake temperatures after driving test route*

| | Rear Brake Type | N | Mean (°C) | Standard Deviation | Sig. |
|---|---|---|---|---|---|
| Hot stopping temp | Drums | 27 | 26.3 | 12.2 | p= 0.001 |
| | Discs | 26 | 43 | 20.7 | |
| Temp after 5 mins | Drums | 27 | 22.9 | 7.5 | p=0.039 |
| | Discs | 24 | 30.8 | 17.7 | |
| Temp after 10 mins | Drums | 25 | 21.7 | 6.4 | p=0.116 |
| | Discs | 22 | 26.9 | 14.8 | |

The mean temperatures recorded were plotted against each time interval and exponential trend lines to reflect the shape of the curve in relation to Newton's law of cooling (see Figure 9.10).

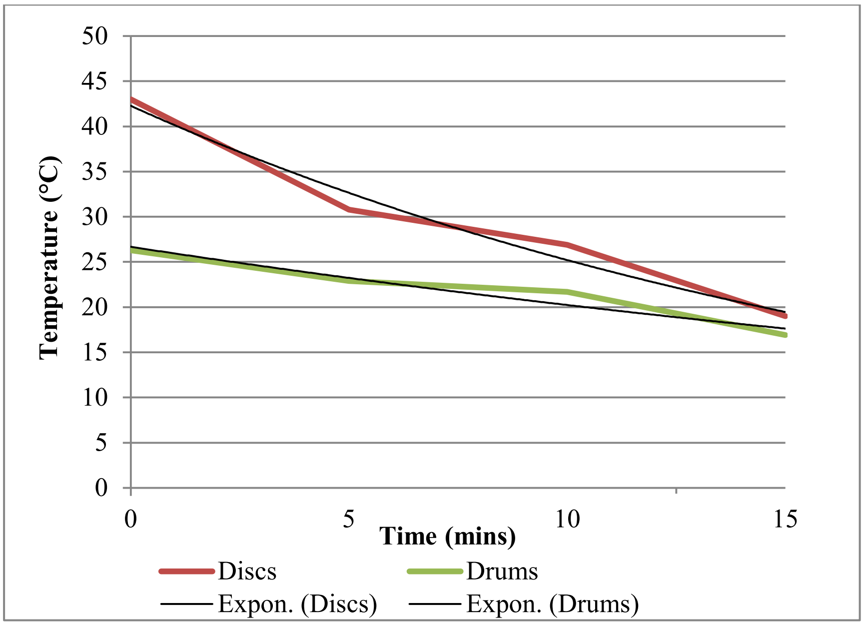



*Figure 9.10 Rate of cooling for discs and drums*

A higher stopping temperature was recorded for the disc brakes but they also demonstrated a faster rate of cooling. This could be related to dimensions and fabric of components and surface area exposed (Talatii and Jalifer, 2009).

### 9.4.3 Vehicles failing to remain stationary

It was considered that the vehicle had failed to remain stationary and a 'roll' was recorded when the vehicle moved forwards and was stopped by the driver applying the footbrake or when the rear wheels made contact with the chocks. As seen in Table 9.6, 18 (36%) of the 50 vehicle cases with lever operated parking brakes rolled. The vehicle rolled in 17 (73.9%) of the 23 cases where rear disc brakes were fitted.

*Table 9.5 Vehicles failing to remain stationary (roll)*

| Gradient | Brake Type | Roll | Roll but stopped | No Roll | Insufficient force | Number |
|---|---|---|---|---|---|---|
| 20% | Drums | 0 | 0 | 12 | 1 | 13 |
| | Discs | 9 | 0 | 0 | 0 | 9 |
| | Total | 9 | 0 | 12 | 1 | 22 |
| 5% | Drums | 1 | 2 | 6 | 0 | 9 |
| | Discs | 5 | 2 | 2 | 0 | 9 |
| | Total | 6 | 4 | 8 | 0 | 18 |
| 10% | Drums | 0 | 0 | 5 | 0 | 5 |
| | Discs | 3 | 1 | 1 | 0 | 5 |
| | Total | 3 | 1 | 6 | 0 | 10 |
| | Drums | 1 | 2 | 21 | 1 | 27 |
| | Discs | 17 | 3 | 2 | 0 | 23 |
| | Total | 18 | 5 | 23 | 1 | 50 |

On the 20% gradient, all 9 vehicles fitted with disc brakes rolled; one of the vehicles fitted with drum brakes rolled due to the driver being unable to apply sufficient force to the parking brake lever to hold the vehicle stationary. Two vehicles rolled in less than 5 minutes, 5 vehicles rolled in 5-10 minutes and 2 vehicles rolled in 10-15 minutes (Mean 9.8, SD 3.5).

On the <5% gradient, 5 of the 9 vehicles fitted with disc brakes rolled. Two vehicles rolled in the 5-10 minute period and 3 vehicles rolled within the 10-15 minute period. Two of the vehicles fitted with drum brakes rolled and then stopped without any intervention from the driver or contact with the chocks (Table 9.6). Although in 2 cases there was audible creaking, the vehicles did not roll within the 15 minute test period.

On the 10% gradient, 3 of the 5 vehicles fitted with rear disc brakes rolled after 5 minutes but in less than 10 minutes. One vehicle rolled but stopped without any intervention from the driver or contact with the chocks. The 5 vehicles fitted with drum brakes and one vehicle fitted with disc brakes remained stationary for the period of the test.

The results indicate a difference in performance between the two brake types in relation to the holding capability of the parking brake system when the brake temperature has been increased and the lever is applied to its minimal holding position (Pearson's chi square 22.0, likelihood ratio 29.77, 2 df, $p<0.001$). Although, the sample size is relatively small, the results indicate that brake cooling is a potential factor in the vehicle failing to remain stationary and that systems which employ disc brakes may be more susceptible to vehicle rollaway. Repeating the study with a larger sample size would further determine this theory.

### 9.4.4 Temperature difference on rollaway

The temperatures recorded on stopping ($T_1$) and rolling ($T_2$) were recorded for each vehicle and are illustrated for each incline in Figure 9.11, 9.12 and 9.13.

The mean temperature difference of the rear disc brakes from stopping to rolling ($T_1$-$T_2$) for the 20% incline (Figure 9.11) was 21.4°C (SD 14.9) with a minimum temperature difference of 5°C and a maximum of 50°C. The mean difference from rolling temperature to ambient air temperature was 21°C (SD 18.2).

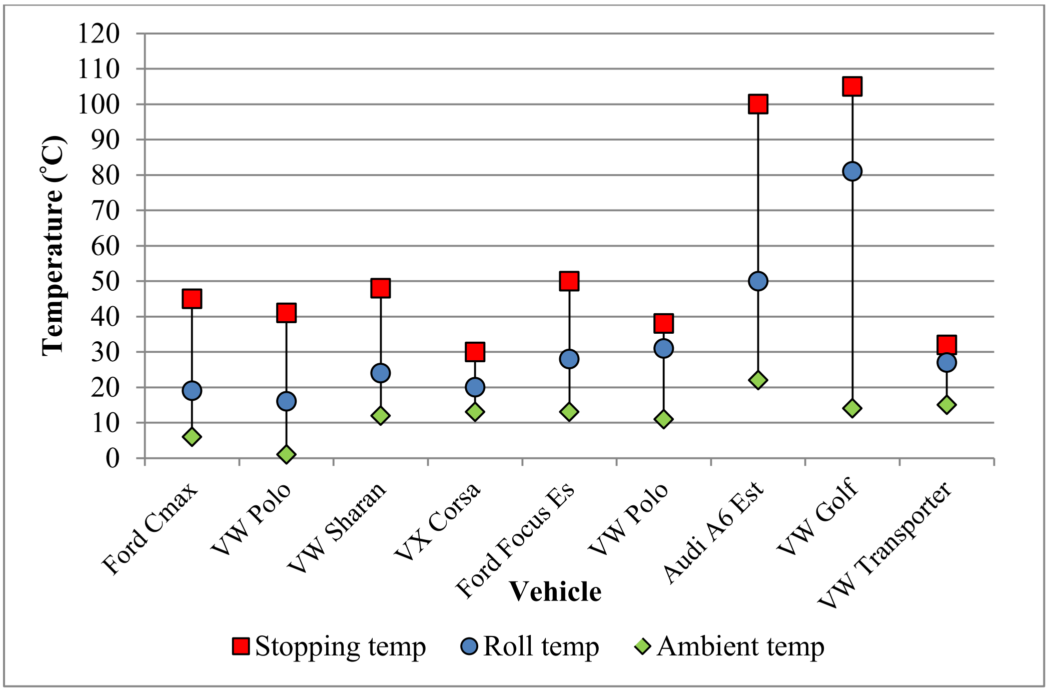



*Figure 9.11 The stopping temperature ($T_1$) and roll temperature ($T_2$) for vehicles which failed to remain stationary on 20% gradient*

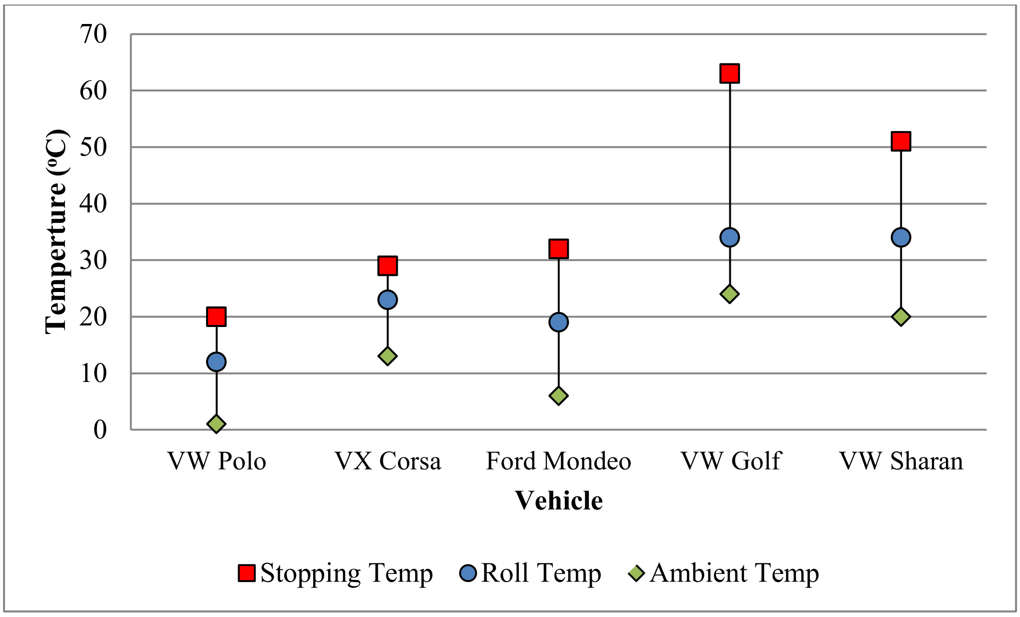



*Figure 9.12 The stopping temperature ($T_1$) and roll temperature ($T_2$) for vehicles which failed to remain stationary on a <5% gradient.*

The mean temperature difference recorded for the disc brakes from stopping to rolling ($T_1$-$T_2$) on the <5% gradient (Figure 9.12) was 14.6°C (SD 9.1) with a minimum temperature difference of 6°C and a maximum of 29°C. The mean temperature difference for temperature recorded at rolling to ambient was 11.6°C (SD 1.8).

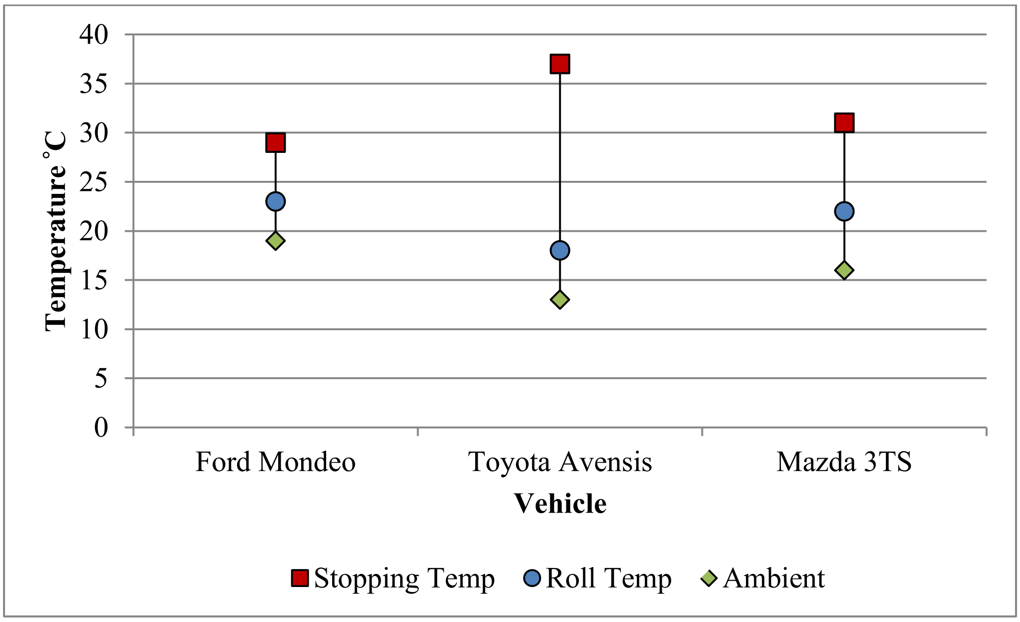



*Figure 9.13 The stopping temperature ($T_1$) and roll temperature ($T_2$) for vehicles which failed to remain stationary on 10% gradient.*

The mean temperature difference recorded for disc brakes from stopping to rolling ($T_1 - T_2$) on the 10% gradient was 11.3°C, (SD 6.8) with a minimum difference of 6°C and a maximum of 19°C. The mean difference from roll temperature to the ambient was 5°C (SD 1).

For the 20% gradient, the mean difference in stopping temperature to roll temperature and the mean difference from rolling temperature to ambient is almost the same. However for the <5% and 10% gradients, the mean difference of stopping temp to roll temperature is greater than the mean difference of roll temperature to ambient. This suggests that for the lesser gradients, rollaway occurs when the rear disc brake temperature cools nearer to the ambient than on the steeper gradient.

### 9.4.5 Lever operated Parking Brake ratchet position

It was considered that if the brake disc material expands with an increase in temperature, would there be a difference in the parking brake lever (pawl on ratchet) position when applied with the brakes at ambient temperature and after driving a pre-determined route.

The 3 vehicles not employing a lever operated parking brake were excluded from this part of the test and there was missing or unclear data for 4 vehicles.

The minimal ratchet position of the parking brake lever necessary to hold the vehicle stationary when parked was recorded before ($R_1$) and after ($R_2$) driving the test route. The difference in ratchet position ($R_2 - R_1$) was calculated for the data of 46 vehicle observations (Table *9.6.*).

*Table 9.6 Ratchet position difference before and after ($R_2 - R_1$) driving test route (N=46)*

| Gradient | Brake Type | Ratchet Position ($R_2 - R_1$) | | |
|---|---|---|---|---|
| | | Same | Less | More |
| <5% | Drums (n=9) | 5 | 3 | 1 |
| | Discs (n=8) | 2 | 5 | 1 |
| 10% | Drums (n=5) | 3 | 1 | 1 |
| | Discs (n=5) | 1 | 2 | 1 |
| 20% | Drums (n=11) | 8 | 0 | 3 |
| | Discs (n=8) | 0 | 5 | 3 |

From the data collated, the ratchet position on parking was the same before and after driving the set route for 16 (65%) of the 25 vehicles tested with drum brakes and 3 (14.3%) of the 21 vehicles with disc brakes. Four (16%) of the vehicles fitted with drum brakes and 12 (57%) of 21 vehicles fitted with disc brakes required one or more ratchets less to hold the vehicle stationary after driving a set route i.e. when the brake temperature had been increased

On the <5% gradient, in 5 (56%) of the 9 vehicles fitted with drum brakes the ratchet position was the same before and after driving the 3 mile route. In 3 of the vehicles it was one ratchet less and in one of the vehicles it was one ratchet more. For the 8 vehicles tested with disc brakes, the ratchet position was the same for 2 (25%) vehicles, one ratchet less for 5 (62.5%) vehicles and one ratchet more for one vehicle.

On the 10% gradient, in 3 (60%) of the 5 vehicles tested fitted with drum brakes, the ratchet position was the same before and after driving 2.7 miles. In one of the vehicles the ratchet position was one more and in one of the vehicles it was two ratchets less. For the 5 vehicles fitted with disc brakes, the ratchet position was the same before and after driving the route in one vehicle, one ratchet more in one vehicle and in 2 (40%) vehicles it was 2 ratchets less.

A lower ratchet position was recorded for 5 (62.5%) of the 8 vehicles with disc brakes parked on the 20% gradient when the brake temperature was raised from ambient after driving a set route (see Figure 9.14). Three vehicles with disc brakes required 2 more ratchets to hold the vehicle when parking on the 20% gradient after driving the 3 mile route.

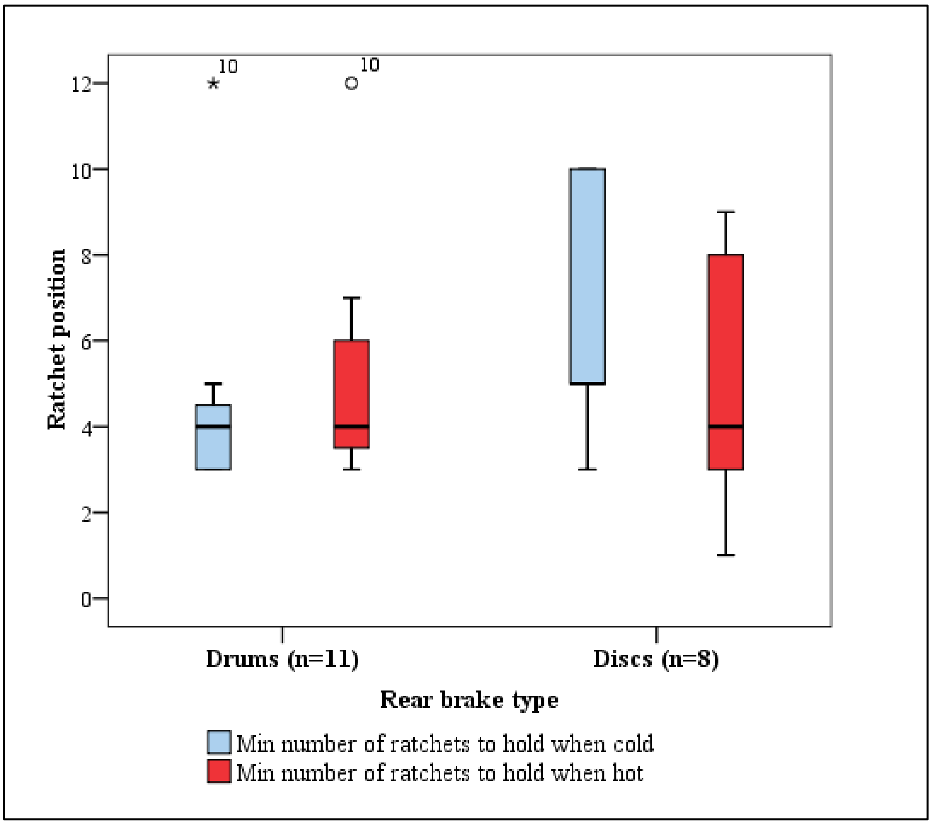



*Figure 9.14 Ratchet position recorded on 20% gradient*

The ratchet position when parking on the 20% gradient was the same before and after driving the 3 mile test route for 8 (73%) of the 11 vehicles fitted with drums. In two of the vehicles with drum brakes one more ratchet was required and in one of the vehicles 3 more ratchets were required. For the vehicles fitted with disc brakes, 5 of the 8 vehicles observed required one less ratchet to hold the vehicle stationary

Overall, a lower ratchet position to hold the vehicle stationary on stopping was recorded for disc brakes when the brake temperature had been raised. A between groups ANOVA comparing drum brakes and disc brakes for ($R_2$-$R_1$) yielded a statistically significant result F= 9.17; 1df; p=0.004 indicating that a lower ratchet position is required to hold the vehicle stationary when disc brakes are hot than when cold compared to drum brakes.

## 9.5 Chapter Summary

The results indicated a significant difference in the holding capability of disc and drum brakes as the rear brake temperature returned to ambient temperature. The vehicle rolled in 17 (73.9%) of the 23 cases where rear disc brakes were fitted supporting previous research that suggested brake cooling effects to be a factor in vehicle rollaway.

On the 20% gradient, the vehicle rolled when the mean difference from ambient to roll temperature was marginally greater than the mean difference between stopping to rolling temperature. Whereas for the <5 and 10% gradients the brake temperature cooled to nearer ambient before the vehicle rolled. This suggests that a combination of a steeper gradient and brake cooling with the vehicle not parked in gear is more likely to reach a point of criticality with a lesser temperature drop than when the vehicle is parked on a shallower gradient.

On all three test gradients, after driving a pre-determined route, a higher stopping temperature was recorded for disc brakes than drum brakes ($p=0.001$) but after 10 minutes there was no significant difference between the brake types as the temperature returned to ambient.

Focusing on the lever operated parking brake, the tests were conducted by applying the parking brake without depressing the release button. Although it may be contrary to driver practice, operation as such reflected the instructions that are typically contained within the owner's manual and provided audible feedback of the lever position.

The results indicated that the pawl position on the ratchet when the system employs disc brakes is less when the temperature of the brakes has been increased than when the disc brakes are at ambient. This suggests that disc brakes may hold at a lower ratchet position when they are hot than when they cool to ambient temperature.

In relation to driver interaction, if the driver practice is to apply the parking brake lever to the point where the vehicle remains stationary, and does not park in gear, the vehicle fitted with rear disc brakes may fail to remain stationary as the brake temperature returns to ambient. This may be particularly relevant where the driver has access to vehicles employing different brake types.

# Chapter 10: Discussion

## 10.1 Introduction

The failure of a parked, unattended vehicle to remain stationary, referred to as vehicle rollaway, is an unwanted event that can have catastrophic consequences. In contrast to previous research which only concentrated on the mechanical/vehicle components as a cause of vehicle rollaway (McKinlay et al., 2004; McKinlay, 2007; Rozaini et al., 2013), the research reported in this thesis explored additional factors related to the driver's interaction with the parking brake system at various interface levels.

Triangulation of data collected from empirical studies captured different dimensions (Bryman, 2012) of the organisational/environmental, mechanical/vehicle and human components of operating the parking brake system, reflecting a general, and road safety, systems approach (Leveson, 2002; Wierwille et al., 2002; Peden et al., 2004; Stanton and Salmon, 2009; Larsson, Dekker and Tingvall, 2010). The areas of exploration are summarised in Figure 10.1.

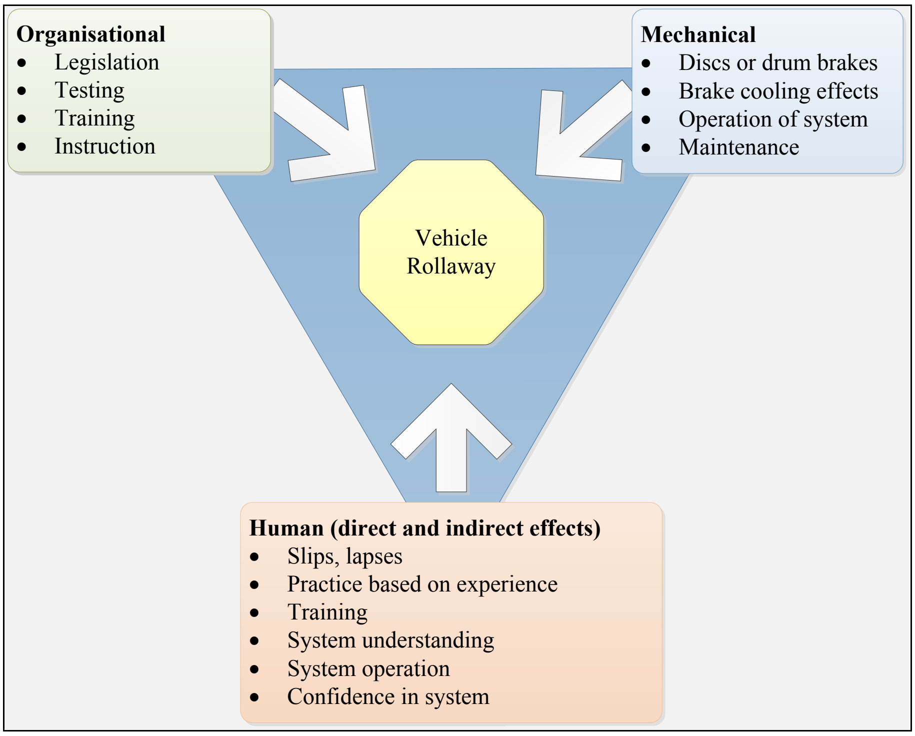



*Figure 10.1 Areas of exploration for contributory factors to vehicle rollaway*

The empirical studies for this thesis included two online surveys which surveyed driver and driving instructor interactive experience of the parking brake system and three observational studies to observe current practice. These studies provided the foundation for a theoretical and methodological approach to explore the factors involved during the successful operation of the parking brake system so that the vehicle remains stationary when left unattended.

The multi-strategy approach of the research combines quantitative and qualitative data to inform and contribute to knowledge associated with failure of the parking brake system. It is representative of an approach that explores the linkages and interactions of the parking brake system to understand the complexity of factors in what would appear to be a simple task.

## 10.2 Overview of the Thesis

The initial method to answer the question "why does the parked unattended vehicle fail to remain stationary, i.e. roll away?" could have been to focus on the mechanical components of the parking brake itself or the driver's ability to operate it. However, a more Ergonomics and Human Factors approach required the adoption of a system based methodology to explore the factors which affect interaction with the system. That is, the organisational and environmental elements such as regulatory controls, training and instruction; operation and performance of the mechanical components; and driver related factors. The Fault Tree in Figure 10.2 is divided into three sections to illustrate these areas of exploration and to identify the potential contributory factors and combination thereof ('AND' 'OR') that may result in the unwanted event of a vehicle rollaway. This methodology provided the basis for a systematic evaluation of why a vehicle rollaway may occur in order to identify precautionary measures and provide direction for future work.

Description of the task and fault tree analysis (Figure 10.2) explored areas where latent or active failures resulting in 'unsafe acts' (Reason, 1990) could occur. Within the fault tree there were areas of overlap of the key components and it demonstrated potential 'AND' 'OR' situations where failure could result. In reference to Reason's Swiss cheese theory (Reason, 1990), and representation in a cause and effect diagram, it was possible to identify areas in the defensive layers of the parking brake system where latent and active failures could occur resulting in a vehicle rollaway.

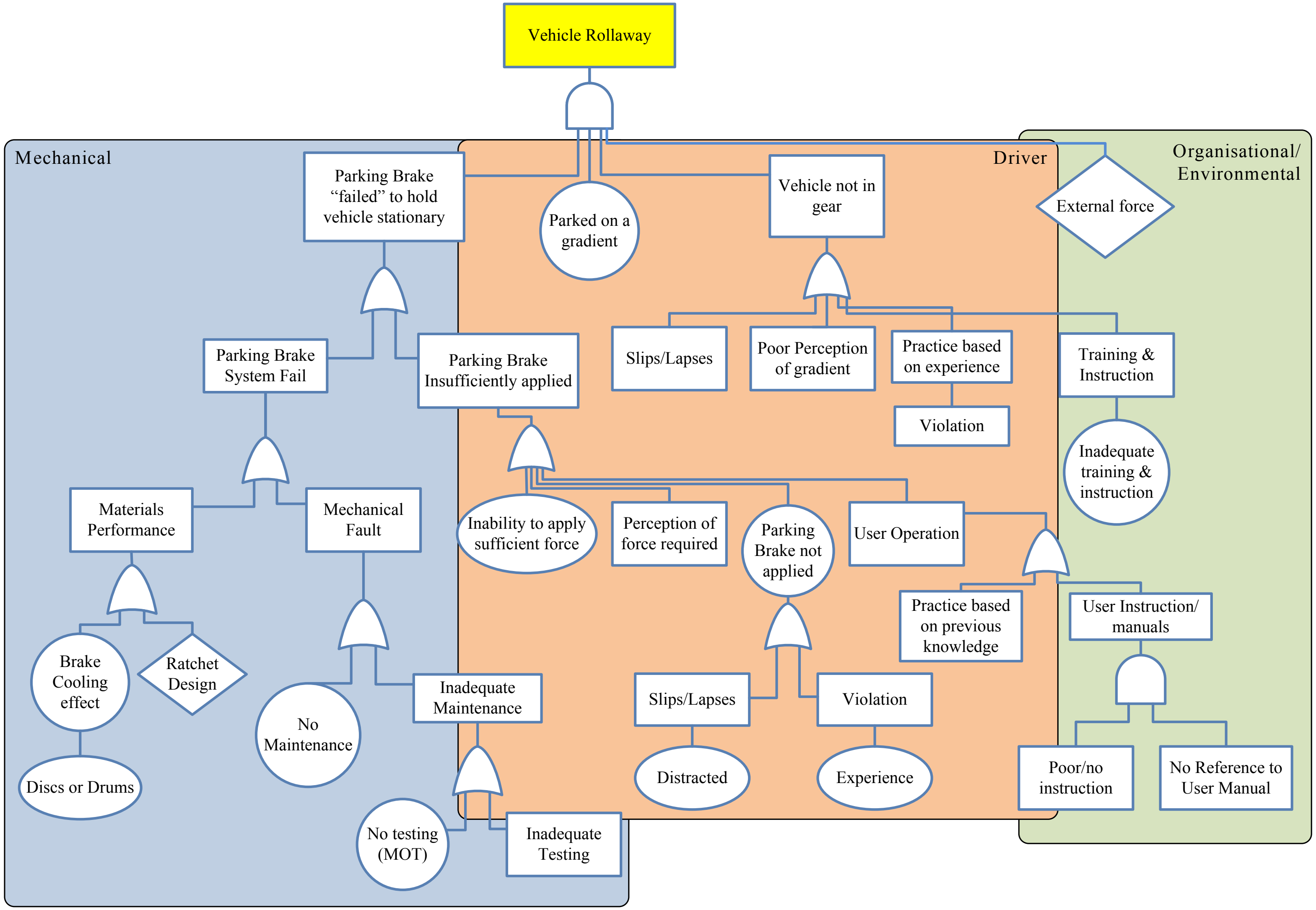



*Figure 10.2 Fault tree analysis indicating mechanical, driver and organisational areas of exploration*

## 10.3 Extent of the Perceived Issue of Vehicle Rollaway

### 10.3.1 Introduction

Data sourced from UK government databases and UK media reports were indicative of the problem of passenger vehicle rollaway but were not considered to be fully representative of its magnitude. Incidents recorded in STATS19 (UK national road accident recording system) by four of the 51 UK Police forces suggested an annual average of three serious injuries or fatality per territory. Reports of vehicle rollaway associated with parking brake failure resulted in 30 vehicle recalls by the Vehicle and Operator Services Agency (VOSA) between July 2008 and August 2012 affecting 11 different manufacturers. A search of UK media for a comparative period indicated that almost half of the 26 cases listed had resulted in a pedestrian fatality suggesting an annual average of four pedestrian fatalities.

Recording of relevant data such as described above, is dependent on the systems employed, the criteria for reporting and the reporting individual's assessment of the incident. Data recorded using STATS19 is subject to the reporting officer's opinion and selection of contributory factors, which may not be specific and following further investigation, may be amended (Smith et al., 2015). Conclusions of that investigation as to why the vehicle rolled away, may not take full account of factors operating at the time of the incident, such as whether the rear brakes were at ambient temperature or an increased temperature following a period of driving and allowed a sufficient period of time to cool to ambient.

Non-injury accidents may not be recorded in STATS19 and incidents where there has been no damage or involvement of the emergency services are unlikely to attract media attention. Therefore the 'near miss' events that did not result in serious injury or excessive damage are unknown. The safety pyramids of Heinrich and Bird (Bird, 2003) suggest that for every major incident there are an estimated 600 near miss incidents. These predictions indicate that there were potentially 7,200 'near miss' vehicle rollaway incidents in the 3 year period 2008-2011 based on the number of fatalities reported in the media. From the data available, the estimated annual average of vehicle rollaway fatalities only represents around 1% of the annual average of 500 pedestrian fatalities recorded by the UK Department for Transport (DfT, 2015). These numbers are small and are only related to rollaway incidents within the UK but in recognition that there is likely to be considerable under reporting and that the problem of vehicle rollaway is not peculiar to the UK, it warranted further exploration.

The costs of vehicle rollaway incidents extend beyond those of property damage and the associated financial implications. When a serious injury or even a fatality occurs there is likely to be emotional and psychological trauma to all involved. Regardless of this, such data pertinent to the nature of the incident and the associated costs did not seem to be recorded. Despite contacting six motor vehicle insurance bodies including the statistics department of the Association of British Insurers, it was reported that data specific to vehicle rollaway or parking brake failure was not held (Mumin, 2012; Watson, 2012) and it was therefore not possible to ascertain the costs of such incidents.

### 10.3.2 Driver reported experience of vehicle rollaway

Data collated within this research indicated that vehicle rollaway is not a rare phenomenon. In response to online surveys, 12% of drivers and 13% of approved driving instructors reported such an experience. More than a quarter (29%) of drivers who participated in the observational studies in their own vehicles reported an experience of vehicle rollaway or recalled a situation where the vehicle had failed to remain stationary.

The research suggested that driver error could be a factor and the self- reported recall of circumstances were categorised into mechanical, driver and environmental or other to reflect the road safety systems approach and Haddon's matrix (Haddon, 1980; Leveson, 2002; Peden et al., 2004; Wierwille et al., 2002).

The responses from the observational study participants indicated that the majority (94%) of the reported vehicle rollaway incidents were driver related with reasons recalled being 'distracted or in a rush' (44%) and 'forgot to park in gear' (50%). Mechanical failure was reported to be attributed to vehicle rollaway by only 6% of the respondents. These results are comparable with the figures reported in the literature that 75% - 90% of crashes are related to driver error (Wierwille et al., 2002; Peden at al. 2004; Harley et al., 2008; Hollnagel, 2014) and distraction is attributed to 23% of crashes and near misses (Young and Salmon, 2012).

Although around a third (36%) of the respondents to both online surveys indicated that factors related to the driver were contributory to vehicle rollaway when the parking brake had been applied, the results suggested that around half (51%) were more likely to associate the failure with mechanical or vehicle factors. The reported mechanical or vehicle factors included faulty or poorly designed parking brake (36%), EPB (10%) and brake cooling effects (5%). Human or driver factors included not selecting a gear (19%) and not applying the parking brake sufficiently (17%) with 19% of these indicating that they ‘forgot’ or were distracted. It was considered that as found by Eboli and Mazulla (2011), the responses provided during the observational studies i.e. face to face interviews, provided more representative results and therefore it is more likely that vehicle rollaway is associated with human failure.

Other factors (12%) reported by the drivers surveyed to affect vehicle rollaway were related to the surrounding environment including steep incline, ice and snow, vibration and external force. While conducting observations of vehicles parked in NHS car parks, the managers of the multi-storey car parks recalled incidents when parked vehicles had rolled out of the parking space. They reported that these incidents were more likely to occur when the carpark was busy and proposed that vibration could be a factor. However there was limited data available to explore this as these incidents were only documented if considerable property damage or injury had occurred. Other external factors that could contribute to the failure of an already compromised system’s holding capability include applying an external force such as leaning against the vehicle, slamming the boot shut or being nudged by another vehicle. Although these factors were considered, controlling the variables in real life studies were outside the scope of this research.

### 10.3.3 Investigation of vehicle rollaway incidents

Investigation of accidents from a human factors or systems perspective requires the exploration of organisational, mechanical and human factors. That approach may be limited in investigations involving private passenger vehicles where a ‘blame or no blame’ conclusion is required. The judicial outcomes of three fatality cases were ‘mapped’ to sections of the fault tree as seen in the grey call out boxes of Figure 10.3 to illustrate examples of rollaway incidents and their outcomes. These three cases were reported in the media and further access to details was gained through personal communication. The investigation outcomes concluded the contributory factors to be human error, parking brake insufficiently applied and brake cooling. Only one of these three incidents occurred on what was referred to as a steep gradient. In all three cases, the vehicle was not parked in gear and two of the three outcomes indicated that this would have avoided a vehicle rollaway.

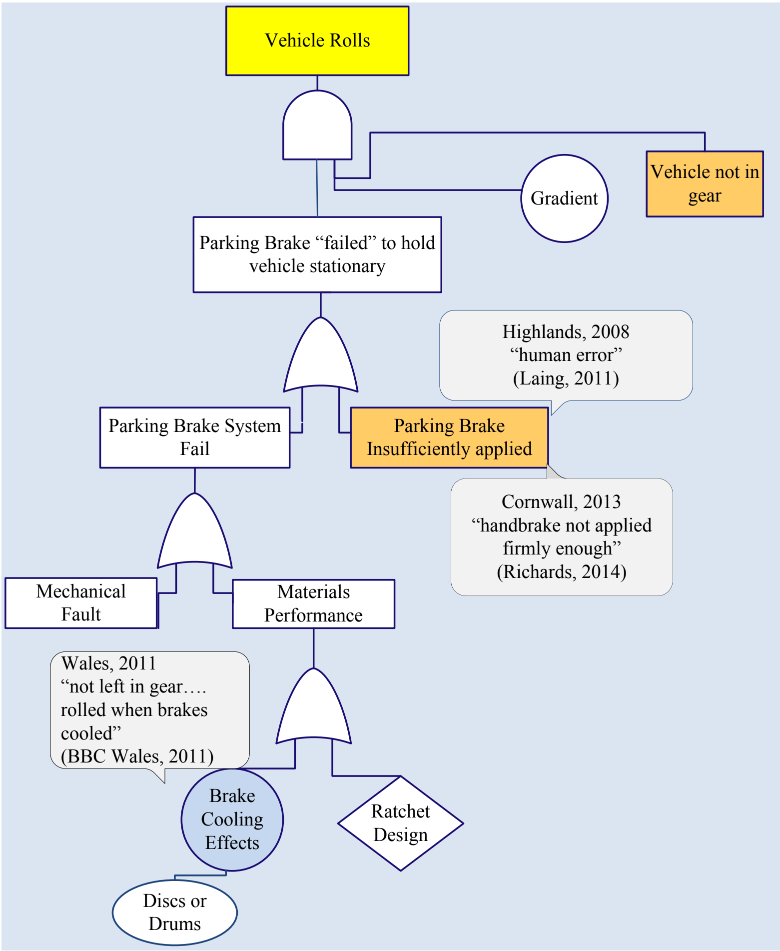



*Figure 10.3 Examples of legal investigation outcomes 'mapped' on event tree (lever operated PB)*

When the conclusions as to the causes of these tragic accidents were made, the contributory factors seemed to be considered in isolation. For example, the fatal incident that occurred in the Highlands (Laing, 2011) was concluded to be as a result of human error in that the driver did not apply the parking brake sufficiently (Laing, 2011). The driver was inexperienced, the gradient was less than 5% and the vehicle was not parked in gear. The report indicated that no mechanical faults were found during the police investigation but the type of rear brakes was not noted or whether the vehicle was tested after being driven so that the brake temperature had been raised. The manufacturer and model of the vehicle involved had been subject to a vehicle recall related to parking brake failure in the previous year.

The vehicle involved in the incident in Cornwall (see Figure 10.3) was parked on a 10% gradient and rolled at around 10 minutes after being parked. The investigation uncovered that the parking brake lever was only applied 2 out of 6 notches. Testing of the vehicle's parking brake holding capability with cold brakes, assessed this to be insufficient to hold the vehicle stationary but when a gear was selected it was concluded that the vehicle would remain stationary even on a 20% gradient (Richards, 2014).

The incident that occurred in Wales (BBC, 2011) and mapped to the brake cooling effects in Figure 10.3, occurred on a private driveway and was instrumental in development of a campaign to encourage people to park in gear (ROSPA, 2012). The vehicle was parked on a steep incline and rolled away after the driver exited the vehicle. The driver could not recall being instructed to park in gear and reported it was not their normal practice. The coroner's report did go some way to consider it was a combination of factors (not parking in gear, the steep gradient and brake cooling) that led to the vehicle failing to remain stationary.

Even when an injury does not occur a vehicle rollaway can cause major disruption to services: such as when a vehicle rolled onto a railway track from a nearby car park (The Railway Accident Investigation Board (RAIB), 2009). Investigation of the incident focused on the environmental control measures and no indication was made as to how parking brake system failure could be addressed In a similar way, any environmental changes in car parks such as barriers along walkways may reduce the consequences and severity of a vehicle rollaway incident but does not contribute to prevention of rollaway itself.

These incidents illustrate how a systems approach to investigating vehicle rollaway incidents can identify the latent failures and help to minimise the consequences of active failures. Using Reason's Swiss Cheese Model, the barriers or defence mechanisms such as legislation, training and instruction, vehicle and system design and driver behaviour can be explored and from there, remedial action can be recommended. This approach is mindful that there may be multiple potential failure factors. It recognises that when the weaknesses or 'holes' in the safety management structure align and an active failure occurs at the driver interaction with the system interface there is an increased risk of rollaway. Exploration of the factors involved requires an understanding of the task to uncover what contributes to an unsafe condition and an unsafe act resulting in an accident.

## 10.4 Interaction with the Parking Brake System

The main function of the parking brake system is to hold the vehicle stationary, even when unattended, whether facing up or down a gradient. Successful operation of the parking brake and completion of the task demands control, co-ordination and safe interaction with the system, the environment and other road users (Salvucci, 2006; DSA, 2011; DVSA, 2014).

The physical application of the manually operated parking brake of right hand drive vehicles requires the driver to grip the lever, apply a force (which should not need to exceed 400N) and pull upwards (UNECE, 2008; 2014; Day, 2014, pp. 259-302) using what is the non-dominant hand for 90% of the UK population (McManus, 2009).

Cognitively, the driver must have an understanding of the surrounding environment, the parking brake system and the level of knowledge, skills and experience required to successfully complete the task (Groeger, 2000; Reece and Walker, 2007). The task requires explicit knowledge of how to operate the parking brake lever and implicit knowledge of the magnitude of force required for successful application in relation to the perceived gradient and surrounding environment. The driver practice may be based on stored knowledge through experience and/or training and instruction.

Interaction of the driver with the parking brake system may be largely an automatic process, but a situation requiring the vehicle to be parked securely is followed by perceptive, diagnostic, prognostic, decisional and psychomotor stages before an outcome is achieved. This reflects the decision making processes described by Van Eslande and Fouquet (2007). Each functional stage of the parking task could be associated with a number of potential failures which through a malfunction in the process results in the vehicle failing to remain stationary. Breaking the task down into its subtasks helps define at what stage the human failure may occur.

## 10.5 Current Driver Practice and Influencing Factors

### 10.5.1 Introduction – vehicle not parked in gear

The UK Highway Code (Sections 23-252; DfT, 2007), and the Driving Standards (element 2.1.4, DSA, 2011), requires that when parked on a gradient, the driver, before leaving the vehicle, applies the parking brake, selects a gear and turns the wheels towards or away from the kerb so that the vehicle remains stationary.

Despite that, some 41% of the rollaway incidents collated from the media reports between 2008 and 2011 indicated that the vehicle was not parked in gear. The factors that influence whether a driver parks their unattended vehicle in gear are discussed in this section. Figure 10.4 illustrates part of the fault tree that explored current practice in relation to parking in gear and the factors that may influence the practice.

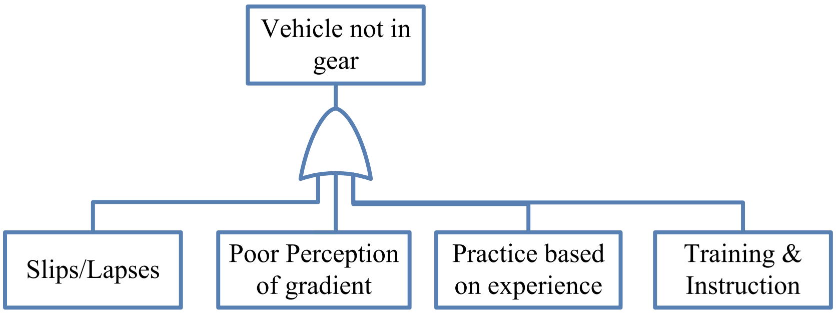



*Figure 10.4 Factors affecting practice of parking in gear*

Although results indicated that around 80% of drivers did park in gear when parked on a slope, only half of those surveyed and none of the drivers observed on a 20% gradient would also turn the wheels. This portrays a level of non-compliance with regulatory bodies and coupled with the fact that around a quarter (24%) of drivers observed selected the incorrect gear in relation to the direction the vehicle was facing some understanding as to why this practice occurs was required.

### 10.5.2 Distraction and interruption in process (slips and lapses)

The task of parking a vehicle carries a degree of automaticity and as such may be vulnerable to error particularly related to distractions. In reference to Reason's unsafe acts taxonomy (Reason, 1990) the error type, whether slip, lapse or mistake may be dependent on the driver indirect and direct causes, the environment and the vehicle. A slip occurs when the attention of the operator or driver is directed elsewhere and not focusing on the task. Lapses are missed actions and omissions, i.e. when somebody has failed to do something due to lapses of memory and/or attention or because they have forgotten something (Dismukes, 2003, 2010)

Fourteen percent of vehicle rollaway incidents reported by the drivers surveyed were identified as slips and lapses where the driver had ‘forgotten to park in gear’ or ‘forgotten to apply the parking brake’, with 9% indicating they had been distracted by a colleague speaking to them as they were parking. For example, one of the drivers reported returning to their car when the parking brake was not applied. Fortunately the vehicle did not rollaway as he had left it parked in gear, whereas another driver who spoke to a colleague while parking later returned to her vehicle to find it had rolled against the car park barrier.

Drivers who were observed parking their own vehicles on a gradient, were asked to recall the order in which they operated the vehicle controls while parking. In some cases, immediate recall was difficult and the driver was observed practising the procedure in order to record the order of events. Observations and interviews with the drivers indicated some individual variation in the order of operating the controls when parking and that order may change in relation to the perceived gradient. For example, 59% of the drivers observed indicated they would select a gear before turning off the ignition when parking on the flat. The number of drivers who would repeat this order on a gradient increased to 71% suggesting a variation in practice across the gradients for 12% of participants and the opportunity to omit a stage in the process.

Regardless of the order of sequence, this routine task is skill based and largely automatic where the cognitive function is mainly one of monitoring (Schneider et al., 1984). As observed, the driver may or may not be able to recall and repeat the order that the components of the task are conducted. Applying the parking brake and parking a vehicle is a highly practised procedure and as described by Dismukes (2003, 2010) is likely to develop ‘look without seeing’ automatic responses which is subject to omissions if the procedural flow is interrupted. For example, if a driver’s normal practice is to select a gear after turning off the ignition and is distracted by a passenger, that stage could be omitted increasing the risk of rollaway.

Although much of the discussion has been in relation to the physical interaction with the parking brake system, there are individual factors in relation to cognition and the contribution to error or failure that require attention. Parallels can be drawn with system failures for more complex systems and play a part in the taxonomy of factors explored that may contribute to the parked unattended vehicle failing to remain stationary.

Almost a quarter (24%) of the drivers observed parking on the 20% gradient selected first gear instead of reverse when the vehicle was facing down the gradient. The vehicle remained stationary but the wrong gear with reference to the UK Highway Code and Driving Standards was selected. While this ‘slip’ may occur due to the driver’s attention being directed elsewhere, it could be a rule based mistake related to the individual’s knowledge and experience as described by Dismukes, (2003, 2014). As reported in the online surveys, a lapse such as forgetting to apply the parking brake or forgetting to park in gear, can result in the vehicle failing to remain stationary. In addition, where the driver does not park in gear, once again it could be related to instruction and experience rather than a violation or conscious ‘unsafe act’.

Factors reported in the online surveys such as ‘being in a hurry’ prevents conscious monitoring of automatic processes and therefore may make the process more vulnerable to slips and lapses (Dismukes, 2003) and as indicated by Harley and Cheyne (2005) and Harley et al. (2008) is a potential contributory factor for vehicle rollaway. This is an area for consideration where private passenger vehicles are used for work purposes e.g. for Health Care workers conducting domiciliary visits with limited time between visits and home delivery franchise drivers.

Slips and rule based mistakes are related to ‘feedforward control’ where actions are based on previous successful experiences but the actions are not carried out as intended or planned. Around 57% of the drivers surveyed related their parking practice to experience or how they parked overnight. One driver, who participated in the incline study, routinely parked his vehicle, with confidence, on an incline with only the parking brake applied. However, he later contacted the researcher to say that his vehicle had rolled away and attributed the incident to mechanical failure, that the parking brake required adjustment.

Mistakes are a specific type of error brought about by a faulty plan/intention, i.e. somebody did something believing it to be correct when it was, in fact, wrong. Could pressing the release button be considered as a mistake? The driver does this as he believes it to be correct and may be the way he was instructed but with reference to the owner's manual it is an incorrect action. Similarly, not parking in gear on an incline may be seen as a 'breach' of the Highway Code or a traffic violation but if the driver's rule base is that he only parks in gear for what he perceives to be a 'hill' and not on shallow gradients or inclines then it can be considered as a mistake rather than a deliberate act.

It is considered that drivers who mistakenly do not park in gear when parking on an incline have not developed the appropriate rule base. As such, they are not deliberately committing a violation but are omitting an action that would be recognised if the knowledge base was sufficient. In that way the plan to complete the task of parking the vehicle so that it remains stationary may be inadequate to achieve the successful outcome. Whereas drivers who consciously do not apply the parking brake may have established a rule base influenced by situational factors.

Unsafe driver behaviour or practice can be a result of an error or a violation. People do not intend to make errors therefore there must be some underpinning by cognitive failures and distractions that can be caused by many factors such as external distractions from e.g. passengers or innate distractions related to the driver's own emotional state. Violations by contrast are deliberate deviations from recommended practice (Reason et al., 1990).

Drivers who reported a vehicle rollaway also indicated that they were more likely to respond positively to 6 of the 8 driver behaviour questions contained in the driver survey than drivers who did not report a rollaway. When the results for the responses were compared, there was a greater percentage response by those who had experienced a rollaway than those who had not to: being in the wrong lane before a roundabout or junction (22%); driving away in 3$^{rd}$ gear (22%); realise no recollection of the road (16%) and misread signs and exit on the wrong road (16%). These figures support reports in the literature such as by Lawton (1998), Salmon (2010) and Af Whalberg, Dorne and Kilne (2011) who suggest a link with distractions in low speed accidents with slips and lapses in other areas of driving.

### 10.5.3 Parking practice

The wording of the UK Highway Code stating "must apply the parking brake" and "should select the appropriate gear…" (DfT, 2007) gives tacit obligation to the driver to understand what is required. A *must* do means anything other than what is required is a violation and direct legislation applies whereas *should* do means it may be a traffic offence but in the UK it may not be enforceable.

The variation in practice and the decision as to whether or not to park in gear could be due to the perception of the gradient. Reference to a "hill" in the Highway Code (sections 238-252) or slope in the driving standards (DSA, 2011) leaves interpretation of the action required to the driver and may be based on a subjective assessment of the gradient and/or surrounding environment.

Most of the drivers surveyed reported that, apart from applying the parking brake, they would take additional measures to ensure the vehicle remained stationary on a slope. Half indicated they would select a gear with a further 39% parking in gear and turning the wheels. However, there was a significant difference ($p<0.05$) in the reasons given for the additional measures. Only 29% related this to the way they had been instructed with 46% relating their practice to 'past experience'. Yet the majority (90%) of Approved Driving Instructors (ADIs) surveyed indicated they would instruct pupils to park in gear and turn the wheels on a 20% gradient. This figure is inclusive of the ADIs who would instruct learners to park in gear and turn the wheels on a 10% gradient (32%) and a 15% gradient (22%).

Despite the results of the online surveys and observational studies portraying some awareness of the risk of the vehicle parked on a 'slope' rolling away, the disparity between reported and observed practice was indicative of drivers over estimating their tendency to follow recommended practice i.e. park in gear and turn the wheels towards the kerb. In addition, almost a quarter of drivers observed selected the wrong gear regardless of the instructions within the Highway Code and some manufacturer owner manuals.

When drivers were observed parking their own vehicles on a 20% gradient to leave it unattended, almost 80% (77%) parked in gear, but none of these turned the wheels towards the kerb. Just over three quarters (76%) of the drivers selected the correct gear (reverse) for the direction they were facing. On the 10% gradient the number of drivers who selected a gear was similar (82%) but only 67% selected the appropriate gear.

Just over half of the respondents to the driver survey reported they would apply the parking brake and select a gear when leaving their parked vehicle in a car park. In comparison, only about a third of the unattended vehicles observed in the five NHS car parks were parked in gear and 46% of the drivers observed parking their own vehicles in the gradient studies selected a gear when parked on the flat.

This interpretation as to what parking practice is required extends to the instruction provided by ADIs. Contrary to the reported and observed practice of drivers, only 16% of ADIs surveyed indicated that they would instruct learners to park in gear on the flat with a significant number ($p<0.05$) indicating they would instruct learners to only apply the parking brake. Although the percentage of ADIs who reported they would instruct their pupils to park in gear and turn the wheels increased as the gradient increased, the online survey of ADIs indicated some variation in this instruction. The results indicated that at the 10% gradient there was least definition (6%) between the percentage of ADIs instructing to park in gear and those also instructing to turn the wheels. The perception of the 10% gradient would appear to be a key marker with a significantly higher percentage of ADIs indicating their instruction would be to park in gear, whether or not the wheels were turned, on gradients of 10% and more.

The regional responses by ADIs suggested a regional influence on instruction with a greater percentage of ADIs in the North East, Scotland, South West, Wales, York and Humberside reporting to instruct learner drivers to park in gear and turn the wheels on 10% gradient. These regions host some of the areas of greater topography within the UK so instruction may be influenced by the surrounding environment. These results were mirrored by the observations conducted in the NHS car parks where a greater percentage of vehicles in regions of higher topography (Scotland and South West) were parked in gear. The least percentage of vehicles with manual transmission and parked in gear was observed in the car park of the flattest region of the UK. These results suggest that despite the level of the car park bays not exceeding 10%, the parking practice may be influenced by the surrounding regional topography and as such reflect the habitual practice of drivers in relation to that. However any conclusions are considered with caution as it cannot be confirmed that all parked vehicles observed were registered and kept in the local area.

‘Past experience’ was indicated to be a significant ($P<0.05$) influencing factor on the habitual practice for both parking on an incline and parking on the flat by drivers surveyed online The results were in response to a closed survey question where ‘past experience’ was a selection option and therefore may be inclusive of personal experience and that of others in relation to rollaway That past experience may also influence the extent of the practice into parking circumstances. For example, drivers who responded to the online survey through the ‘Park in Gear’ (PING) campaign indicated past experience as an influencing factor and reported that they were more aware of the need to park in gear on an incline. However, the results indicated only 61% of these respondents applied this to parking in all circumstances, regardless of the gradient. This is also reflective of how campaigns can improve knowledge and awareness but not necessarily increase the level of compliance with legislation. Only when enforced can the level of compliance with legislation be increased (Broughton, 1984; Peden et al., 2004; Gwilliam, 2009).

It was considered whether past experience of a vehicle rollaway could effect any change in practice for ADIs and the instruction they provided. Of the 13% of ADIs who reported an experience of rollaway in their own vehicle, 88% continued to instruct learners to only apply the parking brake only parking on the flat. However, 20% more ADIs with past experience of a rollaway indicated that they would instruct learners to park in gear on gradients of 5% and 10% than ADIs who did not report any past experience of rollaway.

The suggestion that routine parking practice in relation to a familiar environment, and/or surrounding topography, was explored by asking drivers to indicate how they parked their vehicle overnight. A comparison of online survey respondents indicated that 10% more of the drivers who parked on a slope reported they would park in gear when leaving their vehicle in a car park than those who parked on the flat overnight. Drivers in the face to face studies were asked to rate their level of confidence that their vehicle would remain stationary on an incline and their results were compared with their reported overnight parking practice. The majority (91%) of drivers who parked on a moderate or steep gradient overnight indicated that they were very or extremely confident that their vehicle would remain stationary when parked on an incline. This level of confidence dropped by 26% when they were asked whether the vehicle would hold with only the parking brake applied. In relation to drivers who indicated they parked on the flat overnight, 65% indicated a similar level of confidence that their vehicle would remain stationary on an incline and this was unchanged in relation to whether the vehicle would hold with only the parking brake applied. Further analysis of the results indicated an additional degree of confidence ($p=0.038$, $p<0.05$) is provided by parking in gear for drivers who would normally park in gear on the flat. This degree of confidence may have developed through learned behaviour (Sharit, 2006) as a result of past experience but equally could be influenced by an untoward event. For example, one driver participating in the face to face study confidently did not park in gear at any time and indicated the ability to apply sufficient force to the lever to hold the vehicle stationary. However, during the period of the research, he contacted the researcher to say that his vehicle rolled away on a gradient of less than 10%. He attributed the rollaway to 'mechanical failure' but reported a change in practice as a result i.e. that he would park in gear at all times.

### 10.5.4 Perception of the gradient

In accordance with Curry, Meyer and McKinney (2006), what the driver perceives is influenced by past experiences, education (training and instruction), (safety) cultural values and the task being performed. Due to the familiarity of the task, i.e. parking the vehicle, only a fraction of the information available from the surrounding environment is processed (Curry, Meyer and McKinney, 2006). It is therefore possible that drivers who do not routinely park in gear and routinely park on the flat may introduce a combination of incident causality factors when parking in an unfamiliar environment (Wierwille et al., 2002). Their failure to perceive the gradient and the associated level of risk of vehicle rollaway could be related to inadequate training, knowledge of the system or transference of skills into practice.

Presentation of visual and verbal parking cues during observational pilot studies using a Static Assessment Rig (SAR) and three vehicles parked on a garage forecourt, indicated that drivers adjust the force required to operate the parking lever in relation to the perceived gradient but they may or may not park in gear. In respect of this, during the studies where drivers were observed parking their own vehicle on different gradients, care was taken to avoid influencing drivers' perception of the gradient by avoiding terminology such as gradient, hill or slope during the assessment procedure. Instead phrases such as "can you reverse back to the mark or reverse back until I tell you to stop" were used particularly on the 20% gradient.

The results from the online surveys and observational studies indicated that there is no clear indicator as to what gradient is considered to be a "hill" as stated in the Highway Code. In addition 'slope', incline and gradient adds to the ambiguity of the instruction and at what percentage of gradient the requirements of the Highway Code should be applied.

Presentation of interim results to members of the Vehicle Safety Branch (VSB) of VOSA and to Education leads at the Driving Standards Agency (DSA) led to continued communication and contribution to changes in the wording of the Driving Standards (see Appendix D.3).

The 2015 edition of the official guide to driving encourages drivers to park in gear at all times (DVSA, 2014 pp. 57-58, 240). The instruction "remember when you park your vehicle, always park in gear and make sure that the parking brake is fully on" (DVSA, 2014, p.57) removes any ambiguity as to when to park in gear and does not rely on the perception of the gradient. Based on the results of the empirical studies, the introduction of the amended driving standards required a change of practice for approximately 80% of ADIs and 45-64% of drivers. A review of practice following the amended standards would be recommended.

## 10.6 Interaction with Vehicle Controls

### 10.6.1 Application of force and perceived effort

The UK Highway Code (DfT, 2007) and Driving Standards prior to 2015(DfT, 2012) indicated that the driver must be able to apply the manually operated parking brake firmly when parking on a hill so that the vehicle is held stationary (DFT, 2007; DFT, 2012). Insufficient application of the parking brake was reported to be a contributory factor to vehicle rollaway in 41% of the collated media reports and by 14% of the drivers surveyed who reported such an event. In addition, 55% of ADIs surveyed reported that learner drivers demonstrated difficulty applying sufficient force to operate the parking brake effectively. These results provided the basis for exploration in the section of the fault tree in Figure 10.5.

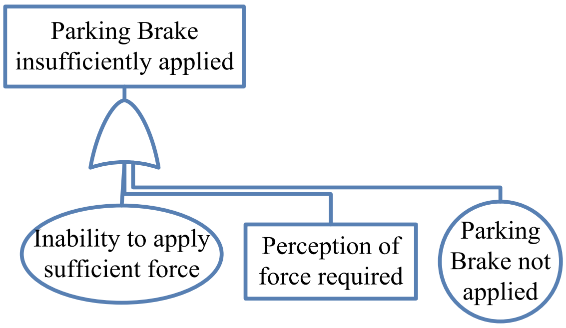



*Figure 10.5 Factors affecting application of the lever operated parking brake*

To apply the parking brake sufficiently so that the vehicle remains stationary, the driver needs to be able to perceive, and apply to the parking brake lever, the magnitude of force required in relation to the situation at that time. European Economic Community (ECE) Regulation 13-H states that the maximum force required to operate the mechanical lever parking brake should not be more than 400N and the driver should be able to apply that force from the driver's seat (UNECE, 2008; 2014).

Drivers responding to the online survey were asked to rate the level of perceived effort to operate the parking brake lever using Borg's rating of perceived exertion (RPE) scale (Borg,1998). The majority (76%) indicated that the perceived level of exertion was not hard ($p<0.05$) i.e. less than 13 on Borg's RPE scale. Less than a quarter (24%) of the drivers surveyed perceived the effort required to be 'somewhat hard' (rating 13) or more. There was no significant difference in the perceived effort reported between genders or across the age groups of respondents. Li and Yu (2011) indicated that the subjective measure of perceived force correlates with hand force required and it is a method widely used in the assessment of physical tasks (Borg, 1990, Li and Yu, 2011). The subjective data collated suggested that the majority of drivers are able to apply sufficient force to the parking brake lever to hold the vehicle stationary. However it did not provide an objective measure of the force applied and further exploration as to the actual force applied to the parking brake lever was required.

Observation of drivers simulating a parking task on a Static Assessment Rig (SAR) and in three stationary vehicles served as a pilot study prior to observing drivers conducting parking tasks in 'real life'. In this pilot study, a handbrake load cell connected to oscilloscope software was applied to the parking brake lever. The driver was instructed to operate the parking brake in response to visual and verbal cues, applying a force to the parking brake lever that was perceived to be required to hold the vehicle stationary. Three parking cues were presented: parking in a car park; parking on a hill and parking in a supermarket car park. In the absence of any tangible feedback, the force which the driver applied to operate the system was an active coupling of stored knowledge and the perception of the virtual gradient. The oscilloscope trace recorded in response to the parking on a hill cue indicated that drivers perceived that a greater force was required to pull up the parking brake lever to ensure the vehicle remained stationary when parking on an incline.

To observe what force drivers applied to the parking brake lever in 'real life' parking situations, 56 drivers with a mean age of 45 years and mean driving experience of 24 years, were asked to park their own vehicle, facing downwards, on a 20%, 10% or <5% gradient. The results for all gradients indicated that the force applied to the parking brake lever was less than 400N with only 7% of drivers recording a force of more than 400N on the 20% gradient.

The mean force recorded for drivers parking in their normal manner on the 20% gradient was 252.5N with only 7% of drivers exerting a force of more than 400N. On the <5% gradient the mean peak force recorded was 186.8N and on the 10% gradient the mean peak force was 228N. These results are comparable with the findings of previous studies by Pettigrew (1981), Kember and Staddon (1987) and McKinlay (2007) using on vehicle tests. The results also relate to the experimental study by Rozaini et al. (2013) which concluded that the minimal force to hold a vehicle stationary with 4 passengers and facing down a 20% gradient was 220N. Testing in the observational studies of this thesis was conducted only with the vehicle facing down the gradient for safety reasons but as Rozaini et al. (2013) found the force applied to the parking brake was greater when the vehicle was facing downwards than upwards, the results are indicative of the force applied in either direction.

Two of the drivers observed indicated difficulty applying sufficient force to operate the parking brake lever and around 55% of ADIs reported that learner drivers initially demonstrated difficulty applying sufficient force to operate the parking brake lever. The results from the study above indicated there was no significant difference in the mean force applied to the parking brake lever in relation to age or gender. While inability to apply sufficient force may be considered as a factor for vehicle rollaway, the drivers who realised their limited capability appeared to find ways of overcoming the problem such as using two hands to pull the lever up and always parking in gear. Although difficulty releasing the parking brake was only observed in one driver and reported by one driver in the online survey, concern regarding the ability to release the mechanism could influence the degree to which the lever pulled up. While 23% of drivers indicated a lower level of confidence that they would be able to release the parking brake after someone else had applied it, the majority of drivers (77%) indicated they were very or extremely confident that they could do so.

Prior to testing in drivers' vehicles, the left hand grip force was recorded using a grip dynamometer as a base level for the force the driver was able to exert. The force applied at the parking brake lever correlated with the hand grip force recorded using the dynamometer beyond the 5% significant level. It is considered that indirect measurement of force in this way could be used to predict whether an individual would be able to apply sufficient force to operate the parking brake lever and could be included in rehabilitative assessment purposes. However this requires further investigation outside the scope of this research.

The results from the observational studies indicated a weak association between shoulder height and the force applied to the parking brake lever. Although the mean force recorded in drivers own vehicles was greater than that recorded in the SAR, there was little difference in the regression values. In contrast, there was a stronger relationship between the measurement forwards from the hip to the parking brake grip in the SAR than in the driver's own vehicle. While these results relate to the left upper limb they reflect the experimental studies of Wang et al. (2011) who concluded that the maximum effort applied (all be it by the right upper limb) to the parking brake lever was when it was positioned furthest away from the shoulder. However in respect of the ability to apply sufficient force to hold the vehicle stationary, as per the findings of Kang and Duffy (2011) the anthropometry and gender did not have a significant effect on the co-ordination of the force required to pull up the parking brake lever.

### 10.6.2 Operating the parking brake lever

Four of 11 major vehicle manufacturers stated in their owner manuals ***not*** to push the button in when pulling up the lever operated parking brake. In some cases this was a recommended action following vehicle recall (VOSA, 2011; 2012) and media investigations (Which, 2007). For the other seven manufacturers, reference to the release button was only made for releasing the parking brake.

However, drivers may or may not be aware of the instruction in the owner manual and/or continue to operate the lever based on past experience and previous knowledge (Figure 10.6).

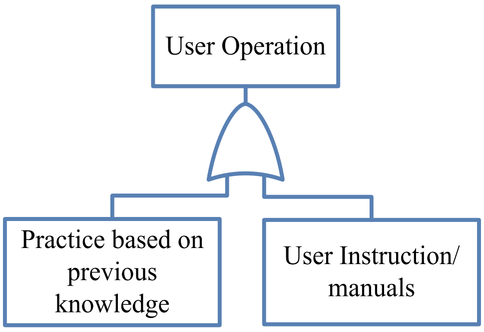



*Figure 10.6 Influencing factors for operating the parking brake lever*

Investigations by the Vehicle Safety Branch (VSB) of the Vehicle and Operator Services Agency (VOSA) indicated that the pawl and ratchet system may not engage correctly if the release button is depressed when pulling up the parking brake lever (Ryder, 2013a). The issue of the ratchet and pawl tooth on tooth was explored by the VSB and found that 22% of parking brakes tested demonstrated slippage or 'drop off' when the parking brake was not applied as per manufacturer's recommendations.

Twenty four owner manuals from 11 different manufacturers reviewed either made no reference to the release button on application of the parking brake or gave specific instruction such as 'do not'. Six of the manufacturers also instructed drivers in which gear to select whether parked up or downhill and to turn the wheels.

Despite owner manuals instructing drivers not to push the button in when applying the parking brake, only 20% of drivers surveyed indicated this as their normal practice with 80% of respondents reporting they pushed the button in. Only 9% of drivers surveyed reported referring to the operator manual indicating that the majority of drivers had a preconceived knowledge of how the system worked. This is supportive of the findings of Mehlenbacher, Wogalter and Laughery (2002) who indicated that only around half of drivers refer to the operating manual and that safety critical information should be visible in the vehicle.

Only two drivers participating in the observational studies did not push the button in. Almost all (96%) were seemingly unaware of the contents of the owner manual. The reasons provided for pulling the lever up with the release button depressed were generally: “as instructed, wears out the ratchets, don’t like the noise it makes”. In contrast to the findings by the Ryder (2013a), no slippage of the pawl on ratchet was observed during the observation of vehicles parked on an incline indicating that the drivers had successfully applied sufficient force to hold the vehicle stationary and engaged the pawl and ratchet system.

Although 15% of ADIs surveyed indicated they would advise pupils to refer to the operating manual, only 11% reported they would instruct learners not to push the release button in when pulling the parking brake lever up. Therefore it would appear that instruction as part of the initial learning stage and driver practice is contradictory to manufacturers’ recommendations.

In reference to Gibson’s theory of perception (Bellet, 2011) and Norman’s characteristics of design (Norman, 2013), the conflicting driver practice with instruction in the operating manual could be related to the perception of a simple system with perceived affordances. The lever affords the action of pulling and the button affords the action of pushing (action affordance). The outcome or perceived function (functional affordance) is that when the lever is pulled up sufficiently the vehicle will remain stationary. The majority (89%) of drivers surveyed in 2012 reported over 10 years driving experience and unless targeted as an owner of a vehicle which was subject to a parking brake recall they may be unaware of the amended manufacturer’s instructions for vehicles manufactured after 2003. Therefore, although applying the parking brake may be an automatic skill, the mistake of depressing the button when pulling the lever up is rule based where the driver practice deviates from the manufacturer's recommendations. If a change of practice is required, how that can be communicated, implemented and monitored requires further work. The evidence presented here provides a base for manufacturers to consider and evaluate what intervention is required including designing out this factor.

## 10.7 Mechanical Considerations of the Parking Brake System

### 10.7.1 Introduction

Previous research acknowledged the effects of brake cooling and described how as rear disc brakes cool, the disc material contracts and the contact force becomes insufficient to counteract the weight of the vehicle so that it rolls away (McKinlay et al., 2004; McKinlay 20017; Rozaini, 2013). Ryder (2013a) indicated that if the release button of the parking brake lever was depressed while it was pulled up the pawl and ratchet mechanism may not engage adequately.

This section discusses the effects of parking a vehicle on a gradient after the rear brake temperature has been raised and applying force to pull up the lever to engage at the lowest ratchet position required to 'just hold' the vehicle stationary. The mechanical performance is considered as part of the fault tree (see Figure 10.7)

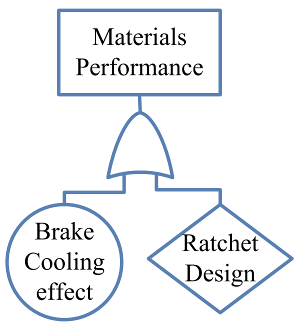



*Figure 10.7 Mechanical/vehicle factors affecting the parking brake system*

### 10.7.2 Operating the pawl and ratchet mechanism and brake cooling

Pulling the parking brake lever up without depressing the button allows the pawl to move over each ratchet and provides audible feedback to the engagement of the system. Instructing drivers to apply the parking brake ratchet by ratchet during the observational studies, although contrary to their normal practice, reflected manufacturer's recommendations, negated any effects of 'slippage' as described by Ryder (2013a) and allowed for recoding of the lever position.

A significantly lower ($p<0.05$) peak force was recorded to hold the vehicle stationary when the lever was pulled up ratchet by ratchet than when the button was depressed. The oscilloscope trace reflected a graduated increase in force application as the pawl moved over each ratchet. In view of this, instructing drivers to operate the parking brake lever without pushing the button in would overcome any difficulties experienced in the ability to apply sufficient force to hold the vehicle stationary.

To compare the holding capability of the parking brake system and explore the application of ECE Regulation 13-H and previous research in 'real life', the rear brake temperature of 53 privately owned passenger vehicles was recorded before and after driving a set route and monitored at 5 minute intervals while the vehicle remained parked on a <5%, 10% or 20% gradient.

The results indicated that the pawl position on the ratchet when the system employed *disc brakes* was lower when the temperature of the brakes had been increased than when the disc brakes were at ambient ($p=0.004$). For systems employing drum brakes, there was no statistically significant difference in the pawl on ratchet position when the brake temperature had been increased than when at ambient. This is likely to be related to the expansion of the brake disc material when the temperature is raised. In contrast, as engineering research indicates, a raised temperature has little effect on drum brakes and so expansion is minimal or none (Rozaini et al., 2013; Ishak et al., 2016). Based on these results, it is considered that when a driver follows manufacturer's instructions to apply the parking brake lever but relies on the number of 'clicks' to engage the system, the holding capability of a system with disc brakes is compromised.

These findings support the recommendation by McKinlay (2007) that drivers should be educated to apply the parking brake to the next 'notch' to allow for the cooling effects of the parking brake system. Encouraging this practice may also be a more effective way of addressing the perceived issue of 'slippage' when the tooth of the pawl sits on the tooth of the ratchet. In respect that reported and observed practice indicates that drivers continue to depress the release button when pulling the lever up, the instruction to 'pull up one more notch' may be an easier practice to implement and is an area for further exploration.

Previous research by McKinlay (2007) and Rozaini et al. (2013) reported a reduction in brake torque and holding capability as the temperature of the rear brakes returned to ambient after parking. McKinlay (2007) concluded that the likelihood of rollaway occurring was directly linked to the temperature of the brake when the vehicle is parked and the risk could be reduced by lowering the temperature of the brake prior to parking.

ECE Regulation 13-H, which is applicable to UK registered vehicles, states that the vehicle should remain stationary on a gradient of 20% for 5 minutes but does not specify an initial brake temperature for testing. Whereas, Federal Motor Vehicle Standards (FMVSS) 135, applicable in the US, includes a pre-testing temperature of 65°C to 100°C. Industrial testing such as the Federal Mogul hot hill test (McKinlay, 2007) considers the brake cooling effect and performance on different gradients: brake temperatures are raised to 50°C, 100°C, 200°C and 300°C on 3 different gradients and the vehicle is expected to remain stationary for 20 minutes.

The surface temperatures for rear disc brakes (mean 43°C) and for rear drum brakes (mean 26°C) recorded after driving a set route were lower than that of the industrial testing procedures and the experimental set ups by McKinlay (2007) and Rozaini et al. (2013), where the brakes were heated to 300°C and 200°C respectively. Despite that, vehicle rollaway occurred on all gradients even with a relatively small drop in temperature. Statistical analysis indicated a significant difference in temperature between discs and drums on initially stopping ($p=0.001$) which reduced after 5 minutes ($p=0.039$). This is explained by the fact that the frictional contact area is smaller in disc brakes than in drums and there is therefore the potential for a greater amount of heat to be generated. Previous research indicated that the rapid cooling is associated with the materials and the surface area exposed (Talatii and Jalifer, 2009; Ishak, 2014). As the brakes cool, the disc material contracts and when the contact force is insufficient to counteract the weight of the vehicle, rollaway occurs (McKinlay et al., 2004; McKinlay, 2007).

As the rear brake temperature returned to ambient, the vehicle rolled in 36% of the test cases. The vehicles rolled in 74% of the 23 cases where rear disc brakes were fitted. All nine of the vehicles fitted with disc brakes rolled on the 20% gradient with 22% of these failing to remain stationary in less than 5 minutes after stopping. Over half (55%) rolled between 5 and 10 minutes and 22% rolled after 10 minutes had lapsed but under 15 minutes. The mean temperature difference from stopping to rolling was 21°C with the minimum being 5°C. Only one vehicle fitted with drum brakes rolled due to the driver being unable to pull the lever up sufficiently to hold the vehicle when initially stopped.

There is cause for concern that 88% of the parking brake systems with disc brakes tested on the 20% gradient met the performance criteria required of ECE Regulation13-H i.e. to hold the vehicle stationary on a 20% gradient for 5 minutes with a force applied to the lever of less than 400N. Yet with a brake temperature increase consistent with a short commute, but lower than test temperatures employed in previous research, the vehicle could roll after 5 minutes of being left unattended.

Sixty percent of the vehicles with rear disc brakes parked on the 10% gradient and 56% of the vehicles with rear disc brakes on the <5% gradient rolled after a time period of 5 minutes had lapsed but within the 15 minute test period. On the near flat gradient (<5%), two of the vehicles with rear disc brakes and two of the vehicles with drum brakes rolled but stopped before reaching the chocks. This was not considered to be the stick/slip motion described by McKinlay (2007) as the vehicles remained stationary for the remainder of the test. However further work could explore whether the application of an external force such as forcibly closing the boot would provide the momentum required to initiate a rollaway in the 'rolled but stopped' scenarios.

Conducting the research with 'on the road' vehicles has confirmed that brake cooling is a potential factor in the vehicle failing to remain stationary even at relatively low rear brake temperatures and that systems employing disc brakes are more susceptible to vehicle rollaway.

For the 20% gradient, the mean difference from stopping to roll temperature was marginally less than the mean difference between roll to ambient temperature. For the <5 and 10% gradients the mean difference from stopping to roll temperature was greater than the mean difference in temperature between rolling and ambient. These results indicate that on a steeper gradient and where the vehicle is not parked in gear, a point of criticality is likely to be reached with a lesser temperature drop than when the vehicle is parked on a lesser gradient.

In relation to *driver interaction* with the parking brake system, if the driver practice is to:

- apply the parking brake lever to the point where the vehicle remains stationary AND/OR
- judges the position of the pawl on the ratchet by that required when the brakes were at ambient (possibly in reference to audible feedback) AND/OR
- does not park in gear

a vehicle fitted with disc brakes may fail to remain stationary as the brake temperature returns to ambient.

The demonstration that the holding capability of the parking brake system that employs disc brakes is likely to reduce as the brake temperatures return to ambient temperature, even at lesser gradients than 20%, is supportive of the change of practice to park in gear at all times. Pulling the lever up one further notch, or ratchet, than the ‘just hold’ position increases the input load to the system and increases the its holding capability. This change in practice requires additional education and awareness of drivers and approved driving instructors and improved communication from manufacturers. Further work is required on how this can be implemented and/or how manufacturers can alert drivers to the risk of failure. Some manufacturers have acknowledged the fact that current legislation may not allow for the effect of brake cooling and include testing at increased brake temperatures with extended cooling down periods. It is recommended that ECE Regulation 13-H be reviewed and amended to reflect brake cooling to encourage a standardised approach.

## 10.8 Limitations and Critique of the Studies

The studies within this thesis were conducted independently without commercial support. As such, data collection was subject to resource constraints and was reliant on positive relationships with key collaborators. The aim to explore the factors that could contribute to vehicle rollaway from a Human Factors, systems perspective and within a 'real life' framework resulted in some methods of exploration being amended and/or developed as the research progressed.

The absence of reliable data related to vehicle rollaway in the UK and limited related literature made it difficult to fully determine the magnitude of the problem. However, the accessible data and the results of online surveys indicated that the issue of vehicle rollaway, although not highly reported, was a real problem with potentially serious consequences and required further investigation. The sample size of drivers surveyed through convenience and snowballing sampling methods was small (less than 200), and responses from drivers who were aware of the 'park in gear' campaign could have introduced some bias towards practice in relation to past experience. The use of a closed selection choice for 'past experience' may have limited the responses as the response relied on subjective interpretation of the statement. A prompt for the respondents to explain their response might have indicated trends as to what past experience influenced their practice although identifying trends may unwittingly induce researcher bias.

Further exploration with a larger sample size could be achieved by distribution of the survey through motoring organisations such as the Automobile Association (AA) or the Royal Automobile Club (RAC). Only UK drivers were surveyed but future research extended to other countries where EU legislation applies would provide additional data in relation to practice and operation e.g. parking brake handedness, and comparison of results.

Observations conducted in a Static Assessment Rig (SAR) and in three static vehicles served as an effective pilot for development of the studies using drivers with their own vehicles. Although the parking brake lever in the SAR did not offer a comparable resistance with an on the road vehicle, the results did demonstrate the force the driver applied to pull up the lever in relation to the perceived gradient. It was originally planned that observational studies would continue with vehicles which are used for driver disability assessments and could be equipped with the appropriate instrumentation such as used for naturalistic studies (Foster et al., 2002; Gkikas, Richardson and Hill, 2009). However, review of the method indicated that the limited availability of vehicles and the restricted recruitment of participants would limit the data that could be collated and would not be reflective of real life practice.

Observational studies provide a 'real life' insight of the task, are likely to have face validity and produce data which allows for interpretation and challenge (Robson, 2011; Stanton et al., 2013). However, as found in the course of this research, such studies can be time consuming and when reliant on the availability of participants, weather conditions and general traffic movement, the variables can be difficult to control. It was absolutely essential that positive relationships with the study participants and the management personnel for the test areas were developed for the research to continue effectively.

Observation of drivers in their own vehicles introduced a multitude of variables but provided access to a number of vehicle models from several manufacturers in addition to drivers with varying experience and practice. Although the age of the vehicle and any dates of servicing or MOT testing were noted, no assessment was made as to the mechanical condition of the braking system. The only controls that could be set were that the vehicles were in a roadworthy condition, were not heavily laden and that all drivers had held their license for at least one year.

During the observational studies, instrumentation of vehicles could have provided additional data but it was not practical when using drivers' own vehicles and within tight time frames. As was discovered using the SAR, trying to set up different sets of data recording equipment for each test can be problematic for a single researcher and demonstrated the importance of pilot studies (Lancaster, Dodd and Williamson, 2004). To maintain a consistent quality of data and for ease of operation, methods were kept as simple as possible. The load cell and data acquisition combination that was developed for the studies was easily transferable between vehicles. Some consideration was given as to whether the load cell's position would alter the driver's hand grip on the parking brake lever and affect the force applied. As the release button was not depressed during application the hook grip enabled the pull up force to be applied perpendicular to the centre of the lever hand grip area as indicated in industrial test procedures. Like any study using technology, there can be equipment failure, but using data collection techniques which are not wholly dependent on software, and hardware, means the assessment time has not been wasted.

The load cell was able to detect the frequency that the parking brake was applied and the amplitude of the force applied to the lever throughout the duration of the test.

However, the number of times the brake foot pedal was depressed during driving the test route was not recorded to reflect what was required to increase the brake temperature. The route was controlled and included three types of braking performance but the braking practice was dependent on driver behaviour.

For future work, instrumentation of vehicles that may improve the efficiency of data collection methods should be considered. This may make the study more naturalistic, providing insight into parking behaviour on everyday trips unaffected by any observational related biases (Barnard et al., 2016). For example, use of mounted cameras to record physical operation of the lever; brake sensors could detect the frequency and type of braking required to raise brake temperature and thermocouples within brakes could record changes of temperature. Digitally recording any brake noises associated with stick and slip motion or any noises prior to rollaway may further inform engineers as to the nature of brake cooling and rollaway. That said, the additional technology would require additional skills of the researcher and access to resources to interpret the data collated.

The short duration of the 'controlled' test was more likely to receive participants and the researcher as observer within the vehicle was able to direct drivers on the pre-determined route while gaining information about their driving experiences. While the presence of an observer may have unknown reactive effects on the driver behaviour (Bryman, 2012, pp.279-282) it was considered that the interaction was valuable if not providing some reassurance to the driver with cautious awareness of observational bias (Robson, 2011; Stanton et al., 2013).

On reflection, asking drivers to estimate the gradient on which they were instructed to park could have added another dimension to the study to explore what drivers perceived to be a slope or a hill. The perceived gradient could be compared between drivers, and with online survey responses in relation to parking practice

Anecdotal feedback from participants in the observational studies indicated an increased awareness of their parking practice. A follow up interview of participants would have provided further data as to whether there was a change in practice following participation and quantify any increased awareness of the risk of vehicle rollaway.

Mixed methods studies were employed to explore the factors associated with vehicle rollaway. For future work, these data collation methods could be further refined to provide more data and extended statistical analysis for mechanical and electro-mechanical parking brake systems. Adding sensors to parking brake systems should no longer be technically difficult and the data provided will aid further understanding to investigate vehicle rollaway incidents in real life.

## 10.9 The Electronic Parking Brake (EPB) and Future Work

An electronic parking brake (EPB) replaces the mechanical system with an electrical one and so removes the need for any physical pulling up of a lever. Instead, the parking brake is actuated electromechanically via cables or an electric motor directly attached to the rear disc brake caliper. This is done by the driver activating a switch or automatically when the vehicle stops.

TRW Automotive projected that by 2015, 20% of all European built vehicles would be fitted with EPB as standard (Challen, 2010) and the amended ECE R13-H includes more specific requirements for EPB (UNECE, Feb 2014). SMMT figures for 2011 indicated that two of the 10 most popular vehicles purchased in the UK were fitted with EPB and the data collated in 2012 from five NHS public car parks across the UK indicated that EPB was starting to feature in newer vehicles. This seemed true of higher cost models with the expectation that it would eventually feature across most model ranges. However, only 12% of the drivers surveyed in 2012 reported their main vehicle to be fitted with EPB and the majority of ADIs reported that no more than 5% of learners used a vehicle with EPB.

In 2015, three out of the 10 most popular vehicle models purchased, equivalent of 26% of the total number of vehicles sold, were fitted with EPB as standard. Although this exceeds TRW's projection, almost half (47%), including the top two most popular vehicles sold, Ford Fiesta and Vauxhall Corsa, (SMMT, 2016) were fitted with lever operated parking brake as standard. The remainder of the top ten models were equipped with EPB or a lever operated parking brake dependent on level of specification. Given that the average age of UK vehicles between 2012 and 2015 was 7.7 years (Statista, 2016), vehicles manufactured in for example, 2015 with a manually operated parking brake system could still be on the road at least until 2022.

This signifies that research into interaction with the manually operated parking brake system remains relevant but the approach could be developed and extended to electronic and electro-mechanical parking brake systems.

The findings during this research suggest there is a lack of confidence in the EPB system and some confusion on its operation. During the observations in the NHS carparks, 45% of vehicles fitted with EPB were parked in gear compared with 34% of vehicles with lever operated parking brakes suggesting that parking in gear provided an additional level of security that the vehicle would remain stationary.

In all car parks the percentage of vehicles left in gear and fitted with EPB was greater than the percentage of vehicles left in gear and fitted with manually operated parking brakes.

This observation leads to further questions including:

*"Does this indicate a lack of confidence by the driver in the electro-mechanical system?"* particularly when survey respondents cite perceived system unreliability as an 'other' reason for parking practice.

Unlike the traditional lever operated parking brake which offers an 'action affordance', a change in design and lack of standardised operation with electro-mechanical parking brake systems presents a structural variance and a 'hidden affordance' where the driver does not know how the system operates.

During the course of the study, five drivers of vehicles with electro-mechanical parking brakes voiced concerns related to the operation of EPB. While the driver had established previous knowledge on how to operate a lever operated parking brake, operation of the EPB system required development of a new skill base and referral to the owner manual. Establishing whether the EPB was applied automatically when stopping without having to activate the switch; EPB not applying or releasing automatically if seatbelt was disengaged; how to release the system once applied; realising that the vehicle if parked on a steep gradient, the switch should be activated twice were reported.

The survey of ADIs indicated that 80% of respondents had some concerns about learners using EPB despite it being acceptable in driving tests since November 2010.

These concerns included learners understanding of how the system operated and their ability to drive vehicles not fitted with EPB.

Automation of any system has benefits but it can also introduce new problems such as operation confusion and complacency (Woods and Billings, 1997; Gkikas, 2011; Norman, 2013). The successful interaction with the automation of the parking brake system may be affected by the lack of standardisation across manufacturers and also the transfer of knowledge and previous experience. For example, one car driver described how his own vehicle was equipped with automatic transmission and an electronic parking brake which activated automatically. However his wife's vehicle was equipped with a manual transmission and a lever operated parking brake. On using his wife's car, he stopped and parked and began to exit the vehicle however he had failed to apply the parking brake or leave the vehicle in gear due to his practised automaticity.

Despite the removal of the physical application of the parking brake reports of either failure of the system or difficulty in its operation coupled with a perceived reduced level of confidence in the EPB systems indicates further work to explore the driver interaction is warranted. The fault tree analysis was altered to consider the EPB system (Figure 10.8) and could be used to compare the interaction with the components at the various interface levels of the parking brake systems.

In view of the findings of this thesis, it is expected that the focus would be in relation to the areas highlighted in yellow on the fault tree in Figure 10.8:

- operation of the system in terms of instruction offered and the driver's understanding of operation
- current parking practice and how that compares with instruction to park in gear
- the perceived level of confidence in the system
- whether learner drivers who use a vehicle with EPB as a learner are able to transfer those skills to a lever operated parking brake

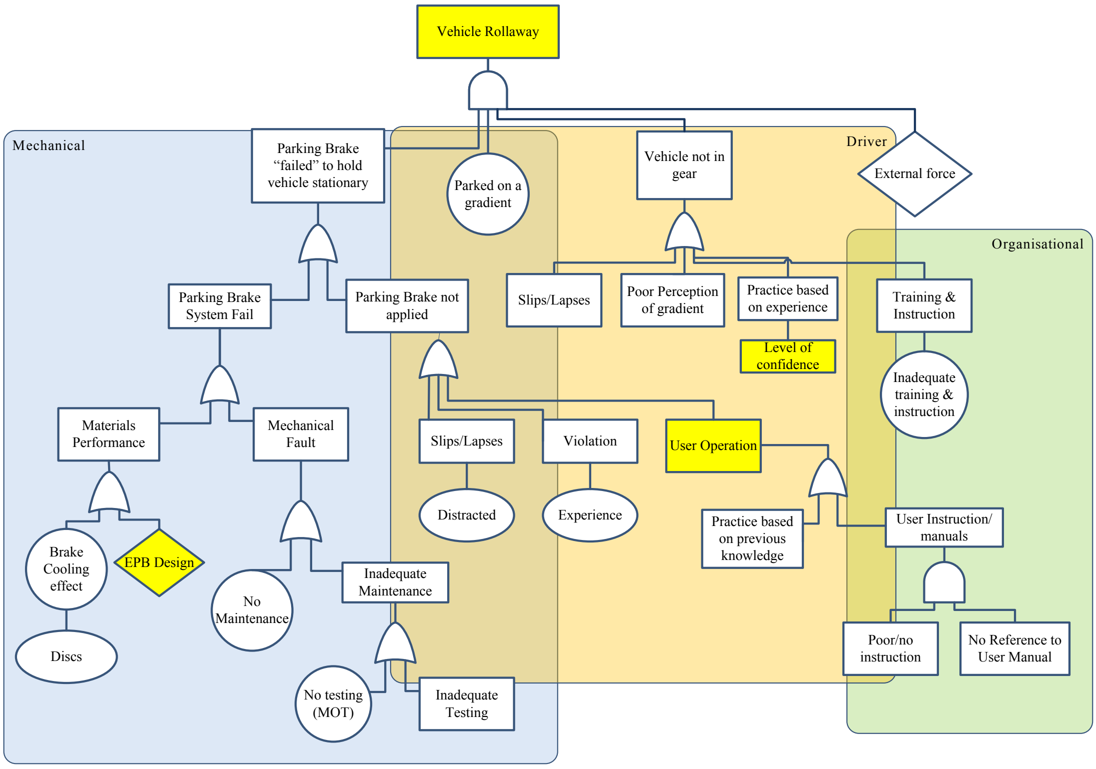



*Figure 10.8 Fault tree analysis of rollaway for vehicles fitted with EPB*

## 10.10 Overview of the Systems Approach

This thesis brings together a range of diverse data sources and empirical results to indicate the multi-dimensional nature of the problem and the complex interaction of different factors in a Human Factors systems approach. It is considered that the approach taken provides a conceptual model for understanding the factors associated with the task of parking a vehicle so that it remains stationary when unattended. It explores how the driver interacts with the system and contributes to knowledge to inform policy on the utility of use of the lever operated parking brake system and individual variables that could influence the operation of parking brake systems to prevent vehicle rollaway.

Reason's Swiss Cheese Model (Figure 10.8) has been applied to the parking brake system to provide a graphic representation of incident causation resulting from system failure. It highlights the defensive layers or barriers wherein a combination or accumulation of failures (represented as holes in the cheese) can result in the unwanted event of vehicle rollaway.

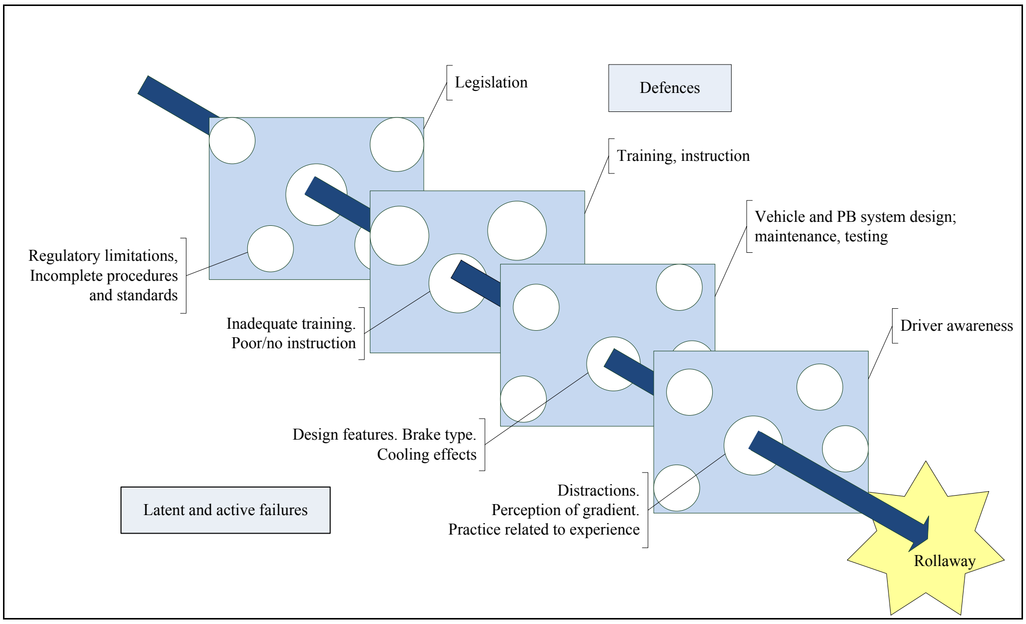



*Figure 10.9 Reason (1990) Swiss cheese model applied to the parking brake system*

The Swiss Cheese model helps to illustrate the contributory factors that lie dormant in the system (latent conditions) and how an active failure e.g. the driver not parking in gear, is an unsafe act within that process rather than the only cause. The defences or barriers within the system are considered here as organisational such as legislation; training and instruction; vehicle and mechanical design and the individual driver themselves.

The model implies that with enough defence layers in place and at least with holes that do not align the risk of vehicle rollaway is reduced. It demonstrates how with attention to the organisational and mechanical factors the demands at the driver interface level are reduced so that the risk of failure or rollaway is reduced. However any changes to the defence layers or introduction of new layers must ensure that new latent conditions and interaction issues are not provoked. For example, the design of the parking brake without instruction and understanding of its operation by the driver has the potential to provoke new errors which could lead to rollaway. In this case even if the design itself is intended to combat the risk of rollaway, the combination of design flaws, a contributory factor or latent condition from the previous defence layer i.e. training and instruction and an active failure when the driver interacts with the system indicates the possible consequences.

The use of the fault tree to explore the latent and active failures within the interaction with the parking brake system illustrates the factors that are organisational, mechanical and human. While the active failure occurs at the driver interaction interface, there are latent conditions and failures within the system that can combine to contribute to the consequences of vehicle rollaway.

These conditions and failures can be further illustrated in the accident taxonomy of Figure 10.10. This model is similar to that used in accident investigations (HSE, 2015) and it is recommended that the model could be applied to investigations of vehicle rollaway and be considered in design and development or parking brake systems.

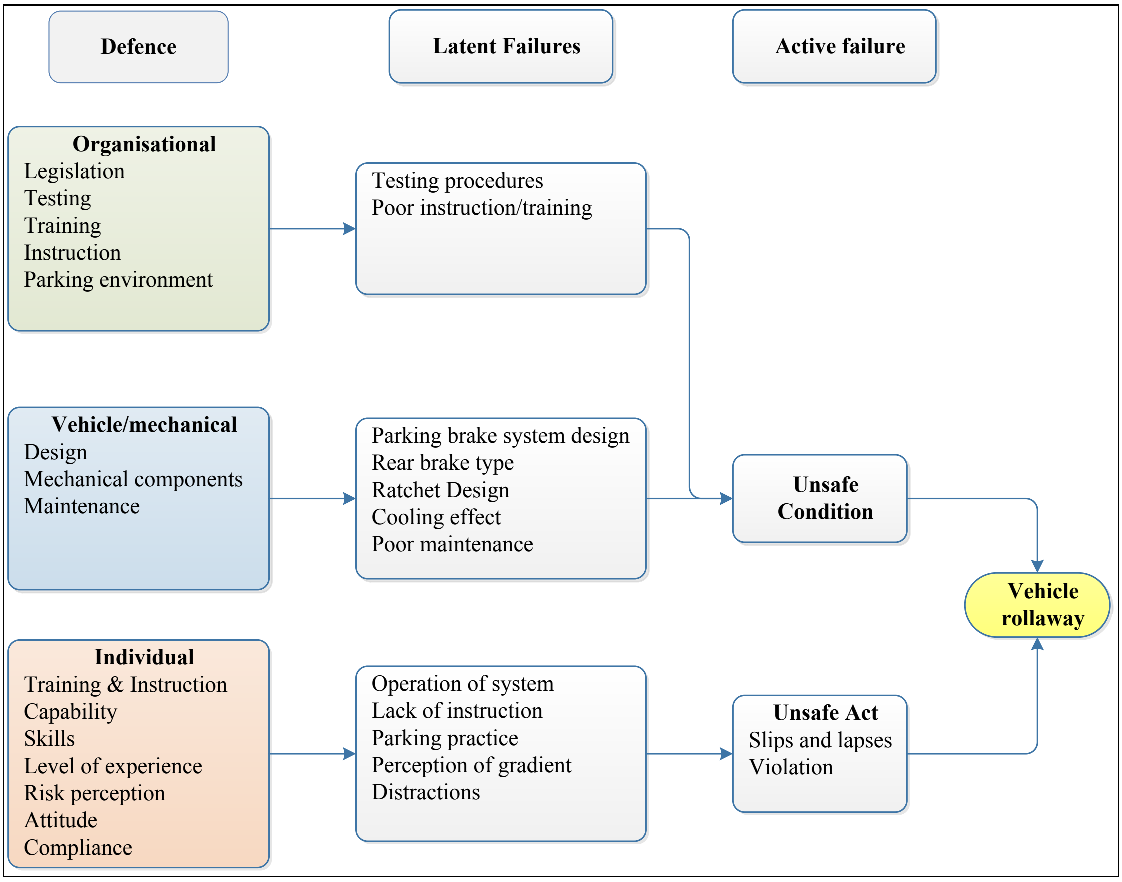



*Figure 10.10 Accident taxonomy for vehicle rollaway*

It can be seen that there is no one factor responsible for vehicle rollaway but a combination of system failures that become the recipe for vehicle rollaway. The

Swiss cheese model and fault tree analysis have been used as a framework to visualise and explore the contributory factors to vehicle rollaway.

Although fault tree analysis has typically been employed to explore complex systems, throughout this thesis the fault tree has been a useful tool to direct the reader to the area of exploration. Its application to researching the failure of what is perceived as a relatively simple system but yet could reach safety critical levels with catastrophic consequences, demonstrated how the generic technique can be applied in any domain (Stanton et al., 2013).

The research within this thesis, through the empirical studies, demonstrated that in addition to the mechanical components explored in previous research there are organisational and human components to consider. A systems approach to exploring the prevention of vehicle rollaway was adopted and is encouraged for future development.

# Chapter 11: Conclusions and Recommendations

## 11.1 Importance of Findings

When the parking brake system fails to hold a vehicle stationary in the absence of the driver, the resulting rollaway can have catastrophic consequences. This thesis is believed to be the first collection of research studies to explore the issue of passenger vehicle rollaway using an ergonomics and human factors systems approach. Where previous research has focused on the mechanical, vehicle components, the empirical studies within this thesis explored the organisational, mechanical and driver factors which can contribute to vehicle rollaway. The results of the studies indicate that in keeping with Reason's Swiss Cheese model, there are latent failures that lie dormant in interaction with the parking brake system and when these latent failures are triggered by an unsafe condition or unsafe act, a rollaway will occur. The research highlights that there may not be one single causative factor but a combination thereof and although the driver action of parking in gear is considered a remedial action, other components in the system interaction cannot be ignored.

More recent investigations into commercial vehicle rollaway accidents have employed a human factors systems approach but to date this has not been employed in passenger vehicle incidents. As vehicles become more automated, it is key that Human Factors principles are employed at an early stage to 'design out' the risk of vehicle rollaway as a result of human failures in the system. The focus of this research has been on lever operated parking brakes, but it demonstrates that when the physical effort required is not a potential source of human failure there are other factors within both the mechanical and electro-mechanical systems which can contribute to vehicle rollaway.

## 11.2 Organisational Factors – Legislation, Training and Industrial Testing

- UK drivers do not necessarily comply with current legislation related to the parking of unattended vehicles. The requirement to park in gear on a 'hill' or on a 'slope' is subject to interpretation as to what percentage of gradient the rule applies. Despite recent campaigns to increase awareness, parking practice is not enforced so any change of practice may be limited and is more likely to be influenced by past experience than instruction.

- A recommended change to Driving Standards requiring the driver to park the vehicle in gear at all times removes any ambiguity but may require a change in practice for drivers and up to 80% of Approved Driving Instructors. Further work is required as to how this will be implemented and monitored and extended beyond current 'park in gear' campaigns which tend to focus on child pedestrians and driveway safety.
- ECE Regulation 13-H states that the parking brake must be capable of holding a vehicle on a 20% gradient for 5 minutes but unlike some industrial tests it does not specify an initial, or pre-test, brake temperature.
- The results from 'real life' studies using drivers' own vehicles indicated that as the rear brakes cooled towards ambient temperature, vehicles fitted with disc brakes were susceptible to rollaway on gradients of less than 20% and after a period of 5 minutes had elapsed. These findings were supportive of previous research which indicated a reduction of holding capability in disc brakes as a raised rear brake temperature returned to ambient.
- It is recommended that legislation, and accident investigations, regarding the holding capability of parking brake systems allow for brake cooling effects in testing procedures such as already adopted by some manufacturers.
- A systems approach can be used retrospectively and proactively to consider the organisational, mechanical and human related contributory factors to vehicle rollaway. It is recommended that this approach be used to investigate vehicle rollaway incidents and the use of an accident taxonomy applied to the parking brake system is proposed.

## 11.3 Mechanical/Vehicle Components

- The manually operated parking brake employs a pawl and ratchet mechanism to engage the system. Previous investigations indicated that if the release button of the parking brake lever was depressed as the lever was pulled up, the pawl could fail to lock between the teeth of the ratchet resulting in the parking brake releasing. Contrary to instruction in owner manuals *not* to push the button in, the majority of drivers indicated that pushing the button in when pulling the lever up was their normal practice.

- The results from observational studies indicated that even at relatively small temperature changes, when the parking brake is applied without pushing the release button in until it just holds the vehicle stationary when initially parked, and the vehicle is not parked in gear, there is an increased risk of vehicle rollaway. This suggests that following the manufacturer's instruction may not necessarily reduce the risk of rollaway and all factors within the system framework should be considered.
- The findings indicated that in vehicles fitted with disc brakes the pawl and ratchet may engage at a lower ratchet position when the brake temperature is raised than when at ambient. This supports a recommendation from previous research to apply the lever one more notch to counteract the risk of rollaway due to brake cooling.
- It is recommended that manufacturers explore ways of alerting drivers to the risk of rollaway and explore preventative measures such as technology being used in commercial sectors can offer.

## 11.4 Driver Interaction with the Parking Brake System

- Despite mandatory instruction by the UK Highway Code and the risk of committing a road traffic offence, the results indicated that up to a quarter of drivers did not park in gear when parked on a slope and less than half of those who did would turn the wheels. Drivers who reported an increased awareness to park in gear on a gradient may not apply this awareness to all parking situations.
- Practice was influenced mostly by past experience, such as of a vehicle rollaway or parking brake system failure, and observation of parked unattended vehicles suggested this may also be related to the surrounding environment.
- Contrary to recommendations in owner manuals and the outcome of investigations five years previously, most drivers indicated they would depress the release button when applying the parking brake and the majority of Approved Driving Instructors would instruct learners in this method.
- Vehicle rollaway was not peculiar to lever operated parking brakes. Drivers who experienced rollaway involving the Electronic Parking Brake (EPB) tended to relate it to mechanical failure. The physical effort required to operate the parking brake may have been removed but a new problem of understanding how the

system works may increase the cognitive demands of driver interaction such as level of confidence in the system.

- A fault tree was used to explore the possible failure events and associated factors for the manually operated parking brake system. The method is just as applicable to EPB systems to explore the human factors that may affect interaction with the system and could contribute to vehicle rollaway.

Employing a Human Factors Systems approach to exploring vehicle rollaway has contributed to an understanding that failure of the parking brake system may be as a result of a combination of factors related to its organisational, mechanical and driver components. The graphic description of the contributory factors within a fault tree framework illustrates how these factors may relate to each other and where there are areas of overlap. Exploring driver interaction with the system at different levels of interface has provided evidence for further work not solely focused on the lever operated parking brake system. As parking brake systems develop, considering and designing for both the physical and cognitive abilities of the driver should be key to the prevention of passenger vehicle rollaway.

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# List of Appendices

# Appendix A

## A.1 STATS 19

Sept. 2004

MG NSRF/A

ACCIDENT STATISTICS

Incident URN

Other ref.

1.3 ACCIDENT REFERENCE

*FATAL / SERIOUS / SLIGHT

1.9 TIME H H M M

DAY* Su M T W Th F S

1.7 DATE D D M M 2 0 Y Y

1st Road Class & No. or (Unclassified - UC) (Not Known - NK)

1st Road Name

Outside House No. or Name or Marker Post No.

at junction with / or

metres N S E W * of

2nd Road Class & No. or (Unclassified - UC) (Not Known - NK)

2nd Road Name

Town

Sector /Beat No.

County or Borough

Parish No. or Name

1.10 Local Auth No. (if known)

1.11 Grid Reference E→ N↑

REPORTING OFFICER Name

Number

BCU/Stn

1.2 Force

Tel Number

1.5 Number of vehicles

1.6 Number of casualties

| 1.14 ROAD TYPE | ✗ |
|---|---|
| Roundabout | 1 |
| One way street | 2 |
| Dual carriageway | 3 |
| Single carriageway | 6 |
| Slip road | 7 |
| Unknown | 9 |

1.15 Speed Limit (Permanent)

| 1.16 JUNCTION DETAIL | ✗ |
|---|---|
| Not at or within 20 metres of junction | 00 |
| Roundabout | 01 |
| Mini roundabout | 02 |
| T or staggered junction | 03 |
| Slip road | 05 |
| Crossroads | 06 |
| Multiple junction | 07 |
| Using private drive or entrance | 08 |
| Other junction | 09 |

JUNCTION ACCIDENTS ONLY

| 1.17 JUNCTION CONTROL | ✗ |
|---|---|
| Authorised person | 1 |
| Automatic traffic signal | 2 |
| Stop sign | 3 |
| Give way or uncontrolled | 4 |

| 1.20a PEDESTRIAN CROSSING - HUMAN CONTROL | ✗ |
|---|---|
| None within 50 metres | 0 |
| Control by school crossing patrol | 1 |
| Control by other authorised person | 2 |

| 1.20b PEDESTRIAN CROSSING - PHYSICAL FACILITIES | ✗ |
|---|---|
| No physical crossing facility within 50m | 0 |
| Zebra crossing | 1 |
| Pelican, puffin, toucan or similar non-junction pedestrian light crossing | 4 |
| Pedestrian phase at traffic signal junction | 5 |
| Footbridge or subway | 7 |
| Central refuge — no other controls | 8 |

| 1.22 WEATHER | ✗ |
|---|---|
| Fine without high winds | 1 |
| Raining without high winds | 2 |
| Snowing without high winds | 3 |
| Fine with high winds | 4 |
| Raining with high winds | 5 |
| Snowing with high winds | 6 |
| Fog or mist — if hazard | 7 |
| Other | 8 |
| Unknown | 9 |

| 1.23 ROAD SURFACE CONDITION | ✗ |
|---|---|
| Dry | 1 |
| Wet / Damp | 2 |
| Snow | 3 |
| Frost / Ice | 4 |
| Flood (surface water over 3cm deep) | 5 |

| 1.21 LIGHT CONDITIONS | ✗ |
|---|---|
| Daylight: street lights present | 1 |
| Daylight: no street lighting | 2 |
| Daylight: street lighting unknown | 3 |
| Darkness: street lights present and lit | 4 |
| Darkness: street lights present but unlit | 5 |
| Darkness: no street lighting | 6 |
| Darkness: street lighting unknown | 7 |

| 1.24 SPECIAL CONDITIONS AT SITE | ✗ |
|---|---|
| None | 0 |
| Auto traffic signal out | 1 |
| Auto traffic signal partially defective | 2 |
| Permanent road signing or marking defective or obscured | 3 |
| Roadworks | 4 |
| Road surface defective | 5 |
| Oil or diesel | 6 |
| Mud | 7 |

| 1.25 CARRIAGEWAY HAZARDS | ✗ |
|---|---|
| None | 0 |
| Dislodged vehicle load in carriageway | 1 |
| Other object in carriageway | 2 |
| Involvement with previous accident | 3 |
| Pedestrian in carriageway - not injured | 6 |
| Any animal in carriageway (except ridden horse) | 7 |

| 1.26 Did a police officer attend the scene and obtain the details for this report? | ✗ |
|---|---|
| Yes | 1 |
| No | 2 |

***Subject to local directions, boxes with a grey background need not be completed if already recorded***

* Circle as appropriate

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# VEHICLE RECORD

Sept. 2004

**2.26 VEHICLE REGISTRATION MARK**

| | |
|---|---|
| Vehicle 001 | |
| Vehicle 002 | |
| Vehicle 003 | |
| Vehicle 004 | |

**2.28 FOREIGN REGISTERED VEHICLE ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Not foreign registered vehicle | 0 | | | | |
| Foreign registered vehicle LHD | 1 | | | | |
| Foreign registered vehicle RHD | 2 | | | | |
| Foreign reg' vehicle-two wheeler | 3 | | | | |

**2.5 TYPE OF VEHICLE ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Pedal cycle | 01 | | | | |
| M/cycle 50cc and under | 02 | | | | |
| M/cycle over 50cc and up to 125cc | 03 | | | | |
| M/cycle over 125cc and up to 500cc | 04 | | | | |
| Motorcycle over 500cc | 05 | | | | |
| Taxi / Private hire car | 08 | | | | |
| Car | 09 | | | | |
| Minibus (8-16 passenger seats) | 10 | | | | |
| Bus or coach (17 or more passenger seats) | 11 | | | | |
| Other motor vehicle | 14 | | | | |
| Other non-motor vehicle | 15 | | | | |
| Ridden horse | 16 | | | | |
| Agricultural vehicle (include diggers etc) | 17 | | | | |
| Tram / Light rail | 18 | | | | |
| Goods vehicle 3.5 tonnes mgw and under | 19 | | | | |
| Goods vehicle over 3.5 tonnes mgw and under 7.5 tonnes mgw | 20 | | | | |
| Goods vehicle 7.5 tonnes mgw and over | 21 | | | | |

**2.6 TOWING AND ARTICULATION ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| No tow or articulation | 0 | | | | |
| Articulated vehicle | 1 | | | | |
| Double or multiple trailer | 2 | | | | |
| Caravan | 3 | | | | |
| Single trailer | 4 | | | | |
| Other tow | 5 | | | | |

**2.21 SEX OF DRIVER ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Male | 1 | | | | |
| Female | 2 | | | | |
| Driver not traced | 3 | | | | |

**2.22 AGE OF DRIVER (Estimate if necessary)**

| | | | |
|---|---|---|---|
| Vehicle 001 | | Vehicle 002 | |
| Vehicle 003 | | Vehicle 004 | |

**2.27 DRIVER HOME POSTCODE**
or Code: 1- Unknown 2- Non UK Resident 3 - Parked & unattended

| | | |
|---|---|---|
| Vehicle 001 | | |
| Vehicle 002 | | |
| Vehicle 003 | | |
| Vehicle 004 | | |

**2.23 BREATH TEST ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Not applicable | 0 | | | | |
| Positive | 1 | | | | |
| Negative | 2 | | | | |
| Not requested | 3 | | | | |
| Refused to provide | 4 | | | | |
| Driver not contacted at time of acc' | 5 | | | | |
| Not provided (medical reasons) | 6 | | | | |

**2.24 HIT AND RUN ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Not hit and run | 0 | | | | |
| Hit and run | 1 | | | | |
| Non-stop vehicle, not hit | 2 | | | | |

**2.29 JOURNEY PURPOSE OF DRIVER/RIDER ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Journey as part of work | 1 | | | | |
| Commuting to / from work | 2 | | | | |
| Taking school pupil to/from school | 3 | | | | |
| Pupil riding to / from school | 4 | | | | |
| Other/Not known | 5 | | | | |

**2.9 VEHICLE LOCATION AT TIME OF ACCIDENT RESTRICTED LANE/AWAY FROM MAIN C'WAY ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| On main carriageway not in restricted lane | 00 | | | | |
| Tram / Light rail track | 01 | | | | |
| Bus lane | 02 | | | | |
| Busway (inc. guided busway) | 03 | | | | |
| Cycle lane (on main carriageway) | 04 | | | | |
| Cycleway or shared use footway (not part of main carriageway) | 05 | | | | |
| On lay-by / hard shoulder | 06 | | | | |
| Entering lay-by/ hard shoulder | 07 | | | | |
| Leaving lay-by / hard shoulder | 08 | | | | |
| Footway (pavement) | 09 | | | | |

**2.10 JUNCTION LOCATION OF VEHICLE ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Not at or within 20m of junction | 0 | | | | |
| Approaching junction or waiting /parked at junction approach | 1 | | | | |
| Cleared junction or waiting/ parked at junction exit | 2 | | | | |
| Leaving roundabout | 3 | | | | |
| Entering roundabout | 4 | | | | |
| Leaving main road | 5 | | | | |
| Entering main road | 6 | | | | |
| Entering from slip road | 7 | | | | |
| Mid junction– on roundabout or on main road | 8 | | | | |

**2.7 MANOEUVRES ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Reversing | 01 | | | | |
| Parked | 02 | | | | |
| Waiting to go ahead but held up | 03 | | | | |
| Slowing or stopping | 04 | | | | |
| Moving off | 05 | | | | |
| U turn | 06 | | | | |
| Turning left | 07 | | | | |
| Waiting to turn left | 08 | | | | |
| Turning right | 09 | | | | |
| Waiting to turn right | 10 | | | | |
| Changing lane to left | 11 | | | | |
| Changing lane to right | 12 | | | | |
| O'taking moving veh on its offside | 13 | | | | |
| O'taking stationary veh on its offside | 14 | | | | |
| Overtaking on nearside | 15 | | | | |
| Going ahead left hand bend | 16 | | | | |
| Going ahead right hand bend | 17 | | | | |
| Going ahead other | 18 | | | | |

**2.11 SKIDDING AND OVERTURNING ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| No skidding, jack-knifing or overturning | 0 | | | | |
| Skidded | 1 | | | | |
| Skidded and overturned | 2 | | | | |
| Jack-knifed | 3 | | | | |
| Jack-knifed and overturned | 4 | | | | |
| Overturned | 5 | | | | |

**2.12 HIT OBJECT IN CARRIAGEWAY ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| None | 00 | | | | |
| Previous accident | 01 | | | | |
| Roadworks | 02 | | | | |
| Parked vehicle | 04 | | | | |
| Bridge-roof | 05 | | | | |
| Bridge-side | 06 | | | | |
| Bollard / Refuge | 07 | | | | |
| Open door of vehicle | 08 | | | | |
| Central island of roundabout | 09 | | | | |
| Kerb | 10 | | | | |
| Other object | 11 | | | | |
| Any animal (except ridden horse) | 12 | | | | |

**2.13 VEHICLE LEAVING CARRIAGEWAY ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Did not leave carriageway | 0 | | | | |
| Left carriageway nearside | 1 | | | | |
| Left carriageway nearside and rebounded | 2 | | | | |
| Left carriageway straight ahead at junction | 3 | | | | |
| Left carriageway offside onto central reservation | 4 | | | | |
| Left carriageway offside onto central reserve and rebounded | 5 | | | | |
| Left carriageway offside and crossed central reservation | 6 | | | | |
| Left carriageway offside | 7 | | | | |
| Left carriageway offside and rebounded | 8 | | | | |

**2.14 FIRST OBJECT HIT OFF CARRIAGEWAY ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| None | 00 | | | | |
| Road sign / Traffic signal | 01 | | | | |
| Lamp post | 02 | | | | |
| Telegraph pole / Electricity pole | 03 | | | | |
| Tree | 04 | | | | |
| Bus stop / Bus shelter | 05 | | | | |
| Central crash barrier | 06 | | | | |
| Nearside or offside crash barrier | 07 | | | | |
| Submerged in water (completely) | 08 | | | | |
| Entered ditch | 09 | | | | |
| Other permanent object | 10 | | | | |

**2.16 FIRST POINT OF IMPACT ✗**

| | Code | Vehicle 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Did not impact | 0 | | | | |
| Front | 1 | | | | |
| Back | 2 | | | | |
| Offside | 3 | | | | |
| Nearside | 4 | | | | |

**2.17 FIRST CONTACT BETWEEN EACH VEHICLE**
Example: In a 3 car collision vehicle 1 collides with the rear of vehicle 2 pushing it into vehicle 3.

Example Code:

| | | | |
|---|---|---|---|
| Vehicle 001 first collides with vehicle 002 | 0 | 0 | 2 |
| Vehicle 002 first collides with vehicle 001 | 0 | 0 | 1 |
| Vehicle 003 first collides with vehicle 002 | 0 | 0 | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vehicle 001 | 0 | | | Vehicle 002 | 0 | | |
| Vehicle 003 | 0 | | | Vehicle 004 | 0 | | |

***Subject to local directions, boxes with a grey background need not be completed if already recorded***

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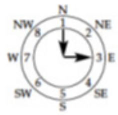
**2.8 DIRECTION OF VEHICLE TRAVEL**

1. Using the Example shown complete the FROM and TO boxes for the vehicles concerned, indicating direction of travel FROM and TO
2. If PARKED enter '00'

| Vehicle 001 | | Vehicle 002 | |
|---|---|---|---|
| FROM | TO | FROM | TO |
| | | | |
| **Vehicle 003** | | **Vehicle 004** | |
| FROM | TO | FROM | TO |
| | | | |

EXAMPLE

FROM 1 TO 3




# CASUALTY RECORD

**3.4 VEHICLE REFERENCE NUMBER**
Enter VEH No. which CASUALTY occupied (for pedestrians, code vehicle that struck them) e.g. 001,002 etc.

| | | | |
|---|---|---|---|
| Casualty 001 | 0 | Casualty 002 | 0 |
| Casualty 003 | 0 | Casualty 004 | 0 |
| Casualty 005 | 0 | Casualty 006 | 0 |

**3.18 CASUALTY HOME POSTCODE**
or Code: 1- Unknown
2- Non UK Resident

| | |
|---|---|
| Casualty 001 | |
| Casualty 002 | |
| Casualty 003 | |
| Casualty 004 | |
| Casualty 005 | |
| Casualty 006 | |

**3.7 SEX OF CASUALTY ✗**

| | | CASUALTY | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Male | 1 | | | | | | |
| Female | 2 | | | | | | |

**3.8 AGE OF CASUALTY** (Estimate if necessary)
For children less than a year enter 00

| | | | |
|---|---|---|---|
| Casualty 001 | | Casualty 002 | |
| Casualty 003 | | Casualty 004 | |
| Casualty 005 | | Casualty 006 | |

**3.6 CASUALTY CLASS ✗**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Driver/Rider | 1 | | | | | | |
| Veh./pillion Passenger | 2 | | | | | | |
| Pedestrian | 3 | | | | | | |

**3.9 SEVERITY OF CASUALTY ✗**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fatal | 1 | | | | | | |
| Serious | 2 | | | | | | |
| Slight | 3 | | | | | | |

**3.13 SCHOOL PUPIL CASUALTY ✗**

| | | CASUALTY | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| School pupil on journey to or from school | 1 | | | | | | |
| Other | 0 | | | | | | |

**3.15 CAR PASSENGER (not driver) ✗**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Not a car passenger | 0 | | | | | | |
| Front seat passenger | 1 | | | | | | |
| Rear seat passenger | 2 | | | | | | |

**3.16 BUS OR COACH PASSENGER ✗**
(17 passenger seats or more)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Not a bus or coach passenger | 0 | | | | | | |
| Boarding | 1 | | | | | | |
| Alighting | 2 | | | | | | |
| Standing passenger | 3 | | | | | | |
| Seated passenger | 4 | | | | | | |

## PEDESTRIAN CASUALTIES ONLY

**3.10 PEDESTRIAN LOCATION ✗**

| | | CASUALTY | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| In carriageway, crossing on pedestrian crossing facility | 01 | | | | | | |
| In carriageway, crossing within zig-zag lines at crossing approach | 02 | | | | | | |
| In carriageway, crossing within zig-zag lines at crossing exit | 03 | | | | | | |
| In carriageway, crossing elsewhere within 50m of pedestrian crossing | 04 | | | | | | |
| In carriageway, crossing elsewhere | 05 | | | | | | |
| On footway or verge | 06 | | | | | | |
| On refuge, central island or central reservation | 07 | | | | | | |
| In centre of carriageway, not on refuge, island or central reservation | 08 | | | | | | |
| In carriageway, not crossing | 09 | | | | | | |
| Unknown or other | 10 | | | | | | |

**3.11 PEDESTRIAN MOVEMENT ✗**

| | | CASUALTY | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Crossing from driver's nearside | 1 | | | | | | |
| Crossing from driver's nearside-masked by parked or stationary veh' | 2 | | | | | | |
| Crossing from driver's offside | 3 | | | | | | |
| Crossing from driver's offside-masked by parked or stationary veh' | 4 | | | | | | |
| In carriageway, stationary - not crossing (standing or playing) | 5 | | | | | | |
| In carriageway, stationary -not crossing (standing or playing), masked by parked or stationary veh' | 6 | | | | | | |
| Walking along in carriageway-facing traffic | 7 | | | | | | |
| Walking along in carriageway-back to traffic | 8 | | | | | | |
| Unknown or other | 9 | | | | | | |

**3.12 PEDESTRIAN DIRECTION ✗**

| | | CASUALTY | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Standing still | 0 | | | | | | |
| Northbound | 1 | | | | | | |
| Northeast bound | 2 | | | | | | |
| Eastbound | 3 | | | | | | |
| Southeast bound | 4 | | | | | | |
| Southbound | 5 | | | | | | |
| Southwest bound | 6 | | | | | | |
| Westbound | 7 | | | | | | |
| Northwest bound | 8 | | | | | | |
| Unknown | 9 | | | | | | |

**3.19 PEDESTRIAN INJURED IN THE COURSE OF 'On The Road' WORK**
Work actively carried out on public road (e.g. delivery services, road maintenance, postal delivery, traffic control etc.) ✗

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| No | 0 | | | | | | |
| Yes | 1 | | | | | | |
| Not known | 2 | | | | | | |

## LOCAL STATISTICS

***Subject to local directions, boxes with a grey background need not be completed if already recorded***

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## CONTRIBUTORY FACTORS

Sept. 2004

1. Select up to six factors from the grid, relevant to the accident.
2. Factors may be shown in any order, but an indication must be given of whether each factor is **very likely (A)** or **possible (B)**.
3. Only include factors that you consider contributed to the accident. (i.e. do NOT include "Poor road surface" unless relevant).
4. More than one factor may, if appropriate, be related to the same road user.
5. The same factor may be related to more than one road user.
6. The participant should be identified by the relevant vehicle or casualty ref no. (e.g. 001, 002 etc.), preceded by "V" if the factor applies to a vehicle, driver/rider or the road environment (e.g. V002), or "C" if the factor relates to a pedestrian or passenger casualty (e.g. C001).
7. Enter U000 if the factor relates to an uninjured pedestrian.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Road Environment Contributed | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | |
| | | Poor or defective road surface | Deposit on road (e.g. oil, mud, chippings) | Slippery road (due to weather) | Inadequate or masked signs or road markings | Defective traffic signals | Traffic calming (e.g. speed cushions, road humps, chicanes) | Temporary road layout (e.g. contraflow) | Road layout (e.g. bend, hill, narrow carriageway) | Animal or object in carriageway | |
| | Vehicle Defects | 201 | 202 | 203 | 204 | 205 | 206 | | | | |
| | | Tyres illegal, defective or under-inflated | Defective lights or indicators | Defective brakes | Defective steering or suspension | Defective or missing mirrors | Overloaded or poorly loaded vehicle or trailer | | | | |
| Driver/Rider Only (Includes Pedal Cycles and Horse Riders) | Injudicious Action | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 | 309 | 310 |
| | | Disobeyed automatic traffic signal | Disobeyed 'Give Way' or 'Stop' sign or markings | Disobeyed double white lines | Disobeyed pedestrian crossing facility | Illegal turn or direction of travel | Exceeding speed limit | Travelling too fast for conditions | Following too close | Vehicle travelling along pavement | Cyclist entering road from pavement |
| | Driver/ Rider Error or Reaction | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 | 409 | 410 |
| | | Junction overshoot | Junction restart (moving off at junction) | Poor turn or manoeuvre | Failed to signal or misleading signal | Failed to look properly | Failed to judge other person's path or speed | Passing too close to cyclist, horse rider or pedestrian | Sudden braking | Swerved | Loss of control |
| | Impairment or Distraction | 501 | 502 | 503 | 504 | 505 | 506 | 507 | 508 | 509 | 510 |
| | | Impaired by alcohol | Impaired by drugs (illicit or medicinal) | Fatigue | Uncorrected, defective eyesight | Illness or disability, mental or physical | Not displaying lights at night or in poor visibility | Cyclist wearing dark clothing at night | Driver using mobile phone | Distraction in vehicle | Distraction outside vehicle |
| | Behaviour or Inexperience | 601 | 602 | 603 | 604 | 605 | 606 | 607 | | | |
| | | Aggressive driving | Careless, reckless or in a hurry | Nervous, uncertain or panic | Driving too slow for conditions or slow vehicle (e.g. tractor) | Learner or inexperienced driver/rider | Inexperience of driving on the left | Unfamiliar with model of vehicle | | | |
| | Vision Affected by | 701 | 702 | 703 | 704 | 705 | 706 | 707 | 708 | 709 | 710 |
| | | Stationary or parked vehicle(s) | Vegetation | Road layout (e.g. bend, winding road, hill crest) | Buildings, road signs, street furniture | Dazzling headlights | Dazzling sun | Rain, sleet, snow or fog | Spray from other vehicles | Visor or windscreen dirty or scratched | Vehicle blind spot |
| | Pedestrian Only (Casualty or Uninjured) | 801 | 802 | 803 | 804 | 805 | 806 | 807 | 808 | 809 | 810 |
| | | Crossing road masked by stationary or parked vehicle | Failed to look properly | Failed to judge vehicle's path or speed | Wrong use of pedestrian crossing facility | Dangerous action in carriageway (e.g. playing) | Impaired by alcohol | Impaired by drugs (illicit or medicinal) | Careless, reckless or in a hurry | Pedestrian wearing dark clothing at night | Disability or illness, mental or physical |
| | Special Codes | 901 | 902 | 903 | 904 | | | | | | *999 |
| | | Stolen vehicle | Vehicle in course of crime | Emergency vehicle on a call | Vehicle door opened or closed negligently | | | | | | Other – Please specify below |

| | 1st | 2nd | 3rd | 4th | 5th | 6th |
|---|---|---|---|---|---|---|
| **Factor in the accident** | | | | | | |
| **Which participant? (e.g. V001, C001, U000)** | | | | | | |
| **Very likely (A) or Possible (B)** | | | | | | |

* If 999 Other, give brief details ..............................

(Note: Only use if another factor contributed to the accident and include it in the text description of how the accident occurred)

*These factors reflect the reporting officer's opinion at the time of reporting and may not be the result of extensive investigation*

UNCLASSIFIED

## A.2 Freedom of Information Requests

[redacted]

Freedom of Information Officer
Northern Constabulary
Police Headquarters
[redacted]

Telephone: [redacted]
Facsimile: [redacted]

**Your Ref.** **Our Ref 66/2011**
23rd February 2011

Dear Sir/Madam,

Thank you for your e-mail of 1st February 2011 in which you ask for information under the Freedom of Information (Scotland) Act 2002.

You have asked:

**Failed engagement of the parking brake is anecdotally a reasonably frequent occurrence (Consumer Action Group, 2010) and the outcome can range from a near miss or minor property damage to fatality and devastation.**
**There is very little information in the public domain in regards to the extent of this issue and the human factors which may be involved. I would therefore be extremely grateful for answers to the following:**

1. **In the last 3 years how many incidents have involved rollaway vehicles?**
2. **In how many of the above was hand brake failure cited as a potential factor?**
3. **What manufacturer, model and age of vehicle was involved?**
4. **What were the demographic characteristics of the driver i.e. age, gender, nationality, number of years driving experience.**

In response:

Under the Freedom of Information (Scotland) Act 2002 an applicant should give their name. I assume that you are requesting information on behalf of a company and technically should have required you to give me a contact name. However, I am nevertheless providing this reply.

This has been difficult for us to research as we cannot electronically search for the parameters in which you are interested. We were unable to retrieve data relating to 'runaway vehicles'. Every reported Road Traffic Collision would require manual interrogation of the base documents in order to retrieve this information. To give you an idea of the magnitude of this task, since April 2010 we have recorded 2500 reports of Road Traffic Collisions and as it is estimated that each would take 10 minutes to manually interrogate, the cost of locating and retrieving the information would exceed the "appropriate level" as stated in Freedom of Information (Scotland) (Fees) Regulations 2004. In accordance with Section 12 (1), Excessive cost of compliance, of the Freedom of Information (Scotland) Act 2002, this letter represents a Refusal Notice for your request.

However, we have retrieved 32 collisions where handbrake failure was noted as a potential causation factor as we were able to electronically search on this parameter. This report does not give the age of the vehicle. We do not record age, gender, nationality and years of

experience on this data base. Indeed there is no requirement for us to record the two latter metrics on our incident reporting/recording system. I have manually interrogated each base document reporting the incident relating to the 32 collisions to determine the gender and year of birth of the driver, if recorded. The results have been added to the report retrieved and are detailed on the enclosed spreadsheet. I have also given you the number of vehicles involved, the road conditions and weather notes in case they are of interest to you.
Please note that not all forces can retrieve the same level of information as we use different recording systems.

I hope this information will be of assistance to you.

*If you require any further clarification, please do not hesitate to contact me. However if you are not satisfied with the way in which your request has been dealt with, you are entitled, in the first instance, to request a review of the decision made by the Force. Should you wish to request such review, please write to me within 40 days of receiving this letter. I will arrange for a senior officer, who has not been involved in my decision making process, to conduct a review as required by the Act. If, after having been informed of the review panel's decision, you are still not satisfied, you are then entitled to apply to the Scottish Information Commissioner for a decision within 6 months of receipt of the outcome of the Internal Review.* [redacted]

Yours faithfully,

[redacted]
Freedom of Information Officer

Freedom of Information Response Northern Constabulary

| NO OF VEH | DATE | WEATHER | ROAD STATE | MAKE AND MODEL | Gender of driver | Year of birth driver | SEV OF ACC |
|---|---|---|---|---|---|---|---|
| 2 | Feb-08 | DRY/FINE WITHOUT HIGH WINDS | DRY | VW GOLF & VW POLO | F | 1951 | NON INJURY |
| 1 | Apr-08 | SUNNY AND CLEAR | TARMACADAM - GOOD CONDITION | VW POLO | F | 1953 | NON INJURY |
| 2 | May-08 | DRY | GOOD | FORD FOCUS & VW POLO | M | 1928 | NON INJURY |
| 1 | May-08 | FINE WITHOUT HIGH WINDS | DRY | AUDI A4 | M | N/A | SLIGHT |
| 1 | May-08 | DRY AND CLEAR | GOOD STATE OF REPAIR | KIA PICCANTO | M | 1962 | NON INJURY |
| 1 | May-08 | DRY | GOOD REPAIR | VAUXHALL CORSA | M | N/A | NON INJURY |
| 1 | Apr-08 | FINE WITHOUT HIGH WINDS | DRY | FORD ESCORT | F | 1976 | NON INJURY |
| 1 | May-08 | DRY AND SUNNY | WET AND IN GOOD REPAIR | NISSAN PRIMERA | F | 1966 | NON INJURY |
| 1 | Jul-08 | DRY AND FINE | DRY/GOOD STATE OF REPAIR | VAUXHALL ASTRA SXI | M | 1989 | FATAL |
| 1 | Jun-08 | FINE AND DRY | DRY AND GOOD STATE OF REPAIR | PEUGEOT 307 | M | 1986 | NON INJURY |
| 1 | Aug-08 | FINE AND DRY | GOOD | HYUNDAI | F | 1988 | NON INJURY |
| 2 | Dec-08 | DARK AND WET | GOOD STATE OF REPAIR | KIA RIO & CITROEN BERLINGO | M | 1955 | NON INJURY |
| 2 | Sep-08 | GOOD | WELL MAINTAINE | FORD MONDEO & VW POLO | M | 1949 | NON INJURY |
| 2 | Dec-08 | | | PEUGEOT 306 & VAUXHALL CORSA | M | 1962 | NON INJURY |
| 2 | Jan-09 | DRY AND NIGHT | GOOD REPAIR | FORD FOCUS & PEUGEOT 206 | M | N/A | NON INJURY |
| 2 | Jan-09 | DRY | GOOD STATE OF REPAIR | IVECO PANEL VAN & HONDA CIVIC | M | 1944 | NON INJURY |
| 2 | Apr-09 | GOOD/DRY/FIN E | IN GOOD REPAIR | NISSAN MICRA & VAUXHALL ASTRA | F | CHILD PLAYING IN CAR | NON INJURY |
| 1 | Jul-09 | DRY | GOOD STATE OF REPAIR | PEUGEOT 207 | F | N/A | NON INJURY |
| 1 | May-09 | DRY AND CLEAR | GOOD STATE OF REPAIR | RENAULT LAGUNA | M | 1937 | NON INJURY |
| 2 | Aug-09 | FINE | GOOD REPAIR | PEUGEOT 306 & VAUXHALL SIGNUM | F | 1968 | NON INJURY |
| 3 | Sep-09 | FINE | DRY | VW PASST, YAMAHA R1 & YAMAHA FZ1 | M | 1963 | NON INJURY |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Dec-09 | DRY | GOOD | PEUGEOT 107 | M | 1982 | NON INJURY |
| | | | | | | | |
| NO OF VEH | DATE | WEATHER | ROAD STATE | MAKE AND MODEL | Gender of driver | Year of birth driver | SEV OF ACC |
| 1 | Jan-10 | DRY, CLEAR | GOOD STATE OF REPAIR | FORD MONDEO | M | 1965 | NON INJURY |
| 2 | Feb-10 | FINE | GOOD | FIAT PUNTO & KIA SEDONA | F | N/A | NON INJURY |
| 1 | Feb-10 | SNOW | GOOD STATE OF REPAIR - ICY | PEUGEOT 307 | M | 1965 | NON INJURY |
| 2 | Mar-10 | RAINING WITH HIGH WINDS | WET/DAMP | FIAT PUNTO & FIAT SCUDO | M | 1985 | NON INJURY |
| 1 | Mar-10 | FINE | DRY, GOOD REPAIR | FORD COUGAR | F | N/A | NON INJURY |
| 2 | Jun-10 | DRY, DAYLIGHT | TARMAC, GOOD REPAIR | VAUXHALL VECTRA & HONDA CRV | M | 1987 | NON INJURY |
| 1 | Aug-10 | DRY-NIGHTIME | SINGLE CARRIAGE WAY, GOOD REPAIR | SAAB | M | 1969 | NON INJURY |
| 1 | Oct-10 | DRY | TARMAC, GOOD REPAIR | ROVER 75 | M | 1970 | NON INJURY |
| 2 | Sep-10 | RAINING | GOOD REPAIR | FORD KA & VAUXHALL CORSA | M | N/A | NON INJURY |
| 1 | Jun-10 | FINE WITHOUT HIGH WINDS | GOOD STATE OF REPAIR | KIA PICANTO | F | 1968 | NON INJURY |

https://www.whatdotheyknow.com/request/accidents_associated_with_run_aw#outgoing-108011

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P·O·L·I·C·E
*Keeping our communities safe*

Freedom of Information Office
Information Disclosure Unit
[redacted]

[redacted]
foienquiries@grampian.pnn.police.uk
www.grampian.police.uk

Our Ref: FOI/259/11/js
Your Ref:

Date: 26 March 2011

[redacted]

By Email

Dear Sir/Madam,

**FREEDOM OF INFORMATION REQUEST 259/11**

I refer to your email of 4 May 2011, in which you requested information in terms of the Freedom of Information (Scotland) Act 2002.

All accidents reported to Grampian Police are recorded on our Accident File system. It is often possible to extract accidents caused by the same type of contributory factor, by looking at the causation factors attributed to the accident. However, having checked the list of all causation factors, there is not one for failing to apply the handbrake.

Therefore, there is no way to isolate the relevant accidents, except from reading the circumstances of each accident, to find if there are any which fit within the remit of your request.

From 1 January 2008 – 31 December 2010, there are a total of 16210 accidents recorded on Accident File and each would need to be read to provide a response to your request. This would take hundreds of hours to complete and therefore would significantly exceed the prescribed sum as outlined in the Freedom of Information (Fees for Required Disclosure) (Scotland) Regulations, 2004 and, consequently, we are not in a position to undertake this work for you, in terms of Section 12 of the Act – Excessive cost of compliance.

**FREEDOM OF INFORMATION REQUEST 320/11**

I refer to your email of 8 June 2011, in which you requested information in terms of the Freedom of Information (Scotland) Act 2002.

I have repeated your questions hereunder, for your ease of reference;

**1. The number of collisions with the following causations factors from 1 Jan 2010 – 31 Dec 2010, which relate to the driver not applying the handbrake correctly.**

**203 – Defective Brakes**
**605 – Learner/inexperienced driver**
**607 – unfamiliar with model of vehicle**
**999 - Other**
**503 - Fatigue**
**505 – Illness, disability (mental or physical)**
**602 – Careless, reckless, in a hurry**
**603 – Nervous, uncertain, panic**

A search was made of the force accident recording system for accidents with the aforementioned causation factors.

It has been possible to read through all of the relevant accidents, except those with the causation factor of 'Careless/Reckless/In a hurry' as there was a total of 676 accidents with this factor. To read all of these accident reports would significantly exceed the prescribed sum as outlined in the Freedom of Information (Fees for Required Disclosure) (Scotland) Regulations, 2004 and, consequently, we are not in a position to undertake this work for you, in terms of Section 12 of the Act – Excessive cost of compliance.

However, all of the reports relating to the other causation factors were read, as this was possible within cost limits.

| Causation Factor | Number of accidents with this factor | handbrake not being applied |
|---|---|---|
| Defective Brakes | 30 | 2 |
| Disability or Illness, mental or physical | 6 | 0 |
| Fatigue | 45 | 0 |
| Illness or disability, mental or physical | 35 | 0 |
| Inexperienced or learner driver/rider | 212 | 1 |
| Inexperience with type of vehicle | 42 | 0 |
| Nervous/Uncertain/Panic | 64 | 0 |
| Other – please specify | 81 | 0 |

# Devon & Cornwall Police

Record 1

## Freedom of Information Act Request No: 001278/11

**In the last 12 months:**

1. **How many incidents resulting in fatality have cited hand brake or parking brake as a potential factor?**
2. **How many incidents resulting in serious injury have cited hand brake or parking brake as a potential factor?**
3. **What was the manufacturer, model and age of the vehicle involved?**
4. **What was the age, gender and nationality of the driver involved?**

The Performance and Analysis Department have provided the following information:

Data was taken from the Operational Information System (OIS) for the calendar year of 2010. A free text search of 'Handbrake' was made and the descriptions for incidents closed as 'Transport' were checked for relevancy. Data with a contributory factor of 'Defective Brake' was also selected and the accident description read for relevancy

1. **How many incidents resulting in fatality have cited hand brake or parking brake as a potential factor?**

None

2. **How many incidents resulting in serious injury have cited hand brake or parking brake as a potential factor?**

Four incidents resulting in injury were found. The injuries were recorded as:
Broken leg
Grazes
Minor injury to leg
Minor Shoulder injury

Example of Communication with Insurance Bodies

**From:**
**To:** Valerie Noble
**Subject:** RE: Incidents associated with parking brake failure/roll away vehicles
**Date:** 06 June 2011 17:06:49

---

Dear Valerie

Thank you for email.

I'd like to point out that we do not collect the detail information you are requesting. You may need to contact the DVLA for this level of information. We have some information on motor by gender see attached link.
http://www.abi.org.uk/Facts_and_Figures/Data_by_Age_and_Gender.aspx

[redacted].

Regards

[redacted]
Analyst, Savings & Protection Research Directorate

[redacted]

Association of British Insurers 51 Gresham Street
London EC2V 7HQ

# Appendix B

## B.1 Legislation and Industrial Testing

ECE Regulation No. 13-H

Uniform provisions concerning the approval of passenger cars with regard to brak

**Addendum 12-H: Regulation No. 13-H Revision 2**

### 5. Specifications

5.1.2.3. Parking braking system

The parking braking system must make it possible to hold the vehicle stationary on an up or down gradient even in the absence of the driver, the working parts being then held in the locked position by a purely mechanical device. The driver must be able to achieve this braking action from his driving seat. (pp 11)

5.2.2.4. The parking braking system must be so designed that it can be actuated when the vehicle is in motion. This requirement may be met by the actuation of the vehicle's service braking system, even partially, by means of an auxiliary control;

### Annex 3: Braking tests and performance of braking systems

2.3. Parking braking system

2.3.1. The parking braking system must be capable of holding the laden vehicle stationary on a 20 per cent up or down gradient.

2.3.2. On vehicles to which the coupling of a trailer is authorized, the parking braking system of the motor vehicle must be capable of holding the combination of vehicles stationary on a 12 per cent up or down gradient.

2.3.3. If the control device is manual, the force applied to it must not exceed 40 daN.

2.3.4. If it is a foot control device, the force exerted on the control must not exceed 50 daN.

2.3.5. A parking braking system which has to be actuated several times before it attains the prescribed performance is admissible.

2.3.6. To check compliance with the requirement specified in paragraph 5.2.2.4. of this Regulation, a Type-0 test must be carried out, with the engine disconnected, at an initial test speed of 30 km/h. The mean fully developed deceleration on application of the control of the parking brake system and the deceleration immediately before the vehicle stops, shall not be less than 1.5 $m/s^2$. The test shall be carried out with the laden vehicle. The force exerted on the braking control device shall not exceed the specified values. (pp 37)

Test procedure for FMVSS 135 (Feb 2012)

**DATA SHEET 24**
**14.19 PARKING BRAKE @ GVWR (S7.12)**

| | | | | | |
|---|---|---|---|---|---|
| VEHICLE: | | NHTSA NUMBER: | | DATE: | |
| TEMP.: | | WIND VELOCITY: | | ROAD PFC: | |
| ODOMETER START: | | ODOMETER FINISH: | | | |

Test Weight: Total = _____ kg; Front = _____ kg; Rear = ____ kg

Parking Brake: Hand Control? ____Foot Control? ___ *Electrically-Actuated?* ______

S7.12.1 Vehicle Conditions:

A. Vehicle Load: GVWR

B. Transmission Position: In Neutral

C. Parking Brake Burnish:

For vehicles with parking brake systems not utilizing the service brake friction elements, the friction elements of such systems are to be burnished prior to parking brake tests according to the manufacturer's published recommendations as furnished to the purchaser. If no recommendations are furnished, test the system in an un-burnished condition. If recommendations are furnished, record method used.________________________________________________

S7.12.2 Test Conditions and Procedures:

A. Parking brake systems utilizing service brake friction materials.

IBT: ≤100°C

(No additional burnishing or artificial heating prior to the start of the parking brake test is allowed).

B. Parking brake systems utilizing non-service brake friction materials.

IBT: Ambient Temperature
(No additional burnishing or artificial heating prior to the start of the parking brake test is allowed).

PEDAL FORCE:

Hand control: ≤400 N

Foot control: ≤500 N

Drive onto 20% grade. Apply service brake just enough to hold vehicle stationary, and shift to Neutral. Apply park brake to force of ≤ 400 N hand control and ≤ 500 N foot control.

Release service brake; If vehicle remains stationary, start the measurement of time. Terminate after 5 minutes. If vehicle is not held stationary, reapply service brake just enough to hold vehicle on the grade. Reapply the specified force to parking lever or pedal (without releasing ratchet mechanism).

Release service brake. If vehicle still doesn't hold, repeat application. If vehicle is not held stationary for 5 minutes after two re-applications, check with engineer for further instructions. Repeat test in the opposite direction.

Did parking brake indicator operate each time the parking brake was applied?

Yes _____ No _____

S7.12.3 Performance Requirements:

The parking brake must hold the vehicle stationary in both directions for 5 minutes.

Comments:

RECORDED DATA

| | | 20% Grade - Uphill | | | 20% Grade - Downhill | | |
|---|---|---|---|---|---|---|---|
| | | Initial Apply | 1st Reapply | 2nd Reapply | Initial Apply | 1st Reapply | 2nd Reapply |
| Service Brake Force to Hold Vehicle Stationary (N) | | | | | | | |
| Parking Brake Force Applied (N) | | | | | | | |
| Number of Clicks (Optional) | | | | | | | |
| Vehicle Stationary for 5 minutes? | | | | | | | |
| Initial Brake Temperature (°C) | Left | | | | | | |
| | Right | | | | | | |
| | Average | | | | | | |

Data Indicates Compliance: YES NO

Comments:

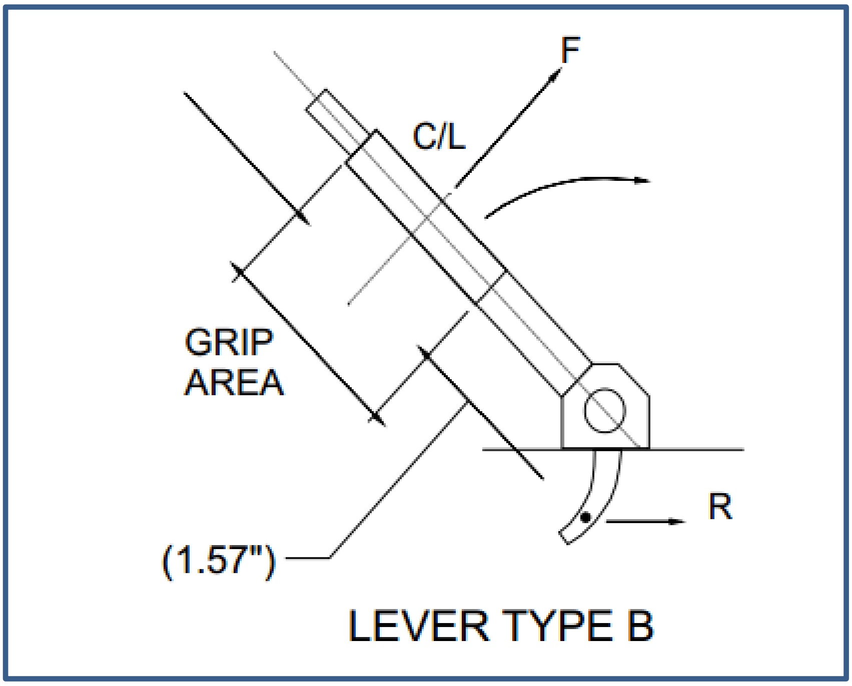



*Figure B.1.1 NTSA FV135 position for measuring force*

Hand Force Measurement Locations: The force required for actuation of a hand-operated brake system is measured at the centre of the hand grip area or at a distance of 40 mm (1.57 in) from the end of the actuation lever as illustrated in Figure 3.

The parking brake system shall hold the vehicle stationary for 5 minutes in both a forward and reverse direction on the grade

Ambient temperature (S6.1.1) — The ambient temperature is any temperature between 0° C (32 °F) and 40°C (104°F) (NHTSA, 2012)

*Table B.1.1. Ministry of Transport (MOT) Testing – 3 years post registration and annually thereafter*

| Method Of Testing | Reason for failure/rejection |
|---|---|
| 1.<br>Check that the vehicle has a parking brake designed to prevent at least two wheels from turning, or with a three-wheeled vehicle, at least one wheel from turning. | 1.<br>The vehicle does not have a parking brake designed to prevent: at least two wheels from turning with a three-wheeled vehicle, at least one wheel from turning. |
| 2.<br>Check the method of operation. | 2.<br>For vehicles first used on or after 1 January 1968 the parking brake is not capable of being maintained in operation by direct mechanical action only. |
| 3.<br>While sitting in the driver's seat, check the presence, security and condition of the parking brake lever or control. | 3.<br>The brake lever or control:<br>a. missing<br>b. insecure<br>c. defective or located so that it cannot be satisfactorily operated. |
| 4.<br>With the brake lever in the 'off' position:<br>a.<br>check the amount of side play in the lever pivot by moving the lever from side to side<br><br>Note: Some vehicles have sideways movement of the parking brake lever when new. Movement is a reason for rejection only when:the pawl is moved clear of the ratchet, and the brake does not hold in the 'on' position | 4.<br>a.<br>Side play in the brake lever pivot to the extent that the pawl may inadvertently disengage |
| b.<br>check the security of the lever and pawl mechanism pivots, their associated mountings and the presence and effectiveness of retaining and locking devices | b.<br><br>the lever or pawl mechanism pivots and their associated mountings are insecure or a locking or retaining device is insecure or missing. |
| 5.<br>Without operating the pawl mechanism, apply the parking brake slowly and check the effective operation of the pawl mechanism by listening for definite and regular clicks as the pawl moves over the ratchet teeth. | 5.<br>The pawl spring is not pushing the pawl positively into the ratchet teeth or the ratchet has broken, or excessively worn teeth. |

| | |
|---|---|
| 6.<br>When the brake is fully applied:<br>a.<br>knock the top and each side of the lever and check that the lever stays in the 'on' position<br><br>b.<br>check that the lever is not at the end of its working travel and that there is no fouling of adjacent parts<br><br>c.<br>check that the lever is not impeded in its travel. | 6.<br><br>a.<br>When knocked, the lever is not held in the 'on' position<br><br>b.<br>when the brake is fully applied there is no possibility of further travel of the lever because the lever is: at the end of its working travel on the ratchet, or fouling adjacent parts of the vehicle<br>c.<br>the lever is impeded in its travel. |
| 7.<br>On vehicles with an electronic parking brake, operate the switch to release and apply the parking brake and check that a malfunction is not indicated. | 7.<br>Electronic parking brake warning indicates a malfunction.<br>Note: An EPB malfunction may alternatively be indicated by a message on the dashboard. |
| 8.<br>Check the parking brake lever or control for any inappropriate repair or modification. | 8.<br>A parking brake lever or control inappropriately repaired or modified. |
| 9.<br>Check the condition of the vehicle structure around the mountings of any:<br>a.<br>mechanical parking brake lever mechanism<br><br>b.<br>electro-mechanical actuator unit.<br><br>Note: It may be necessary to check the mounting of the parking brake lever or EPB electro-mechanical actuator unit 'prescribed areas' from the vehicle underside when it cannot be checked from the inside the cabin. | 9.<br>Deliberate modification which significantly reduces the original strength, excessive corrosion, severe distortion, a fracture or an inadequate repair of a load bearing member or its supporting structure or supporting panelling within 30cm of the parking brake mechanism or associated mounting(s), that is, within a 'prescribed area', |

(http://www.motuk.co.uk/manual_310.htm)

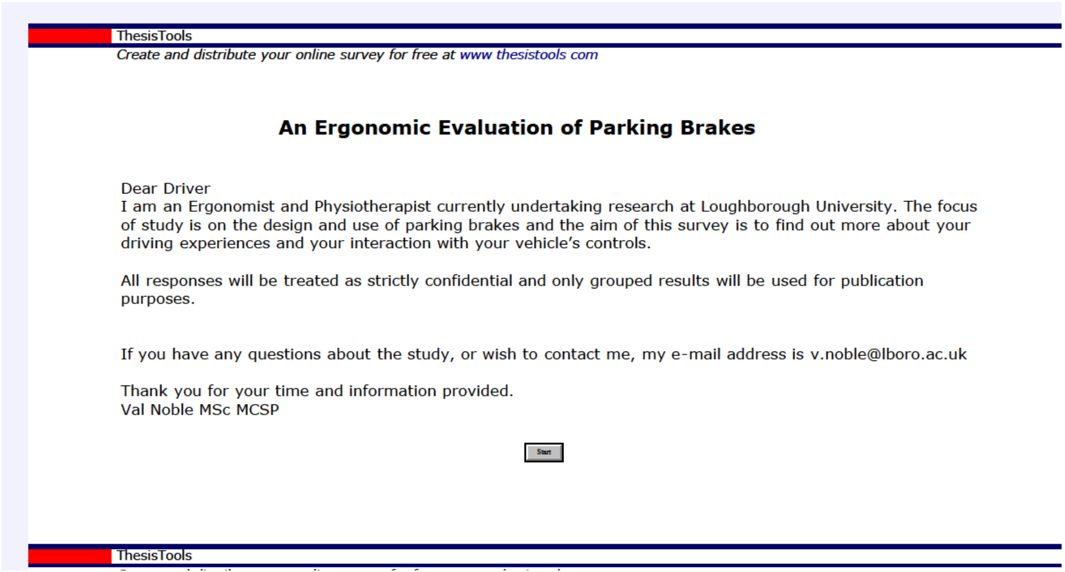
## B.2 Task Decomposition

***B2 Task decomposition for parking a vehicle to remain stationary when unattended***

| | | | |
|---|---|---|---|
| 1. Plan to park | *Decisions Required:*<br><br>Is it safe to park? – environmental factors<br>Pedestrian and other road user safety | *Skills/training:*<br><br>Awareness of Highway code and Road traffic legislation | *Communication:*<br><br>Inform other road users of intention to stop and park |
| | *Initiating cue/event:*<br><br>Requirement to park | | |
| 2. Stop | *Actions Required:*<br><br>Depress clutch and footbrake | *Skills/training;*<br><br>Training, instruction<br>Highway code | *Co-ordination:*<br><br>Depress clutch and footbrake |
| 3. Pull lever | *Actions required:*<br><br>Apply force, pull the lever up<br>Release footbrake and check vehicle secure | *Decisions required*<br><br>How much force?<br>Is vehicle secure? | *Controls used:*<br><br>PB lever<br>Foot brake |
| | *Co-ordination requirements:*<br><br>Release foot brake after PB engaged | *Skills/training:*<br><br>Driving standards<br>Manufacturer's instructions | *Performance:*<br><br>Able to apply sufficient force.<br>Vehicle stationary |
| | *Errors/problems:*<br><br>Insufficient application of force<br>Incorrect operation | *Hardware/mechanical features:*<br><br>PB system components | |
| 4.Select gear | *Sequence of activity:*<br><br>Order of operation of controls may vary | *Skills/training:*<br><br>Formal instruction<br>Past experience | *Information:*<br><br>DVSA, Highway code, owner manuals |
| | *Decisions required*<br><br>Whether to park in gear<br>Which gear?<br>Should wheels be turned? | *Controls used:*<br><br>Depress clutch.<br>Select reverse/first gear | *Likely/typical errors:*<br><br>Not parked in gear |
| 5.Switch engine off | *Sequence of activity:*<br><br>? in gear before/after engine off | *Action required:*<br><br>Turn ignition key/ push button<br>Check vehicle secure | *Outcome:*<br><br>Vehicle stationary |

# Appendix C

## C.1 Driver survey


ThesisTools

*Create and distribute your online survey for free at www thesistools com*

**An Ergonomic Evaluation of Parking Brakes**

Dear Driver
I am an Ergonomist and Physiotherapist currently undertaking research at Loughborough University. The focus of study is on the design and use of parking brakes and the aim of this survey is to find out more about your driving experiences and your interaction with your vehicle's controls.

All responses will be treated as strictly confidential and only grouped results will be used for publication purposes.

If you have any questions about the study, or wish to contact me, my e-mail address is v.noble@lboro.ac.uk

Thank you for your time and information provided.
Val Noble MSc MCSP

Start

ThesisTools

## An Ergonomic Evaluation of Parking Brakes

1.

**About you:**

| | |
|---|---|
| What is your age (in years)? | 10 |
| What gender are you? | ○ Male ○ Female |
| What is your weight? (please indicate whether in stones and pounds or Kg) | |
| What is your height? (Please indicate whether in feet and inches or in metres) | |
| Are you right or left hand dominant? | |
| Do you have any physical disability or discomfort which affects your daily activities? (If yes, please indicate what part of the body is affected e.g. right leg) | |
| What are the first 4 characters of your postcode? | |

2.

**How many years have you been driving?**

-- please choose --
0-2
3-5
6-10
more than 10

3.

**About your driving experience.**

| | Driving experience |
|---|---|
| Did you learn to drive in the UK? | |
| If NO, where did you learn to drive (country)? | |
| Did you learn to drive in a right hand drive vehicle? | |
| Do you regularly e.g. weekly, drive a left hand drive vehicle? | |

4.

**Your driving experience.**
Please consider your typical routine to indicate your driving activities on most days.

| | |
|---|---|
| Considering your typical routine, how many days a week do you drive? | |
| How many miles a week do you drive? | |
| How many short trips (less than 5 miles) do you normally do in a day? | |
| Do you normally park your vehicle on the flat or on a slope overnight? | |

5.

**Use of your vehicle**
Please indicate the percentage of driving you do for each road type over the course of a year.

| | |
|---|---|
| Motorway (including dual carriageways) | 0 % |
| Rural (e.g. country lanes) | 0 % |
| Urban (e.g. residential areas, non city centre) | 0 % |
| City (e.g. city centre) | 0 % |

6.

**Please indicate how often do you**

| | Never | Hardly ever | Occasionally | Quite often | Frequently | Nearly all the time |
|---|---|---|---|---|---|---|
| Hit something when reversing that you had not previously seen | ○ | ○ | ○ | ○ | ○ | ○ |
| Intending to drive to destination A, you "wake up" to find yourself on the road to destination B | ○ | ○ | ○ | ○ | ○ | ○ |
| Get into the wrong lane approaching a roundabout or a junction | ○ | ○ | ○ | ○ | ○ | ○ |
| Switch one thing, such as the headlights, when you meant to switch on something else,such as the wipers | ○ | ○ | ○ | ○ | ○ | ○ |
| Attempt to drive away from the traffic lights in third gear | ○ | ○ | ○ | ○ | ○ | ○ |
| Forget where you left your car in a car park | ○ | ○ | ○ | ○ | ○ | ○ |
| Misread the signs and exit from a roundabout on the wrong road | ○ | ○ | ○ | ○ | ○ | ○ |
| Realise that you have no clear recollection of the road along which you have just been | ○ | ○ | ○ | ○ | ○ | ○ |

7.

**What is the year, make and model of the vehicle(s) you drive?**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Year | ☐ | ☐ | ☐ |
| Make (e.g. Ford) | ☐ | ☐ | ☐ |
| Model (e.g. Focus) | ☐ | ☐ | ☐ |
| level of trim (e.g. Zetec) | ☐ | ☐ | ☐ |

8.

**Does the vehicle have a manual or automatic gear box?**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| manual | ☐ | ☐ | ☐ |
| automatic | ☐ | ☐ | ☐ |

9.

**How long have you had this vehicle?**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| years | ☐ | ☐ | ☐ |
| months | ☐ | ☐ | ☐ |

10.

**How much of your total driving time do you spend driving each vehicle?**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Percentage of total driving time | ☐ | ☐ | ☐ |

11.

**Are the vehicles you drive regularly right or left hand drive?**

| | vehicle 1 | vehicle 2 | vehicle 3 |
|---|---|---|---|
| Right hand drive | ☐ | ☐ | ☐ |
| Left hand drive | ☐ | ☐ | ☐ |

12.

**How is the Parking Brake applied in your vehicle(s)?**
(Please select one answer per vehicle)

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Hand operated lever (Hand brake) | ☐ | ☐ | ☐ |
| Foot operated pedal | ☐ | ☐ | ☐ |
| Electronic/push button | ☐ | ☐ | ☐ |
| Automatic | ☐ | ☐ | ☐ |
| Don't know | ☐ | ☐ | ☐ |

**If foot operated, electronic or automatic parking brake go to Q15**

13.

**If the parking brake is a hand operated lever (HAND BRAKE), where is it positioned?**
(Please select one answer per vehicle)

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Close to the driver's seat | ☐ | ☐ | ☐ |
| Centrally between the front seats | ☐ | ☐ | ☐ |
| Close to the passenger seat | ☐ | ☐ | ☐ |
| On the dashboard to the left of the steering wheel | ☐ | ☐ | ☐ |
| On the dashboard to the right of the steering wheel | ☐ | ☐ | ☐ |
| Under the steering wheel | ☐ | ☐ | ☐ |
| Other | ☐ | ☐ | ☐ |

14.

**How do you apply the HAND BRAKE (manually operated hand lever) in the vehicle(s) you drive?**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| With one hand, pull up without pushing the button in | ☐ | ☐ | ☐ |
| With one hand, push the button in and pull up | ☐ | ☐ | ☐ |
| With two hands, pull up without pushing the button in | ☐ | ☐ | ☐ |
| With two hands, push the button in and pull up | ☐ | ☐ | ☐ |
| Other | ☐ | ☐ | ☐ |

15.

**If the parking brake is foot operated, automatic or electronic where is the release handle or control positioned?**
(Please select one answer per vehicle)

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Close to the driver's seat | ☐ | ☐ | ☐ |
| Centrally between the front seats | ☐ | ☐ | ☐ |
| Close to the passenger seat | ☐ | ☐ | ☐ |
| On the dashboard to the left of the steering wheel | ☐ | ☐ | ☐ |
| On the dashboard to the right of the steering wheel | ☐ | ☐ | ☐ |
| Under the steering wheel | ☐ | ☐ | ☐ |
| Other | ☐ | ☐ | ☐ |

16.

**Has the parking brake been modified in any way specifically for you as the driver?**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Parking brake modified? | yes / no | | |
| If yes, how has it been modified? | | | |

17.

**Please indicate the amount of exertion you feel is required to operate the parking brake:**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| 6 No exertion at all | ☐ | ☐ | ☐ |
| 7 Extremely light | ☐ | ☐ | ☐ |
| 8 | ☐ | ☐ | ☐ |
| 9 Very light | ☐ | ☐ | ☐ |
| 12 | ☐ | ☐ | ☐ |
| 13 Somewhat hard | ☐ | ☐ | ☐ |
| 14 | ☐ | ☐ | ☐ |
| 15 Hard (Heavy) | ☐ | ☐ | ☐ |
| 16 | ☐ | ☐ | ☐ |
| 17 Very Hard | ☐ | ☐ | ☐ |
| 18 | ☐ | ☐ | ☐ |
| 19 Extremely Hard | ☐ | ☐ | ☐ |
| 20 Maximal Exertion | ☐ | ☐ | ☐ |

18.

**When you drove your vehicle for the first time, in relation to the parking brake, did you:**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Know how the system operates without instruction? | ☐ | ☐ | ☐ |
| Work out how the system operates without instruction? | ☐ | ☐ | ☐ |
| Request instruction from the dealer, supplier or manufacturer? | ☐ | ☐ | ☐ |
| Refer to the vehicle handbook? | ☐ | ☐ | ☐ |
| Require further instruction even after consulting the handbook and/or dealer? | ☐ | ☐ | ☐ |

19.

**When you park your vehicle to leave it unattended, e.g. in a car park do you normally?**

-- please choose --
Apply the parking brake only
Leave in gear only (manual)
Leave in park only (automatic)
Apply the parking brake and leave in gear (manual) or park (automatic)
Apply the parking brake, leave in gear or park and turn the wheels

20.

**Why do you park your vehicle as indicated in question 19?***

- ○ How instructed when learning to drive
- ○ Because of where I park overnight
- ◉ Past experience
- ○ Other ______

21.

**When you park your vehicle(s) ON A SLOPE to leave it unattended do you?**
(Please select one answer for each vehicle)

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| Apply the parking brake only | ☐ | ☐ | ☐ |
| Leave car in gear only | ☐ | ☐ | ☐ |
| Leave car in "park" only | ☐ | ☐ | ☐ |
| Apply the parking brake and leave in gear (manual) or park (automatic) | ☐ | ☐ | ☐ |
| Apply the parking brake, leave in gear or park and turn the wheels | ☐ | ☐ | ☐ |

22.

**Why do you park your vehicle as indicated in question 21?***

- ○ How instructed when learning to drive
- ○ Because of where I park overnight
- ◉ Past experience
- ○ Other (please specify) ______

23.

**Since you have been driving your current vehicle(s), please indicate if you have**

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|---|---|---|---|
| returned to your vehicle to find the parking brake was not applied when it normally would be | ▾ | ▾ | ▾ |
| found your vehicle has rolled and the parking brake was not applied | ▾ | ▾ | ▾ |
| found your vehicle has rolled but the parking brake was applied | ▾ | ▾ | ▾ |

24.

**If you answered yes to any of question 23, can you recall the circumstances e.g. in a hurry, distracted, mechanical fault**

______

25.

**Please indicate whether, over the last two years, you have experienced any of the following "events".**
Please complete the number of times this has happened, the vehicle(s) involved, whether injury occurred (e.g.minor, moderate, serious, fatality) and any property damage.

| | Yes/No? | Number of times? | Vehicle Involved? | Injury to person? | Property Damage? |
|---|---|---|---|---|---|
| Returned to parked vehicle to find it had rolled away. | | | | | |
| Vehicle rolled away while still in the vehicle | | | | | |
| Vehicle rolled away while trying to get out of the vehicle | | | | | |
| Vehicle rolled away while working on the vehicle | | | | | |

25.

**Please indicate whether, over the last two years, you have experienced any of the following "events".**
Please complete the number of times this has happened, the vehicle(s) involved, whether injury occurred (e.g.minor, moderate, serious, fatality) and any property damage.

| | Yes/No? | Number of times? | Vehicle involved? | Injury to person? | Property Damage? |
|---|---|---|---|---|---|
| Returned to parked vehicle to find it had rolled away. | | | | | |
| Vehicle rolled away while still in the vehicle | | | | | |
| Vehicle rolled away while trying to get out of the vehicle | | | | | |
| Vehicle rolled away while working on the vehicle | | | | | |

26.

**If you answered yes to any of question 25, can you recall the circumstances e.g. in a hurry, distracted, mechanical fault**

27.

**Please feel free to add any comments you feel may be relevant to the use of parking brakes**

Please submit

# Appendix D

## D.1 Approved Driving Instructor (ADI) Survey

Loughborough University

**Vehicle Controls Research - Operation of Parking Brake Instruction**

Introduction

I am an Ergonomist and Physiotherapist currently undertaking research at Loughborough University. My focus is on the design and use of parking brakes and the human factors affecting effective application. The aim of this survey is to find out more about driver training and instruction and the experiences of you, and your learner drivers, when interacting with the vehicle's controls.
All responses will be treated as strictly confidential and only grouped results will be used for publication purposes.

Val Noble MSc MCSP
PhD Research Student
Design School
Loughborough University
LE11 3TU

v.noble@lboro.ac.uk

Loughborough University

## Vehicle Controls Research - Operation of Parking Brake Instruction

### Driving Instructor Details

**1. Which category below includes your age?**

- ◯ 18-20
- ◯ 21-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60-69
- ◯ 70 or older

**2. What is your gender?**

- ◯ Female
- ◯ Male

**3. How long have you been a Driving Instructor?**

- ◯ 0-5 years
- ◯ 6-10 years
- ◯ 11- 15 years
- ◯ 16-20 years
- ◯ 20+ years

Loughborough University

**Vehicle Controls Research - Operation of Parking Brake Instruction**

About Your Work

**4. Please indicate what best describes your work situation**

- ◯ Self employed, own driving school
- ◯ Self employed, part of franchise
- ◯ Employed -private driving school
- ◯ Employed - franchise
- ◯ Other

Other (please specify)

*** 5. Please indicate the nearest town/city to where you work**

**6. What professional organisations do you belong to?**

**7. How are you made aware of any new information?**

- ☐ Conferences
- ☐ Local/regional meetings
- ☐ Internet
- ☐ Professional Newsletters
- ☐ DSA bulletins

Other (please specify)

**8. How many "new" pupils do you have each month?**

- ◯ 0-2
- ◯ 3-5
- ◯ 6-10
- ◯ more than 10
- ◯ other
- ◯ N/A fleet

Loughborough University

## Vehicle Controls Research - Operation of Parking Brake Instruction

### Parking Brake Operation

**9. How do you teach your pupils to operate a manually operated parking brake (Hand Brake)?**

| | All of the time | Most of the time | Sometimes | Rarely | Never |
|---|---|---|---|---|---|
| Push the button in and pull on the lever | ○ | ○ | ○ | ○ | ○ |
| Push the button in and pull on the lever then pull up to hear "1-2 clicks" | ○ | ○ | ○ | ○ | ○ |
| Pull up without pushing the button in (audible clicks) | ○ | ○ | ○ | ○ | ○ |
| Refer to Vehicle operating manual | ○ | ○ | ○ | ○ | ○ |

Other (please specify)

**10. How do you teach pupils to park their vehicle as if to leave it?**

| | flat | 5% incline | 10% incline | 15% incline | 20% incline or more |
|---|---|---|---|---|---|
| Parking Brake only | ○ | ○ | ○ | ○ | ○ |
| Parking brake and in gear (manual) or park (automatic) | ○ | ○ | ○ | ○ | ○ |
| Parking Brake and in gear/park and wheels turned | ○ | ○ | ○ | ○ | ○ |

Other (please specify)

**11. Do any of your learner drivers experience difficulty applying sufficient force to apply the manually operated parking effectively?**

- ◯ Yes
- ◯ No

If "Yes" please indicate a percentage and provide some details

**12. What percentage of your pupils drive vehicles fitted with electronic parking brakes (EPB)?**

- ◯ 0-5%
- ◯ 6-10%
- ◯ 11-15%
- ◯ 16-20%
- ◯ 21-25%
- ◯ 26-30%
- ◯ 31-40%
- ◯ 41-50%
- ◯ 51-60%
- ◯ more than 60%

**13. Do you think that learning to drive a vehicle fitted with EPB presents any difficulty in the following areas?**

- ☐ understanding how the system works
- ☐ preparing for the driving test
- ☐ during the driving test
- ☐ driving other vehicles not fitted with EPB

Other (please specify)

Loughborough University

## Vehicle Controls Research - Operation of Parking Brake Instruction

### Vehicle Roll Away

**14. Have you ever experienced your unattended vehicle rolling?**

- ◯ Yes
- ◯ No

If yes, can you recall and decribe the circumstances?

[ ]

**15. If yes, what was the outcome?**

- ◯ No damage or injury
- ◯ Minor property damage (includes vehicles)
- ◯ Moderate property damage
- ◯ Major property damage
- ◯ Minor Injury (no hospital treatment)
- ◯ Serious Injury

**16. Have any of your pupils experienced their unattended vehicle rolling?**

- ◯ Yes
- ◯ No

If yes, are you able to describe the circumstances

[ ]

**17. If yes, what was the outcome?**

- ◯ No damage or injury
- ◯ Minor property damage (includes vehicles)
- ◯ Moderate property damage
- ◯ Major property damage
- ◯ Minor Injury (no hospital treatment)
- ◯ Serious Injury

**18. Please add any comments you feel may be relevant to this area of research (Parking Brake Application)**

[ ]

Loughborough University

**Vehicle Controls Research - Operation of Parking Brake Instruction**

Thank you

Thank you very much for completing the questionnaire. If you wish to be contacted in relation to future work or to receive a copy of the results, please provide an email address

**19. If you wish to be contacted, at what email address would you like to be contacted?**

## D.2 Tables of Results

*Table D.2.1 Age and gender of respondents*

| | Gender | | Response | |
|---|---|---|---|---|
| **Age Bracket** | **Female** | **Male** | **Percent** | **Count** |
| 21-29 | 0 | 1 | 0.7% | 1 |
| 30-39 | 4 | 2 | 4.2% | 6 |
| 40-49 | 13 | 25 | 26.8% | 38 |
| 50-59 | 16 | 48 | 45.1% | 64 |
| 60-69 | 2 | 26 | 19.7% | 28 |
| 70 or older | 0 | 5 | 3.5% | 5 |
| | | | ***answered question*** | **n = 142** |

*Table D.2.2 Approved Driving Instructor (ADI) Experience*

| | Gender | | Response | |
|---|---|---|---|---|
| **Length of time as ADI** | **Female** | **Male** | **Percent** | **Count** |
| 0-5 years | 10 | 37 | 32.9% | 47 |
| 6-10 years | 16 | 38 | 37.8% | 54 |
| 11- 15 years | 8 | 12 | 14.0% | 20 |
| 16-20 years | 1 | 3 | 2.8% | 4 |
| 20+ years | 1 | 17 | 12.6% | 18 |
| | | | ***answered question*** | **n = 143** |

*Table D.2.3 Instruction to pupils on how to operate a manually operated parking brake*

| Method of Application Instructed | Female | Male | Response Count |
|---|---|---|---|
| Push the button in and pull on the lever | | | |
| All of the time | 28 | 58 | 86 |
| Most of the time | 1 | 5 | 6 |
| Sometimes | 1 | 5 | 6 |
| Rarely | 0 | 2 | 2 |
| Never | 0 | 5 | 5 |
| | 30 | 75 | 107 |
| Push the button in and pull on the lever then pull up to hear '1-2 clicks' | | | |
| All of the time | 0 | 8 | 8 |
| Most of the time | 0 | 3 | 3 |
| Sometimes | 1 | 8 | 9 |
| Rarely | 2 | 2 | 4 |
| Never | 9 | 26 | 35 |
| | 12 | 47 | 59 |
| Pull up without pushing the button in (audible clicks) | | | |
| All of the time | 1 | 13 | 14 |
| Most of the time | 0 | 3 | 3 |
| Sometimes | 2 | 6 | 8 |
| Rarely | 0 | 2 | 2 |
| Never | 12 | 28 | 40 |
| | 15 | 52 | 67 |
| Refer to Vehicle operating manual | | | |
| All of the time | 2 | 17 | 19 |
| Most of the time | 0 | 2 | 2 |
| Sometimes | 2 | 7 | 9 |
| Rarely | 0 | 7 | 7 |
| Never | 9 | 16 | 25 |
| | 13 | 49 | 62 |
| Other | | | 11 |
| | | *answered question* | n = 129 |

*Table D.2.4 Instruction to pupils on how to park their car as if to leave it unattended.*

| Parking Practice Instructed | Female | Male | Response Count |
|---|---|---|---|
| | Parking Brake only | | |
| flat | 26 | 78 | 104 |
| 5% incline | 3 | 5 | 8 |
| 10% incline | 1 | 2 | 3 |
| 15% incline | 0 | 2 | 2 |
| 20% incline or more | 0 | 0 | 0 |
| | 30 | 87 | 117 |
| | Parking brake and in gear (manual) or park (automatic) | | |
| flat | 3 | 17 | 20 |
| 5% incline | 6 | 27 | 33 |
| 10% incline | 13 | 16 | 29 |
| 15% incline | 4 | 4 | 8 |
| 20% incline or more | 4 | 8 | 12 |
| | 28 | 72 | 102 |
| | Parking Brake and in gear/park and wheels turned | | |
| flat | 0 | 4 | 4 |
| 5% incline | 1 | 7 | 8 |
| 10% incline | 7 | 27 | 34 |
| 15% incline | 6 | 19 | 24 |
| 20% incline or more | 17 | 19 | 36 |
| | 30 | 76 | 106 |
| Other | | | 8 |
| | | *answered question* | 131 |

## D.3 Driving Standards- Communication and Proposed Amendments

Driving Standards Agency

# Safe and Responsible Driving (Category B)™

The National Driving Standard describes the skills, knowledge and understanding needed to be a safe and responsible driver of a category B vehicle.

| Role 2 Guide and control the vehicle | |
|---|---|
| Unit 2.1 Start, move off, stop and leave the vehicle safely and responsibly | |
| Element 2.1.4 Park the vehicle safely and responsibly | |
| Performance Standards<br><br>You must be able to<br><br>1. select a safe, legal and convenient place to stop and park and, once stationary, secure the vehicle on gradients, facing both up and down slope, as well as on the level<br>2. apply the parking brake to hold the vehicle<br>3. if needed, select a gear to hold the vehicle safely when parked<br>4. switch the engine off<br>5. make sure that vehicles fitted with automatic transmission are left with the lever in the Park position<br>6. make sure lights are left on where required<br>7. check for oncoming cyclists, pedestrians and other traffic before opening your door | Knowledge & Understanding Requirements<br><br>You must know and understand<br><br>1. what factors to take into consideration when looking for a safe, legal and convenient place to stop or park<br>2. the pros and cons of reversing or 'pulling through' into a parking space rather than reversing out<br>3. that you must switch off the headlights, fog lights if fitted and engine when parked<br>4. the rules in the Highway Code that apply when leaving your vehicle on different roads and in different lighting and weather conditions<br>5. how and when to set the position of the steering wheels of the vehicle to increase its security when parked on a gradient<br>6. that when parking a vehicle with manual transmission on a gradient, selecting a gear will help to hold the vehicle if the parking brake should fail<br>7. the possible outcomes of opening a door, particularly on the offside of the vehicle, when not safe to do so |

Version 4.0
27 September 2012

dft.gov.uk/dsa/standards

**From:** [redacted]
**To:** Valerie Noble
**Subject:** RE: Changes to the driving standard
**Date:** 28 January 2014 16:00:05
**Attachments:** image001.png

We did discuss this – but it was felt that checking out of gear was enough, and adding in a number of choices would over-complicate. Of course, if someone did habitually depress the clutch when starting we would view that as being equivalent to checking that the vehicle was out of gear. As an aside, if you just start the car with the clutch depressed you might start to move thinking you are in first when in fact you are in reverse. Probably only a small chance, but we decided to keep the statement as simple as possible.

[redacted]

**From:** Valerie Noble [mailto:V.Noble@lboro.ac.uk]
**Sent:** 28 January 2014 15:36
**To:** [redacted]
**Subject:** RE: Changes to the driving standard

Thank you.
2.1.4. looks good. Did you want to include anything about depressing the clutch when starting the engine in 2.1.1. as with push button start vehicles as an additional measure or do you feel checking out of gear is sufficient?

Val

**From:** [redacted]
**Sent:** 28 January 2014 15:21
**To:** Valerie Noble
**Subject:** Changes to the driving standard

Hi Val,

I'm well thank you. I hope you are too.

The meeting went well and the suggested changes to the standard were approved – the revised version will be up on Gov.Uk shortly. I'll let you know when it's there. The attached extract of the standard shows the changes that were agreed. The yellow highlight indicates any statement linked to parking (not all of the highlighted statements have changed).

As always, I'm happy to discuss any of the changes that we've made and any further suggestions you might have about the standard.

Regards,
[redacted]

[redacted]
Driver and Vehicle Standards Agency | [redacted]m
NG1 6LP

[redacted]

Driver & Vehicle Standards Agency

Incorporating the Driving Standards Agency and Vehicle and Operator Services Agency

Find out more about government services at www.gov.uk/dsa

**From:** Valerie Noble [mailto:V.Noble@lboro.ac.uk]
**Sent:** 28 January 2014 11:46
**To**[redacted]
**Subject:** RE: [redacted]

[redacted]

How did your meeting go? I am currently writing up about driver instruction and training so any developments would be most helpful.
Thank you
Val

**From:** [redacted]
**Sent:** 30 December 2013 10:29
**To:** Valerie Noble
**Subject:** [redacted]

[redacted]

Our meeting to agree the content of the Standards is next week - initial discussions have yielded a willingness to strengthen the statements, going further than we discussed and recommending that people always park in gear (not just on a slope). I don't want to pre-empt the discussions next week but I'm hopeful that we will have a positive outcome.

Regards,
[redacted]

[redacted] | Education Advisor
Driver and Vehicle Standards Agency [redacted]
NG1 6LP
[redacted]

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<table>
<tr><th colspan="2">Role 2 Guide and control the vehicle</th></tr>
<tr><th colspan="2">Unit 2.1 Start, move off, stop and leave the vehicle safely and responsibly</th></tr>
<tr><th colspan="2">Element 2.1.1 Start the vehicle</th></tr>
<tr><td>Performance Standards<br><br>You must be able to<br><br>1. carry out pre-start checks on<br>• doors<br>• parking brake<br>• seat<br>• steering<br>• seatbelt<br>• mirrors<br>2. disengage anti-theft devices<br>3. make sure the gear lever is in neutral (or ‘P’ or ‘N’ if driving an automatic vehicle)<br>4. consider the effect of starting the engine on other road users, particularly vulnerable road users such as passing cyclists, pedestrians or horse riders<br>5. monitor vehicle instrumentation and gauges during engine start up<br>6. respond correctly to information given by instrumentation and gauges during engine start up<br>7. start the engine correctly<br>~~8. switch lights on, if required~~</td><td>Knowledge & Understanding Requirements<br><br>You must know and understand<br><br>1. how to read and respond correctly to instrumentation such as<br>• gauges<br>• indicators<br>• warning lights<br>• on-board diagnostic systems and other aids fitted to the vehicle to allow you to monitor its operation and performance<br>2. that different vehicles may have different starting mechanisms, types of instrumentation, parking brakes and other aids, and that it is vital to use the vehicle handbook to find out how they work<br>3. how to start the engine when it is cold<br>4. the benefits of using anti-theft devices, and how to apply and disengage them</td></tr>
</table>

| Role 2 Guide and control the vehicle | |
|---|---|
| **Unit 2.1 Start, move off, stop and leave the vehicle safely and responsibly** | |
| **Element 2.1.2 Move off safely and smoothly** | |
| **Performance Standards**<br><br>You must be able to<br><br>1. carry out all-round visual checks, including blind spots, to make sure that it is safe to move-off<br>2. signal your intention to move off to other road users, where needed<br>3. move off straight-ahead, on the level and on slopes, safely and smoothly, keeping control of the vehicle at all times<br>4. move off at an angle from behind a parked vehicle or obstruction, safely and smoothly, keeping control of the vehicle at all times<br>5. check that controls are operating correctly<br>6. restart quickly and safely if the vehicle stalls | **Knowledge & Understanding Requirements**<br><br>You must know and understand<br><br>1. the importance of carrying out all-round, effective observation of the road and other road users before moving off<br>2. the importance and location of blind spots and how to carry out blind spot checks before moving away<br>3. the importance of using a safe, systematic routine to help you to move off safely and smoothly<br>4. the importance of applying the footbrake before selecting drive on an automatic vehicle<br>5. where applicable, the relevance of the 'biting point', that is the point at which the clutch plate and the flywheel come into firm contact and start to transmit drive<br>6. the operation of the parking brake release mechanism<br>7. the limitations of hill assist systems, where fitted<br>8. the effects of 'dry steering', that is turning the wheels when the vehicle is not moving, on tyres etc.<br>9. how to check controls, such as steering and brakes, are operating correctly |

<table>
<tr><th colspan="2">Role 2 Guide and control the vehicle</th></tr>
<tr><th colspan="2">Unit 2.1 Start, move off, stop and leave the vehicle safely and responsibly</th></tr>
<tr><th colspan="2">Element 2.1.3 Decelerate and bring the vehicle to a stop safely</th></tr>
<tr><td>Performance Standards<br><br>You must be able to<br><br>1. use the accelerator and brakes correctly to regulate speed and bring the vehicle to a stop safely<br>2. stop the vehicle safely and under control in an emergency<br>3. use the parking brake when stationary, where needed</td><td>Knowledge & Understanding Requirements<br><br>You must know and understand<br><br>1. how to apply a safe, systematic approach when stopping<br>2. the distance a vehicle requires to stop from different speeds and in different road and weather conditions<br>3. that a vehicle's overall stopping distance consists of two parts<br>a. thinking distance - which is the distance travelled from the point where you decide to brake to the point where you start braking<br>b. braking distance - which is the distance travelled from the point where you start to brake to the point where you stop<br>4. the importance of anticipation and judgement to allow for progressive use of the brakes<br>5. how aids such as ABS can help in safe and effective braking</td></tr>
</table>

# Proposed amendments to parking

| Role 2 Guide and control the vehicle | |
|---|---|
| **Unit 2.1 Start, move off, stop and leave the vehicle safely and responsibly** | |
| **Element 2.1.4 Park the vehicle safely and responsibly** | |
| **Performance Standards**<br><br>You must be able to<br><br>1. select a safe, legal and convenient place to stop and park and, once stationary, secure the vehicle on slopes, facing both up and down, as well as on the level<br>2. ~~firmly apply~~make sure the parking brake is applied effectively~~to hold the vehicle~~<br>3. ~~if needed,~~ select a gear to hold the vehicle safely when parked<br>4. switch the engine off<br>5. make sure that vehicles fitted with automatic transmission are left with the lever in the Park position<br>6. make sure lights are left on where required<br>7. check for oncoming cyclists, pedestrians and other traffic before opening your door | **Knowledge & Understanding Requirements**<br><br>You must know and understand<br><br>1. what factors to take into consideration when looking for a safe, legal and convenient place to stop or park<br>2. the pros and cons of reversing or 'pulling through' into a parking space rather than reversing out<br>3. that you must switch off the headlights, fog lights if fitted and engine when parked<br>4. the rules in the Highway Code that apply when leaving your vehicle on different roads and in different lighting and weather conditions<br>5. how and when to set the position of the steering wheels of the vehicle to prevent it rolling away~~on a slope~~<br>~~5.~~6. how to ensure that the parking brake is applied effectively<br>~~6.~~7. that, when parking a vehicle with manual transmission~~on a slope~~, selecting a gear will help to hold the vehicle if the parking brake should fail<br>~~7.~~8. the possible outcomes of opening a door, particularly on the offside of the vehicle, when not safe to do so |

# Appendix E

## E.1 Ethical Approval

Ref No: R12-P5

**LOUGHBOROUGH UNIVERSITY**
**ETHICAL ADVISORY SUB-COMMITTEE**

**RESEARCH PROPOSAL**
**INVOLVING HUMAN PARTICIPANTS**

---

**Title:** Ergonomic Evaluation of Parking Breaks

**Applicant:** R Frampton, J Richardson, V Noble

**Department:** Design School

**Date of clearance:** 17 January 2012

**Comments of the Sub-Committee:**

The Sub-Committee agreed to issue clearance to proceed subject to the following conditions:

- That information was provided on the Senior Investigators' experience of the methods to be used in the study.
- That more information was provided on how points 1.2 and 2 regarding what Participants will be asked to do, how they will be recruited etc, and that Information Sheets and Consent Forms were provided for these parts of the study.
- That clarification was provided as to why the Investigator specified that a chaperone of the opposite gender will be present for measurements in Question 15.
- That confirmation was provided that the Investigator had permission to use the public sector email system and Driving Assessment Centre Database to recruit participants, and that the persons with records in the database and email system had given permission to be contacted in this way for research purposes.
- That more information was provided on how and where exactly the data collected would be stored and protected.
- That confirmation was provided as to whether or not the photographs taken would have any personal detail obscured or if they would be kept in their original state. If the latter, this information should be added to the Participant Information Sheet and Consent Form.
- That the Participant Information Sheet was amended to:
    - Include that Participants should bring their glasses, if worn, to the 'Is there anything I need to bring with me?' section.
    - Alter the sentence, 'Second testing session: (You will be informed at the familiarization session whether you will be requested to participate in the second session)' to, 'Second testing session: (At the familiarization session, you may be asked if you would be happy to participate in the second session)'
    - Alter the word 'sued' to 'used' in the paragraph which begins, 'Digital images may be used for illustrative purposes…' in the section, 'Will my taking part in this study be kept confidential?'
- That confirmation was provided that all the questions in the Health Screen Questionnaire were necessary or that unnecessary questions were removed.

**From:** [redacted]
**To:** Valerie Noble
**Subject:** RE: Ergonomic Evaluation of Parking Brakes
**Date:** 06 June 2012 09:59:58

Hi Val,

A full application is not required for this amendment. I can confirm that this amendment is acceptable, and I will add this amendment to your file.

Kind Regards,

[redacted]

**From:** Valerie Noble
**Sent:** 06 June 2012 08:54
**To:** Zoe Stockdale
**Subject:** Ergonomic Evaluation of Parking Brakes

Hi Zoe
We have had to change part 2 of the original proposal and will now be requesting participants to park their own vehicles on a slope in a designated area. As before, all participants will be over 18 with at least one year's driving experience: drivers over 65 who volunteer to participate will not be excluded.
I have reviewed the checklist and although I am not directly targeting this age group, when they complete their personal details I will know their age.

Is a full application required for an amendment? Both my supervisors are on leave so I will be unable to get this signed off for today's deadline.

Thank you
Val Noble

## E.2 Documentation for Observational studies

Loughborough University

**An Ergonomic Evaluation of Parking Brakes**
**Participant Information Sheet**

**Main Investigator:** Mrs Val Noble, Design School, Loughborough University, LE11 3TU. v.noble@lboro.ac.uk. Tel: [redacted]
**Project Supervisors:** Dr Richard Frampton, Design School, Loughborough University, LE11 3TU. R.J.Frampton@lboro.ac.uk. Tel: [redacted]
Mr John Richardson, Design School, Loughborough University, LE11 3TU. J.H.Richardson@lboro.ac.uk Tel: [redacted]

**What is the purpose of the study?**
The study is to assess and evaluate the human factors which may be involved with applying a passenger vehicle parking brake. The physical demands, such as effort and posture will be evaluated by measuring the force required to operate a manually operated parking brake and observing your posture during this operation. The way in which you normally apply your parking brake is also important and you may be asked questions in relation to this.
It is hoped that information gained from this study will be beneficial to manufacturers in designing vehicles, personnel conducting driver assessments and driving instructors

**Who is doing this research and why?**
This study is part of a PhD Student research project supported by Loughborough University. The main investigator is Val Noble, a Physiotherapist and Ergonomist. The project is supervised by Dr Richard Frampton and John Richardson of Loughborough Design School.

**Are there any exclusion criteria?**
Drivers who drive a vehicle with an adjusted parking brake are excluded from the study. Drivers who demonstrate symptoms which could be exacerbated by assessment outside of normal driver assessment testing will be excluded.

**Once I take part, can I change my mind?**
After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form, however if at any time, before, during or after the sessions you wish to withdraw from the study please just contact Val Noble (v.noble@lboro.ac.uk, Tel: [redacted]). You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing.

**Will I be required to attend any sessions and where will these be?**
The assessment will take part at St Lukes Hospice, Turnchapel..

**How long will it take?**
The initial assessment should take 15-20 minutes. If you are requested to participate in part 2, which involves driving on a short predetermined route, the entire assessment will take around 60 minutes.

Updated Jan 2011

**Is there anything I need to do before the sessions?**
No.

**Is there anything I need to bring with me?**
If you require medication, such as an inhaler, please bring it with you. If you normally wear glasses for driving, please bring them with you.

**What type of clothing should I wear?**
Please wear clothes and footwear you would normally drive in. Some measurements will be recorded prior to the assessment so light clothing under heavier outer layers is advised.

**Who should I respond to?**
Any information you are asked to complete and return, will be provided with an envelope with a return label. Any information requested electronically should be returned to v.noble@lboro.ac.uk

**What will I be asked to do?**

**Participation in this project involves:**

- Completion of a consent form
- Recording of personal details and body measurements
- Reversing your vehicle and parking it on an incline.
- Recording of activities electronically and digitally (audio, photographs and/or video)
- Assessment of parking brake operation
- Discussion with the researcher in relation to operation of vehicle controls.
- Driving on a predetermined route (part 2 only)

## At your session

**Please park your vehicle in Parking space A –** please note this space will only be available to you for your agreed session time.


The details of the project will be explained and your consent to participate confirmed. Personal details such as age, weight, height and several body measurements will be recorded. You will be requested to remove any heavy outer layers of clothing for these measurements. You will be asked to reverse onto the incline and park in a marked area as if you were leaving the vehicle. You may be asked some further questions in relation to the

Loughborough University

## An Ergonomic Evaluation of Parking Brakes

**INFORMED CONSENT FORM**
**(Please complete after reading Participant Information Sheet)**

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that audio, video and digital image recording will be conducted.
I understand that images may be used for presentation and publication purposes.

I consent to my photograph taken at ………………………………………………. on (…………..) being used for the following purposes (please tick as appropriate):

☐ Publications associated with the research conducted (internal and external)

☐ Publication on the University Intranet (accessible only to Intranet users)

☐ Publication on the Internet (accessible to all Internet users)

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name ______________________________

Your signature ______________________________

Signature of investigator ______________________________

Date ______________________________

EAPB Consent Jan2012

Loughborough University

# PARKING BRAKE STUDY

| | |
|---|---|
| Participant Number: | |
| Age: | Gender: M/F |
| Left/ Right Handed: L/R | Driving Experience (years): |
| Vehicle: (Make, Model and year) | |
| Average miles per week?: | Number of short trips (<3 miles) per week: |
| Where is your vehicle parked overnight? Garage/Drive/Road/Car Park; flat/moderate incline/steep incline | |

For each item identified below, circle the number to the right that best fits your judgment of its quality. Use the scale above to select the quality number.

| **Vehicle Controls** | **Scale** | | | | |
|---|---|---|---|---|---|
| | **Poor** | | **Good** | | **Excellent** |
| 1. How would you rate the layout of your vehicle's primary controls? | 1 | 2 | 3 | 4 | 5 |
| 2. How would you rate their ease of operation? | 1 | 2 | 3 | 4 | 5 |
| 3. What do you think of the overall design of the controls? | 1 | 2 | 3 | 4 | 5 |
| 4. How effective do you think your parking brake is? | 1 | 2 | 3 | 4 | 5 |
| 5. Are there any aspects of the controls you would change? | Yes | | | No | |
| 6. If yes, what would you change? | | | | | |

*EAPB/Incline study0712*

Loughborough University

PARKING BRAKE STUDY

| Parking Brake Controls | Not all confident | | | | Extremely confident |
|---|---|---|---|---|---|
| 7. How confident were you that your vehicle would remain stationary? | 1 | 2 | 3 | 4 | 5 |
| 8. How confident are you that your vehicle would remain stationary with only the parking brake applied? | 1 | 2 | 3 | 4 | 5 |
| 9. How confident are you when parking on an incline? | 1 | 2 | 3 | 4 | 5 |
| 10. How confident are you when you are stopped on an incline and need to move forwards? (hill start) | 1 | 2 | 3 | 4 | 5 |
| 11. How confident are you that you can apply sufficient force to operate your parking brake fully? | 1 | 2 | 3 | 4 | 5 |
| 12. How confident are you that you can release the parking brake if someone else has applied it? | 1 | 2 | 3 | 4 | 5 |

**Additional Questions**

Have you ever experienced your vehicle rolling away?

Can you recall a time when you returned to your vehicle and the parking brake was not applied?

Can you recall what were the circumstances?

*EAPB/Incline study0712*

Loughborough University

What order do you park in?

Initial Observation (flat)

| | |
|---|---|
| Apply Parking Brake | |
| Button in/out | |
| Select Gear | |
| Switch Engine off | |
| Out of Gear | |

Incline

| | |
|---|---|
| Apply Parking Brake | |
| Select Gear | |
| Button in/out | |
| Switch Engine off | |
| Out of Gear | |

Incline Hot

| | |
|---|---|
| Apply Parking Brake | |
| Button in/out | |
| Select Gear | |
| Switch Engine off | |
| Out of Gear | |

Flat Hot

| | |
|---|---|
| Apply Parking Brake | |
| Button in/out | |
| Select Gear | |
| Switch Engine off | |
| Out of Gear | |

How do you normally park?

Flat? Incline?

*EAPB/Incline study0712*

## E.3 Data Collation - Force Applied to Parking Brake Lever

### E.3.1 Technical Data for Handbrake Load Cell

The Aluminium F268–Z0979 1600N (F319) handbrake load cell was fitted directly to a handbrake lever. It was adapted for production tests by using an easy fit socket moulding. To avoid measuring hand clamping forces in addition to the handbrake pull force a 'dorsal fin' was used in the moulding to ensure hand clamping was avoided.

"The double shear web design and rigid low profile finger grip combine to maintain the same precision of measurement along the entire finger grip length. The typical unevenly distributed force applied by the human hand is measured with good repeatability and minimum error in a sense normal to the lever axis" (Novatech, 2008; updated 2017).

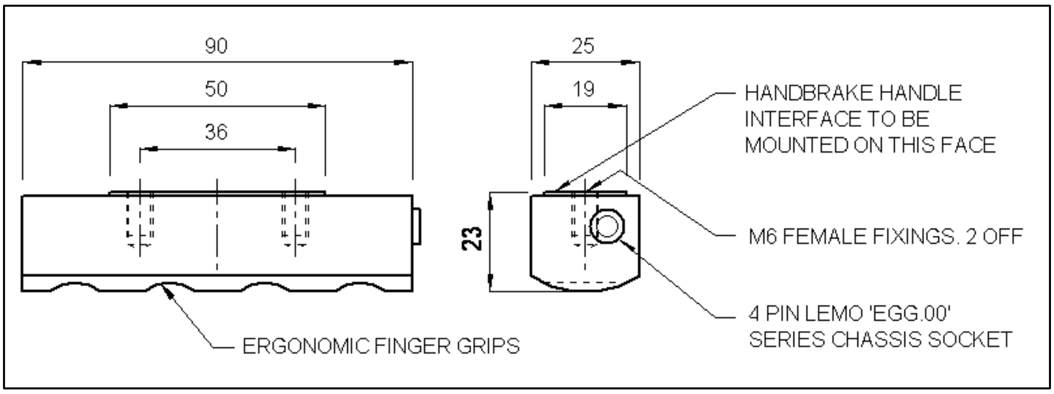



*Figure E.3.1 Handbrake load cell outline diagram (Novatech, 2008).*

### Application Tests

#### Uneven Hand Loading Errors

The uneven load distribution of a human hand has been replicated by applying point loads over the length of the load cell. In the worst case, the extreme ends, the error is limited to <1% of the applied force.

#### Handbrake Angle Vector Errors

The load cell measures force perpendicular or normal to the parking brake lever. Variations of lever inclination angle can produce angular deviations between the applied force and the load cell's normal measurement axis. For deviations up to 33° to the load cell's normal axis the load errors are limited to <1% of the applied force.

### E.3.2 Data acquisition hardware

The Novatech TR100 portable transducer readout provided with the load cell was replaced by customised data acquisition hardware to enable connection to oscilloscope software loaded on a Toshiba Portege laptop. The load cell was connected to a strain gauge signal conditioning interface (Figure E.3.2) which was connected to a Fosc-21 PC oscilloscope. This allowed a trace of the force applied to be recorded and viewed for later analysis.

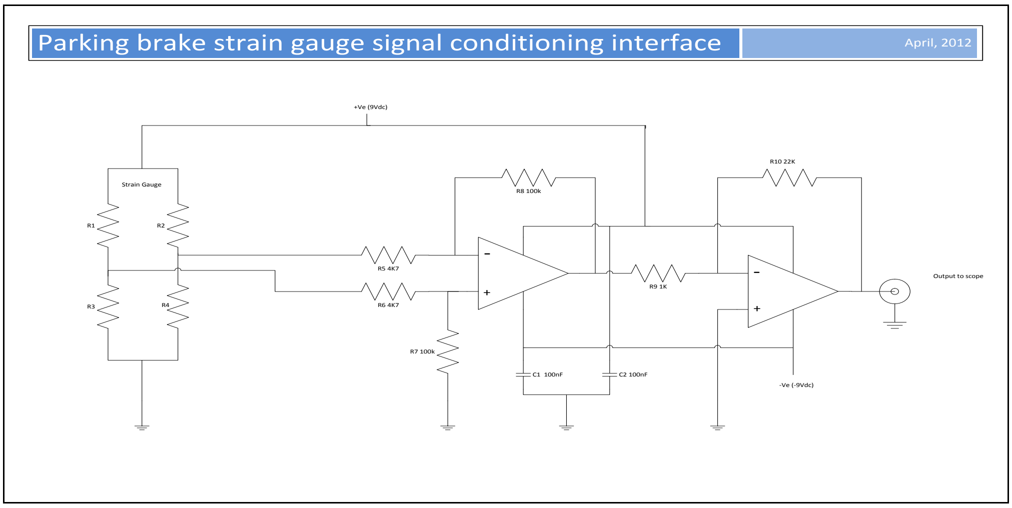



*Figure E.3.2 Circuit diagram for data acquisition hardware*

The combination of the load cell, signal conditioning interface and the 2 channel Fosc-21 USB based PC oscilloscope (*http://www.focussz.com*) can be seen in Figure E.3.3.

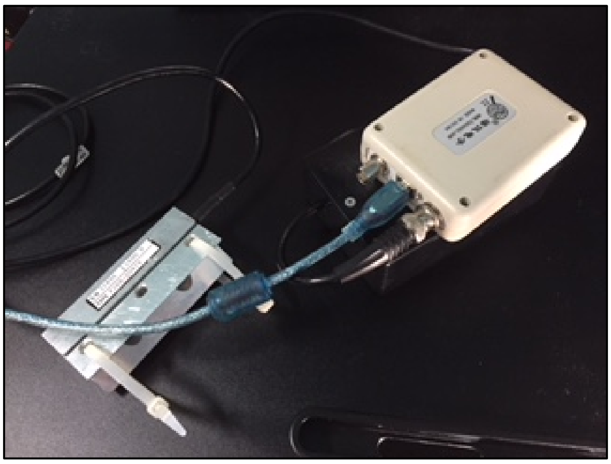


*Figure E.3.3 Load cell and data acquisition equipment*

## E.4 Test Procedures and Risk Assessment

**Risk Assessment for Parking on an Incline Study**

| **Activity:** Observation of drivers parking their own vehicles on an incline | | | **Location:** St Lukes Hospice, Plymouth | | **Assessment by:** Val Noble, Researcher; P Davies-Gregory, Health & Safety Focus, St Lukes Hospice | |
|---|---|---|---|---|---|---|
| **Hazard** | **Risk** | **Control Measures** | **Further Action** | **Action By** | **Completion Date** | |
| Moving Vehicles | Risk of Injury to researcher from open door if vehicle rolls | Vehicle parked facing down hill and "chocks" used | Researcher must remain on up hill side of open door | VN | 13/07/2012 | |
| | Risk of injury to pedestrians | All pedestrians involved in the study must wear high visibility vests/jackets | Pedestrians to keep clear of moving vehicles | VN | 13/07/2012 | |
| | | Area marked off with bollards | Ensure area marked before commencing test procedure | VN/PDG | 13/07/2012 | |
| | Risk of damage to vehicle or property | Clear instructions given to driver. Area clearly marked. Chocs used against wheels to prevent vehicle rolling. | Continue to monitor area and be aware of other vehicles | VN | 13/07/2012 | |
| Incline could be slippery when wet | Risk of pedestrian slipping or vehicle skidding | Avoid testing in adverse weather conditions, check for fuel spillages etc | Monitor Area | VN/PDG | Ongoing | |

**Layout of Parking Area**


"Test" Area

20% gradient incline

Markers positioned at upper part of slope to indicate to driver when to stop. "Keep Clear/no parking" Bollards positioned at the bottom of the slope to keep the area clear.

**Procedure for Testing for Brake Cooling Effects**

- Procedure explained and consent gained
- Load Cell applied
- Reverse onto gradient (<5% or 20%) drive/reverse on to incline 10% to face down gradient
- Apply parking brake lever ratchet by ratchet to minimal position to hold
- Ratchet position recorded
- Switch engine off and leave out of gear
- Driver remains in situ
- Measure temp of brakes, chalk mark and place chocks in front of rear wheels
- Record temperature at 5 min intervals and check for movement
- Record any creaking or movement
- If no movement after 15 mins record as no roll

When complete, remove chocks and advise driver when safe to start up and leave.
Test Conditions:

A – from ambient on <5% B – from hot on <5%
C – from ambient on 20% D – from hot on 20%
E –from ambient on 10% F –from hot on 10%
Drive around set route and repeat for both conditions.
Amendment:
To complete the entire process would take around an hour.
To reduce participant time : For cold starts measure the force applied and whether holds for 5 minutes (don't wait 15 mins) so only testing holding capability over 15 mins from a hot start.

Record Sheet for Cooling Effects Testing

**Record Sheet - Testing for Hold/Roll**

Date.................. Ambient Temp........... Weather....................................Parking Brake Type.......................................................

| Vehicle Make | Model | Year | Mileage | Discs/Drums | MOT Date | Service Date? | Recent work? |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**From Cold Start** **HB Travel:**

| **Incline** | | **5%** | | | **10%** | | | | **20%** | | | | **Comments** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min Force | | | | | | | | | | | | | |
| Time | Brake Temp | Move? | Activity | Move? | Brake Temp | Move? | Activity | Move? | Brake Temp | Move? | Activity | Move? | |
| 0 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | |

**From Warm Start** **HB Travel:**

| **Incline** | | **5%** | | | **10%** | | | | **20%** | | | | **Comments** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min Force | | | | | | | | | | | | | |
| Time | Brake Temp | Move? | Activity | Move? | Brake Temp | Move? | Activity | Move? | Brake Temp | Move? | Activity | Move? | |
| 0 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | |

* activity relates to door opening, movement within vehicle

## E.5 List of Vehicles Tested on Gradients

| Gradient | Manufacturer | Rear brake type | | Total |
|---|---|---|---|---|
| | | Drums | Discs | |
| <5% | BMW | 0 | 1 | 1 |
| | Ford | 1 | 3 | 4 |
| | Kia | 1 | 0 | 1 |
| | Peugeot | 1 | 0 | 1 |
| | Rover | 1 | 0 | 1 |
| | Skoda | 1 | 0 | 1 |
| | Toyota | 1 | 0 | 1 |
| | Vauxhall | 1 | 2 | 3 |
| | VW | 2 | 3 | 5 |
| 10% | Audi | 0 | 1 | 1 |
| | Citroen | 1 | 0 | 1 |
| | Fiat | 1 | 0 | 1 |
| | Ford | 2 | 1 | 3 |
| | Mazda | 0 | 1 | 1 |
| | Mercedes | 0 | 1 | 1 |
| | Nissan | 0 | 1 | 1 |
| | Saab | 0 | 1 | 1 |
| | Toyota | 1 | 1 | 2 |
| 20% | Audi | 0 | 2 | 2 |
| | Citroen | 1 | 0 | 1 |
| | Fiat | 1 | 0 | 1 |
| | Ford | 3 | 2 | 5 |
| | Nissan | 1 | 0 | 1 |
| | Peugeot | 2 | 0 | 2 |
| | Rover | 1 | 0 | 1 |
| | Skoda | 3 | 0 | 3 |
| | Vauxhall | 0 | 1 | 1 |
| | VW | 1 | 5 | 6 |
| Total | | 27 | 26 | 53 |

## E.6 Summary of Owner Manuals

| Make | Model | Year | Button In | In gear/park uphill | In reverse/park downhill | Turn wheels |
|---|---|---|---|---|---|---|
| Ford | C Max | 2013 | Do not | ✓ | ✓ | ✓ |
| Ford | Fiesta | 2008 on | Do not | ✓ | ✓ | ✓ |
| Ford | Mondeo | 2007 on | Do not | ✓ | ✓ | ✓ |
| Ford | Focus | 2007 on | Do not | ✓ | ✓ | ✓ |
| Ford | Galaxy | 2007 on | Do not | ✓ | ✓ | ✓ |
| Vauxhall | Astra | 2006 | Do not | - | - | - |
| Vauxhall | Astra | 2012 | Do not | ✓ | ✓ | ✓ |
| Vauxhall | Corsa | 2009 on | Do not | ✓ | ✓ | ✓ |
| Vauxhall | Zafira | 2007 | - | - | - | - |
| Vauxhall | Zafira | 2010 | Do not | - | - | - |
| Nissan | Note | 2010 | - | - | - | - |
| Nissan | Micra | 2010 | - | - | - | - |
| Nissan | Juke | 2012 | - | - | - | - |
| Skoda | Fabia | 2009 | - | - | - | - |
| Skoda | Fabia | 2012 on | - | - | - | - |
| VW | Polo | 2010 | - | All times | Not specified | ✓ |
| Volvo | C30 | 2009 | Do not | All times | ✓ | ✓ |
| Honda | Civic | 2012 | Do not | ✓ | ✓ | ✓ |
| Peugeot | 208 | 2013 | - | ✓ | ✓ | ✓ |
| Renault | Clio | 2012 | - | - | - | - |
| Toyota | Yaris | 2004/5 | - | - | - | - |
| Toyota | Yaris | 2012 | - | - | - | - |
| BMW | 3series | 2005 | - | - | - | - |
| BMW | 3series | 2013 | - | - | - | - |

Instructions contained in owner manuals for vehicles tested in observational studies. A tick indicates specific advice in relation to parking in gear. A dash indicates no reference to the release button when applying the parking brake.

## Parking

- Always apply the parking brake without pressing the release button. Apply as firmly as possible on a downhill slope or uphill slope. Depress the foot brake at the same time to reduce operating force.
- Switch off the engine. Turn the ignition key to position 0 and remove it or, with the vehicle stationary, press the Start/Stop button and open the driver's door. Turn the steering wheel until the steering wheel lock is felt to engage.

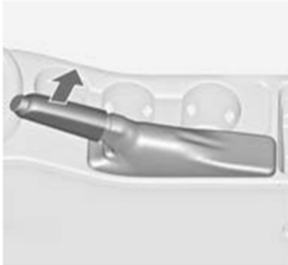
  For vehicles with automatic transmission, the key can only be removed when the selector lever is in the P position. If P is not engaged or the parking brake is not applied, "P" flashes for a few seconds in the transmission display.
- If the vehicle is on a level surface or uphill slope, engage first gear or set the selector lever to P before switching off the ignition. On an uphill slope, turn the front wheels away from the kerb.

  If the vehicle is on a downhill slope, engage reverse gear or set the selector lever to P before switching off the ignition. Turn the front wheels towards the kerb.
- Lock the vehicle and activate the anti-theft alarm system with button ═ on the radio remote control or with the sensor in a front door handle.

  To activate the anti-theft locking system, press button ═ twice or touch the sensor in a front door handle twice.
- Do not park the vehicle on an easily ignitable surface. The high temperature of the exhaust system could ignite the surface.
- On vehicles with manual transmission automated, control indicator (ⓘ) flashes for a few seconds after the ignition is switched off if the parking brake has not been applied ⇨ 105.
- Close windows and sunroof or TwinTop.

## Parking brake

### Manual parking brake



Always apply parking brake firmly without operating the release button, and apply as firmly as possible on a downhill or uphill slope.

To release the parking brake, pull the lever up slightly, press the release button and fully lower the lever.

To reduce the operating forces of the parking brake, depress the foot brake at the same time.

Control indicator ⇨ 109.

*Figure E.6.1 Vauxhall Owner's Manual, 2013 Edition, pp. 17,166*

## PARKING BRAKE

### All vehicles

**WARNING**

⚠ Vehicles with an automatic transmission should always be left with the selector lever in position **P**.

- Press the foot brake pedal firmly.
- Pull the parking brake lever up smartly to its fullest extent.
- Do not press the release button while pulling the lever up.
- If your vehicle is parked on a hill and facing uphill, select first gear and turn the steering wheel away from the kerb.
- If your vehicle is parked on a hill and facing downhill, select reverse gear and turn the steering wheel towards the kerb.

To release the parking brake, press the brake pedal firmly, pull the lever up slightly, depress the release button and push the lever down.

*Figure E.6.2 Ford Fiesta Owner's Manual, 2008 p.92; 2012, p.102*