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ERGONOMICS OF PARKING BRAKE APPLICATION – FACTORS TO FAIL?

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The vehicle parking brake may be foot, lever or electronically operated but its function remains the same: i.e. to hold the vehicle stationary whether on an up or down gradient even in the absence of the driver. Failure to do so can have serious consequences. Around 8% of drivers surveyed reported experience of “vehicle roll away” with around 55% citing the causative factor to be mechanical or system related. (Noble, Frampton, Richardson, 2013). The ergonomic factors associated with the effective application of the mechanical lever operated parking brake are explored and the potential contribution to failure considered.

Introduction

The function of the vehicle parking brake system is to “hold the vehicle stationary on an up or down gradient even in the absence of the driver” (UNECE, 2008). Failure of the unattended parked vehicle to remain stationary can result in minor property damage, injury or even fatality. Although not considered to be a significant problem, evidence suggests that “vehicle roll away” is not a rare phenomenon. However, determining the extent of these incidents is difficult as they are not consistently reported and those that are may not be reliably recorded.

A task analysis of applying the parking brake to hold the vehicle stationary indicates there is a complexity of potential factors which can contribute to a successful or unsuccessful outcome. These may include driver behaviour and demographics, training and instruction, mechanical or system and environmental factors. This paper illustrates an initial exploration of physical and mechanical factors to be considered when the driver interacts with the lever operated parking brake system.

The manually operated lever parking brake (handbrake) employs a simple ratchet and pawl arrangement. This type of mechanism is considered to be of relatively low cost, and has been regarded as 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 and the force applied to operate it should not exceed 40daN (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. Parking brake related faults resulted in 29 vehicle recalls by several manufacturers in a 5 year period 2006-2010. (VOSA, 2011).

The parking brake system is a secondary system applied independently of the service brakes and may utilise a drum or disc design. The drum design is considered to be ideal as a parking brake due to a higher brake factor in relation to the friction coefficient (Limpert, 1999). With an increase in temperature, the disc brake assembly expands. As the system cools and returns to ambient temperature the discs and pads contract with a potential loss in braking force. In drums, the drum diameter increases as the temperature increases but cooling has little or no reduction in the friction coefficient (McKinlay, 2007).

The complexity of a control action that is regarded as relatively simple is illustrated in figure 1. The driver must apply the parking brake before leaving the vehicle and if parked on an incline he/she should select the appropriate gear (if manual) or park (automatic) and turn the wheels of the car in the appropriate direction (DFT & DSA, 2007). If this is incomplete and the parking brake's holding capability is compromised the risk of the vehicle failing to remain stationary is increased.

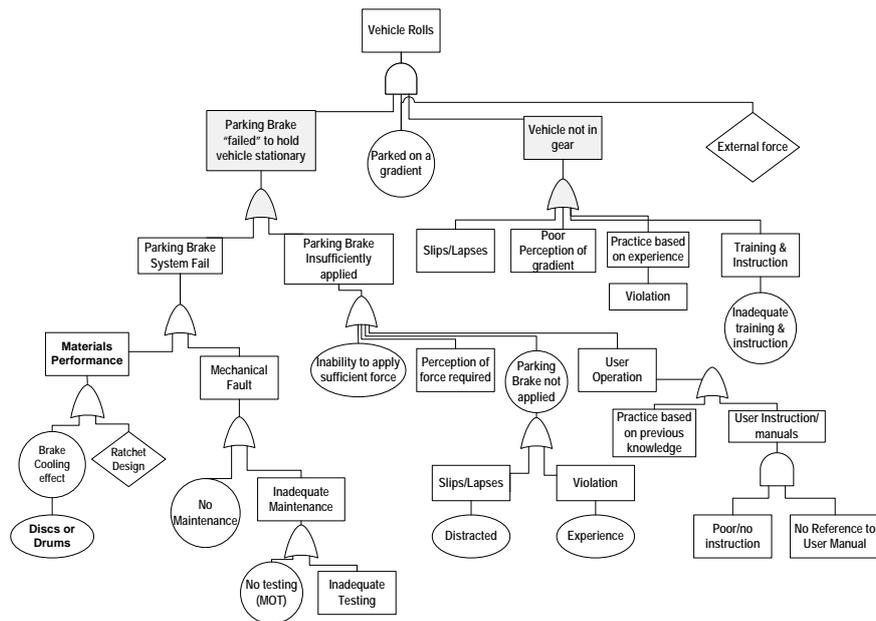


Figure 1. Fault tree analysis for parked vehicle failing to remain stationary

The fault tree analysis (Stanton et al 2005,) depicts an incident where a “vehicle rolls” and identifies areas for further investigation and data analysis.

Materials and Methods

Online survey

An on-line survey to explore the question: *What is the driver's perception and experience of the parking brake system?* (effort, usability, vehicle roll away) was distributed through a local health care organisation, professional networks and social media sites.

Participants

One hundred and thirty eight drivers aged 20 - 80 years (mean 52.7(SD 13.6) with a 3:1 ratio of male to female and around 91% reporting over 10 years experience responded. All but 6 drivers passed their driving test in the UK and 14 (10.69%) of the respondents reported regularly driving a left hand drive vehicle. The driving environment represented was reasonably evenly spread across motorway, rural and urban categories with least responses to city driving (14%).

Observation of Driver Interaction in Static Assessment Rig

An established static rig was used to observe and evaluate the interaction of individual drivers with a lever operated parking brake in a controlled environment and served as a pilot for a study of drivers in their own vehicles. The following questions were explored:

What force do individuals apply to the handbrake lever?

How does the interaction with the geometric layout affect the force applied?

Participants

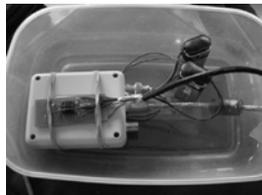
Twenty eight licensed drivers aged 21-59 years with varying levels of driving experience were recruited from the staff of the Cornwall Disability Assessment Centre and medical students on clinical placement who were familiarised with the operation of the rig.

Equipment and Materials

Force Applied to Parking Brake



A Novatech F268 handbrake load cell was fixed to the parking brake lever with plastic tie wraps. The force applied was recorded using custom made data acquisition hardware powered by 2 cell batteries connected to Focus Oscilloscope software (Photographs 2, 3.). Calibration was performed using a known weight and testing of the system indicated the combination was appropriate for data collection.



Photograph 2. Raw materials



Photograph 3. Final version in casing

Procedure

Pre test measurements

Static anthropometric measurements recorded for the seated participant included: Body height, shoulder height, upper arm length, lower arm length, elbow height, grip length, hand length, hand thickness, thumb length. Observations were conducted with participants wearing indoor clothing and comfortable driving shoes.

Test Scenario

Participants were instructed to adjust the seat to their preferred driving position. The body landmark locations and seat position in relation to the parking brake were recorded. Six static road scenes were displayed in front of the driver as a visual cue to either park or drive. The driver was instructed that for the parking cue they were to stop and park as if they were leaving the vehicle. When a picture of a driving scene was displayed, the driver was instructed to release the parking brake and drive on. 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.

Observation of Parking on an Incline

To observe driver interaction in a “real life” setting, a 2 part study was developed where drivers parked their own vehicle on a 20% incline to address the following questions: *What force does the driver apply to the parking brake to hold the vehicle stationary?*

What are the mechanical considerations-is there any difference in application and performance between brake types?

Participants

Twenty three female and 14 male (2 left hand dominant) drivers aged between 21 and 70 (mean 48.4, S.D. 13.4) with an average driving experience of 25 years participated in part one of the incline study.

In part 2, 16 vehicles registered 1999 - 2013 were tested before and after driving a set route. Nine of the vehicles were fitted with disc brakes and 7 with drums type.

Procedures

In part one, drivers were asked to reverse onto a 20% incline and park their vehicle. As part of the risk assessment, chocks were positioned in front of the rear wheels. The Novatech F268 load cell was applied to the parking brake lever and connected through the custom made data acquisition hardware to Focus Oscilloscope software on a Toshiba Portege laptop. The drivers were then requested to release and re-apply the parking brake. Anthropometric measurements were recorded to explore the geometric layout and hand grip force tested using a dynamometer. Drivers were questioned about their driving experience and vehicle controls and asked to rate their confidence in the parking brake holding capability on a scale of 1 to 5 (not all confident to extremely confident).

In part two, the minimal force required to hold the vehicle stationary, the travel distance of the parking brake and the temperature of the rear brakes was recorded before and after driving a pre-determined route. Force application was recorded as before and the temperature of the brakes was recorded at 5 minute intervals up to 15

minutes using a handheld infrared pyrometer. Any creaking and settling of the brakes was noted and a “roll” recorded when the vehicle rolled forwards and made contact with the chocks.

Results

Survey Results

A hand lever operated parking brake was employed in the vehicles of 105 (88.24%) respondents with 8 foot activated and 22 electronic parking brakes in the remainder. Contrary to most manufacturer’s owner manuals, 84.7% reported pulling the lever up while pushing the button in. Twenty seven (25.7%) of the respondents operating a lever hand brake reported the effort required to be somewhat hard or heavy on a perceived exertion scale (Borg, 1998).

Around 5% of respondents reported returning to their car to find the parking brake was not applied. Eleven (8%) respondents reported an experience where their vehicle had rolled, and in 4 of these the parking brake had not been applied. Five (45%) respondents documented distraction or error as a reason and 6 (55%) indicated the causative factor to be mechanical or system related

Application of Force

The mean forces recorded in response to visual cues for parking in the car park, parking on a hill and parking at the supermarket were 100.8N, 145.8N and 94.5N respectively. The mean figures recorded in relation to shoulder height are illustrated in figure 2. It would appear that drivers apply an increased force to the parking brake when they perceive there to be an incline.



Figure 2. Force applied in response to visual cues in relation to shoulder height

In the *incline study*, the recorded force that the driver applied to the parking brake ranged from min 152N to max 432N (mean 255N, S.D. 93.05). Twenty five (67.7%) of the drivers parked in gear. The male driver recording the maximum force reported that he never parks in gear and has not experienced a roll away. However, his wife cannot release the handbrake when he has applied it. The female driver recording

the smallest force reported she always parks in gear as “sometimes the handbrake doesn’t hold”.

In part one of the incline study, 28 (80%) of the participants rated their confidence parking on an incline to be 4 or 5 indicating they were very confident conducting this task. Thirty two (91%) also considered they were very or extremely confident that they could apply sufficient force to the parking brake to operate it. Thirteen drivers (37%) indicated they were moderately confident or less (rating of 2 or 3) that the parking brake alone would hold the vehicle stationary. The results are illustrated in figure 3.

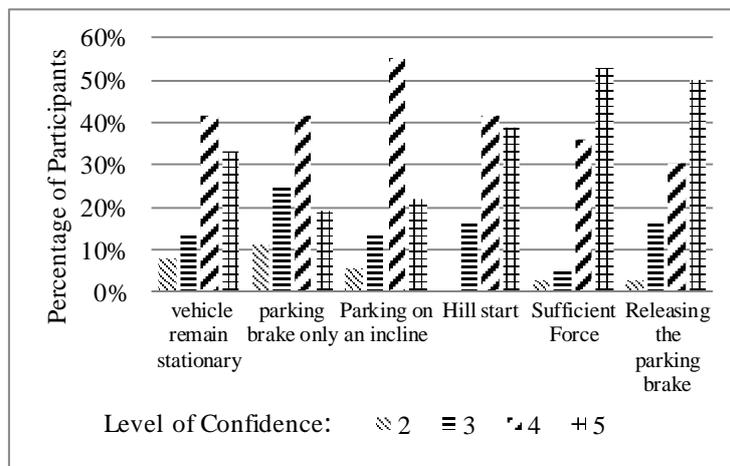


Figure 3. Level of confidence in relation to parking brake task (n=35)

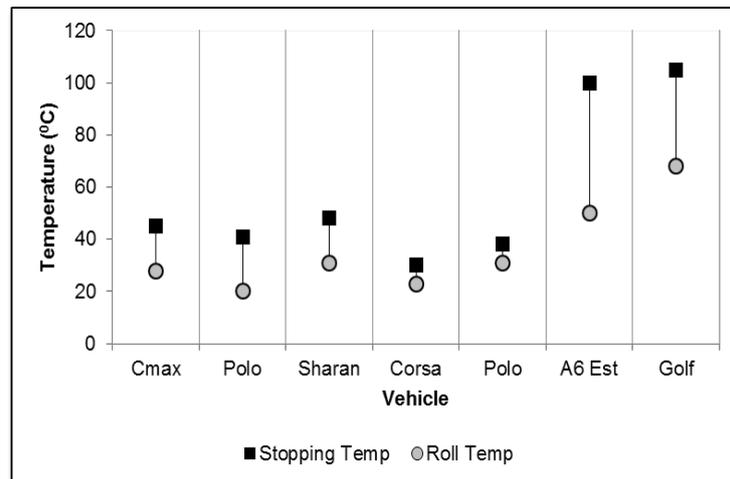


Figure 4. Brake temperatures from stopping to rolling per vehicle observed.

In part 2 of the incline study, 7 of the 9 vehicles fitted with disc brakes rolled (5 of these were registered between 2010 and 2013). Brake temperature differences from stopping to rolling ranged from 7⁰C to 50⁰C with a mean difference of 20.9⁰C and is illustrated for the relevant vehicles in figure 4.

Discussion

The fault tree analysis illustrates that the task of applying the parking brake to hold a vehicle stationary is multifaceted with a complexity of variables which could lead to failure. Discussed here are just 2 of these factors – physical and mechanical and the studies presented are part of a larger project.

Force Applied

Early results indicate that the force which is applied to the parking brake varies across individuals and vehicles. This could concur with the findings of Chateauroux and Wang where the force applied depended on the subject group and location of the parking brake, in that a greater force was recorded when the parking brake was low. (Chateauroux and Wang, 2012). Larger forces recorded when the “parking on a hill” visual cue was displayed suggest that drivers’ perception of the gradient affects the degree of parking brake application. The mean force of 255N recorded using driver’s own vehicles is less than the figure used for testing purposes where the vehicle should remain stationary on a 20% incline for 5 minutes and the force should not exceed 40daN (UNECE, 2008; Curry, Suffolk, 2011). Observation of practice demonstrated that drivers re-apply the parking brake as necessary to hold the vehicle and may or may not park in gear. The 8 drivers observed who did not park in gear, parked on the flat overnight and 2 had experienced a roll away where they had forgotten to apply the parking brake. There did not appear to be a relationship between age, gender or years driving experience but further investigation is required.

Confidence in the System

If the driver applies the parking brake sufficiently to hold the vehicle stationary at the time of stopping and leaving the vehicle, will it remain stationary if not in gear? Drivers reported a reduced level of confidence as to whether the vehicle would remain stationary on an incline and whether it would remain stationary with only the parking brake applied i.e. not in gear. This reduced confidence may not be isolated to lever operated systems and may be a factor as to whether drivers park in gear.

Mechanical Compromise

Responses from drivers who had experienced a roll away and a review of media reports (Noble, Frampton, Richardson, 2013), suggests that there is a delay in the time from stopping the vehicle to it rolling. It is possible this is due to a “cooling effect”. The results communicate how with a relatively small drop in disc brake temperature, friction contact can be reduced, compromising the function, and the vehicle could roll. The key factor may not be the length of time itself but the time that it takes for the brake system temperature to reduce to the critical point where the brake force is no longer sufficient to hold the vehicle stationary. Where a driver is

unaware of this effect and does not park in gear or park on an incline, the risk of roll away is increased.

Although an increase in the fitting of Electro-mechanical parking brake systems, negating the application of force by the driver, is projected, further research is required into the mechanical efficiency of and driver interaction with parking brake systems employing disc brakes.

Conclusion

The project continues to uncover further areas for investigation and discussion with key stake holders such as Association of Driving Instructors (ADI), Vehicle Operators and Service Agency (VOSA) and Driving Standards Agency (DSA). It may be difficult to draw conclusive significance to any one causative factor but, exploring the potential contributory factors could provide the evidence base for recommendations. Despite the constraints, exploring driver interaction with the parking brake system in “real life” has provided useful data for future work.

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