FRONTAL IMPACT PROTECTION: TAILORING SAFETY SYSTEM PERFORMANCE BY THE PREDICTION OF DRIVER SIZE AND SEATED POSITION

Margaret Galer Flyte
Vehicle Safety Research Group
Loughborough University
Leicestershire
United Kingdom
Paper Number 98-S1-O-09

ABSTRACT

The design of systems to protect occupants in car crashes assume that the size and seated position of the driver is 'average'. If the occupant protection system had information that the driver is larger or smaller than 'average', sitting closer to or further from the steering wheel, the system could tailor its performance and enhance the protection offered. In this study measurements of anthropometric characteristics of drivers and their position were taken and analyses carried out to identify correlations between the measures. It is possible to predict a driver's physical dimensions and seated position from these data. The algorithms provided an input to the determination of the physical characteristics of the driver and their seated position in relation to the steering wheel, from sensors in the seat and seat mounting.

INTRODUCTION

There is considerable potential for improving occupant protection in crashes by the application of smart systems technology. Galer and Jones (1994a) describe a number of ways in which intelligent secondary safety systems can be developed, and provide indications of which strategies would be preferable from a design perspective. Intelligent systems technology can effectively be applied in three main areas in secondary safety. These are providing information on the characteristics of the environment in which the system is operating i.e. the vehicle, the occupant and the crash; interpreting that information to provide appropriate occupant protection; and the initiation of that protection via actuators. The intelligent system can gather relevant data, interpret it, tailor and initiate a response which optimises the protection of the occupant.

At present a seatbelt or airbag will perform in a crash irrespective of the size of the occupant or their proximity to the steering wheel. If information about the occupant such as this could be made available to an occupant protection system via sensors in the seat and its mountings, it would be possible to make the seatbelt or airbag operate in a way that is tailored to the characteristics of that particular occupant. For example, the airbag could deploy more quickly if the occupant is short, (positional information from sensors in the seat runners) who will be sitting closer to the steering wheel and currently runs the risk of hitting a deploying airbag. The intelligence is now available to make decisions about how an adaptable system should be deployed (Galer and Jones, 1994b). Smith, Bergfried and Faye's paper (1994) concerning their SMART™ Airbag System provides information about system optimisation and how algorithms could be developed for an adaptive system if data about occupant size, position, crash severity and ambient conditions were known. Schulte and Weyersberg (1994) describe ways in which smart seatbelts could help provide optimal impact protection for a wider range of individuals than at present.

The seated position adopted by car drivers depends on their physical characteristics, the adjustability options provided by the vehicle package and, to some extent, personal preference. Drivers must maintain proper control of the vehicle, so they need to be able to reach the pedals, gear selector, steering wheel and other controls; they must also be able to see out of the vehicle in the forward, side and rear view. In order to achieve a seated position that enables the driver to undertake these activities the vehicle package offers a range of adjustments. Primarily, these are fore and aft movement of the seat and seat back rake angle. The driver has the opportunity to adjust these variables until an acceptable driving position is attained. When a vehicle is involved in a crash the injury outcome to the occupants will depend principally on the direction and energy of the impact. However, also of importance is the amount of space the occupants have to move in before the safety system, the vehicle interior or intruding objects are contacted. In the case of drivers involved in frontal impacts their position in relation to the steering wheel is a key element in the nature and severity of injuries they receive (Aibe, Watanabe, Okamoto and Nakamori, 1982; Hyde, 1992). The performance of the seatbelt and airbag will also have a major effect on the nature and severity of injuries. The main purpose of the seat belt is to slow down the occupant and absorb the energy of the crash. The purpose of the Euro-sized airbag is to absorb the energy of the head as it is about to strike the steering wheel, thus reducing facial injuries. The interaction between the occupant and the safety system is critically dependent on the size of the occupant and their proximity to the steering wheel.

Developments such as retractors and webbing grabbers have improved the performance of seatbelts. Seatbelt reel and buckle pre-tensioners pull the seatbelt tightly round the occupant when a frontal crash is detected. This reduces slack in the belt, couples the occupant into the crash and reduces the energy of the impact with the belt. The airbag deploys very rapidly and with a great deal of energy, then gradually deflates through vents in the rear. It is important, therefore, that the occupant does not hit the airbag while it is deploying, nor hit it too late when deflation is occurring. Until recently the deployment characteristics of airbags were fixed, however, further developments in technology have made it possible to adjust the performance of airbags in car crashes. For example, the airbag inflators can have variable deployment time, maximum inflation pressures and gas flow rates (Galer, 1993). This capability, together with the availability of microprocessor based control systems, has made it possible to provide the intelligence needed to make decisions about how an adaptable system should be deployed to more closely meet the requirements of the individual occupant.

This research programme was concerned with finding means to provide an adaptable secondary safety system with information about the physical characteristics of the vehicle occupants, specifically the driver, such as their size and position in relation to the interior of the vehicle. With this information the secondary safety system could respond according to whether the occupant was, for example, large or small, sitting close to or further away from the steering wheel.

RESEARCH RATIONALE

It can be seen that there could well be benefits in terms of injury reduction to be able to tailor the performance of the safety system to the physical characteristics of the occupant and/or to their seated position. The issue addressed in this paper is how to obtain the necessary information on occupant size and seated position. The latter option of gathering the information from sensors in the vehicle seat and its mountings was chosen for a number of reasons including reliability, cost and nearness to likely market implementation.

The two elements to be identified, therefore, are occupant size and proximity to the steering wheel (seated position). The research programme measured certain key anthropometric dimensions of drivers, their position in the vehicle and in relation to the steering wheel, and analysed the data to identify correlations. Algorithms were then established. A seat and its mountings were instrumented with sensors and trials undertaken with drivers to investigate whether the algorithms were correct and whether occupant size and/or seated position could be established from such sensors. This work is reported in more detail in Grafton, Galer Flyte, King and Jackson, 1995.

Aims of the Research

1. To investigate which vehicle-related measures can be used reliably to classify and categorise drivers according to their size and seated position in the vehicle.
2. To investigate what vehicle-related measures can be used reliably to locate drivers with respect to injury producing features such as the steering wheel.
3. To make recommendations from significant relationships as to which seat variables could be used to categorise drivers and their seated position, and so be used for the formulation of algorithms.
4. To investigate the feasibility of using smart sensor technology to obtain information about the characteristics of the occupant with which to tailor the performance of the vehicle occupant protection systems. The information about the occupant would come from sensors in the seat and its mountings.
5. To build and test a technology demonstrator of a 'Smart Seat'.

Research Strategy

The research involved a number of experimental approaches.

Anthropometric Studies: Measurements were taken of members of the driving public to record their anthropometric characteristics and the seated position they adopted in their own vehicle. Significant correlations between vehicle-related and occupant-related measures were identified and algorithms established (Perchard, 1994). These algorithms were tested in trials with drivers in the technology demonstrator.

MADYMO Modelling: Investigations with MADYMO were undertaken to show whether improvements could be made to the performance of an existing safety system if the safety designer could assume that the size and the position of the occupant were known prior to the final design of the system. The outcome of the investigations was expected to be a broad 'yes' or 'no' answer to the above question and an indication of how extensively an existing safety system would have to be changed to make it adaptable. This is reported in Galer Flyte and Grafton, 1997.

Instrumentation Exercise: An instrumentation exercise was also undertaken to identify the ways in which a seat could be made smarter to provide the information required to position and classify occupants. Sensors and other instrumentation were fitted to a vehicle seat and the fundamental design work was undertaken in the laboratory.

Construction And Testing Of A Technology Demonstrator: A technology demonstrator was created to verify the operation and usefulness of the occupant position sensing and to validate the findings of the study on the prediction of occupant size and seating position from vehicle related parameters. Verification of the system's reliability, repeatability and immunity to error was undertaken by conducting trials with drivers of known anthropometric characteristics.

ANTHROPOMETRIC STUDIES

A study of the anthropometry of British car drivers was conducted by Haslegrave in 1980, and although the study was extensive it measured only the drivers and did not include their seated position in the vehicle. Parkin, Mackay and Cooper (1993) undertook a study to relate drivers' seated position to the positions specified for dummies in crash tests. Their research found that drivers do not necessarily sit in the positions dummies are placed for crash testing, and that the discrepancies can be large. For example, they calculated that a 5th percentile female actually sits up to 9.2 cm further forward than would be expected on the basis of the dummy position requirements. The measures were taken from video recordings of drivers in moving cars. Although there are a number of studies concerned with occupant size, posture and comfort these do not provide the vehicle-related information required for this study. This study, therefore, measured driver related factors, vehicle related factors, and driver-vehicle interaction related factors with a view to finding the minimum number of measures needed to categorise the driver reliably in terms of size and seat position. This work is reported in more detail in Perchard, 1994.

Measurements were taken of the drivers, the vehicles and the driver-vehicle interaction as described below.

Measurements Of The Drivers

Stature
Leg length (top of greater trochanter to floor by heel)
Chest/bust circumference
Waist circumference
Hip circumference
Weight (st. lb.)
Trunk length was computed from stature and leg length, and age was also recorded.

Measurements Of The Vehicles

Runner on door sill to top of steering wheel (vertical)
Runner on door sill to centre of steering wheel (vertical)
Runner on door sill to seat back rake fulcrum (vertical)
Diameter of steering wheel
Base of 'A' pillar to top of steering wheel
Base of 'A' pillar to front edge of seat (horizontal)
Front edge of seat to brake pedal (horizontal)
Seat length i.e. front of seat edge to seat back rake fulcrum (horizontal)
Seat back rake angle (in degrees)
Seatbelt payout (without driver)

Measurements Of The Driver-Vehicle Interactions

Nasion to top of steering wheel
Nasion to centre of steering wheel hub
Nasion to runner on door sill (vertical)
Sternum/seatbelt junction to top of steering wheel
Sternum/seatbelt junction to centre of steering wheel hub
Sternum/seatbelt junction to runner on door sill (vertical)
Seatbelt payout with driver
Seatbelt payout difference was calculated from seatbelt payout with and without driver.

What Vehicle Related Measures Can Be Used To Classify And Categorise Drivers According To Their Size And Seated Position In The Vehicle?

Multiple regression analyses were performed for the vehicle related variables for each of the anthropometric variables. The main findings are summarised below.

<u>Trunk Length</u> For males, trunk length can be calculated from the 'A' pillar to seat front distance with a high probability of accuracy.

No reliable way of predicting trunk length for females was found.

<u>Leg Length</u> For males, leg length can be calculated from an equation including the door sill to the top of the steering wheel distance, the distance from the seat rake fulcrum to the door sill, the 'A' pillar to seat front, and the seat back rake angle.

No reliable way of predicting leg length for females was found.

<u>Chest/Bust, Waist And Hip Circumferences</u> No accurate or reliable way of predicting these circumferences was found.

<u>Weight</u> Weight of males can be predicted reliably and with a good degree of accuracy from the brake pedal to seat front distance.

Weight of females can be predicted with a high degree of accuracy and a high level of reliability from the seatbelt payout and the brake pedal to seat front distance.

What Vehicle Related Measures Can Be Used Reliably To Locate Drivers With Respect To Injury Producing Features Such As The Steering Wheel?

The measures used in the study to locate the driver in relation to injury producing features, 'injury distances', are the distances from the head and chest to the steering wheel.

<u>Nasion To Top Of Steering Wheel</u> The nasion to top of steering wheel can be calculated reliably for a combined males and females data set from the door sill to centre of steering wheel distance, seatbelt payout, 'A' pillar to top of steering wheel distance, 'A' pillar to seat front distance, seat back rake angle, and seat length.

__Nasion To Centre Of Steering Wheel__ The nasion to centre of steering wheel distance can be calculated with a high degree of accuracy and reliability for a combined males and females data set from the brake pedal to seat front distance, seatbelt payout, 'A' pillar to seat front distance, and seat back rake angle.

__Sternum To Top Of Steering Wheel__ The sternum to top of steering wheel distance can be calculated for a combined male/female data set from the brake distance to seat front distance, door sill to centre of steering wheel distance, seatbelt payout, seat rake angle, 'A' pillar to seat front distance, and 'A' pillar to top of steering wheel distance.

__Sternum To Centre Of Steering Wheel__ The combined male/female data set reliably predicts the sternum to centre of steering wheel distance to a very high degree of accuracy. This is calculated from seat rake angle, 'A' pillar to seat front distance, seatbelt payout, 'A' pillar to top of steering wheel distance, seat fulcrum to door sill distance, door sill to centre of steering wheel, and door sill to top of steering wheel distances.

CONSTRUCTION AND TESTING OF THE 'SMART SEAT' TECHNOLOGY DEMONSTRATOR

Construction of the technology demonstrator consisted of fitting the instrumented seat and seatbelt into a Rover 400 vehicle buck. The system components were integrated into the vehicle buck, the system calibrated and trials run to see how accurately the seat position measures related to actual occupant position. The technology demonstrator instrumented seat provided data from sensors with which to locate the occupant in the vehicle and classify them into broad size categories. The drivers and their position in the vehicle were measured and these actual measurements compared with the measures provided by the sensors in the 'smart seat' installed in a stationary car buck. Participants of known anthropometric characteristics could then be measured by the system to 'calibrate' it for a particular vehicle. Verification experiments were subsequently carried out on different participants to determine the accuracy of the system output.

The aim of the verification trials was to validate the operation of the 'smart seat' system and sensors by establishing reliable relationships between data from the seat and the occupants' actual size and position with the vehicle. Two types of measurement were taken, those the 'smart seat' system measured directly, for example, seatbelt payout and seat back rake angle, and those that needed to be calculated, for example, sternum to steering wheel distance. Table 1 shows the measurements taken in the trials.

Anthropometric measurements were taken to record the size and shape of persons taking part in the study. The occupant was located relative to the interior of the vehicle by measuring from the centre of the steering wheel to their nasion and to the point where the seatbelt crossed their sternum. These two distances are critical for the safety system. Measures of the seat position, seatbelt payout and the distance of the occupant's head from the head restraint were taken automatically by the computer and a graphical display on the computer screen showed where they were sitting.

Table 1.
Measurements Taken During The Verification Trials

Calculated variables	Measured variables
Stature	Seat fore / aft
Leg length	Seat height
Weight	Seat back rake angle
Sternum to centre of driving wheel	Head position sensor output
Nasion to centre of driving wheel	Seatbelt payout without driver
	Seatbelt payout with driver

Multiple regression analysis compared each factor to be calculated against all of the factors that could be measured. An overview of the results is shown in Figure 1 below. The size of the dot in each box indicates how well each measured variable predicts each calculated variable. No dot indicates the correlation is poor or non-existent. An example of this would be that the two variables that predict height are the seat fore/aft position and the back rake angle. Of the two predictors, the fore/aft position is strong and the rake angle is weak.

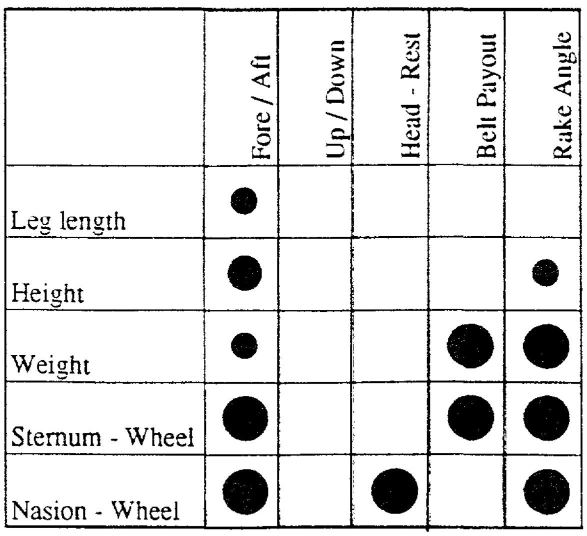

Figure 1. Prediction matrix used in analysis of data.

The strongest relationships from the 'smart seat' sensing system can be seen in Figure 1. The sternum to steering wheel distance and nasion to steering wheel distance are strongly predicted by the three factors that can be measured.

DISCUSSION

Driving is a dynamic activity and the position of the driver varies continually. The method used to obtain data on seated position took measurements of a static driver in a static car. The seat position adjustments, however, were reliable as the participants had driven their own cars to the test site and had not subsequently altered the adjustments. The variation, therefore, was only in the more subtle movements of head and chest position in relation to the steering wheel, both of which vary continuously during driving. Hence any variations for individuals would be small if the seat adjustments remained the same. There are also boundaries in that drivers cannot sit further away from the steering wheel than the measures taken in this study, as they are constrained by the seat back and the head restraint. They may only sit or move closer to the steering wheel by leaning forward. This was addressed by the seat back/head restraint mounted sensors (Grafton et al., 1995) developed later in the programme. The results were compared with those found in Parkin et al. (1993) but could only be made for the direct 'nasion to centre of steering wheel' measure. Only an approximate fit was possible, however, the variation in distance was not greater than 2 cm or 3.4% which occurs at the 95th percentile level. This indicates that the results of this study are supported by Parkin et al. (1993) where the sample size was 1000 and where the measurements were determined from videos of drivers who were unaware of the camera in the dynamic, real life situation of driving a vehicle.

The study did not attempt to obtain exact measures of each individual driver but measures that would enable the drivers and their seated position to be classified into broad bands that would, in turn, facilitate some tailoring of the occupant protection system. It is sufficient at this stage of technological development that the system knows that the driver falls outside the 'normal' seated position of the 50th percentile male for which the systems are primarily designed.

It was not easy to deduce logically or reliably the predictor variables through the simple association of one variable with another, hence stepwise regression analysis was implemented in order to obtain reliable and accurate results. It was also difficult to predict all the variables that would have a significant influence in the results and it is possible that not all the useful variables have been included in the analysis.

The low sample size has undoubtedly introduced errors, but as sound relationships were found for a small population they will only improve as the sample size increases and the distribution normalises.

For the data to be considered valid for a range of vehicle types, the investigations would have to be carried out on a number of different vehicles. One reason for the strength of the correlations between factors in this experiment is that the vehicle type was the same throughout the investigation.

However, it appears possible to use a seat based sensor system to measure and predict the position of the occupant relative to the interior of the vehicle if the occupant adopted a normal driving posture. It is also possible, but with less accuracy, to give an indication of the occupant's physical size characteristics.

The results are highly vehicle specific but it seems probable that relationships similar to those identified during this study will exist for other vehicle types.

CONCLUSIONS

There is an opportunity to enhance the performance of current secondary safety systems in frontal collisions by tailoring the performance to the characteristics of the driver.

Algorithms have been established which enable the prediction of occupant size and seated position.

Certain critical characteristics and dimensions can be measured and/or calculated from data obtained from the seat and seatbelt configuration.

Sensors have been implemented in a prototype Smart Seat that predict the physical characteristics of the seat occupant and their location with regard to critical vehicle features such as the steering wheel.

This is a very exciting and forward looking research activity.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contribution of members of the Vehicle Safety Research Group at Loughborough University, especially the outstanding work of Andy Grafton who constructed and tested the Smart Seat demonstrator and of Mark Perchard who carried out the anthropometric studies of drivers. The author would also like to thank Rover Group for supplying project equipment and advice, and Mike Jackson and Paul King of the Department of Mechanical Engineering for their contributions to the study. This project was funded by Loughborough University Strategic Fund and by Rover Group.

REFERENCES

Aibe, T., Watanabe, K., & Nakamori, T., Influence of Occupant Seating Posture and Size on Head and Chest Injuries in Frontal Collisions. Proceedings of 9th International Technical Conference on Enhanced Safety of Vehicles. 1982.

Augenstein, J.S., Perdeck, E., Stratton, J., Digges, K., Lombardo, L. & Malliaris, A., Injuries Sustained by Air Bag Occupants in Frontal Crashes. Proceedings of 14th International Technical Conference on Enhanced Safety of Vehicles. 1994.

Galer, M.D., Advanced Technology Applications for Primary and Secondary Safety. C642/2/091. In C462/2 Road Transport Informatics, Institution of Mechanical Engineers, London. 1993.

Galer, M.D. & Jones, S.R., (1994a), Intelligent Occupant Protection Systems, Proceedings of the 14th International Technical Conference on the Enhanced Safety of Vehicles, 94 S3 O 11, Munich, May 1994, pp 491-498.

Galer, M.D. & Jones, S.R., (1994b), Opportunities for Intelligent Secondary Safety Systems. Proceedings of Convergence '94, International Conference on Transportation Electronics, Dearborn, Michigan, USA, SAE Technical Paper 946022, Society of Automotive Engineers, Warrendale, USA, 1994.

Galer Flyte, M.D. & Grafton, A.J., The development of a 'Smart Seat' occupant size and position sensing system for the enhancement of occupant protection. International Journal of Crashworthiness, Vol. 2, No. 2, pp 153-164, 1997.

Grafton, A.J., Galer Flyte, M.D., King, P.D. & Jackson, M.R., Pre-crash sensing of occupant characteristics and position: Enhancing secondary safety system performance. Proceedings of the 1995 International Conference on the Biomechanics of Impact, Brunnen, Switzerland, September 1995, pp 311-323.

Haslegrave, G.M., Anthropometric profile of the British car driver. Ergonomics, 1980, Vol. 23, No. 5, pp 437-467.

Hyde, A.S., Crash Injuries: How and why they happen. Hyde Associates Inc., Key Biscayne, Florida. 1992.

Mackay, G.M., Smart Seat Belts - Some Population Considerations Applied to Intelligent Restraint Systems, in: Society of Automotive Engineers, Warrendale, USA. SAE Technical Paper 940531, 1994.

Mackay, G.M. & Hill, J.R., The Kinematics of Restrained Front Seat Occupants in Frontal Crashes as Deduced from In-depth Crash Investigations. Proceedings of the 26th International Symposium on Automotive Technology and Automation. Dedicated Conference on Road and Vehicle Safety. 1993.

Parkin, S., Mackay, G.M. & Cooper, A., How Drivers Sit in Cars. 37th Annual Proceedings, Association for the Advancement of Automotive Medicine. 1993.

Perchard, M.F., The Anthropometry of Car Drivers for the Optimisation of Secondary Safety Systems in Frontal Collisions. Unpublished M.Sc. Thesis, Department of Human Sciences, Loughborough University, UK. 1994.

Schulte, U. & Weyersberg, A., Theoretical Optimisation of an Airbag System. Proceedings of the 14th International Technical Conference on Enhanced Safety of Vehicles. 1994.

Smith, B.W., Bergfried, D. & Faye, I., SMART™ Airbag System. Proceedings of the 14th International Technical Conference on Enhanced Safety of Vehicles. 1994.