The Influence of Body Mass Index and Weight on Injury Severity in Motor Vehicle Crashes

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ABSTRACT

Vehicle safety testing standards in Australia list dummies of three specific proportions to represent adult drivers and passengers in laboratory crash testing: the 50th percentile male, 5th percentile female and the 95th percentile male. However, only the historically ascertained 50th percentile male dummy is required for test compliance. Given the vastly differing physical proportions of adult vehicle occupants across the population, it is conceivable that they will suffer different injuries in a motor vehicle crash relative to their differing physical proportions. The aim of this study was to investigate the influence of occupant Body Mass Index[1] (BMI) and body weight on the injury severity of front seated adult occupants in frontal motor vehicle crashes. This is the first study using real-world Australian data to investigate this issue. In-depth crashed vehicle data collected by the Monash University Accident Research Centre (MUARC) were analysed. Differences in injury severity were compared against BMI and weight and analysed against other relevant variables including measurements of crash severity. Multivariate logistic regression analysis showed the risk of moderate to critical injury (Abbreviated Injury Scale - AIS2+ injury) was significantly related to lower occupant BMI, and higher equivalent barrier speeds of the crashed vehicle. This paper outlines the importance for vehicle safety testing standards and injury prevention strategies to consider the needs of adult occupants who differ from the designated test standard physiological dimensions.

INTRODUCTION

The most common cause of death and serious injury for adults in Victoria is driving a motor vehicle. Road trauma continues to be a significant public health issue in Australia, and one which needs accurately defining in order to target effective injury reduction measures (Victorian State Trauma Outcome Registry and Monitoring Group, 2004). Injuries sustained by any motor vehicle occupant involved in a crash depends on the severity of the impact, the extent to which the vehicle is able to protect the occupant against this impact, and the ability of the occupant to withstand impact forces. Subsequent to the outcome of these injurious mechanisms are the resuscitative efforts of the emergency personnel and post trauma medical care. The influence of an occupant's physical proportion on their injury risk in a motor vehicle crash has been the subject of a limited number of studies with conflicting results; as such this issue remains incompletely understood.

BACKGROUND

Vehicle design

One of the most significant areas of research has been in improving the crashworthiness of the vehicle, through modifications to vehicle structural design as well as restraint system design, including airbags. Current design regulations that apply to vehicles to be sold in Australia (as with most developed countries) mandate adherence to occupant protection specifications based on an historically ascertained 50th percentile male dummy. As such, national car manufacturers and importers must comply at least with the Australian Design Rule 69, (ADR69–Full Frontal dynamic crash requirement) which demands compliance of the vehicle in crash testing to the occupant protection specifications using the 50th percentile male Hybrid III Crash Dummy (H3CD). The H3CD thus plays a major part in vehicle design.

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[1] BMI = weight (kg) / height (m)^2. BMI categories are: Underweight (below 20), Normal (20-25), Overweight (25-30) and Obese (greater than 30).

Moran, McGwin, Metzger, Windham, Reiff and Rue (2002) have shown that as the occupant's body habitus differs from that of the H3CD, the related injury pattern changes – a finding attributed to a difference in the performance of safety features as the vehicle cabin to occupant body fit is altered. McCarthy, Chin and Hill (2001) similarly concluded that occupants in the extreme ranges of body size – for both weight and height, are at risk of greater injury in frontal and side collisions.

Gender

Given the tendency for female body habitus to differ from that of a male, there is suggestion that standards need to consider the safety aspects of a vehicle to enhance protection for a wider range of occupants. Currently female drivers and vehicle occupants are represented by the 50^{th} percentile male dummy in combination with the 5^{th} percentile female dummy as outlined earlier. Nonetheless an examination of the UK population by Welsh and Lenard (2001) found a significant 90% of female drivers were lighter and shorter than the 50^{th} percentile male dummy.

A case-control study of real-world crashed vehicles evaluating the effectiveness of ADR 69 in preventing injuries to passenger car occupants was conducted by MUARC in 2001 (Morris, Barnes, Fildes, Bentivegna and Seyer). Whilst the study concluded strongly that the ADR 69 requirement had been successful in addressing some of the outstanding injury prevention issues for drivers involved in frontal impacts, the analysis did not separate or attempt to investigate the influence of gender in injury outcomes.

Height

Drivers of shorter stature have been shown to have a higher than average risk of AIS2+ injuries to the head, pelvis and lower limbs. Welsh and Morris (2003) found this risk to be statistically at less than 160cm in height. Dischinger (1996) had previously found that drivers shorter than 170cm of both genders could expect an increased risk of 64% in fracture rates to lower extremities. The areas of greatest injury were found to be the ankle and tarsals. Previous research related the increased risk of lower limb injuries only to the female gender, however later research found this to be confounded by their shorter heights (Dischinger, Kerns and Kufera, 1995).

BMI and Weight

There has been limited research into the relationship between body weight, BMI and injury risk and what has been presented thus far is conflicting. Arbabi, Wahl, Hemmila, Kohoyda-Inglis, Taheri and Wang (2003) showed an overweight cohort to have a statistically significant decreased Injury Severity Score (ISS) compared to a lean cohort; however this lower ISS was not seen comparing the obese and lean cohorts. These authors found an increased fatality risk associated with obesity for motor vehicle crash occupants; confirming the findings of Moran, McGwin, Reiff and Rue (2001). Neville, Brown, Weng and Demetriades (2004) found this mortality risk to relate to all obese blunt trauma patients in their case-control study, not only those from motor vehicle crashes. Zhu, Layde, Guse, Laude, Pintar, Nirula and Hargarten (2006) reported an increased risk of death for males as occupants of motor vehicle crashes at both ends of the BMI continuum. This risk was not found for females however. Mock, Grossman, Kaufman, Mack and Rivara (2002) found only increased body weight to be associated with an increased risk of death; with increased body weight and BMI relating to a greater risk of sustaining an ISS≥9. They also reported AIS2+ chest injury risk to be 2.7% greater for each unit increase of BMI. Finally, and again conversely Wang, Bednarski, Patel, Yan, Kohoyda-Inglis and Kennedy (2003) described increased subcutaneous fat depth to be associated with significantly decreased injury severity to the abdominal region in females.

No studies were found that considered the injury severity risk of blunt trauma victims of lighter frame.

Study Aim

The aim of this study is to investigate the influence of occupant Body Mass Index (BMI) and body weight on the injury severity of front seated adult occupants in frontal motor vehicle crashes using a sample of real-world in-depth Australian crash data.

METHOD

In-depth Databases

A database was formed by combining data from three merged in-depth crashed vehicle projects, each created by and held at Monash University Accident Research Centre. Recruited participants had been hospitalised as a result of injuries sustained in a motor vehicle crash. The definition of serious injury used in this study is consistent with the International Road Traffic and Accident Database (IRTAD) definition. The IRTAD, which holds data from member countries of the Organisation for Economic Cooperation and Development (OECD), defines seriously injured (or 'hospitalised') road users as accident victims admitted to hospital as in-patients and who remain there for at least 24 hours, excluding those who die.

1. The Australian National Crash In-Depth Study (ANCIS)[2] is an ongoing project (commencing April 2000) studying seriously injured occupants of motor vehicle crashes involving vehicles built since 1989.
2. The Holden Crash Injury Research Program is an ongoing collection of crashed Holden vehicles (commencing 1996); similar in nature to ANCIS, except that it uses a tow-away vehicle entry criterion.
3. The third database was acquired between 1995 and 2000, when MUARC was commissioned by the Australian Federal Office of Road Safety (FORS, now the Australian Transport Safety Bureau) to evaluate, by case-control design, ADR69 and its effect on occupant injury.

There were universal core data points across the three databases, which enabled them to be collapsed into one; however, a large number of cases were unable to be incorporated due to the decision to include only those cases for which Equivalent Barrier Speed (EBS) had been calculated, due to its known significance as a measure of crash severity. Other cases had Delta-V calculation only, as another measure of crash severity and one from which it is sometimes possible to recalculate an EBS. This was not done for this project therefore these cases were excluded.

Data collection procedures for each of the studies similarly included ethical approval, informed patient consent, vehicle owner consent if different to patient, patient interview unless consent obtained from a third party, injury data collection and profiling, vehicle inspection, and site inspection. Passenger carrying vehicles only are included in these studies. This excludes motorcycles, trucks, buses and taxis. For the ANCIS project, patients could only be included if they were the occupant of a vehicle whose manufacture year was at least 1989.

Inclusion Criteria

Study entry was limited to front-seated occupants involved in motor vehicle crashes that were hospitalised as a result of the injuries they sustained in the crash. Occupants who had injuries treated and were discharged from an emergency department without admission were not included, nor were fatalities.

[2] ANCIS partners include the Federal Department of Transport and Regional Services; Autoliv Australia; Ford Motor Company Australia Ltd; Motor Accidents Authority of NSW; Holden Ltd.; IAG Ltd; National Roads and Motorists' Association, Royal Automobile Club of Victoria Ltd.; Roads and Traffic Authority (NSW); Transport Accident Commission (Vic); Toyota Motor Corporation; and VicRoads. The Federal Chamber of Automotive Industries, Mitsubishi Motors Australia Ltd and the Australian Automobile Association (AAA) participate as observers.

Children were not included, to avoid comparing differing injury profiles between children and adults, given their vastly different anthropometric proportions and ability to withstand blunt trauma.

The following variables were required information for database inclusion:

- Occupant aged over 17 years
- Height, Weight and BMI (kg/m^2)
- Occupant injury coding given for up to 40 injuries for each occupant using the Abbreviated Injury Scale (AIS)
- Maximum AIS score overall and for each body region
- Injury Severity Score (ISS)
- Principal area of deformation on vehicle=frontal
- Collision Deformation Classification (CDC)
- Equivalent Barrier Speed (EBS)
- Airbag fitment and deployment status for driver and front passenger
- Seat belt usage, as derived from vehicle inspection
- Vehicle year of manufacture and vehicle kerb weight

Statistical Analysis

A multi-variate logistic regression model was developed, including relevant explanatory variables in order to predict the relative odds or likelihood of occupants sustaining an AIS2+ injury, as the dependent variable. Inclusion of explanatory variables into the multi-variate model was based on the outcomes of primary univariate (logistic) exploration. Logistic regression modelling was chosen for its capacity to control statistically for the variety of differences in occupant, vehicle and crash characteristics.

RESULTS

Occupant Data

In total, 175 participants of the datasets described above satisfied the inclusion criteria, of which there were 89 males and 86 females. The mean age for males was 43.5 years (SD=16.1, Median=40, Range=18-87 years). For females the mean age was 47.9 years (SD=17.9, Median=48.5, Range= 17-85 years). Of all participants, 80.6% (141) were drivers and 19.4% (34) were front left passengers. With respect to injury, the Injury Severity Score (derived by summing the squares of the AIS scores of the three most severely injured body regions) was measured but not included as such in the analysis. The mean ISS for the sample was 10.2 (SD=7.8, Median=9, Range=1-41). The table below describes the summary anthropometric data, again shown separately for males and females. For each variable below, the mean and median values are similar, indicating relatively normal distributions.

Table 1: Anthropometric Data

	Mean	SD	Median	Range
Weight (kg)				
Females	67.17	14.53	65	35-100
Males	82.72	14.98	82	42-122
Total Sample	75.08	16.65	74	35-122
Height (cm)				
Females	164	7.43	164	149-180
Males	176.82	6.82	178	159-200
Total Sample	170.52	9.78	171	149-200
BMI (kg/m^2)				
Females	24.97	5.14	23.71	15.15-39.35
Males	26.41	4.42	25.46	16.61-39.84
Total Sample	25.69	4.97	25	15.15-39.84

Vehicle and Crash Characteristics

Equivalent Barrier Speeds in the study population ranged from 7 to 109km/h, with a mean of 46.4km/h (SD 18.8, Median 44.2). EBS proved to be a highly significant predictor of AIS2+ injury, with initial univariate significance of p=<0.001, OR 1.077 (95% CI 1.035 – 1.12). The adjusted p value was unchanged, with a slight increase in the Odds Ratio to 1.081 (95% CI 1.037-1.127). The risk of an occupant sustaining an AIS2+ injury in a frontal crash is therefore 8.1% greater for every km/h higher of EBS.

The mean vehicle kerbweight was 1323 kg (SD=257, Median=1349, Range=813-2378kg), with the mean year of vehicle manufacture being 1996 (SD=3.26, Median 1996, Range=1988-2002). Safety features such as airbags and seatbelt pretensioners in full frontal crash protection are well documented to decrease injury risk to the head and chest region (Fitzharris, Fildes, Newstead and Logan, 2004). The fitment and deployment of a frontal airbag was assessed univariately and not found to be significantly related to the risk of sustaining an AIS2+ injury.

The last digit of the Collision Deformation Code (CDC) gives an indication of the extent of crush of the vehicle post crash. Unsurprisingly this was a significant predictor of AIS2+ injury (p=0.008, OR=1.818, 95% CI 1.172-2.82) It was not however selected in the final model, probably due to its reasonable correlation with EBS (r=0.509, p= <0.001).

The crash type of the occupant was examined; showing 58.9% (103) to have impacted with another vehicle, while 41.1% (72) impacted a fixed object. Univariate analysis of this on AIS2+ injury risk showed no relationship.

BMI, Weight and Injury Risk Analysis

Multivariate analyses were conducted examining the effect of occupant BMI and body weight on the risk of sustaining a Maximum AIS score of 2 or more, after adjusting for potential confounders. Variables that were associated with AIS2+ and/or occupant BMI in univariate analysis and thus included in the multivariate model were occupant age, gender, BMI, Equivalent Barrier Speed (EBS) and the last digit of the CDC. Occupant weight was significant but given it is a component of the BMI and thus cannot be fitted as an interaction, two separate models were fitted - one with BMI and one with weight.

Larger BMI values were associated with an increased risk of AIS2+ injury. The odds ratio for sustaining an AIS2+ injury was 0.878 (p= 0.021 95%CI: 0.786 – 0.981). This represents a decrease in AIS2+ injury risk of 12% for each unit increase of BMI. The model for body weight after adjusting for the variables mentioned above (excluding BMI) concluded an odds ratio of 0.966 (p=0.042, 95% CI 0.933-0.999). The graphs below present these injury risk probabilities to both BMI and weight. The H3CD (50th percentile male) dummy values are shown in each graph as a vertical dotted line.

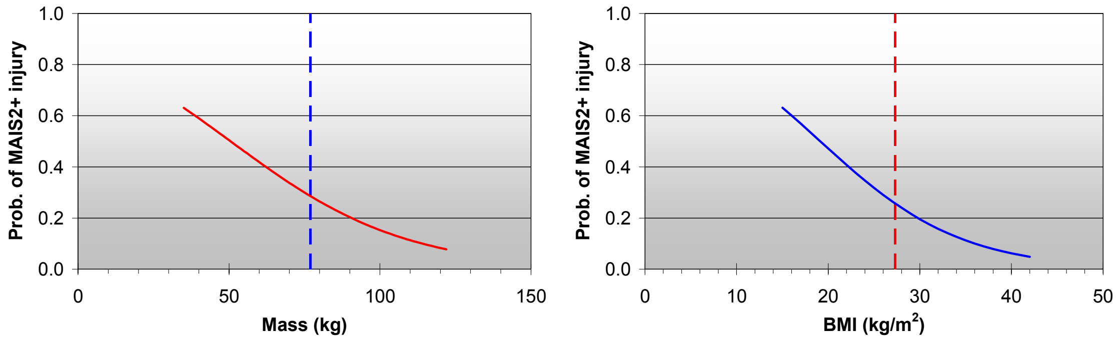

Figure 1. Probability of AIS2+ injury for mass and BMI (H3CD value demonstrated vertically).

The influence of age is often known to confound injury risk; this was considered in this study and was not found to be the case. Gender was also investigated as a potential confounder, but no differences were found between males and females in the sample with respect to injury risk, neither was height found to be associated univariately with the outcome of interest.

DISCUSSION

The findings of previous works have predominantly addressed fatality risk related to obesity and overweight, yet have not considered or adjusted for co-morbidities present in this population. It is known that being overweight is associated with various other chronic diseases; as such it is expected that these will affect mortality risk. Findings that relate particularly to injury severity risk, such as is considered in this study, are limited and inconclusive. The results presented here suggest that lower BMI and lower body weight are associated with an increased risk of an AIS2+ injury. It is proposed that a slighter frame, for both males and females, may withstand less opposing blunt force than those with larger frames. These findings reflect the proposal made by Arbabi, Wahl, Hemmila, Kohoyda-Inglis, Taheri and Wang (2003) of a 'cushion effect' with an increase in insulating adipose tissue. Research relating to injury risk with respect to smaller frame has referred to the paediatric population. As only adults were considered in this study these findings have not been compared with paediatric measures, however it is known that even some young teenagers will be equivalent in size to the lower percentiles both for height and weight of the adult population.

The primary limitation of this study was small sample size. This resulted from the relevant inclusion criteria, whereby for most variables, cases were not included unless they had a complete set of data. Unfortunately approximately 150 cases were missing one or more required data points, preventing them from being included. Secondly the selection bias implicit in such data collection must be considered. The sample is therefore not necessarily representative of the crashed population at large. Because of the inclusion and exclusion criteria for each of the in-depth studies there are many reasons for which a crashed victim may not be eligible or indeed choose not to participate; each having unique effects on the final sample. A systematic bias is not expected however, as weight and height data were not part of the selection criteria, and in this sample were found to be normally distributed.

As a measure of body anthropometry, it is recognised that BMI is not without its limitations. BMI does not take into account muscle mass, therefore a person with increased muscle mass related to physical training (and therefore heavier body weight), will have a BMI in the 'overweight' range, yet they would not be considered to be characteristically overweight. There are suggestions that abdominal waist circumference may be a better measure of overweight and obesity than BMI. These measures are currently not taken in the projects described above.

The benefits of in-depth data are encouraging, however slow and costly to collect. It is recommended that with larger numbers and techniques to weight the sample for representativeness also, it would be of interest to repeat this study. Simultaneously, an investigation of the injury risks to different body regions by BMI and body weight is suggested. Finally, it is evident that prior attempts to quantify the relationship of BMI and body weight to injury risk has focussed on obesity and fatality risk, with a paucity of understanding on the slighter framed adult population and their ability to withstand traumatic blunt force. The results of this study recommend further investigation into this issue.

CONCLUSION

This study adds to the somewhat divisive body of literature that investigates the influence of body anthropometry in motor vehicle crash injury outcomes. Notwithstanding recognised limitations, there are inferences from these data that support the recommendation to more seriously consider the anthropometric proportions of the vehicle occupant in vehicle design. It is evident that there is still much work to be done, and despite the 5^{th} percentile female and 95^{th} percentile male being more frequently employed in the development of vehicle standards, as recognised above this will not cater for the majority of motor vehicle occupants. Whilst the impracticalities of a vehicle designed to suit the entire population are acknowledged, advances in vehicle safety design are increasingly able to reflect occupant differences; as such varying anthropometry demands attention.

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