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FRONTAL IMPACTS AND THE EFFECT OF AUSTRALIAN DESIGN RULES 10A AND 10B FOR STEERING COLUMNS

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FRONTAL IMPACTS AND THE EFFECT OF AUSTRALIAN DESIGN RULES 10A AND 10B FOR STEERING COLUMNS

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Abstract

Australian Design Rules (ADRs) 10A and 10B are aimed at reducing injuries to drivers who strike steering columns. ADR 10B is also aimed at limiting rearward displacement of steering columns in frontal collisions.

Information from the Royal Australasian College of Surgeons Pattern of Injury Survey of crashes and injuries in Victoria was analysed to measure the effect of the ADRs on injury severity. The problem that there were relatively few drivers of ADR 10A or 10B cars in the data was solved by developing injury prediction models as functions of the type of occupant, vehicle and crash circumstances. The models were then used to estimate the expected injury pattern in the absence of the ADRs, for comparison with the actual injuries of drivers of ADR 10A or 10B cars who contacted steering assemblies in frontal impacts.

The limited number of drivers of ADR 10B cars in the data meant that the effectiveness of ADR 10B could not be assessed separately and in fact the results primarily relate to ADR 10A.

Abstract (continued)

The report concludes that the ADRs are effective in reducing the severity of injury to the abdomen/pelvis, chest and face of some types of drivers who strike steering assemblies in frontal impacts and are not ejected. The effect applies particularly to drivers involved in frontal crashes on the open road. Although not explicitly tested in the analysis, there was some evidence of disbenefits due to the ADRs in terms of the severity of head injury of drivers of small cars, and of leg injury of belted male drivers and those aged up to 24 driving small cars.

Due to the absence of crash severity information from the data analysed, the conclusions could not be considered definitive. However, they may be considered strongly indicative due to the analysis method of considering parallel changes in the injury patterns of a control group composed of drivers who did not contact steering assemblies.

To Sonya, Jamie and Miranda,
who inspired me during this work,
and to Michael,
who gave me the strength to complete it.

FRONTAL IMPACTS AND THE EFFECT OF AUSTRALIAN DESIGN RULES 10A AND 10B FOR STEERING COLUMNS

Table of Contents

INTRODUCTION

AUSTRALIAN DESIGN RULES 10A AND 10B

Australian Design Rule (ADR) 10A for steering columns applied to passenger cars and derivatives manufactured on and after 1 January 1971. The intention of this ADR is to minimise crushing or penetrating injuries to drivers due to the steering column as a result of frontal impact. Implicit in the test procedure for this ADR is the intention that the steering column will collapse or deform on contact and thus absorb some of the energy which would otherwise be transmitted to the driver.

ADR 10B for steering columns applies to passenger cars and derivatives manufactured on and after 1 January 1973. Its stated intention is the same as ADR 10A. However, as well as the intention that steering columns should absorb energy on contact, the rule includes a test of rearward displacement of the steering column in a barrier collision; the added intention being to limit rearward displacement so that contact is not made with drivers (presumably particularly those who are restrained by a lap/sash seat belt).

It is understood that manufacturers of Australian cars have met the energy-absorbing criterion (as distinct from the rearward displacement criterion) of these design rules by fitting steering assemblies with, in general, either:

(a) steering columns which collapse axially, or

(b) steering wheels which deform to align with a contacting chest or abdomen, so that the contact load is spread over a broad area.

LITERATURE ON ENERGY-ABSORBING STEERING SYSTEMS

Gloyns (1973) has critically reviewed the literature up to early 1973 on the effectiveness of energy-absorbing steering systems. The overall picture emerging from much of the early American literature on the subject was one of essentially satisfactory performance of axial-collapse steering systems (Gloyns and Mackay 1974), but Gloyns felt impelled to comment on the unsatisfactory nature of the data contained in much of the American literature. Gloyns and Mackay (1974) felt that later work had tended to show less clear benefits available from axial-collapse steering assemblies.

Gloyns (1973) and Gloyns and Mackay (1974) have reported a study of the relative effectiveness of two types of energy-absorbing steering systems when contacted by unrestrained drivers in severe frontal impacts in Britain. The study compared (a) the more-traditional axial-collapse column systems, using either a metal diamond mesh or convoluted steel tube as the energy-absorbing element, with (b) self-aligning steering wheel systems, where a three-spoke wheel with broad sheet-metal spokes is mounted directly onto a short convoluted steel can, which is in turn mounted on a conventional rigid steering column. The study found that the self-aligning systems, but not the axial-collapse systems, were effective in preventing serious chest and abdominal injuries. Serious injuries to the head and neck, and also to the lower limbs, were more common in the cars equipped with axial-collapse columns. These injuries were thought to be due to drivers striking the rigid column support structure with their knees, pivoting about this point, and striking their heads on the windscreen header area. (Lundstrom et al (1969) reported increased chance of head injury in American cars with predominantly axial-collapse columns at that time.) The absence of serious lower limb injuries to drivers with self-aligning wheels may have been an artefact of the particular makes of vehicle in which they were installed in Britain at the time of the study, i.e. instrument panels may have been relatively small and parcel shelves may not have been fitted.

Based on a comparison of steering assembly damage produced in accidents and in laboratory tests, the failure of axial-collapse systems to prevent serious chest and abdominal injuries was thought to be due to binding of the telescoping section caused by bending of the column. This bending is a result of primary damage to the column initiated by deformation of the car's body shell, as well as high bending moments gathered when the driver hits the steering wheel, at a time when its mounting angle has been increased due to lower-end damage. Garrett and Hendricks (1974) also found that as the angle of force application shifts from the perpendicular, the compression of axial-collapse columns decreases.

Gloyns (1973) also studied the injuries of lap/sash belted drivers with energy-absorbing steering systems in cars involved in somewhat less severe frontal impacts than the impacts involving the unrestrained drivers described above. He found that whilst the unbelted driver strikes the steering wheel with his chest and abdomen, the belted driver tends to hit the wheel with his head. There was no detectable difference in the occurrence or severity of head injuries of belted drivers of cars equipped with the two types of steering assemblies, but there were too few data to make a valid comparative or absolute measure of the effectiveness of energy-absorbing steering systems for restrained drivers.

DuWaldt (1973) discusses a number of potential refinements to the energy-absorbing steering system package which could enhance driver survivability. These include the steering column jacket energy absorber, air cushion, intruder/absorber, four bar linkage, knee bar, and hub pad (see reference for details).

McLean (1973, 1974) compared the overall injury severities of drivers of front-impacted American cars equipped with a rigid column or one of three types of axial-collapse column, namely:

1. GM Saginaw I (steel mesh outer jacket),
2. Ford (slotted tube column),
3. GM Saginaw II (ball-and-tube column).

He found that the latter types of energy-absorbing column provided a significant reduction in the severity of driver injury when compared to the performance of the rigid column. The effectiveness of these columns was independent of, and additive to, that provided by a lap-type seat belt.

Anderson (1974) compared the injury patterns of drivers of front-impacted cars manufactured before the US standard for energy-absorbing steering assemblies with those driving cars manufactured after the standard. For overall injury, the energy-absorbing system was effective in reducing the injury risk for lap belted drivers, and relatively ineffective for unrestrained drivers (except in high speed accidents). For specific injuries, the results were similar for both unrestrained and lap belted drivers, namely decreases in risk of head injury and no influence on the risk of thorax injury.

Grant (1977) reported preliminary results of a large crash injury study based on a major hospital in Southern England. He compared the injury patterns of car drivers who contacted the steering wheels of the following types of steering assemblies:

1. Rigid,
2. 'Energy-absorbing wheel' (presumably the self-aligning steering wheel type of system),
3. 'Energy-absorbing column' (presumably one of the axial-collapse column systems).

Compared to rigid systems, the energy-absorbing wheel appeared to be effective in reducing the risk of injury to the chest and abdomen, and also to the head. Energy-absorbing columns appeared to have no beneficial effect and may even have been detrimental in terms of chest and abdomen injuries.

Phillips et al (1978) sought to make a comparative evaluation of an axial-collapse (ball-and-tube) column system and a self-aligning wheel system fitted in sub-compact cars with unrestrained drivers involved in frontal accidents. The axial-collapse cars were all crashed and investigated in the US, whereas the self-aligning wheel cars were essentially the same cases of that type studied by Gloyns (1973) and Gloyns and Mackay (1974), i.e. crashed and investigated in the Birmingham area. In the event, the differences in methods of data collection dominated the analysis and this problem, together with the limited number of cars, prevented the authors from making conclusions about differences in performance of the two types of steering assembly.

In summary, most of the past research on energy-absorbing steering systems has been conducted in the context of large cars, or unrestrained drivers, or both. The limited research on restrained drivers has pertained to lap-type seat belts or non-compulsory wearing of lap/sash belts. Thus the past research may not be wholly relevant to Australian conditions. No previous study of the effects of ADRs 10A and 10B had been published at the time of writing.

REPORT STRUCTURE

The accident and injury data on which this study was based were collected in Victoria in June 1971 to May 1974. The appearance of relatively few cars with ADR 10A or 10B in the data presented considerable problems of statistical analysis. For this reason the study was more of a dialogue with the data and cannot be described in the classical 'data/analysis/results/discussion' form. It was considered better to structure this report to reflect the actual course of the analysis so that the reader may understand the critical decisions made at each stage. The alternative, of presenting the analysis and results as if they arrived by divine inspiration, would be artificial, but may be suitable for a later paper summarising this study.

The report first describes the preliminary analysis of the data, along the lines recommended by Cameron and Wessels (1975). The preliminary results were inconclusive and identified the need to use specific body region injury criteria and, because there were relatively few occupants of ADR 10A or 10B cars in the data, the need to revise the analysis approach.

The main analysis first investigated interaction effects on injury severity of variables related to crash energy transfer and injury susceptibility. The identified interactions were included in the development of injury prediction models as functions of the type of occupant, vehicle and crash circumstances.

The injury prediction models were then used to estimate the expected injuries (in the absence of energy-absorbing steering systems) of drivers of ADR 10A or 10B cars who made contact with steering assemblies in frontal impacts. The difference between actual and expected injury severity measured the effect of the ADRs. The variation of this difference with characteristics of drivers and size of vehicle was also investigated. The final stages of the main analysis pooled open road and built-up area crashes, which had been analysed separately to this stage, so that the effect of variations in driver/vehicle type could be investigated more thoroughly.

DATA

The data on which this study was based were collected during the Royal Australasian College of Surgeons (RACS) Pattern of Injury Survey of Victorian road casualties (Nelson 1974). From 1 June 1971, legislation was in force in Victoria requiring hospitals to supply, on a Road Trauma Report (RTR) form, details of injuries for all road accident victims treated. In the RACS Survey these data were supplemented by RTRs filled out using post-mortem reports on fatally-injured road users. In addition, Road Crash Report (RCR) forms describing the crash circumstances of occupant casualties were completed by ambulance officers. As there was no legal compulsion associated with this source, RCR forms were returned for only about one-third of crashes attended by ambulances, with a bias toward rural crashes. Examples of the two data collection forms are shown in Appendix A.

A matched file of trauma and crash reports for the first two years was originally created for analysis by Nelson (1974). This file was later supplemented by data for the third year. The full matched file covers 8537 occupants of passenger cars and car derivatives. These occupants are grouped into three subfiles:

- Matched file 1971-73 (6526 cases). The same cases were analysed by Nelson (1974, Chapter 11) and Cameron and Nelson (1977). RTRs to match RCRs for the 387 fatalities in the file were obtained by Nelson from coroners' records.

- Matched file 1973-74 (1667 cases). Created in exactly the same way as the 1971-73 matched file except that RTRs to match RCRs for the 138 fatalities in the file were obtained from coroners' records by the Department of Transport.

- Pre-matched fatalities file 1973-74 (344 cases). Both crash and injury data were extracted from coroners' records for the remaining fatally-injured occupants of passenger cars and derivatives involved in crashes in 1973-74. Some crash information was necessarily deficient compared with that provided by ambulance officers on RCRs for the other two subfiles.

Further details of the return rates, matching rates, bias, accuracy, and the mnemonics used for each item of data in the computer file (see following chapters) are given in Cameron (1977), Nelson (1974) and Cameron and Wessels (1975).

PRELIMINARY ANALYSIS

INTRODUCTION

Cameron and Wessels (1975) recommended that ADR 10A (and the energy-absorbing effects of ADR 10B) should be evaluated by considering unrestrained drivers in frontal impacts as a treatment group. Such drivers recorded as having contacted the steering column/wheel were suggested as a more refined treatment group, but the accuracy of information on the RCR regarding steering assembly contacts could not be checked by comparison with another source (Nelson (1974) checked the accuracy of seating position, seat belt use, point of impact, occupant sex and crash location by comparison of a sample of RCRs with corresponding Police accident reports). Cameron and Wessels also recommended that restrained drivers, and unrestrained and restrained front passengers, should be used as control groups. Occupant casualties of cars with ADR 10A (1971-2 year of manufacture) and ADR 10B (1973-4) would be compared with those occupying earlier model cars, and any change in the injury patterns of the treatment group relative to the control groups could be taken as an effect of the ADRs.

Cameron and Wessels' recommended analysis programme was based on the assumptions that occupant casualties in the control groups would have had few steering assembly contacts and that unrestrained drivers involved in frontal impacts would have had a high contact rate. If these assumptions were true, then the recommended analysis programme would not rely heavily on data on steering assembly contacts. This was desirable as the contact data recorded on the RCR were of unknown accuracy. However, this is not to suggest that there was any evidence that information on steering assembly contacts was inaccurate or biased.

Cameron and Wessels also suggested that their recommended analysis programme may lead to invalid conclusions if the treatment variable (i.e., presence or absence of the ADR) was correlated with other variables which affect either:

(a) the energy exchange in a crash (e.g., urban/rural location), or

(b) the susceptibility to injury at a given level of energy exchange (e.g., occupant age and sex).

The variables listed in brackets are those available in the RACS data, but are not necessarily the best measures of energy exchange or injury susceptibility. The data also include variables related to the transfer of crash energy to the vehicle occupant, namely ejection and vehicle size (seating position and seat belt use were already included in the recommended analysis). Cameron and Wessels recommended that a safeguard against invalid conclusions would be to conduct separate analyses sub-divided by any variables found to be correlated with the treatment variable and known or suspected to be associated with crash energy exchange or injury susceptibility.

Cameron and Wessels further recommended that the part of ADR 10B aimed at limiting rearward displacement of the steering column should be evaluated not using change in injury pattern alone. The evaluation of this part of ADR 10B should be supplemented by consideration of the change in the proportion of drivers who contacted the steering column/wheel.

DATA AND VARIABLES AVAILABLE FOR ANALYSIS

At the time of the preliminary analysis, the full matched file of trauma and crash reports covering 8537 car or car derivative occupant casualties from crashes in Victoria during June 1971 to May 1974 was available. Appended to the file were a number of derived variables and summary injury severity scores used by Nelson (1974) in his analysis of the first two years data. However, the file did not yet include the body region Abbreviated Injury Severity (AIS) scores (States 1969) nor Baker *et al's* (1974) Injury Severity Score described by Cameron (1977).

The following is a list and brief description (where necessary) of the variables used in the preliminary analysis. Further details are given in Cameron (1977).

- Body zone injury counts (Z1 to Z10). Number of severe injuries (AIS greater than one) in each of ten body zones defined by Nelson (1974). Only head, neck and torso zones were considered here (see Table II).

- Fractured ribs - flail (C13). Incidence of this injury.

- Square root of Nelson's ISS (AISQ). Nelson's Injury Severity Score is the sum of squares of the AIS scores for all specific injuries, including those with AIS equal one (cf. Baker's ISS described later).

- Square root of Nelson's Central ISS (CAISQ). Derived like AISQ, except that only the head, neck and torso body zones (Z1 to Z10 above) are considered.

- Killed/injured (FATAL).

- Year of manufacture - edited (KYR). Year of manufacture recorded on the RCR, edited by registration number issue schedules to increase accuracy.

- Point of impact on vehicle (IMPACT). Derived from impact sub-section of section E on the RCR. Frontal impacts were defined as those vehicles with one or both of "Head On" and "Side - Front" recorded, after Nelson (1974).

- Crash location (DIST). Metropolitan or country location of crash. The main analysis altered this choice of crash location to ROAD (open road v. built-up area), following Cameron (1979).

- Ejection indicator (OBJ16).

- Size of vehicle (SIZE). Derived from make of vehicle recorded on the RCR, using a detailed make/model classification of cars and station wagons by length (above and below 4.32 m.) given by ABS (1975). About 20 per cent were inadequately described and were classified as size unknown; these vehicles may represent an intermediate size group.

- Seating position (SEAT).

- Seat belt use (BELT).

- Occupant age (AGE).

- Occupant sex (SEX).

- Steering column/wheel contact indicator (OBJ3).

RESULTS FROM PRELIMINARY ANALYSIS

Introduction

The preliminary analysis closely followed that recommended by Cameron and Wessels (1975). Data regarding steering assembly contacts were not used to define a more refined treatment group because their accuracy was unknown. Occupant ejection was controlled by eliminating ejectees and occupant age was partially controlled by considering only drivers and front left passengers aged over 17. Vehicles manufactured before 1950 were not considered and the remaining vehicles were grouped by year of manufacture as follows:

- 1950-59
- 1960-68
- 1969-70: lap/sash seat belts fitted to front outboard seats under ADR 4
- 1971-72: ADR 10A (and ADR 4)
- 1973-74: ADR 10B (and ADR 4/4A).

ADR 4 required that lap/sash seat belts be fitted to outboard seating positions and lap belts be fitted to other seats. It applied to the front seats of passenger cars and derivatives manufactured on and after 1 January 1969 and additionally to the rear seats of such vehicles manufactured on and after 1 January 1971. ADR 4A upgraded ADR 4 by requiring fixed buckle locations of seat belts installed in vehicles manufactured on and after 1 April 1974. During the period when the crash data were collected (June 1971 to May 1974), all vehicle occupants aged 8 or more occupying seating positions with fitted belts were required to wear those belts under the compulsory seat belt wearing legislation in Victoria. Some 75 to 80 per cent of front outboard occupants observed in Melbourne and 68 to 75 per cent of like occupants observed on highways through six Victorian provincial towns were wearing lap/sash belts, where fitted to their seating positions, in February 1973 (Vulcan 1977). Rear seat occupants were not surveyed at that time, but in observations of rear seat occupants aged 8 or more in Melbourne in December 1975, 41 to 47 per cent of rear outboard occupants wore available lap/sash belts and 26 per cent of rear centre passengers wore lap belts, where available (Boughton, Cameron and Milne, in preparation).

Comparison of Treatment and Control Groups

Table I shows injury severity scores by vehicle year of manufacture for the treatment group (unbelted drivers) and for the control groups (remainder). Similar analyses were produced for each body zone injury count and for the incidence of flail fractured ribs. Table II shows that these latter injury variables have greater variability than the general injury severity scores included in Table I.

Figure I shows plots of the mean injury severity scores given in Table I. Inspection of Figure I in conjunction with the standard errors (standard deviation of mean) in Table I indicates there are no significant differences by year of manufacture when

TABLE I : Injury severity scores of non-ejected driver and front left passenger (FLP) casualties aged over 17 involved in frontal impacts.

Occupant Type Year of manufacture	No. of occupant casualties	Square root of Nelson's ISS		Square root of Nelson's Central ISS		Percentage of casualties killed	
		Mean score	Std. dev. of mean	Mean score	Std. dev. of mean	Mean (%)	Std. dev. of mean
Unbelted Drivers							
1950-59	71	2.49	0.22	1.69	0.18	4.2	2.4
1960-68	345	2.84	0.15	2.06	0.12	9.6	1.6
1969-70	85	3.10	0.29	2.11	0.24	10.6	3.4
1971-72	49	3.03	0.41	2.22	0.35	10.2	4.4
1973-74	13	4.38	0.95	3.23	0.91	23.1	12.2
Belted Drivers							
1950-59	28	2.19	0.19	1.56	0.32	3.6	3.6
1960-68	232	2.27	0.14	1.53	0.11	5.2	1.5
1969-70	127	2.68	0.23	1.82	0.17	10.2	2.7
1971-72	118	3.09	0.30	2.04	0.23	16.1	3.4
1973-74	29	3.61	0.81	2.95	0.68	24.1	8.1
Unbelted FLPs							
1950-59	23	2.54	0.42	1.30	0.20	4.4	4.3
1960-68	125	2.58	0.24	1.89	0.22	8.8	2.5
1969-70	38	3.56	0.51	2.62	0.46	18.4	6.4
1971-72	26	2.44	0.42	1.65	0.36	7.7	5.3
1973-74	2	8.20	2.80	5.95	3.95	50.0	50.0
Belted FLPs							
1950-59	9	1.96	0.43	1.28	0.39	0.0	0.0
1960-68	81	2.28	0.24	1.57	0.19	7.4	2.9
1969-70	49	2.74	0.39	1.99	0.28	12.2	4.7
1971-72	45	2.92	0.40	2.14	0.33	8.9	4.3
1973-74	13	3.06	1.31	2.04	1.06	15.4	10.4
TOTAL	1508	2.74	0.07	1.92	0.06	9.6	0.8

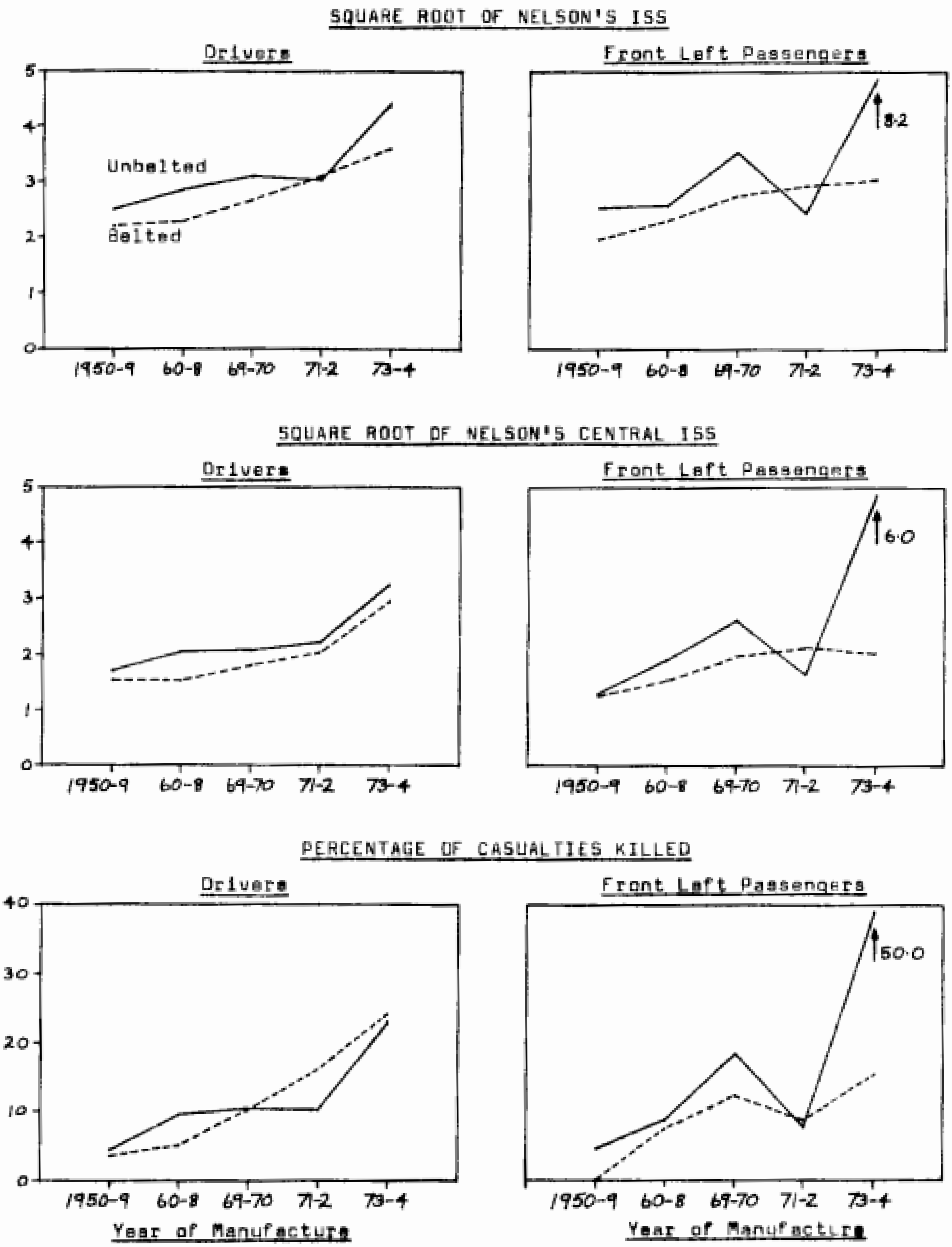

FIGURE 1: Injury severity scores of non-ejected driver and front left passenger casualties aged over 17 involved in frontal impacts

TABLE II : Coefficients of variation for injury scores of driver and front left passenger casualties involved in frontal impacts.

Body Zone Injury Counts	Coefficient of variation (std. dev. ÷ mean)
Head	3.28
Face	3.17
Neck	4.79
Central thoracic	4.83
Central abdominal	14.36
Central pelvic	13.63
Left lateral chest	4.35
Right lateral chest	4.50
Left lateral abdomen	5.72
Right lateral abdomen	5.01
Flail Fractured Ribs	5.90
General Injury Severity Scores	
Square root of Nelson's ISS	0.99
Square root of Nelson's Central ISS	1.15
Percentage of casualties killed	3.07

unbelted and belted casualties are compared, for drivers and front left passengers separately. Failure to detect differences by year of manufacture may have been due to the variability of the general injury severity scores rather than the non-effectiveness of ADRs 10A and 10B. The situation may have been even worse for the other more-specific injury variables listed in Table II.

The validity of the comparisons made from Table I relies heavily on the assumption that occupant casualties in the various vehicle year of manufacture groups do not differ with respect to their distributions of crash energy exchange or susceptibility to injury. If so, a solution is to conduct "controlled" analysis described earlier, i.e. sub-divide the analysis by variables related to energy or susceptibility, or both if necessary.

Need for Controlled Analysis

To establish the need for controlled analysis, the interaction between year of manufacture and each of the following variables was investigated for each of the four occupant types in Table I:

- Crash location,
- Size of vehicle,
- Occupant age,
- Occupant sex, and
- Steering column/wheel contact.

There was considerable evidence of interactions and in some cases they were statistically significant, summarised as follows:

- For all four occupant types, the older vehicles tended to be large and the newer vehicles tended to be small,
- For unbelted drivers, those aged 60 and above tended to occupy early or late model vehicles,

- For belted drivers, those aged 18 to 29 tended to occupy early or late model vehicles, and
- For belted drivers, those occupying vehicles manufactured in 1971-74 were less likely to have contacted the steering assembly.

The latter interaction (Table III) was significant at the 5 per cent level (one-tailed test, for a decrease in the proportion contacting). A similar comparison of the proportion of belted drivers of 1973-74 cars who contacted steering assemblies (38 per cent) with a like figure for drivers of 1950-70 cars (48 per cent) was not statistically significant.

Thus, according to the recommendations of Cameron and Wessels (1975), for valid conclusions to be reached the analysis in Table I should be reproduced within categories of vehicle size, occupant age (for drivers, at least), and the incidence or otherwise of steering assembly contact (for belted drivers, at least).

The implications of the preliminary results and the need for further analysis of the same type will be discussed in the following section.

DISCUSSION OF PRELIMINARY RESULTS

1. The preliminary results were inconclusive regarding the energy-absorbing effects of steering assemblies installed under ADRs 10A and B for unbelted drivers involved in frontal impacts. The injury variables relating to specific body zones had high variability and may have been insensitive to effects of the ADRs. Griffiths et al (1976) found that over 70 per cent of life-threatening chest and abdominal injuries to drivers resulted from steering assembly contacts; seat belt use was low in these cases. Mackay (1975) commented that in frontal impacts, unbelted drivers have chest contacts with the steering wheel, whereas belted drivers have head or face contact. Thus there is

TABLE III : Proportion contacting steering assemblies. Non-ejected driver and front left passenger casualties aged over 17 involved in frontal impacts.

Occupant Type Year of manufacture	Occupant casualties contacting steering column/wheel assemblies Not contacted	Contacted	Proportion contacting (%)	
Unbelted Drivers				
1950-59	39	32	45.1	50.9
1960-68	174	171	49.6	
1969-70	33	52	61.2	
1971-72	23	26	53.1	53.2
1973-74	6	7	53.8	
Total	275	288	51.2	
Belted Drivers				
1950-59	15	13	46.4	47.8
1960-68	124	108	46.6	
1969-70	63	64	50.4	
1971-72	73	45	38.1	38.1
1973-74	18	11	37.9	
Total	293	241	45.1	
Unbelted FLPs	206	8	3.7	
Belted FLPs	192	5	2.5	

a need to consider separate body regions in any study of steering assembly-caused injuries. The use of Nelson's Central ISS, which has relatively low variability (Table II), was an attempt to do this, but it covered the head, neck and torso body regions and may not have been sufficiently specific. The other general injury severity scores used (Table II) were even less specific.

2. A basic analysis design assumption of Cameron and Wessels (1975), namely that occupant casualties in each of the control groups would have had few steering assembly contacts, appears to be false for belted drivers (Table III). Indeed, the contact rate for unbelted drivers was not much higher at 51 per cent. Thus, the continued use of unbelted drivers as the treatment group in subsequent analysis would act to dilute the apparent effect of the ADRs. It was decided that subsequent analysis would redefine the treatment group as driver casualties who contacted the steering assembly. Belted and unbelted drivers would be included, but mindful of Mackay's comment that the two groups of drivers may have made contact with different parts of their body, the separate effects of the ADRs for these two groups would be evaluated, if necessary.

3. Even with a revised analysis approach, as described above, the need to control for vehicle size and driver age (at least) would probably remain. The traditional method of controlled analysis, namely sub-dividing a table like Table I into categories of the offending variable, would be infeasible. This is because there were only 89 drivers of ADR 10A or B cars who contacted the steering assembly (Table III). If these data were sub-divided into categories of vehicle size or driver age (or both, if necessary), there would be too few cases in each category to produce an adequate estimate of the injury pattern. One solution may be to produce functional models of the expected injury pattern of ADR 10A and B drivers making contacts, based on the injury patterns of occupants of pre-ADR 10A cars. Such models would include variables which need to be controlled for a valid comparison of expected and observed injuries of ADR 10

drivers. Additionally, the models could include other available variables found to explain variations in injury patterns, so that more precise estimates of the expected injuries of ADR 10A and B drivers could be made, thus leading to more sensitive tests of the effect of the ADRs. Examples of such additional variables, which currently do not appear in need of control, are crash location and occupant sex. Crash location is obviously related to impact speed and hence to crash energy exchange, and Patrick (1975) has found that females are much more prone to rib fracture than males for the same severity of collision.

4. Figure I indicated that among the data analysed, injury severity tended to increase with year of manufacture. The reason for this was not understood, but indicated that year of manufacture has some explanatory power for injury patterns, either directly or by proxy for some other causative variable. Thus, year of manufacture should also be considered as an explanatory variable in the functional models described above.

5. A separate evaluation of the energy-absorbing effects of steering assemblies installed under ADR 10B is not feasible, since there were only 18 driver casualties who contacted steering assemblies in ADR 10B cars. It was decided that in subsequent analysis of the energy-absorbing effects of steering assemblies, ADR 10B car occupants would be grouped with ADR 10A car occupants and referred to by the generic title "ADR 10".

6. There was no statistically significant evidence that ADR 10B car driver casualties were less likely to have contacted the steering assembly than driver casualties from pre-ADR 10 cars. However there was evidence that belted driver casualties from ADR 10 cars, as a group, were less likely to have contacted steering assemblies than belted driver casualties of pre-ADR 10 cars. There are two possible explanations of these findings:

(i) Steering assemblies installed under both ADRs are effective in limiting rearward displacement in frontal impacts, thus reducing the likelihood of contact with restrained drivers, or

(ii) The observed results are evidence of the effectiveness of the ADRs in reducing the <u>probability</u> of injury to restrained drivers contacting steering assemblies in frontal impacts, since fewer such drivers would be expected in a file with an injury criterion for inclusion (as has the RACS matched file).

It is not possible to determine which of these explanations is correct. However if subsequent analysis were to find that ADR 10 reduced the <u>severity</u> of injury of belted driver casualties who contacted steering assemblies, then this would <u>suggest</u> that (ii) is the correct explanation.

MAIN ANALYSIS

INTRODUCTION

The major conclusion from the preliminary analysis was that a new method of analysis was required to cope with the problem that the RACS data file contained relatively few drivers of ADR 10 cars who contacted steering assemblies in frontal impacts. There was a need to develop functional relationships of crash, vehicle and occupant variables to estimate the expected injury patterns of drivers contacting steering assemblies in the absence of ADR 10.

Carlson and Kaplan (1975) demonstrated that the development of such functional relationships was feasible for data of the type available in the RACS file. They developed multiple regression models for Overall AIS (OAIS) score injury data collected by North American in-depth accident investigation teams. OAIS is a clinical judgement of the AIS score of a single injury which by itself would be equivalent in terms of overall severity to the cumulative effect of multiple injuries (Joint Committee on Injury Scaling, 1976). Carlson and Kaplan considered various measures of crash severity (vehicle damage, vehicle velocity squared, crash energy) as predictor variables, as well as dummy variables (zero/one) for occupant ejection, windshield bond separation, and single/multiple vehicle crash. They also discussed and resolved the methodological question of applying an analysis technique appropriate to an interval-scale variable to OAIS, which is generally thought of as an ordinal variable.

Carlson (1977, 1978) later extended the methodology to include vehicle weight, occupant age, seating position and restraint use as predictor variables. He fitted the multiple regression models to data within separate crash type categories and also considered the effect on injury severity of the interaction of some predictor variables. For head-on crashes of two vehicles, Carlson (1977) found that the regression model explained 46 per cent of the variation in OAIS scores of 355 occupants. He also found that the following variables made statistically significant contributions to explaining the variation of OAIS:

- Velocity (squared) of each vehicle,
- Weight of each vehicle,

- Occupant age, and
- Dummy variables for driver and front outboard passenger seating position.

Carlson (1978) gave consideration to the relationship between the distribution of OAIS and mean OAIS (since the latter parameter is the objective for prediction by multiple regression models). He concluded that mean OAIS is a useful summary measure of changes in the distribution of OAIS as a function of injury prediction variables.

Watson and Shiels (1975) followed Carlson and Kaplan's approach and developed non-linear multiple regression models for OAIS as a function of vehicle damage and occupant age.

INJURY SEVERITY SCORES

Prior to the main analysis, the data file did not include OAIS nor any other proxy general injury severity measure. Nelson's (1974) Injury Severity Score was not considered an adequate proxy because it gives undue weight to minor injuries. Nor did the data file contain injury severity scores within body regions which, given the highly locational nature of injuries due to steering assemblies (Mackay 1975, Griffiths *et al* 1976), were considered essential tools for providing sensitive discrimination of the potential effect of ADR 10.

To this end, a method was developed for calculating the AIS score of the most severe injury in each of eight body regions (Cameron 1977). Following Nelson (1974) and States (1969), AIS scores were assigned to each injury on the RTR and, for each occupant casualty, the maximum AIS in each body region determined. In the subsequent analysis, only five of the eight body regions were considered specifically:

- Head,
- Face,
- Chest (excluding thoracic spine),
- Abdomen/Pelvis (including pelvic girdle, but excluding lumbar spine),
- Lower Extremities.

This subset was chosen to lighten the analysis task and because it was considered that any potential effect of ADR 10 would be confined to these body regions.

To avoid the danger of missing a positive or negative effect in the other body regions, a whole-body injury severity score was sought for inclusion in the analysis. Nelson's ISS was rejected and OAIS was not available in the file. OAIS could not be derived from the available data because it is a clinical judgement. Baker et al (1974) developed and tested an Injury Severity Score 'which may be a suitable replacement for the Overall AIS' (Joint Committee on Injury Scaling, 1976). Essentially, it is the sum of squares of the maximum AIS scores of the three most severely injured body regions. Hence it was derivable from the information available in the data file. Baker et al showed their ISS to be a good indicator of the threat-to-life due to multiple injuries. Accordingly, it was chosen as the whole-body injury severity score for this main analysis. A square root transformation was taken to avoid methodological problems due to the skewness of its distribution.

In summary, the following six injury severity scores were used as criterion variables in the main analysis to determine the effect of ADR 10:

- Head AIS (H),
- Face AIS (F),
- Chest AIS (C),
- Abdomen/Pelvis AIS (AP),
- Leg (Lower Extremities) AIS (LX), and
- Square root of Baker's ISS.

CONCEPTUAL MODEL

As background to the main analysis, it was considered useful to develop a conceptual model of the relationship between available variables and their effect on injury severity of occupant casualties from frontal impacts. Available variables considered to potentially affect injury severity were grouped as follows:

. <u>Energy of impact</u>

1. Crash location (ROAD)

2. Year of manufacture (KYR) - see earlier discussion of preliminary analysis

3. Crash type indicators
   - Vehicle-to-vehicle (NATURE1)
   - Struck 'object' (NATURE2)

. <u>Transfer of energy to occupant</u>

4. Ejection indicator (OBJ16)
   - if not ejected : 5. Vehicle size (SIZE)
     6. Seating position (SEAT)
     7. Seat belt use (BELT)
     8. Steering column/wheel contact indicator (OBJ3)
     9. ADR 10 (if effective)

. <u>Injury susceptibility of occupant</u>

10. Age (AGE)
11. Sex (SEX)

The crash type indicators were included because Marsh <u>et al</u> (1977) found these two types of frontal crash to be significantly (but differentially in magnitude) associated with fatal outcome in North American in-depth accident data.

It was suspected that many of the variables related to the transfer of energy and injury susceptibility would interact among themselves (and possibly with the energy of impact) in terms of their effect on injury severity. Hence the first step in the main analysis was to investigate such interactions with an aim to incorporating significant interaction terms in the multiple regression models.

INTERACTIONS OF INJURY PREDICTION VARIABLES

Analysis

A series of Analysis of Variance were performed on each of the six injury severity criteria. For this and all subsequent analysis, occupant casualties in the Pre-matched fatalities 1973-74 sub-file were not considered because it was suspected that these cases may distort the injury severity scores based on later model car occupants. Ejected occupants were also excluded on the grounds that ADR 10 could not have been relevant to their injuries.

Initial analysis indicated a number of significant interactions between crash location and variables related to the energy transfer and injury susceptibility. These swamped other interactions, so it was decided to split the data into the two crash locations during the development of the injury prediction models.

Initial analysis also indicated that there was no significant interaction between vehicle size and steering assembly contacts. This allowed the analysis of interactions between injury predictors to be carried out in two parts within the limits of the available computer software (Nie et al 1975). There was a limit of five factors which could be included in the Analysis of Variance and these were chosen as follows:

Factors:

- Seating position (driver/front centre/front left/rear)
- Seat belt use (unbelted/belted)
- Occupant age (1 to 24/25 to 49/50 to 99)
- Occupant sex (male/female)
- (i) Vehicle size (small/large/unknown)
  (ii) Steering column/wheel contact indicator
  (not struck/struck)

Covariate:

- Year of manufacture

Year of manufacture was included as a covariate in the Analyses of Variance in order to reduce the residual variance (and hence increase the sensitivity of the analysis); interactions of year of manufacture with the factors were not considered. With the exception of vehicle size, cases with unknown values for any of the above variables were excluded from this and subsequent analysis.

Results

A large number of interactions between the injury predictors were observed to have 'significant' effects on the injury severity scores (Table IV). A liberal significance level of 0.4 (two-tailed) was used for detecting interactions because it had been observed in trial multiple regressions that such interactions commonly had much higher levels of statistical significance (lower p) than were observed in Analysis of Variance.

For each combination of crash location and injury severity score, the significant interactions in the corresponding column of Table IV were incorporated as candidate injury predictor variables in the multiple regression models developed in the following section.

INJURY PREDICTION MODELS

Method

The expectation or mean value of each of the six injury severity criteria was theorized as being a linear function of the injury predictor variables plus the interactions found significant in the previous section (Table IV). The coefficients of each variable and interaction were estimated by multiple regression. Categorical variables with more than two categories (seating position and vehicle size) were represented by dummy variables (see Appendix B, Table B1). Occupant age was retained as an interval-scaled variable, following Carlson (1977, 1978). Interactions were also represented by dummy variables (Table B2), following Nie *et al* (1975) who give an excellent exposition of multiple regression with dummy variables.

Multiple regressions were fitted to non-ejected occupants of pre-1971 cars involved in frontal impacts separately for the two crash locations. Occupants of 1971 and later cars (ie, those with ADR 10) were excluded from the regressions because the regression coefficients were to be used to estimate the expected injury patterns of these occupants and their inclusion would have biased the estimates.

TABLE IV : Significance levels (p) of 'significant' ($p < 0.4$) interactions between injury prediction variables in Analysis of Variance.

Interaction	Injury Severity Score											
	Head AIS		Face AIS		Chest AIS		Abdomen/ Pelvis AIS		Leg AIS		Square root of Baker's ISS	
	Open road	Built-up	Open road	Built-up	Open road	Built-up	Open road	Built-up	Open road	Built-up	Open road	Built-up
SEAT by BELT					0.23							
SEAT by SEX		0.36	0.14	0.23	0.36			0.39	0.33	0.33		
SEAT by AGE	0.36		0.27			0.25						
BELT by SEX						0.02		0.05	0.22			0.19
BELT by AGE	0.38		0.10		0.09	0.09			0.12	0.14	0.16	
SEX by AGE						0.07			0.03	0.21	0.06	
SEAT by SIZE		0.36		0.34								
BELT by SIZE								0.13		0.39		
SEX by SIZE	0.36	0.10	0.32	0.14			0.21	0.14		0.18		0.22
AGE by SIZE	0.29	0.13	0.22	0.23	0.19		0.06		0.15	0.13	0.38	
SEAT by OBJ3*			0.32	0.32							0.37	0.21
BELT by OBJ3	0.32	0.07	0.21	0.23			0.34	0.003	0.27	0.22		0.28
SEX by OBJ3	0.26	0.25		0.05		0.13						
AGE by OBJ3		0.01				0.22	0.15		0.18			

* OBJ3 : Steering wheel/column contact indicator

Multiple regressions were also fitted to non-ejected occupants of all cars involved in frontal impacts. In these cases, a dummy variable denoting occupants of ADR 10 cars and a dummy variable denoting ADR 10 drivers who contacted the steering assembly were also included (Tables B1 and B2). The coefficient of the latter dummy variable was an estimate of any change in the injury severity of contact-making drivers due to ADR 10. The other dummy variable was included to represent any other change in the injury severity of occupants of post-1970 cars generally compared with earlier cars.

Models based on Pre-1971 Car Occupants

The best of the multiple regression models fitted to pre-1971 car occupants (Tables B3 to B14) explained only 11.8 per cent of the variation of injury severity. This compared unfavourably with the figure of 46 per cent of variance explained found by Carlson (1977) for occupants in head-on crashes. The disparity is probably due to the absence of any crash severity measures from the regressions fitted here. Carlson and Kaplan (1975) and Carlson (1977, 1978) all found that crash severity explained a large and statistically significant proportion of the variation in injury severity in their regressions.

Tables B3 to B14 show the variables (and their estimated coefficients) retained for inclusion in the functions used to estimate the expected injury severities of occupants of ADR 10 cars (see next major section for comparison of expected and observed injury severities). Variables with coefficients significantly different from zero were retained, together with variables satisfying the following criteria:

(a) dummy variables with regression coefficients exceeding 10 per cent of the mean injury severity score, and

(b) interval-scaled variables with regression coefficients exceeding 1 per cent of the mean injury severity score.

Criteria (a) and (b) were added to include variables which potentially made a substantial contribution to injury severity estimates, but which did not have statistically significant coefficients due to the relatively large unexplained variation inherent in the models in the absence of a crash severity measure.

The coefficients in Tables B3 to B14 are unbiased estimates of the contribution of the corresponding variable to injury severity when all other variables included in the regression have been controlled. Thus when interpreted correctly, the coefficients give considerable insight into the mechanisms of injuries in frontal impacts. For example, the estimate of the effect of seat belt use on head injury severity in open road frontal impacts is a reduction of 1.023 units on the AIS scale (Table B3). This effect was statistically significant ($p = 0.002$), but there is also evidence of an interaction between seat belt use and occupant age (variable AGEWEAR; $p = 0.02$). However, due to the limited time available, it is not possible to give a detailed interpretation of the results in Tables B3 to B14 in this report.

Significance of Dummy Variables for ADR 10

In general, the multiple regressions fitted to non-ejected occupants of all cars resulted in regression coefficients similar to those in Tables B3 to B14. These regressions included two dummy variables denoting (i) ADR 10 occupants and (ii) ADR 10 drivers who contacted steering assemblies (Table V). There was a statistically significant ($p = 0.02$) negative coefficient for the dummy variable representing ADR 10 drivers who made steering assembly contacts in open road frontal impacts when regressed on abdomen/pelvis injury severity. This result suggested that there was a reduction in the severity of abdomen/ pelvis injuries to open road drivers who contacted steering assemblies installed under ADR 10 compared with those in pre-ADR 10 cars. There was also evidence that occupants of ADR 10 cars in frontal impacts in built-up areas sustained less severe head and face injuries than like occupants of pre-ADR 10 cars (Table V; significance level ≤ 0.05).

TABLE V : Dummy variables for ADR 10 in multiple regressions fitted to non-ejected occupant casualties from all cars involved in frontal impacts.

Crash location / Injury severity score	Dummy variable for ADR 10 driver contacting steering assembly (ADRHTDR)		Dummy variable for occupant of ADR 10 car (ADR10)	
	Regression coefficient	Significance level (p)	Regression coefficient	Significance level (p)
Open Road				
Head AIS	*	0.96	-0.11	0.54
Face AIS	+0.05	0.82	+0.12	0.36
Chest AIS	-0.17	0.54	+0.17	0.33
Abdomen/ Pelvis AIS	-0.61	0.02	*	0.95
Leg AIS	+0.05	0.85	-0.15	0.31
Square root of Baker's ISS	-0.55	0.22	+0.16	0.57
Built-up Areas				
Head AIS	*	0.98	-0.18	0.02
Face AIS	*	0.98	-0.13	0.05
Chest AIS	-0.06	0.64	+0.12	0.15
Abdomen/ Pelvis AIS	-0.04	0.75	+0.11	0.08
Leg AIS	+0.07	0.62	+0.04	0.64
Square root of Baker's ISS	-0.03	0.91	+0.06	0.65

*Regression coefficient not calculated by computer program because of low significance (high p). Calculated coefficient would be close to zero.

The results in Table V are measures of the effect of ADR 10 over all types of drivers who contacted steering assemblies. ADR 10 may have been more or less effective for some types of drivers. The method of dummy variable multiple regression does not allow a non-cumbersome investigation of the effect of ADR 10 for different driver types. Observed and expected injury severities must be compared and that is the subject of the following section.

COMPARISON OF OBSERVED AND EXPECTED INJURY SEVERITIES

Method

The injury severity prediction functions in Tables B3 to B14 were used to calculate the expected injury severity scores of drivers of 1971-74 cars involved in frontal impacts. These prediction functions did not include dummy variables for ADR 10 and the functions were estimated from data on occupants of pre-1971 cars, so they give the expected injury pattern in the absence of ADR 10. The residual injury severity scores (observed scores minus expected) were calculated for drivers of 1971-74 cars who contacted steering assemblies. These residual scores were taken as raw measures of the effect of ADR 10. They were then discounted by the residual scores for drivers of 1971-74 cars who had not contacted steering assemblies, to allow for the possibility that drivers of 1971-74 cars had sustained more (or less) severe injuries than expected due, for example, to having been involved in more (or less) severe crashes. The residual scores for ADR 10 drivers who made contacts were further discounted by the residual scores of pre-1971 drivers, to allow for any deficiencies in the injury prediction functions in terms of their ability to estimate accurately the injury patterns of drivers either making or not making steering assembly contacts; these deficiencies were expected to be small.

The statistical significance of the final net residual score of each type was tested by Analysis of Variance on the driver residual scores, the factors being:

- Year of manufacture (1971-74/up to 1970), and
- Steering column/wheel contact indicator (not struck/struck).

One-tailed significance levels were calculated, as it was hypothesised that ADR 10 would have resulted in decreases in injury severity in each of the body regions considered. One-tailed levels were also chosen to increase test sensitivity, which had already suffered severely due to the absence of a crash severity measure from the injury prediction functions. Significance levels close to one would be indicative of a statistically significant increase in injury severity which would have been found had a more conservative, two-tailed test procedure been chosen. This may be appropriate in the cases of face, head and leg injuries, in light of previous research (Lundstrom et al 1969, Gloyns 1973, Gloyns and Mackay 1974).

Results

Table VI illustrates the calculation of the net residual score for the whole-body injury severity score (square root of Baker's ISS). Thus, the overall injury severity of ADR 10 drivers who contacted steering assemblies in open road frontal impacts was 19.7 per cent lower than expected in the absence of ADR 10. This difference in injury severity could have been due to chance with probability $p = 0.13$. In built-up area crashes, the analagous difference in overall injury severity was only 1 per cent lower ($p = 0.47$).

The difference between observed and expected overall injury severity for ADR 10 drivers making contacts in open road crashes was due to differences in injury severity in the face, chest and abdomen/pelvis regions (Table VII). Only the net residual in the latter region was statistically significant (maximum significance level $p = 0.1$). There were no statistically significant net residuals for drivers in crashes in built-up areas. However there remained the possibility that there were statistically significant net residuals for specific types of drivers or vehicles in crashes in built-up areas (and in open road crashes). That is the subject of the following.

TABLE VI : Average observed injury severity scores for non-ejected drivers in frontal impacts, plus expected scores from injury prediction models.

Crash Location. Year of manuf. Steering column/ wheel contact	No. of cases	Square root of Baker's ISS Observed (O)	Expected (E)	Residual (O - E)	Net residual as percentage of expected (significance level, one-tail)
Open Road					
1971-74 drivers					
(a) Struck	32	2.905	3.293	-0.388	
(b) Not struck	36	2.726	2.535	+0.191	
(c) Net (a)-(b)				-0.579	
Up to 1970 drivers					
(d) Struck	145	*	*	+0.057	
(e) Not struck	117	*	*	-0.014	
(f) Net (d)-(e)				+0.071	
NET (c)-(f)				-0.650	-19.7 (p = 0.13)
Built-up Areas					
1971-74 drivers					
(a) Struck	52	1.823	1.711	+0.112	
(b) Not struck	77	1.527	1.478	+0.049	
(c) Net (a)-(b)				+0.063	
Up to 1970 drivers					
(d) Struck	296	*	*	+0.069	
(e) Not struck	320	*	*	-0.011	
(f) Net (d)-(e)				+0.080	
NET (c)-(f)				-0.017	- 1.0 (p = 0.47)

*Not explicitly calculated during analysis

TABLE VII : Expected and net residual injury severity scores of non-ejected drivers of ADR 10 cars who contacted steering assemblies in frontal impacts.

Crash Location Injury severity score	Expected score for 1971-74 drivers who contacted steering column/wheel	Net residual score	Net residual as percentage of expected	Significance level (one-tailed)
Open Road				
Head AIS	1.335	+0.093	+ 6.9	0.60
Face AIS	1.176	-0.258	-22.0	0.15
Chest AIS	0.990	-0.263	-26.6	0.24
Abdomen/ Pelvis AIS	1.034	-0.549	-53.1	0.06
Leg AIS	0.969	+0.095	+ 9.8	0.62
Square root of Baker's ISS	3.293	-0.650	-19.7	0.13
Built-up Areas				
Head AIS	1.025	-0.033	- 3.2	0.40
Face AIS	1.001	+0.005	+ 0.5	0.51
Chest AIS	0.575	-0.104	-18.1	0.21
Abdomen/ Pelvis AIS	0.088	+0.010	+11.3	0.53
Leg AIS	0.449	-0.002	- 0.5	0.49
Square root of Baker's ISS	1.711	-0.017	- 1.0	0.47

RESIDUAL INJURY SEVERITIES BY DRIVER/VEHICLE TYPE

Method

Variations in the net residual scores (of ADR 10 drivers who made contacts) by driver or vehicle type were tested for statistical significance by Analysis of Variance with the following factors:

- Year of manufacture (1971-74/up to 1970),
- Steering column/wheel contact indicator, and
- Driver/vehicle type variable, ie.
  - (i) Seat belt use,
  - (ii) Driver sex,
  - (iii) Driver age, or
  - (iv) Vehicle size.

A significant three-way interaction between the factors indicated that there were substantial variations of the net residuals in Table VII between the categories of the driver/vehicle type variable analysed.

For each three-way interaction significant at the 0.2 level, the data were partitioned by the driver/vehicle type variable and net residuals for the corresponding injury severity score calculated in the same manner as Tables VI and VII within each partition.

Results

For ADR 10 drivers in open road crashes, there were indications of substantial variations in face and leg injury severities by driver type (Table VIII). The net residual of face injury severity varied significantly with driver sex and age, and that for leg injury severity varied significantly with seat belt use. In built-up area crashes, there were indications of substantial variations in chest and leg injury severities by driver age and vehicle size (Table VIII). The net residual of chest injury severity also varied significantly with driver sex.

TABLE VIII : Significance levels (two-tailed) of effect on injury severity score of interaction between year of manufacture, steering assembly contact, and driver/vehicle type variable.

Crash Location Injury severity score	Driver/vehicle type variable			
	Seat belt use	Sex	Age	Vehicle size
Open Road				
Head AIS	0.37	0.33	0.47	0.42
Face AIS	0.52	0.05*	0.01*	0.49
Chest AIS	0.36	0.50	0.70	0.85
Abdomen/ Pelvis AIS	0.80	0.90	0.89	0.89
Leg AIS	0.18*	0.35	0.86	0.81
Square root of Baker's ISS	0.87	0.78	0.06*	0.73
Built-up Areas				
Head AIS	0.90	0.41	0.79	0.37
Face AIS	0.58	0.95	0.90	0.59
Chest AIS	0.42	0.13*	0.001*	0.16*
Abdomen/ Pelvis AIS	0.99	0.41	0.42	0.82
Leg AIS	0.43	0.65	0.06*	0.12*
Square root of Baker's ISS	0.16*	0.54	0.11*	0.10*

*Significance levels $\leq$ 0.2.

The reduction in face injury severity of ADR 10 drivers making steering assembly contacts in open road crashes was confined to male drivers and to drivers aged over 24 (Table IX). It was not known at this stage whether these two groups of drivers were substantially the same group.

While there was no evidence of a reduction in leg injury severity of contact-making ADR 10 drivers generally in open road crashes (Table VII), there was evidence of such a reduction among unbelted drivers of this type (Table IX). This reduction was not statistically significant. There was also evidence of an increase in leg injury severity among belted drivers of this type.

In crashes in built-up areas, the reduction in chest injury severity of ADR 10 drivers making steering assembly contacts was confined to female drivers, those aged over 24, and essentially to those driving large cars (Table X).

Although there was no statistically significant evidence of a reduction in leg injury severity of contact-making ADR 10 drivers generally in built-up area crashes (Table VII), there was stronger evidence of a reduction among such drivers aged 25 to 49 ($p = 0.04$) or driving other than small cars (Table X). There was also evidence of an increase in leg injury severity among contact-making ADR 10 drivers aged other than 25 to 49, or driving small cars ($p = 0.04$ if tested for an increase in leg injury severity).

The reductions in chest and leg injury severity were partly reflected in the whole-body injury severity score. This score also exhibited a decrease ($p = 0.13$) for unbelted ADR 10 drivers making steering assembly contacts in built-up area crashes.

Consideration was given to developing unique descriptions of the sub-groups of drivers who exhibited reductions in injury severity when they made steering assembly contacts in ADR 10 cars. Bearing in mind the relatively small numbers of such drivers involved in crashes in the two crash locations separately (Table VI), it was decided to delay this pursuit to the next stage of the analysis where drivers from all crash

TABLE IX : Expected and net residual injury severity scores of non-ejected drivers of ADR 10 cars who contacted steering assemblies in frontal impacts on the open road, by driver type.

Injury severity score Driver type	Expected score for 1971-74 drivers who contacted steering column/wheel	Net residual score	Net residual as percentage of expected	Significance level (one-tailed)
Face AIS				
Male	1.152	-0.467	-40.5	0.06
Female	1.228	+0.700	+57.0	0.95
Age up to 24	1.331	+0.850	+63.9	0.99
Age 25 to 49	1.188	-0.568	-47.8	0.08
Age over 49	0.887	-0.994	-100.0	0.04
Leg AIS				
Unbelted	1.082	-0.530	-49.0	0.18
Belted	0.917	+0.418	+45.6	0.85
Square root of Baker's ISS				
Age up to 24	3.474	+1.261	+36.3	0.90
Age 25 to 49	3.315	-1.198	-36.1	0.09
Age over 49	2.944	-2.054	-70.0	0.05

TABLE X : Expected and net residual injury severity scores of non-ejected drivers of ADR 10 cars who contacted steering assemblies in frontal impacts in built-up areas, by type of driver or vehicle.

Injury severity score / Driver/vehicle type	Expected score for 1971-74 drivers who contacted steering column/wheel	Net residual score	Net residual as percentage of expected	Significance level (one-tailed)
Chest AIS				
Male	0.557	+0.015	+ 2.6	0.53
Female	0.692	-0.669	-96.8	0.04
Age up to 24	0.398	+0.445	+111.6	0.99
Age 25 to 49	0.618	-0.184	-29.8	0.26
Age over 49	1.015	-2.097	-100.0	0.0005
Small vehicle	0.464	+0.334	+72.1	0.91
Large vehicle	0.589	-0.441	-74.9	0.04
Unknown size	0.738	-0.028	- 3.9	0.48
Leg AIS				
Age up to 24	0.400	+0.331	+83.9	0.91
Age 25 to 49	0.429	-0.435	-100.0	0.04
Age over 49	0.296	+0.520	+175.4	0.83
Small vehicle	0.613	+0.568	+92.6	0.96
Large vehicle	0.374	-0.212	-56.7	0.18
Unknown size	0.453	-0.125	-27.7	0.38
Square root of Baker's ISS				
Unbelted	1.900	-0.562	-29.6	0.13
Belted	1.573	+0.233	+14.8	0.78
Age up to 24	1.692	+0.605	+35.8	0.94
Age 25 to 49	1.683	-0.379	-22.5	0.18
Age over 49	1.897	-0.905	-47.7	0.12
Small vehicle	1.571	+0.905	+57.6	0.98
Large vehicle	1.747	-0.342	-19.6	0.19
Unknown size	1.835	-0.419	-22.8	0.28

locations would be considered together. (The amalgamation of data would also allow more sensitive statistical tests of the type carried out so far). While originally the data from the two crash locations were kept separate due to interaction effects on injury severity, it was considered that this problem would not apply to injury severity residuals (because variations in variables related to energy transfer and injury susceptibility had been eliminated by the injury prediction models). However estimates of the effect of ADR 10 on driver injury severities would then be pooled weighted averages of the effects in the separate crash locations.

POOLED CRASH LOCATIONS

Method

The analysis followed exactly that carried out for the two crash locations separately (see above), except that the expected injury severity scores were those calculated from Tables B3 to B14; injury severity prediction functions were not estimated from the pooled crash location data. Thus each driver casualty had exactly the same expected scores and residual scores as earlier. Because drivers in open road crashes in general had substantially higher injury severities than drivers in built-up area crashes (Table VII), the expected scores calculated in this way would explain substantially more of the variation of injury severity of drivers of pre-1971 cars in the pooled locations than in the two crash locations separately. For example, the predicted values of the square root of Baker's ISS explained 12.8 per cent of the variation of this score for drivers of pre-1971 cars in the pooled locations, compared with 8.8 per cent and 8.3 per cent explained in open road and built-up area crashes, respectively (Tables B8 and B14).

Results

There were reductions in injury severity in the face, chest and abdomen/pelvis regions of ADR 10 drivers who made steering assembly contacts in the pooled areas compared with that expected in the absence of ADR 10 (Table XI). Only the net residual severity score in the latter body region was statistically significant ($p = 0.07$).

TABLE XI : Expected and net residual injury severity scores of non-ejected drivers of ADR 10 cars who contacted steering assemblies in frontal impacts in open road or built-up areas.

Injury severity score	Expected score for 1971-74 drivers who contacted steering column/wheel	Net residual score	Net residual as percentage of expected	Significance level (one-tailed)
Head AIS	1.135	+0.014	+1.3	0.53
Face AIS	1.085	-0.064	-5.9	0.31
Chest AIS	0.751	-0.158	-21.0	0.18
Abdomen/ Pelvis AIS	0.449	-0.213	-47.6	0.07
Leg AIS	0.649	+0.024	+3.7	0.56
Square root of Baker's ISS	2.274	-0.249	-11.0	0.17

TABLE XII : Significance levels (two-tailed) of effect on injury severity score of interaction between year of manufacture, steering assembly contact, and driver/vehicle type variable. Drivers in open road or built-up areas combined.

Injury severity score	Driver/vehicle type variable			
	Seat belt use	Sex	Age	Vehicle size
Head AIS	0.41	0.23	0.93	0.20*
Face AIS	0.94	0.28	0.10*	0.57
Chest AIS	0.88	0.06*	0.02*	0.59
Abdomen/ Pelvis AIS	0.96	0.31	0.32	0.94
Leg AIS	0.11*	0.21	0.18*	0.33
Square root of Baker's ISS	0.45	0.48	0.002*	0.11

*Significance levels ≤ 0.2.

There were indications that the net residual severity scores in the head, face, chest and leg regions varied substantially with driver sex and/or age and/or vehicle size (Table XII). Because there were a large number of border-line significance levels in Table XII compared with Table VIII, it was decided to present the net residual scores (as a percentage of the expected score) for all six types of score and all categories of driver/vehicle type (Table XIII).

None of the net reductions in head injury severity were significant for any category of driver/vehicle (maximum significance level $p = 0.1$). The net reduction in face injury severity was significant only for the class of drivers aged over 49 (62 per cent reduction). The net reduction in chest injury severity was significant for female drivers (85 per cent), those aged over 49 (91 per cent) and those driving large cars (40 per cent). It was not known at this stage whether these three groups of drivers were substantially the same group.

For leg injury severity, there was a statistically significant net reduction only for drivers aged 25 to 49 (54 per cent). There were net increases in leg injury severity among belted drivers (50 per cent) and those driving small cars (47 per cent), both of which would have been statistically significant if tested for an increase.

There was no evidence that the statistically significant net reduction in abdomen/pelvis injury severity for ADR 10 contact-making drivers as a class varied substantially with driver/vehicle type (Table XII). The failure of net reductions within some driver/vehicle categories to reach statistical significance may have been due to the limited number of cases within a category rather than the non-existence of a real effect of the ADR on abdomen/pelvis injury severity. Nevertheless, there were significant net reductions in abdomen/pelvis injury severity for female drivers (82 per cent), those aged over 49 (100 per cent) and those driving large cars (68 per cent).

TABLE XIII : Net residual injury severity scores as a percentage of expected score of non-ejected drivers of ADR 10 cars who contacted steering assemblies in frontal impacts in open road or built-up areas, by driver/vehicle type. (One tailed significance levels in brackets).

NET RESIDUAL AS PERCENTAGE OF EXPECTED INJURY SEVERITY SCORE

Driver/vehicle type	Injury severity score					
	Head AIS	Face AIS	Chest AIS	Abdomen/ Pelvis AIS	Leg AIS	Square root of Baker's ISS
All driver types	+1 (0.53)	-6 (0.31)	-21 (0.18)	-48 (0.07)	+4 (0.56)	-11 (0.17)
Seat belt use						
Unbelted	-17 (0.26)	-7 (0.37)	-14 (0.37)	-65 (0.19)	-31 (0.20)	-24 (0.12)
Belted	+11 (0.68)	-10 (0.27)	-22 (0.21)	-42 (0.11)	+50 (0.94)	-6 (0.33)
Driver sex						
Male	-7 (0.34)	-15 (0.15)	-1 (0.49)	-33 (0.20)	+22 (0.77)	-8 (0.28)
Female	+36 (0.89)	+15 (0.76)	-85 (0.007)	-82 (0.05)	-37 (0.16)	-25 (0.12)
Driver age						
Up to 24	+8 (0.63)	+17 (0.85)	+46 (0.89)	-14 (0.38)	+32 (0.85)	+32 (0.97)
25 to 49	-4 (0.44)	-9 (0.31)	-28 (0.22)	-49 (0.19)	-54 (0.10)	-29 (0.06)
Over 49	0 (0.50)	-62 (0.03)	-91 (0.01)	-100 (0.05)	+66 (0.81)	-76 (0.005)
Vehicle size						
Small	+38 (0.94)	+14 (0.75)	+16 (0.64)	-67 (0.12)	+47 (0.90)	+28 (0.92)
Large	-24 (0.15)	-14 (0.22)	-40 (0.10)	-68 (0.10)	-2 (0.48)	-28 (0.06)
Unknown size	+6 (0.57)	-14 (0.29)	-19 (0.36)	-21 (0.34)	-41 (0.22)	-23 (0.16)

The net reductions in the whole-body injury severity score (square root of Baker's ISS) essentially followed the net reductions in the individual body regions. The net reductions in this score for drivers aged 25 to 49 (29 per cent), aged over 49 (76 per cent) and driving large cars (28 per cent) were all statistically significant.

INTER-RELATIONS OF DRIVER/VEHICLE TYPES

Analysis

To determine the inter-relationships between seat belt use, driver sex and age, and vehicle size, the number of non-ejected driver casualties from 1971-74 cars was cross-tabulated by each pair of variables in turn. Drivers of 1971-74 cars who did not contact steering assemblies were included to give more sensitive tests of the association between each pair of variables. Associations were tested for significance by the two-way Chi-square test of independence.

Results

Only two pairs of variables had significant associations (maximum significance level $p = 0.2$, two-tailed), shown in Table XIV. Female drivers were more likely to be wearing a seat belt and older drivers were more likely to occupy large cars or cars of unknown size.

Thus it was not clear whether the significant net reductions in Table XIII for female drivers were due to their sex, their higher rate of seat belt use, or both. Nor was it clear whether the significant net reductions of drivers aged over 49 were due to their age, their tendency to occupy larger cars, or both. To resolve these questions, it was decided to investigate the effect of the interaction of each pair of variables in Table XIV on the net residual injury severities of the ADR 10 drivers contacting steering assemblies (see next section).

TABLE XIV : Non-ejected driver casualties from 1971-74 cars involved in frontal impacts in the pooled crash locations.

(A) SEAT BELT USE by DRIVER SEX

Seat Belt Use		Driver Sex		TOTAL
		Male	Female	
Unbelted	(No.)	48	10	58
	(%)	(32.4)	(20.4)	(29.4)
Belted	(No.)	100	39	139
	(%)	(67.6)	(79.6)	(70.6)
TOTAL	(No.)	148	49	197
	(%)	(100.0)	(100.0)	(100.0)

Chi-square = 2.02 with 1 d.f. (p = 0.16)

(B) DRIVER AGE by VEHICLE SIZE

Driver Age		Vehicle Size			TOTAL
		Small	Large	Unknown Size	
Up to 24	(No.)	37	28	14	79
	(%)	(56.1)	(29.8)	(37.8)	(40.1)
25 to 49	(No.)	27	45	16	88
	(%)	(40.9)	(47.9)	(43.2)	(44.7)
Over 49	(No.)	2	21	7	30
	(%)	(3.0)	(22.3)	(18.9)	(15.2)
TOTAL	(No.)	66	94	37	197
	(%)	(100.0)	(100.0)	(100.0)	(100.0)

Chi-square = 17.08 with 4 d.f. (p = 0.002)

EFFECT OF DRIVER/VEHICLE TYPE INTERACTIONS

Method

Due to the nearly consistent patterns of the net residuals of drivers aged 25 to 49 and those aged over 49, it was decided to pool those categories. Similarly, it was decided to pool drivers of large and unknown size cars. Thus the effect of the following interactions on the net residual injury severities were investigated:

(i) Seat belt use by Driver sex, and

(ii) Driver age (up to 24/over 24) by Vehicle size (small/large or unknown size).

The statistical significance of the interaction effect on each injury severity score was tested by a four-factor Analysis of Variance, the other two factors being:

- Year of manufacture (1971-74/up to 1970), and
- Steering column/wheel contact indicator.

For those injury severity scores where there was evidence of an interaction effect, the data were partitioned into the four categories implied by the interaction (i) or (ii) and net residuals were calculated in the same manner as Table XIII within each partition.

Results

There was evidence of an interaction effect on abdomen/pelvis and leg residual injury severity between seat belt use and driver sex (Table XV). A maximum significance level of 0.3 (two-tailed) was arbitrarily chosen to give sensitivity to the tests for an interaction. Driver age and vehicle size had an interaction effect on residual injury severity in both the chest and abdomen/pelvis regions.

Because the signs of the net residuals of leg injury severity of drivers in the two highest age categories were not consistent (Table XIII), it was decided to pool the highest and lowest categories and again test the interaction effect of driver age and vehicle size on leg injury severity. The test for an interaction was not significant ($p = 0.90$).

TABLE XV : Significance levels (two-tailed) of effect on injury severity score of four-way interaction between year of manufacture, steering assembly contact, and:

(i) seat belt use and driver sex,
(ii) driver age and vehicle size.

Injury severity score	Driver/vehicle type interaction	
	Seat belt use by Driver sex	Driver age by Vehicle size
Head AIS	0.32	0.84
Face AIS	0.57	0.72
Chest AIS	0.61	0.19*
Abdomen/ Pelvis AIS	0.22*	0.13*
Leg AIS	0.23*	0.31
Square root of Baker's ISS	0.92	0.71

* Significance levels ≤ 0.3

Where there was no interaction effect, this suggested that the effects of ADR 10 within the driver/vehicle type categories were additive. However these findings did not avoid the problem inherent in Table XIII that the estimated effects of ADR 10 within categories of two associated variables (ie, seat belt use and driver sex, or driver age and vehicle size) do not represent the differential effects of ADR 10 due to each variable alone. The strongest effects of ADR 10 appeared to lie in the chest, abdomen/pelvis and leg regions, and to reflect in Baker's ISS (Table XIII). It was decided to calculate net residuals for all four of the corresponding injury severity scores within both partitions of the data implied by the interactions (i) and (ii).

The effects of the interaction between driver age and vehicle size were clearly apparent (Table XVI). The net reductions in chest and abdomen/pelvis injury severity for drivers aged over 24 were confined to those driving cars of large or unknown size. The net reduction in abdomen/pelvis injury severity for drivers of small cars was confined to drivers aged up to 24. The net increase in leg injury severity of drivers of small cars was similarly confined to drivers aged up to 24.

The effect of the interaction between seat belt use and driver sex was weaker. The net reduction in abdomen/pelvis injury severity for female drivers was confined to those who wore their seat belts. Similarly, for male drivers it was essentially confined to those who were unrestrained. However the net increase in leg injury severity of belted drivers was confined to those of the male sex.

In contrast, the net reduction in chest injury severity for female drivers applied whether they were belted or unbelted. This illustrated the absence of a significant interaction between seat belt use and driver sex inthe chest region.

TABLE XVI : Net residual injury severity scores as a percentage of expected score of non-ejected drivers of ADR 10 cars who contacted steering assemblies in frontal impacts in open road or built-up areas, by driver/vehicle type. (One-tailed significance levels in brackets).

NET RESIDUAL AS PERCENTAGE OF EXPECTED INJURY SEVERITY SCORE

Driver/vehicle type	Injury severity score			
	Chest AIS	Abdomen/ Pelvis AIS	Leg AIS	Square root of Baker's ISS
All driver types	-21 (0.18)	-48 (0.07)	+4 (0.56)	-11 (0.17)
Male drivers				
Unbelted	+12 (0.60)	-76 (0.16)	-41 (0.17)	-21 (0.17)
Belted	-3 (0.47)	-15 (0.37)	+81 (0.97)	-3 (0.43)
Female drivers				
Unbelted	-100 (0.05)	+39 (0.57)	+16 (0.59)	-35 (0.24)
Belted	-76 (0.02)	-85 (0.03)	-18 (0.36)	-22 (0.17)
Drivers aged up to 24				
Small vehicles	+5 (0.54)	-95 (0.05)	+78 (0.95)	+43 (0.96)
Large/NK vehicles	+70 (0.89)	+29 (0.65)	-18 (0.35)	+19 (0.79)
Drivers aged over 24				
Small vehicles	+29 (0.62)	+64 (0.53)	-8 (0.46)	-5 (0.45)
Large/NK vehicles	-66 (0.02)	-74 (0.05)	-23 (0.28)	-51 (0.002)

SUMMARY AND DISCUSSION

There was evidence that ADR 10 reduced the severity of injury to the abdomen/pelvis of drivers who were not ejected and who struck the steering assembly when involved in frontal impacts. The effect applied particularly to frontal crashes on the open road, where the potential for a reduction in abdomen/pelvis injury severity was considerably higher than in crashes in built-up areas (Table VII). The effect appeared to be confined to the following types of driver:

(a) Drivers aged over 24 driving cars of large or unknown ('intermediate') size,

(b) Drivers aged up to 24 driving small cars,

(c) Female drivers wearing their seat belts, and

(d) Male drivers not wearing seat belts.

There was also evidence that ADR 10 reduced the chest injury severity of some types of drivers who were not ejected and who struck the steering assembly in frontal impacts. The effect was somewhat greater in open road crashes, where there was more potential for a reduction in chest injury severity (Table VII), and appeared to be confined to the following types of driver:

(a) Drivers aged over 24 driving cars of large or unknown ('intermediate') size, and

(b) Female drivers, either belted or unbelted.

In addition, there was evidence that ADR 10 reduced the face and leg injury severity of some types of non-ejected drivers who struck steering assemblies in frontal crashes on the open road. The effect on face injuries appeared to be confined to drivers aged over 24 (particularly those over 49) and to male drivers (Tables IX and XIII). The effect on leg injuries was essentially confined to drivers aged 25 to 49 and unbelted males.

There was no evidence of an effect of ADR 10 in reducing head (excluding face) injury severity of non-ejected drivers who struck steering assemblies in frontal impacts.

In general, changes in overall (whole-body) injury severity of drivers affected by ADR 10 reflected the reductions in body region injury severities described above. The major exception was drivers aged up to 24 driving small cars, whose overall injury severity when affected by ADR 10 was 43 per cent higher than expected, even though their injury severity in the abdomen/pelvis was 95 per cent lower than expected (Table XVI). Their reduction in abdomen/pelvis injury severity may have been off-set by an increase in leg injury severity experienced by the same drivers and an increase in head injury severity to drivers of small cars generally (Table XIII), since young drivers were the usual drivers of small cars (Table XIV).

The effectiveness of ADR 10 appeared to vary considerably with crash location and driver/vehicle type. The higher levels of effectiveness in frontal crashes on the open road compared with built-up areas may have been due to the impacts more frequently exceeding some threshold at which the energy-absorbing characteristics of ADR 10 steering assemblies become operative. McLean (1974) found that the later American energy-absorbing columns offered significant benefits only in frontal crashes resulting in moderate or severe vehicle damage. He commented that 'the threshold load required for initial collapse is unlikely to be reached in relatively minor collisions'.

Thus male drivers wearing seat belts in the data analysed here may not have contacted the steering assemblies with sufficient force for the energy-absorbing effects of ADR 10 to become operative. For female drivers, with their higher susceptibility to rib fracture (Patrick 1975), the picture was more complicated and they appeared to enjoy benefits even when making steering assembly contacts while restrained.

The essential confinement of the beneficial effect of ADR 10, where it was consistent in specific body regions and in general terms, to drivers aged over 24 driving other than small cars, may reflect the historical basis of ADR 10. ADRs 10A and 10B were based on earlier American vehicle standards, which in turn were developed in the context of relatively large vehicles. Thus energy-absorbing steering assemblies defined in the American standards and in ADR 10 may not be as effective in small cars as they may be in larger cars. McLean's (1974) study was confined to 'standard' (ie, 'large' in Australian terms) cars produced by major American manufacturers.

There was no statistically significant evidence that seat belted drivers, as a group, experienced a reduction in overall injury severity when affected by ADR 10. This finding tends to negate the proposition (put in the discussion of the preliminary analysis) that the decrease in the proportion of belted driver casualties who contact steering assemblies in ADR 10 cars compared with the proportion in pre-ADR 10 cars (Table III) is suggestive of a reduction in the probability of injury due to ADR 10. The alternative proposition now appears more likely, viz. that the ADRs were effective in limiting rearward displacement of the steering assembly in frontal impacts. However the evidence for this proposition is tenuous due to the injury criterion for inclusion of data in the file.

To increase the sensitivity of the statistical tests comparing observed and expected injury severities, one-tailed significance levels for a reduction only due to ADR 10 were universally calculated in this study. Thus any apparent increases in injury severity due to ADR 10, no matter how large, were deemed not significant (see Tables XIII and XVI). Net increases with a significance level close to one would be statistically significant in two-tailed tests (for an increase or decrease in injury severity due to ADR 10). Thus, for example, the net increase in head injury severity of drivers of small ADR 10 cars who contacted steering assemblies would have been statistically significant (Table XIII). Similarly, the net increases in leg injury severity of contact-making ADR 10 drivers who were either belted males or aged up to 24 driving small cars would have been statistically significant.

The choice of one-tailed or two-tailed tests is one of the basic dilemmas of hypothesis testing. The absence of crash severity information from the data file, with the consequent reduction in statistical test sensitivity, forced the choice of one-tailed tests here to avoid an unnecessarily high probability of a Type II error (ie, fail to detect an effect due to ADR 10, presumably beneficial). However sufficient information is given with the results for the reader to calculate two-tailed significance levels if desired.

In those categories of driver/vehicle type where there was a net reduction in injury severity to drivers of ADR 10 cars who contacted steering assemblies, it is possible that those drivers may have been involved in less severe frontal impacts and hence had less severe injuries than predicted by the injury prediction function when applied to characteristics of the driver, vehicle and crash location. The risk of this possibility was reduced somewhat by also considering the residual injury severity score of ADR 10 drivers who did not contact steering assemblies. Nevertheless, some risk remained, which may have invalidated the analysis. As such, the results of this study cannot be considered definitive regarding the beneficial effects of ADR 10, but may be considered strongly indicative due to the analysis method of considering parallel changes in the injury patterns of ADR 10 drivers who did not contact steering assemblies.

Consideration was given to evaluating separately the effects of the two basic types of energy-absorbing steering assemblies employed by manufacturers in response to ADR 10, namely (a) axial-collapse columns and (b) self-aligning steering wheels (see Introduction for further details). However only 6.4 per cent of the casualties in the data file could be identified as occupying vehicles whose manufacturers were understood to have fitted self-aligning steering wheels (Chrysler Valiant and Ford Escort). These were considered too few to make a statistically meaningful comparison.

Moreover, it appeared that the study reported here was essentially about the effectiveness of axial-collapse energy-absorbing columns, since these assemblies represented the bulk of those fitted in the cars occupied by the driver casualties studied. As such, the results may be compared with those of Gloyns (1973) for vehicles with axial-collapse columns. His cars were all small in Australian terms and his major findings were confined to unrestrained drivers who were almost exclusively male and predominantly in the 26 to 49 age group (more so than the drivers of small cars in the present study) (Gloyns et al 1973). In contrast to the study reported here, Gloyns found no evidence of benefits from axial-collapse systems in terms of abdominal injuries, whereas such benefits appear to be enjoyed by unbelted male drivers in ADR 10 cars (Table XVI). However Gloyns did find increased probability of serious injury to the head and legs of drivers of cars with axial-collapse columns compared with those with self-aligning wheels. This is consistent with the findings given here of disbenefits in terms of the severity of head and leg injuries of small car drivers due to ADR 10 (Table XIII). However the comparison may be dubious as Gloyns was making a comparative evaluation of steering assemblies in contrast with the absolute evaluation attempted here.

It should be further noted that the results of this study primarily relate to the effectiveness of ADR 10A and not 10B. This is because the number of drivers of vehicles complying with ADR 10B in the data was low. In addition, the use of the criterion of examining the effect of the ADRs only on drivers who contacted steering assemblies, meant that any effect of ADR 10B in limiting intrusion of steering columns could not be adequately evaluated.

The results of this study are summarized in Table XVII.

TABLE XVII : Beneficial effects of ADR 10 (primarily ADR 10A), by body region and driver/vehicle type. Statistically significant negative (ie, benefit) net residual injury severity scores of non-ejected drivers of ADR 10 cars who contacted steering assemblies in frontal impacts (maximum significance level 0.2).

	No Seat Belt	Seat Belt	Small Car	Large Car	Unknown ('intermediate') Size Car
Males	AFL	F			
Females	C	AC			
Up to 24			A	H	
25 to 49			L	ACLH	ACL
Over 49			F	ACFH	ACF

Key : A = Abdomen/Pelvis

C = Chest

F = Face

L = Leg

H = Head (excluding Face)

Unknown region

CONCLUSIONS

1. ADR 10 (primarily ADR 10A) is effective in reducing the severity of injury to the abdomen/pelvis, chest, face and legs of some types of drivers who strike steering assemblies in frontal impacts and are not ejected.

2. The beneficial effect applies particularly to drivers involved in frontal crashes on the open road.

3. The beneficial effect on abdomen/pelvis injury severity is confined to open road crashes and to:

   (a) drivers aged over 24 driving large or intermediate size cars,

   (b) drivers aged up to 24 driving small cars,

   (c) female drivers wearing seat belts, and

   (d) male drivers not wearing seat belts.

4. The beneficial effect on chest injury severity is confined to:

   (a) drivers aged over 24 driving large or intermediate size cars, and

   (b) female drivers, either belted or unbelted.

5. The beneficial effect on face injury severity is confined to open road crashes and to:

   (a) drivers aged over 24 (particularly over 49), and

   (b) male drivers.

6. The beneficial effect on leg injury severity is essentially confined to:

   (a) drivers aged 25 to 49, and

   (b) unbelted male drivers.

7. Although not explicitly tested in the analysis, there is some evidence of disbenefits due to ADR 10 in terms of the severity of head and leg injuries of some types of drivers who strike steering assemblies in frontal impacts and are not ejected. There is evidence of increases in injury severity to the head of drivers of small cars, and to the legs of belted male drivers and those aged up to 24 driving small cars.

8. Due to the absence of crash severity information from the data analysed, the above conclusions could not be considered definitive. However, parallel consideration of a control group of drivers in the analysis suggested that the conclusions were strongly indicative.