LOWER BACK AND NECK STRAIN INJURIES: THE RELATIVE ROLES OF SEAT ADJUSTMENT AND VEHICLE/SEAT DESIGN

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ABSTRACT

The incidence of "whiplash" injuries is rising despite the almost universal introduction of head restraints in cars. The incidence of lower back strains is also significant. This paper describes a study of road accident victims suffering from lower back and neck strain injuries. Injury severity was assessed by a disability scoring system, and patients' progress was followed for 12 months. Vehicles were examined to assess impact speeds and seat characteristics. Where possible, measurements were carried out with victims sitting in their vehicles.

No differences in victims' symptoms were found between rear as opposed to frontal impacts. Women suffered significantly greater disability than men, despite ostensibly more favourable head restraint positioning. For long-term outcome, smaller horizontal distance from head to restraint was significantly associated with higher disability, contrary to expectations. Seat back inclination was important in lumbar strain cases. There was no clear dependence of injury severity on head restraint vertical positioning, impact direction or impact speed.

The possible implications of these results, and possible future strategies for reducing the incidence and severity of neck and lower back strain injuries are discussed.

INTRODUCTION

The increasing incidence of soft tissue cervical sprain injury - also referred to as "whiplash" injuries - and their concomitant clinical manifestations, termed Whiplash Associated Disorders (WADs) by Spitzer *et al* (1995) has been well-documented (Galasko *et al*, 1996, Morris and Thomas, 1996), and has occurred against a background of the increasingly prevalent fitment of head restraints in the front seats and, more recently, the rear seats of cars. These head restraints are fitted to prevent neck injury by limiting rearward hyperextension of the neck in a typical rear impact. While rearward hyperextension is undoubtedly a mechanism for crushing and breakage of the cervical vertebrae in very severe cases, it has also been assumed to be the mechanism for the less severe, AIS1, whiplash-type injuries, despite the fact that the precise clinical definition of these non-life-threatening, but highly debilitating, injuries is not known. Mertz and Patrick (1967) showed that eliminating head motion relative to the torso completely, by having a volunteer's head permanently in contact with a high, rigid seat back, allowed very severe rear impacts to be survived without ill effect. Thus, publicity campaigns have been mounted, urging people to adjust their restraints to be as close to the head as possible horizontally, and to be about level with the ears, or the back of the head, vertically. The current WAD "epidemic" is frequently blamed on the fact that very many people can be observed to ignore these recommendations.

But having one's head close to a softly padded head restraint is not the same as being permanently in contact with a rigid structure. Even where the restraint is rigidly attached to the seat and made of fairly stiff material, head movement, particularly for drivers, is essential in modern traffic conditions, and this is incompatible with keeping the head permanently in contact with the restraint.

Rearward hyperextension of the neck, however, if it is implicated at all in whiplash injury, cannot be the sole mechanism, since these injuries are also observed in victims of frontal and side impacts, where rearward hyperextension is presumed not to be a major factor (Maag *et al*, 1990, Foret-Bruno *et al*, 1991, Von Koch *et al*, 1995, Morris and Thomas, 1996). Some have sought to define whiplash as exclusively a rear impact phenomenon, linking the injury, by implication, to the rearward hyperextension mechanism. But since the injury is defined entirely by its symptoms (it is rare that any physical injury can be identified in these victims), and since it has been generally impossible to differentiate between impact directions in terms of symptoms, it seems rather unfair to define out of existence a large number of neck strain sufferers on the basis of an assumed mechanism for this undefined injury. Indeed, although Lövsund *et al* (1988) have shown that the risk of sustaining whiplash injuries is greater in rear impacts, Morris and Thomas (1996) have shown that frontal impacts actually produce greater absolute numbers of WAD sufferers, because the number of frontal impacts which occur is much greater.

The effectiveness of head restraints in preventing whiplash injuries has been investigated by a number of authors. Nygren *et al* (1984) obtained figures of 25% (fixed restraint) and 15% (adjustable), compared to no restraint (rear impacts only).

Other estimates of effectiveness have ranged from 63% (Foret-Bruno *et al*, 1991) to no detectable effect (Morris and Thomas, 1996). Such wide variations in estimates seem to indicate that the causes of whiplash injury and the interaction between occupant, seat back and head restraint are but poorly understood.

One of the aims of setting up the Whiplash/Vehicle Study (WVS) was to try to obtain definitive evidence that head restraint adjustment does have an effect on neck strain injury outcome, in order to inform publicity campaigns urging people to use their head restraints properly.

METHODOLOGY

We did not address the incidence of neck strain injuries, but examined the injury severity of a sample of WAD sufferers. Any patient presenting at the Accident & Emergency department of a large hospital in the Manchester area with a whiplash injury as a result of a road traffic accident was considered for inclusion in the study. Other injuries at the level of cuts and bruises were allowed, but any injury with an AIS > 1, or which could have interfered with the assessment of the whiplash injury resulted in exclusion from the study. Casualty records at the hospital were examined on a daily basis to identify possible recruits, who were then invited to join the study.

A detailed personal interview was carried out by qualified medical personnel in the patient's home. The extent of impairment suffered by a patient in each of over 20 categories of activity and movement associated with everyday life was assessed, and these individual scores were converted into an "Overall Disability" rating, on a scale of 0-9 (see Murray *et al*, 1993, 1994 for details of the scoring system). Zero on this scale indicates no disability, and 9 represents a serious level of impairment, including being unable to return to work and/or difficulties maintaining an independent lifestyle. All patients had two follow-up interviews, at six months and twelve months after the accident.

The vehicles in which the patients had been travelling were examined by accident investigation specialists in sufficient detail to allow an estimate to be made of the impact speed. Some vehicles had no measurable damage, or suffered multiple impacts; impact speeds could not be estimated in these cases. Failure to examine a patient's vehicle for any reason resulted in that patient being dropped from the study. Patients were encouraged to be present at the examination so that details of seat and head restraint adjustment at the time of impact could be discussed. Photographs of the vehicle and, where possible, of the occupant in the vehicle were taken. Figure 1 shows the head to restraint distances which were measured.

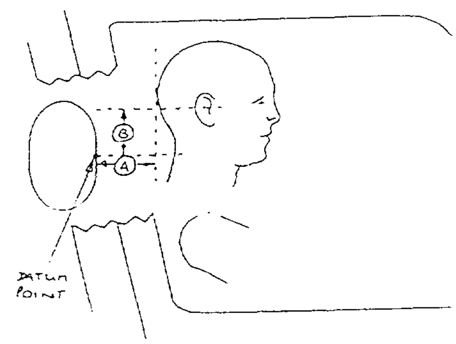

Figure 1. Head to Restraint Distances Measured

An unexpected finding which emerged during the recruitment phase of the project was the discovery of large numbers of patients with lower back strains. Many of these had not been diagnosed as such on the hospital casualty records, but the pain had developed by the time of the first assessment, a few days after the accident. By the time the potential size of this problem had become apparent, the study was well under way, so it was decided not to modify the recruitment criteria, but to record the presence and longevity of lumbar pain for each patient, so that this sub-group could be separated out in the analysis if necessary.

RESULTS

Of 227 initial recruits, 174 remained in the study for the full twelve months, and formed the final sample. These 174 had been occupants in 152 vehicles. The overall male:female ratio in the final dataset was 65:109, and this is similar to the male:female neck injury risk ratio found by Morris and Thomas (1996). Just over half the sample were involved in rear impacts, almost one quarter suffered frontal impacts, with side impacts accounting for the remainder.

Impact speeds could be estimated for 143 occupants. Due to lack of information regarding the second vehicle in the collision, the impact damage measured on each vehicle was converted to an "Equivalent Test Speed" (ETS), related to barrier impacts.

A number of patients were unable to attend the vehicle examination, and this reduced the sample available for analyses involving head restraint distance measurements to 103 occupants. A few of these had very large horizontal head to restraint distances, but very low disabilities. It was found that all those with a horizontal distance greater than 22cm (three in the final sample, more in the initial group) were actively leaning forward at the time of impact, either at junctions or actively bracing themselves for impact in a hunched-forward posture. Their disability scores were significantly lower than the rest of the sample, despite a (non-significantly) higher average impact speed. They have been excluded from the analysis, bringing the sample size down to 171, of which 100 had known restraint measurements and 140 had known ETS. Fourteen occupants had no head restraint.

Comparison with the General Population

Data on head restraint adjustment in the general population have been published elsewhere. Table 1 compares the average horizontal and vertical restraint distances for male and female front seat occupants in the Whiplash/Vehicle Study (WVS) with those reported by Parkin *et al* (1994) (drivers), and Cullen *et al* (1996) (front passengers). Parkin's figures have been adjusted to allow for the fact that they were measured from the centre of the body of the restraint, as opposed to the front face. No population figures are available for rear occupants.

Table 1.
Occupant Distribution and Average Horizontal and Vertical Head Restraint Measurements.
(Distance measurements are in centimetres)

Seat Position	Sex	Number (WVS)	Horizontal Dist. (WVS)	Population Ave (Hor)	Vertical Distance (WVS)	Population Ave (Vert)
Driver	M	41	10.3	10.1	6.9	10.0
	F	45	9.4	10.1	3.4	10.0
Front Passenger	M	4	10.5	6.6	7.0	8.0
	F	9	7.0	6.6	2.4	4.0

Comparing our sample with the reported population measurements, it is clear that there is a much smaller variation due to seating position, and a larger variation between the sexes. Drivers in our sample had horizontal head restraint distances similar to the population average. Vertical measurements, particularly for women drivers, were smaller than the population average. The smaller group of front seat passengers, on the other hand, were apparently in a more risky situation horizontally, but not vertically, compared to the general population. If horizontal and vertical restraint distances were really correlated with risk of sustaining whiplash injury, one would expect a whiplash sample to display greater average distances than the general population, not the similar or even smaller ones seen in Table 1 for most occupants.

Analysis of Whiplash/Vehicle Study Results

The statistical test used was an Analysis of Variance, using the F ratio. In the following, the threshold of statistical significance is taken to be 5% (95% confidence, p=0.05), and such cases appear in **bold** in the tables. In addition, p-values between 0.05 and 0.1, although not meeting this criterion for significance, are quoted in the text where applicable. Each factor was analysed separately because missing values in the dataset would have reduced the sample size dramatically if only cases with complete data had been considered.

Analysis by Average Disability scores: Gender. Average values of the overall disability scores at each of the three assessments were calculated and compared for a number of sample sub-groups. The most clearly unambiguous result to emerge from the analysis was the difference between average disabilities for males and females:

Table 2.
Average Disability vs Gender:

Gender	Number	Average Disability at Assessment...		
		1st	2nd	3rd
Male	64	**2.94**	**1.94**	**1.05**
Female	107	**3.54**	**2.57**	**1.58**

As would be expected, as time passes, people recover from their injuries; this is reflected in the decreasing values of the disability scores at the three assessments (initial, six month and twelve month). However, 57% of the sample still had some degree of disability a year after their accidents, and 10% scored four or more at this stage. Men consistently had lower average disabilities than women, and the differences were significant (p=0.032 maximum) for all three assessments. This is despite the observed gender differences as regards distances from head to restraint (Table 1), which should put men at a disadvantage compared to women. The possibility that this result may be due to differences in impact speed are explored in Table 3:

Table 3.
Average Disability vs Gender and Equivalent Test Speed:

Gender	Number	Ave Disability at Assessment...		ETS (km/h)
		1st	3rd	
Male	53	2.91	**0.98**	19.9
Female	87	3.46	**1.64**	19.7

The estimated speeds are almost identical, and the third assessment scores have remained significantly different ($p=0.014$), despite the reduction in numbers. The initial assessment scores now just fail to achieve significance ($p=0.078$). All further analysis was carried out on the male and female subgroups separately.

Analysis by Average Disability Scores: Other Factors. Tables 4, 5 and 6 show average disabilities against a number of other likely influencing factors for the two gender groups. Each category in these tables has also been tested for differences in estimated speeds. No significant differences were found.

Table 4.
Average Disability vs Awareness of Impending Impact and Sex:

Sex	Awareness	Number	Average Disability at Assessment...		
			1st	2nd	3rd
Male	Aware	34	2.76	1.94	1.06
	Unaware	24	3.33	1.96	0.96
	Not known	6	2.33	1.83	1.33
Female	Aware	38	3.42	2.45	1.45
	Unaware	48	3.52	2.50	1.50
	Not known	21	3.81	2.95	2.00

Awareness of impending impact, rather surprisingly, does not seem to be a factor in whiplash injury outcome, with no significant differences between the aware and unaware groups.

The "female, awareness not known" group seems to be anomalous, with average scores markedly higher than the other groups, but again the differences were not significant ($p>0.1$).

Table 5.
Average Disability vs Impact Direction and Sex:

Sex	Category	Number	Average Disability at Assessment...		
			1st	2nd	3rd
Male	Rear Impact	33	3.00	1.61	**0.67**
	Not Rear	31	2.87	2.29	**1.45**
Female	Rear Impact	55	3.45	2.53	1.69
	Not Rear	52	3.63	2.62	1.46

Average disability in rear impacts was significantly below that for other impact directions for males at the third assessment ($p=0.02$). But the other trends were not consistent over the three assessments, nor between males and females.

This indicates that, for males, the long-term prospects for recovery are worse if they received their injury in a frontal impact. However, if this effect is real, it is surprising that it is not confirmed by the larger sample of females.

Table 6.
Average Disability vs Head Restraint Type and Sex:

Sex	Restraint Type	Number	Average Disability at Assessment...		
			1st	2nd	3rd
Male	No restraint	2	5.00	1.00	0.00
	Fixed	11	3.45	1.55	0.55
	Adjustable	51	2.75	2.06	1.17
Female	No restraint	12	3.42	2.42	1.58
	Fixed	8	2.50	2.25	1.38
	Adjustable	87	3.66	2.62	1.60

Apart from males at the first assessment, fixed head restraints appear to be better than adjustable restraints, but none of the differences was significant. More surprisingly, the "no restraint" cases were not significantly different from the others, either. Since head restraints are more likely to be beneficial in rear impacts, Tables 7 and 8 show the Head Restraint Type data further subdivided by impact direction:

Table 7.
Average Disability by Headrest Type and Impact Direction: Males only

Imp Dir	H/rest Type	Number	Average Disability at Assessment...		
			1st	2nd	3rd
Rear	No restraint	2	**5.00**	1.00	0.00
	Fixed	4	**4.75**	1.25	0.25
	Adjustable	27	**2.59**	1.70	0.78
Not Rear	No restraint	-	-	-	-
	Fixed	7	2.71	1.71	0.71
	Adjustable	24	2.92	2.46	1.67

Table 8.
Average Disability by Headrest Type and Impact Direction: Females only

Imp Dir	H/rest Type	Number	Average Disability at Assessment...		
			1st	2nd	3rd
Rear	No restraint	8	3.00	2.38	1.88
	Fixed	4	2.50	2.25	1.50
	Adjustable	43	3.63	2.58	1.67
Not Rear	No restraint	4	4.25	2.50	1.00
	Fixed	4	2.50	2.25	1.25
	Adjustable	44	3.68	2.66	1.52

In Table 7, adjustable restraints were significantly better than either fixed or no restraints ($p < 0.01$) for males at the first assessment after a rear impact. But every other category of assessment, impact direction and gender in Tables 7 and 8 shows fixed restraints to be better than adjustable, albeit the differences are non-significant. This is also the only category which shows a statistically significant disadvantage in not having a head restraint.

__Analysis by Banded Disability Scores.__ The analysis so far has used average disability scores to test for differences between a number of dichotomous variables (sex, restraint type, impact direction etc). To test for the effect of continuous variables, such as impact speed, seat back height, occupant weight etc, the disability scores were grouped into "low" (score 0-3), "medium" (score 4-6) and "high" (score 7-9) bands, and the average values of the variables under investigation calculated and compared for each disability band. The analysis was carried out on the initial disability scores (first assessment) for the whole sample, then for males and females separately. The whole process was then repeated for the final disability scores (third assessment).

No correlations were found between disability and occupant-related factors, such as height, age, weight, seated height, seat back height or the ratio of seated height to seat back height. Tables 9 and 10 show the data for seat back inclination, equivalent test speed and head restraint horizontal and vertical measurements, for the complete sample at the first and third assessments:

Table 9.
Initial Disability vs Occupant/Vehicle Factors:

	Initial Disability (grouped)						Group Total	
	Low or none		Medium		High		Mean	Valid n
	Mean	Valid n	Mean	Valid n	Mean	Valid n		
S/back angle (degrees)	18.6	98	19.5	52	21.1	9	19.0	159
ETS (km/hr)	19.4	87	19.5	43	24.2	10	19.7	140
H/rest Horiz. Dist.(cm)	9.6	65	9.4	33	9.5	2	9.6	100
H/rest Vert. Dist. (cm)	5.3	65	4.2	33	3.0	2	4.9	100

For the initial disability scores, both seat back inclination and equivalent speed show a monotonic rise through the disability groups, implying that greater values of these parameters are associated with higher disability, though the differences are not significant. For horizontal distance between head and restraint, there is no monotonic trend, while for vertical distance, the trend indicates that lower disability is associated with the restraint being at a greater distance below the ears. This trend is, however, not significant. Splitting the sample into male and female subgroups did not clarify the situation.

Table 10.
Final Disability vs Occupant/Vehicle Factors:

	Final Disability (grouped)						Group Total	
	Low or none		Medium		High		Mean	Valid n
	Mean	Valid n	Mean	Valid n	Mean	Valid n		
S/back angle (degrees)	19.0	143	18.2	15	32.0	1	19.0	159
ETS (km/hr)	19.7	124	20.3	15	16.0	1	19.7	140
H/rest Horiz. Dist.(cm)	**9.9**	92	**5.9**	8	-	0	9.6	100
H/rest Vert. Dist. (cm)	5.0	92	4.1	8	-	0	4.9	100

For the final disability scores (Table 10), seat back angle and equivalent speed are no longer monotonic. Head restraint vertical distance shows a similar trend to that in Table 9, but again, it is not significant. For head restraint horizontal distance, the medium disability group had a significantly smaller mean distance than the low disability group ($p=0.038$). Splitting the sample by gender did not clarify the seat back angle, speed or vertical distance trends. For horizontal distance, the female low and medium disability groups, at 9.5 and 5.4cm respectively, just failed to achieve significance ($p=0.051$), due to the smaller sample size. The male subset showed a similar trend, but with only one case in the medium disability group, the difference was not significant. The direction of the trend for the horizontal distance result, coupled with the fact that these are third assessment scores and there were no significant differences at the first assessment, leads to the conclusion that a large horizontal distance between head and restraint is associated with better recovery from whiplash injury, in contradiction to the results of similar studies conducted elsewhere.

LUMBAR INJURY

Just under half the sample reported lumbar pain continuing for more than a week after the first assessment. The incidence among males was similar to that among females, though males tended to recover slightly more quickly. There was a very slight tendency for rear impacts to carry a higher risk of lumbar injury than non-rear impacts.

The presence of a large proportion of people with lower back strains in the WVS sample could represent a serious complication. The study was based on measuring the overall impairment, or disability, of each patient. In the absence of any clinically observable injuries, this is the only usefully graded variable available which gives a measure of the severity of injury. However, the underlying source of this disability in any individual patient was not known. At the outset, it was assumed that it would be almost entirely due to neck strain injuries, but a lower back injury could also contribute to the overall score, and it would be very difficult to estimate what proportion of disability was caused by each injury.

Factors Influencing the Incidence of Lumbar Injury

Initially, an attempt was made to identify factors which correlated with the incidence of lumbar injury in the WVS sample. The sample was split into those who reported lumbar pain continuing for more than a week after the accident and those who did not. The average values of the "standard set" of vehicle parameters were compared for these two groups, as shown in Table 11:

Table 11.
Incidence of Lumbar Injury:

	Early Lumbar Pain	Number	No Early Lumbar Pain	Number
S/back angle (degrees)	**20.1**	80	**18.0**	79
ETS (km/hr)	20.3	66	19.3	74
H/rest Hor. Dist. (cm)	**10.6**	52	**8.4**	48
H/rest Vert. Dist. (cm)	4.5	52	5.3	48

Seat back angle and horizontal distance to head restraint were found to have a significant effect on the incidence of lumbar injury in this sample ($p=0.032$ and 0.034 respectively), and the trends for these variables were such that the lumbar injury cases were associated with greater seat back inclination and greater horizontal distance from the head restraint compared to the non-lumbar groups. Having said this, it is difficult to see why the distance between head and restraint should have an effect on lower back injuries, when it has no clear effect on the initial severity of the neck strain injuries which the head restraint is supposed to mitigate. One would expect the distance from head to restraint to be correlated to seat back angle and, indeed, it was, although back angle only accounted for 10% of the variation in restraint distance. It may be that this linkage is what is being "discovered" here.

Separation of Lumbar Injury Cases

Because the vehicle factors influencing lumbar injury and whiplash may be different, the sample was separated into those with "pure" whiplash and those who also had lumbar injury. Disability scores were banded, as in Tables 9 and 10 above, and initial disability scores and initial lumbar status were used.

The analysis was carried out for the entire dataset (171 non-leaning forward cases), then repeated for front and rear impacts and for aware/unaware categories (a total of seven selected subsets). The sequence was then repeated for the male and for the female subsets. For conciseness, only those subsets which showed better than 10% significance in one group or the other are presented. These are indicated by italics, while cases showing better than 5% significance are in bold. Seat back angle is measured in degrees, equivalent speed in kilometres per hour and horizontal and vertical head restraint distances in centimetres. Trends in the data are regarded as "sensible" in the discussions if they agree with some reasonable hypotheses. These are that higher disability will be associated with greater seat back angle, higher impact speed, greater horizontal distance between head and restraint and, finally, greater vertical distance of the centre of the head above the centre of the restraint.

Influence of Seat Back Angle In Table 12, trends in the "whiplash only" group were mixed, and none were significant, indicating that seat back angle is not of major importance in pure WAD. In the lumbar groups, several significant results were found, and most of the trends were sensible, particularly for males. Reverse, or counterintuitive, trends were traced to females, and were associated with frontal impacts, and with being aware of impending impact - indeed, the reverse trend was significant for the "Female, Aware, All Impact Directions" group. All trends in the rear impact subset were sensible except for the "Female, Aware" group (non-significant). Seat back angle is thus seen to be important for lumbar injury cases, especially in rear impacts. Awareness of impending impact, which has not been found to influence overall disability outcome, nevertheless has a confounding effect on the seat back angle trends for females with combined lumbar and whiplash injury.

Table 12.
Seat Back Angle:

		Initial Disability Score							
		Whiplash With Lumbar Injury				Whiplash Injury Only			
		0 - 3	4 - 6	7 - 9	p-value	0 - 3	4 - 6	7 - 9	p-value
Full sample, Unaware, All Impact Directions	mean	*18.00*	*21.88*	*25.00*	0.068	17.78	17.00	-	-
	n	15	17	3		18	16	0	
Full sample, Rear Impact, All Awareness	mean	**16.85**	**21.69**	**30.00**	<0.01	18.61	18.65	20.00	-
	n	20	16	1		23	17	1	
Males, All Impact Directions, All Awareness	mean	*18.88*	*23.45*	*20.00*	0.074	17.27	18.33	20.00	-
	n	17	11	1		26	6	1	
Male, Rear Impact, All Awareness	mean	**19.33**	**25.29**	-	0.047	18.15	19.25	20.00	-
	n	6	7	0		13	4	1	
Female, All Impact Directions, Aware	mean	**25.62**	**16.25**	**16.67**	<0.01	19.75	21.86	-	-
	n	8	4	3		16	7	0	
Female, All Impact Directions, Unaware	mean	*17.09*	*19.50*	*27.50*	0.060	18.60	16.25	-	-
	n	11	10	2		10	12	0	
Female, Rear Impact, All Awareness	mean	**15.79**	**19.50**	**30.00**	0.033	19.20	18.46	-	-
	n	14	10	1		10	13	0	
Female, Rear Impact, Unaware	mean	**15.89**	**20.71**	**30.00**	0.047	20.14	15.63	-	-
	n	9	7	1		7	8	0	

Influence of Impact Speed In Table 13, although there were more significant results in the lumbar category, there was no indication that the trend directions were different from the pure whiplash category. Trends generally were mixed. Significant trends in the sensible direction were associated with being aware of the impending impact, particularly for rear impact. Reverse trends were associated with being unaware of the impending impact, again particularly for rear impact. If anything, one would have expected that sensible trends would have been more likely to be associated with being unaware of the impending impact.

Table 13.
Equivalent Test Speed:

		Initial Disability Score							
		Whiplash With Lumbar Injury				Whiplash Injury Only			
		0 - 3	4 - 6	7 - 9	p-value	0 - 3	4 - 6	7 - 9	p-value
Full sample, Aware, All Impact Directions	mean	**16.65**	**15.63**	**31.33**	<0.01	18.52	24.25	28.00	-
	n	17	8	3		25	8	1	
Full sample, Unaware, All Impact Directions	mean	*26.71*	*21.40*	*20.33*	0.093	20.59	17.33	-	-
	n	14	10	3		17	15	0	
Full sample, Unaware, Rear Impact	mean	**27.00**	**21.89**	**21.00**	0.024	20.33	18.82	-	-
	n	12	9	1		12	11	0	
Female, All Impact Directions, Aware	mean	**13.33**	**14.25**	**31.33**	0.036	17.50	23.17	-	-
	n	6	4	3		14	6	0	
Female, Rear Impact, Aware	mean	9.00	10.67	-	-	**11.00**	**24.67**	-	0.014
	n	1	3	0		2	3	0	

Influence of Horizontal Restraint Adjustment In Table 14, two significant (better than 5%) results with sensible trends were obtained, both in the pure whiplash subsets, and both relating to males. The first was in the "All Impact Directions" category, but when this was broken down into front and rear impacts, the frontal impact group remained significant and sensible, whereas the rear impact group showed a reverse trend, which just failed to achieve significance. Generally, in the pure whiplash subset, the horizontal distance trends were counterintuitive for all rear impact categories (male and female), and sensible for all male front impact categories. In the lumbar injury subset, trends were mixed in rear impacts, but males continued to show sensible trends in all frontal categories, with one of these nearly achieving significance. Since head restraints are expected to be most beneficial in rear impacts, these results are difficult to interpret.

Table 14.
Horizontal Distance to Head Restraint:

		Initial Disability Score							
		Whiplash With Lumbar Injury				Whiplash Injury Only			
		0 - 3	4 - 6	7 - 9	p-value	0 - 3	4 - 6	7 - 9	p-value
Full sample, All Awareness, Rear Impact	mean	10.64	12.00	-	-	*11.06*	*6.83*	-	0.063
	n	14	13	0		17	6	0	
Male, Aware, All Impact Directions	mean	9.67	9.33	-	-	**7.17**	**14.00**	-	0.025
	n	9	3	0		12	2	0	
Male, All Awareness, Front Impact	mean	*0.00*	*12.00*	-	0.057	**5.67**	**14.00**	-	0.019
	n	2	2	0		6	2	0	
Male, All Awareness, Rear Impact	mean	12.80	14.20	-	-	*13.10*	*4.00*	-	0.078
	n	5	5	0		10	1	0	

Influence of Vertical Restraint Adjustment In Table 15, no clear pattern emerged between lumbar and non-lumbar categories, and no results were significant at better than 5%. Trends were mostly in the reverse direction, except for the male, non-lumbar category, where two sensible trends approached significance, possibly associated with being aware of the impending impact. However, lumbar injury females generally showed reverse trends, one of which approached significance, associated with being unaware of an impending rear impact. Since head restraints should be most beneficial in rear impacts, it is strange that the only near-significant result relating to rear impact was for a reverse trend.

Table 15.
Vertical Distance to Head Restraint:

		Initial Disability Score							
		Whiplash With Lumbar Injury				Whiplash Injury Only			
		0 - 3	4 - 6	7 - 9	p-value	0 - 3	4 - 6	7 - 9	p-value
Male, All Awareness, All Impact Directions	mean	6.23	5.62	-	-	*7.10*	*11.33*	-	0.066
	n	13	8	0		21	3	0	
Male, Aware, All Impact Directions	mean	6.44	3.67	-	-	*6.75*	*12.00*	-	0.079
	n	9	3	0		12	2	0	
Female, Unaware, Rear Impact	mean	*8.75*	*2.83*	-	0.079	1.80	2.33	-	-
	n	4	6	0		5	3	0	

The Horizontal Distance to Head Restraint Problem:

The only previous study known to have examined in detail a whiplash-injured population from real-world accidents, including medical follow-up and anthropometric measurements of the actual victims sitting in the cars that they were injured in was conducted by Olsson *et al* (1990). However, a major difference between Olsson *et al*'s study and ours is that our study was not limited to one make of vehicle - we had 53 different makes and models of vehicles, with a vast range of masses, structural designs and stiffnesses. Olsson *et al*, concentrating on a single make of vehicle (Volvos) produced a statistically significant result from only 33 subjects indicating that a horizontal distance from head to restraint of greater than

10cm was associated with increased severity of whiplash injury (severity was equated with longevity of symptoms). Their results have been used as a criterion for whiplash injury risk, either explicitly or implicitly, in a large proportion of the literature which has been published since.

In addition to the analysis presented above, strenuous efforts have been made to try to confirm the results obtained by Olsson *et al* regarding this 10cm horizontal distance threshold. Differences between average disability scores at each of the three assessments for the "no restraint" group and for the groups with head to restraint distances less than 10cm and greater than 10cm were sought with the data sub-divided by lumbar status, and taking into account impact direction, awareness of impending impact and gender (22 different subsets), and each of the three assessment scores was tested for each subset. The results may be summarised as follows:

Of 66 comparisons of average disability figures, in only 24 cases was the average disability at small distance to the head restraint less than that at large distance, in agreement with Olsson *et al*. In only <u>one</u> case did the difference between the restraint distance figures even approach significance, and that indicated that small distance was associated with *greater* disability, in contradiction to Olsson *et al*. It is also interesting that absence of a head restraint was only found to have a significant effect in two out of 66 comparisons.

SUMMARY OF FINDINGS

1. The results of this study were characterised by very large scatter, making it very difficult to pick out trends. This was compounded by missing data, due to the fact that it was not always possible to calculate an impact speed for the vehicle, and to the failure to obtain head restraint measurements for some occupants. Nevertheless, the sample available was considerably larger than that in any previous comparable study.
2. No discernible medical differences could be found between those involved in rear impacts compared to other impact directions.
3. The majority of the sample were drivers, and their average vertical restraint distance measurements were at least 30% smaller than those reported from observational studies of the general population. This is surprising, in a sample selected for neck strain injuries.
4. No correlations could be found between disability and seat back height as a proportion of occupant seated height, occupant age, height or weight. The non lumbar-segregated sample also showed no correlation between disability and awareness of impending impact or impact speed.
5. Significant gender differences were found, with men having lower disability than women ($p<0.032$). This is despite the ostensibly more favourable situation of women as regards vertical restraint positioning relative to the head, due to their smaller average stature. Women were not found to be more prone to lumbar injury than men.
6. People who had been actively leaning forward at the time of impact had significantly lower disability scores than the rest ($p<0.01$), and had to be excluded.
7. Comparison of restraint types produced inconsistent results. Adjustable restraints were significantly better than fixed restraints or no restraint for males in rear impacts, at the first assessment ($p<0.01$). However, second and third assessment scores for men, and all scores for women, showed that fixed restraints were (non-significantly) better. In general, very few comparisons showed a significant disadvantage in not having a restraint.
8. Comparison of impact directions also produced inconsistent results. Long-term disability outcome for males was found to be better after a rear impact ($p=0.02$), in contradiction to findings elsewhere, but the larger sample of females did not support this.
9. Horizontal distance from head to restraint had no effect on initial disability scores; a significant, but counter-intuitive (ie greater disability at smaller distance) effect was found for the third assessment scores in the overall sample ($p=0.038$). No significant effect was found for vertical restraint adjustment, though non-significant trends indicated that high restraint position was detrimental.
10. Segregating the sample by lumbar injury status revealed that large seat back angle was significantly associated both with incidence of lumbar injury in this sample ($p=0.032$) and with higher disability for those who suffered lumbar injury, especially in rear impacts ($p<0.01$ for the combined male and female sample), although awareness of the impending impact tended to have a confounding effect for females (reverse trend, $p<0.01$). Seat back angle was not important for non-lumbar cases.
11. Impact speed in the lumbar segregated sample showed inconsistent trends, very few of which were significant. Significant sensible trends (ie higher speed giving higher disability) were associated with being aware of impending impact and with rear impact; significant reverse trends were associated with being unaware of impending rear impact.
12. For horizontal restraint adjustment, sensible trends (ie small distance giving low disability) were found for males in frontal impacts in both pure whiplash ($p=0.019$) and lumbar (non-significant) subsets. The pure whiplash subset consistently showed reverse trends for all rear impact categories, though none were significant. No clear picture emerged as regards vertical adjustment.
13. Despite an exhaustive search of the data, including segregation by gender and lumbar injury status, no evidence could be found to support findings elsewhere that a horizontal distance between head and restraint of 10cm marks the threshold of the onset of long-term disability as a result of neck strain injury. Indeed, most of the trends ran counter to this hypothesis.

Our study did not address the incidence of Whiplash Associated Disorders, only the severity of a whiplash injured population. However, measures found to reduce injury severity normally also have a beneficial effect on incidence. Conversely, if a measure fails to have an influence on severity, its efficacy in relation to incidence must be questioned. We have found it all but impossible to find any benefits in terms of injury severity in the current ideas on how people should be encouraged to use their seats and head restraints. Apart from a few isolated sub-groups, people who conformed to the current received wisdom as regards head restraint adjustment were, at best, not found to be significantly different from those who did not. Frequently, they were found to be worse off. Further, the beneficial effects of "good" head restraint adjustment, where they occurred, tended to be concentrated in frontal impacts, where occupant kinematics make it difficult to see why a head restraint should have any effect at all. Certainly, head restraints were never designed with frontal impacts in mind.

A possible source of error in the results is the head restraint distance measurements themselves. These relied on the memories and good faith of the occupants who demonstrated their seating positions. All demonstrations took place within a few days of the accident, so memory should not have deteriorated. As regards good faith, the victims were all assured that the study was not related to any police or insurance company investigation, so as to encourage them to be as truthful as possible in their responses. There remains the possibility that, due to their injuries, some people were unable to adopt their normal, pre-accident posture, despite valiant efforts. However, to account for our results, there would have to be a trend for injured people to demonstrate a position closer to the restraint than they had adopted pre-accident, and for this trend to be greater for more severe injury. In the final analysis, this study (as did that of Olsson *et al*) had to rely on the truthfulness of the participants.

A further possible criticism is that, when the sample is disaggregated by gender, impact direction etc, some of the more controversial results do depend on significant differences between very small groups. However, while agreeing that statistical significance does not necessarily imply causation, it should be pointed out that significance testing does take sample size into account. It should also be borne in mind that, to make the results of this study non-controversial would require the <u>majority</u> of the trends observed (non-significant as well as significant) to be reversed.

DISCUSSION

If rearward hyperextension is, in fact a mechanism for whiplash injury, then a well-adjusted head restraint should counteract this, and our study should very easily have picked this out. The fact that our results generally did not show any benefit in being close to the restraint (in rear impacts, where hyperextension is most likely) could, of course, be accidental - even statistical significance does not necessarily imply absolute truth. But, while we do not advocate the wholesale removal of head restraints from vehicles, we do believe that something is happening which is not easily explained, and that the situation, and its possible solutions, deserve to be approached with an open mind. Two possible sets of tentative conclusions can be drawn from our study:

i. Rearward hyperextension is not a major factor in the mechanism of whiplash injury
ii. Whatever the real mechanism is, head restraints are not counteracting it, and the whole approach to the problem needs to be reconsidered

Alternatively (bearing in mind the wide range of vehicles in our study):

i. Other factors, such as vehicle mass and structural design (which affect the crash pulse experienced by the occupant) and the design and resilience of the seat back are so important that they completely mask the effects of restraint adjustment
ii. If these other factors are so important, then this implies that the car you drive may be more important than how you adjust your head restraint. The possibility that, given an <u>identical</u> car in an <u>identical</u> accident, a "well-adjusted" head restraint will result in less severe injury than a badly adjusted restraint cannot be excluded on the basis of our results but, if such an effect is present, then it is completely swamped by these other factors. The WAD "epidemic" is thus unlikely to be stemmed until whiplash injuries are taken into account in the design and construction of the vehicle and the seat

These two sets of possibilities are, of course, not mutually exclusive.

The Mechanism of Whiplash Injury

Returning to the problem of the mechanism, this must take account of the fact that whiplash injury can occur in frontal impacts, that it has been found to be associated with seat-belt use (Otte and Rether, 1985, Galasko *et al*, 1993) and that its incidence has increased despite the widespread introduction of head restraints (whether "properly adjusted" or not).

<u>The Frontal Impact Mechanism</u> Von Koch *et al* (1995) proposed that the prime injurious event is the forward flexion of the neck caused, in frontal impacts, by the sudden deceleration of the torso by the seat belt. In rear impacts, modern strong, resilient seat backs can cause the torso to rebound violently, again to be suddenly decelerated by the seat belt. Krafft *et al* (1996) found evidence to support this view. We feel it is possible that the use of head restraints with different force/deflection characteristics from those of the seat back could exacerbate this rebound problem by giving the head a different rebound acceleration from the torso. This effect could be more pronounced if adjustable head restraints with very slim supports are extended to a high vertical position; the opposite effect could result from the use of very springy seat back cushioning combined with dense, energy-absorbent foam in the head restraint. The latter case was considered by Spitzer *et al* (1995).

Rear seat occupants have been found to be at significantly lower risk of sustaining whiplash injury than front seat occupants (Carlsson *et al*, 1985, Lövsund *et al*, 1988), despite the fact that the rear seat occupants in these studies did not have head restraints. There were insufficient rear seat occupants in our study for meaningful comparisons to be made, but we feel that it may be significant that one of the differences between front and rear seats is that rear seat backs are much more rigidly attached to the vehicle. The crash pulse experienced by a rear seat occupant in a rear impact therefore tends to be more severe than that experienced by a front seat occupant in a seat with a resilient back, and head rotation, without a head restraint, is likely to be much greater. The rebound from the rear seat, however, will be much less dramatic.

Frontal Mechanism: Implications for Seat Design Some method of preventing seat rebound therefore seems likely to be desirable. Foret-Bruno *et al* (1991) found that collapse of the seat back in a rear impact generally had a beneficial effect on neck injury outcome, and others have reported similar findings (Muser *et al*, 1994, Walz and Muser, 1995, Parkin *et al*, 1995, Morris and Thomas, 1996). Given that seat back breakage is undesirable in terms of preventing serious injuries in severe rear impacts, Von Koch *et al* (1995) suggest that seats should be designed to undergo controlled plastic deformation in rear impacts, though the presence of rear occupants must also be considered. Another possible solution which has not, as far as we are aware, been proposed in the literature, may be to fire the seat belt pretensioners in a rear impact. This should prevent occupant rebound, though an automatic slow release mechanism may be necessary to prevent the occupant being pinned between a tensioned belt and a tensioned seat back.

The Aldman Mechanism A second alternative mechanism for whiplash injury was proposed by Aldman (1986). In this scenario, the most harmful event occurs early in the motion sequence, when the occupant's head is moving backward relative to the shoulders, and in the very early stages of head rotation. This produces shear forces, especially in the uppermost vertebrae, as the neck distorts into an s-shape, and this can also happen in frontal impacts (Walz and Muser, 1995). The transition from the s-shape to the extension mode involves a sudden change in the volume of the spinal canal, and it has been proposed that the pressure gradients induced by the sudden and rapid flow of blood and spinal fluid along the canal and through the associated transverse vessels can result in damage to the spinal ganglia (Boström *et al*, 1996).

Aldman Mechanism: Implications for Seat Design Prevention of the injury, if this proposed mechanism is sound, would involve limiting head movement relative to the torso to an even greater extent than that required to prevent gross hyperextension. The above proposals for reducing seat rebound by allowing controlled movement of the seat back could be counterproductive here, in that there could be a temptation to design the seat back force/deflection curve to be steeper than that of a conventional resilient seat in the early stages, in order to reduce intrusion into the rear passenger space, or to prevent activation of the plastic elements during normal use. This could result in the force exerted on the torso by the seat back, and hence the acceleration of the torso relative to the head, being higher in the early stages of motion, compared to a resilient seat back. A possible solution would be for the seat back to allow the torso to move backwards relatively unimpeded into the cushioning, so that the head can maintain the same orientation relative to the torso, until the head is in contact with the head restraint. From this point on, the acceleration imparted by the head restraint to the head should be the same as that imparted by the seat back to the torso; soft cushioning on the head restraint would not be compatible with this requirement unless the head is allowed to sink through this before significant acceleration force is applied to the torso. The head restraint must also not flex relative to the seat under loading by the head. The acceleration force, applied uniformly to the head and torso, could probably be quite large, but the corresponding deformation of the seat back must occur plastically, not elastically, so as to prevent rebound at the end of the impact sequence.

Prevention of Lumbar Strain Injuries

The foregoing, it is believed, should provide good protection against whiplash-type neck injuries, but what of the rest of the spinal column, particularly the lumbar region which, like the neck, does not benefit from the bracing effects of the rib-cage structure? It is felt to be likely that, if the shape of the underlying seat back structure, in the sagittal plane, is different from the shape which the spine happens to be in at the moment when the torso meets this unyielding structure, then large forces will be exerted on localised regions of the spine, forcing the spine to flex rapidly until it adopts the shape of the underlying structure. Our finding that lumbar strain injury is correlated with seat back inclination may be explained by such a differential loading mechanism, since it is highly likely that, if the seat back is greatly inclined, then the gap between the shoulders and the seat back will be greater than that between the lumbar area and the seat back. In a rear impact, therefore, the lumbar area will experience localised acceleration forces before the upper back. However, another mechanism which could come into play here may be the stretching of the spine axially. This could come about due to the torso being inclined from the vertical and the likelihood that the pelvis will accelerate much more rapidly than the torso in the horizontal direction due to higher friction between the pelvis/thigh area and the seat.

In frontal impacts, lumbar spine injuries have been shown to be associated with use of lap belts, due to flexion of the torso, while the pelvis is held relatively static (Nahum *et al*, 1968). With a three-point belt, rebound from the belt will result in the occupant impacting the seat back in much the same way as he does in a rear impact and, if the seat back is inclined, he will experience the same localised loading of the lumbar region. This "secondary" contact with the seat back from a frontal impact will be much milder than would be the case in a rear impact of equivalent severity. However, in practice, frontal impacts generally tend to be more severe than rear impacts, so the risk of lumbar strain injury to an individual may be poorly correlated with impact direction. In addition, it is likely that an occupant wearing a three-point belt will acquire some rotational motion relative to the pelvis and thighs in the early stages of the impact, as the unrestrained shoulder moves further forward than its partner. As the occupant rebounds from the belt, this rotation will continue until it is damped out by contact with the seat back. An occupant with a highly inclined seat back is therefore likely to achieve a much greater angular displacement of the shoulders relative to the pelvis/thighs before the rotational motion is curtailed, and this, too, is likely to be bad for the lumbar spine. Thus, regardless of impact direction, a highly inclined seat back may be a predictor of lumbar injury risk, as we found in our study.

The first step in counteracting these lumbar strain injuries, therefore, is to discourage vehicle occupants from adopting excessively "laid back" seating postures. This message may be poorly received by some front seat passengers, but in terms of alertness and ability to control the vehicle a reasonably upright posture in drivers is probably desirable anyway. However, some very tall drivers have to incline their seats to keep their heads clear of the roof, and it is understood that very short drivers are being advised to increase the seat back inclination in order to increase their distance from the driver's airbag, because of the injury risk which these devices pose in low-speed impacts.

The second, and more difficult, step is to improve the anthropomorphic characteristics of the underlying seat back structure. It may be that the range of shapes adopted by real people's backs when seated will preclude the specification of a single preferred shape for the metal seat back frame structure, in which case the problem would have to be addressed by the use of foam structures of progressively increasing stiffness between the "comfort cushioning" and the supporting framework, so as to avoid a situation where localised sections of the spine are, at any one time, in contact with much harder structures than adjacent areas of the back.

CONCLUSIONS

1. We were unable to demonstrate any beneficial effect from being close to the head restraint. Three possible reasons for this have been considered:

   i. Some injury mechanisms are not being addressed by current head restraint designs.
   ii. Variations in vehicle mass and stiffness and seat design, particularly resilience, are so important that they totally mask the effects of restraint adjustment. This leaves open the possibility that, given an identical car in an identical accident, a "well-adjusted" head restraint will result in less severe injury than a badly adjusted restraint.
   iii. It is possible that the results have been influenced by the difficulties experienced by injured people in reliably demonstrating their seating positions.

2. Lumbar strain injuries seem to be associated with seat back inclination. Our thoughts on possible mechanisms and remedies have been presented.

3. There is an urgent need for clarification of the mechanism of these neck and back strain injuries, as well as for the development of good mathematical models of the spine and much more biofidelic dummy spines than are currently available.

4. TRL are currently following up the study here presented with a similar study, concentrating on lumbar strain injuries, and with work on mathematical modelling and dummy spine development.

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