CAUSATIVE FACTORS IN WHIPLASH INJURY: IMPLICATIONS FOR CURRENT SEAT AND HEAD RESTRAINT DESIGN

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ABSTRACT

A sample of 174 road accident victims suffering from Whiplash Associated Disorder were studied over a two year period. The vehicles they had been travelling in were examined to assess the impact severity and, where possible, measurements were made of seat and head restraint adjustment with the subject sitting in the vehicle. Each subject was interviewed to assess the disability resulting from their injuries, and their progress was followed up for twelve months. Women suffered significantly greater disability than men, but there was no correlation with occupant age, height or weight. The benefit of having a head restraint fitted could not be consistently demonstrated. The overall sample also showed no correlation between disability and vertical restraint adjustment, awareness of impending impact or impact speed. Comparison of impact directions produced inconsistent results. Horizontal distance from head to restraint had no effect on initial disability scores but, for long-term outcome, small horizontal distance was significantly associated with higher disability, contrary to the received wisdom. A significant proportion of the sample had suffered lumbar strain injury in addition to whiplash, but segregation of the sample by lumbar injury status failed to give a clearer picture. Seat back angle had a significant effect on the lumbar injury cases, but was not important for non-lumbar cases. It is concluded that variations in restraint, seat and vehicle structural design are likely to have swamped the expected variations due to individual restraint adjustment.

SOFT-TISSUE CERVICAL SPRAIN INJURIES, though generally only classified as 1 on the Abbreviated Injury Scale, have been highlighted as having long-lasting and disabling effects. They are frequently referred to as "whiplash" injuries, due to the rapid flexion-extension motion of the head and neck which is usually taken to be the cause of them. Spitzer *et al* (1995) have proposed the term "Whiplash Associated Disorder" (WAD) for injuries of this type. Hopkin *et al* (1993) showed that over half of all car occupants involved in road traffic accidents had these injuries. Nygren (1984) showed that, despite their low AIS rating, neck strain injuries lead to permanent disability in some 10% of cases. By comparison, the risk of permanent disability associated with other AIS 1 injuries is only about 0.1% (Nygren *et al*, 1985).

Symptoms can include pain in the neck or shoulders, headaches, blurred vision, tinnitus, dizziness and numbness in the upper limbs (Bogduk, 1986), and in some cases these can persist for years (Murray *et al*, 1993).

In a rear impact, involving a rapid flexion-extension motion of the neck, it is the extension phase which is usually taken to be the most injurious. Hence, it has been postulated, and widely accepted, that the provision of a head restraint which will prevent rearward hyperextension of the neck will prevent the occurrence of whiplash injuries. However, it has been widely reported (Maag *et al*, 1990, Foret-Bruno *et al*, 1991, Von Koch *et al*, 1995, Morris and Thomas 1996) that whiplash-type injuries can also occur in frontal and side impacts, where rearward hyperextension of the neck is presumed not to be a major factor, if it occurs at all.

A mechanism for WAD must, therefore, take account of occupant motions in frontal as well as rear impacts. 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. It is felt by the present authors 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.

Aldman (1986), proposed that 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).

Whiplash injuries are characteristic of low speed impacts (Larder *et al*, 1985) - cases have even been reported below 10km/hr (Olsson *et al*, 1990). Women are generally acknowledged to be more at risk than men (Otremski *et al*, 1989).

Lövsund *et al* (1988) have shown that the risk of incurring WAD is higher in rear impacts. However, Morris and Thomas (1996) have shown that frontal impacts actually produce greater absolute numbers of WAD victims because the number of frontal impacts which occur is much greater.

A strong link between car mass and WAD risk has been reported by von Koch *et al* (1995) and by Eichberger *et al* (1996). However, there were also large differences between cars of similar mass, which must be due to differences in car structure and the seats fitted.

WAD risk is associated with seat belt use (Otte and Rether, 1985). Galasko *et al* (1993) found an increase of WAD incidence from 8% to 21% associated with a sudden rise in UK belt wearing rates. However, they also went on to report a continued increase in WAD incidence after that time, up to 54% in 1994 (Galasko *et al*, 1996). Others have confirmed this rise over time (Nygren *et al*, 1985, Ono and Kanno, 1993, Morris and Thomas, 1996).

Rear seat occupants have been found to be at significantly lower risk of sustaining WAD than front seat occupants (Carlsson *et al*, 1985, Lövsund *et al*, 1988).

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 also reported this effect (Muser *et al*, 1994, Walz and Muser, 1995, Parkin *et al*, 1995, Morris and Thomas, 1996). Von Koch *et al* (1995) report work on seat rebound using dummies, and suggest that seats should be designed to undergo controlled plastic deformation in rear impacts, though the presence of rear occupants must also be considered.

The present authors 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, but the rebound effect will be much less dramatic. If rebound is, in fact, a major problem, then a 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.

Head restraint effectiveness was found by Nygren *et al* (1984) to be 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).

Only two studies have been found in the literature involving methods similar to ours - ie prospective studies involving long-term medical follow-up coupled with detailed examination of the damaged vehicle.

Olsson *et al* (1990) studied 33 occupants of Volvo cars who had been involved in rear-end collisions, and followed their progress for twelve months. Head position relative to the restraint was measured with the victims sitting in the vehicles, along with seat back angle before and after collision. Vehicle damage was also measured. Medical assessment was by reference to a specified set of symptoms, and longevity of symptoms was used as a surrogate for injury severity. No correlation was found between impact speed and either the initial spectrum of symptoms or the duration of symptoms. A possible beneficial effect of backrest yielding was observed, but could not be confirmed. However, a significant difference was found between duration of symptoms and whether the occupant's head had been more or less than 10cm from the restraint - a distance greater than 10cm correlated with symptoms lasting at least a year, as opposed to less than a year. Eichberger *et al* (1996), in volunteer sled tests, obtained results tending to support this 10cm threshold, although the results related to the initial onset of symptoms rather than long-term disability.

Ryan *et al* (1994) studied 32 WAD victims, and followed their progress for six months. Vehicles were examined to assess crash severity but seat/head restraint parameters for the occupants were not measured. Injuries were assessed by reference to a number of objective measurements of the range of head movement coupled with subjective ratings of severity from the victim and the medical examiner. Correlations were found between injury severity and both velocity change and maximum vehicle deformation. These correlations improved when rear impact only was considered. Victims who had been aware of the impending impact had significantly better outcomes than those who had been unaware, and awareness was the only factor to show any effect on long-term (6-month) outcome.

METHODOLOGY

The Whiplash/Vehicle Study (WVS) did not address the incidence of neck strain injuries, but examined the injury severity of a sample of WAD victims. 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. The vehicles in which the patients had been travelling were examined by accident investigation specialists.

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). Vehicle damage was assessed by engineers in sufficient detail to allow an estimate to be made of the impact speed. 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.

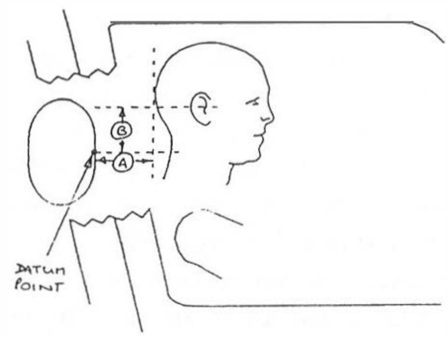

Figure 1. Head to Restraint Distances Measured

Failure to examine a patient's vehicle for any reason resulted in that patient being dropped from the study. A number of patients were unable to attend the vehicle examination, and this reduced the sample available for analyses involving head restraint distance measurements.

All patients had two follow-up interviews, at six months and twelve months after the accident. The final sample available for analysis was 174 subjects. Missing data in some cases reduced this further. 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).

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 AND ANALYSIS

Of the 174 subjects in the final sample, restraint distance measurements were known for 103. 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 were actively leaning forward at the time of impact. They were either turning out of a minor road at a junction and looking to see if it was safe or they were aware of a possible impact and either in the process of turning round to see the vehicle whose tyres were screeching behind them or actively bracing themselves 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.

Generally, the mass and stiffness of the second vehicle in the collision were not available, so the impact damage measured on each vehicle was converted to an "Equivalent Test Speed", related to barrier impacts. Some vehicles had no measurable damage, or were otherwise incapable of being processed, reducing the numbers available for analysis to 143.

COMPARISON WITH THE GENERAL POPULATION: The distribution of occupants within the vehicle and their average restraint distances are shown in Table 1, for male and female front seat occupants whose head restraint distances were known, and are compared to the population averages 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	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. 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 WAD, 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 WVS RESULTS: First, average disabilities were compared for a number of factors that might be expected to influence injury outcome: gender, awareness of impending impact, impact direction and head restraint type. In addition, for those cases in the present study where a head restraint existed, and where the head to restraint horizontal distance was measured, the data have been divided at the threshold suggested by Olsson *et al* (1990), ie 10cm. 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. An Analysis of Variance, using the F ratio, was employed. Significance levels are quoted if they indicate better than 90% confidence; cases exceeding 95% confidence appear in **bold**. The results are displayed in Table 2.

Men were consistently found to have lower average disability scores than women, and the differences were significant for all three assessments (p=0.032 maximum). 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.

Awareness of impending impact was found to result in lower average disability overall, at each assessment, but the differences were not significant. Unfortunately, the average disability of the 27 occupants whose awareness status was unknown was consistently higher than that of either of the other two groups.

Rather higher average disabilities were found for those people whose head to restraint distance was unknown. Measurement of these distances depended on the patient attending the vehicle examination, and a likely reason for non-attendance is that the patient was in too much pain. It is therefore perhaps not surprising that high disability patients should be overrepresented in this group. People who were sitting with their heads more than 10cm

TABLE 2. **Average Disability vs Various Possible Influencing Factors**

Factor	Category	Number	Average Disability at Assessment...		
			1st	2nd	3rd
Sex	Male	64	**2.94**	**1.94**	**1.05**
	Female	107	**3.54**	**2.57**	**1.58**
Awareness	Not known	27	3.48	2.70	1.85
	Aware	72	3.11	2.21	1.26
	Unaware	72	3.46	2.32	1.32
Horizontal Distance to Restraint	h/rest dist<10cm	53	3.08	2.26	1.28
	10≤dist<23	47	2.98	2.21	1.19
	Dist not known	57	3.74	2.53	1.63
Head Restraint Type	None	14	3.64	2.21	1.36
	Fixed	19	3.05	1.84	0.89
	Adjustable	138	3.32	2.41	1.45
Impact Direction	Rear	88	3.28	2.18	1.31
	Not Rear	83	3.35	2.49	1.46

from their restraints (excluding those leaning forward) showed slightly lower average disabilities than those closer than 10cm for all three assessments. Although not statistically significant, this result does not correspond with the findings of Olsson *et al* (1990).

Although fixed restraints produced consistently lower average disabilities than adjustable restraints, the differences were not statistically significant. Perhaps of more interest is that the "no head restraint" cases were not significantly different from the other two either.

Rear impact cases in this sample showed a slight but consistent tendency to have lower average disability than other impact directions, but the differences were not significant.

Each of the groups in this table was also tested for differences in impact speed to see whether this could explain the observed trends. No significant differences were found.

When the sample was separated by gender and each of these factors tested again, awareness of impending impact was not found to be a significant factor in disability outcome, and neither was small or large distance to head restraint. For males, at the first assessment, there was a non-significant trend towards fixed head restraints being less beneficial than adjustable restraints. At the second and third assessments they were (non-significantly) better. For females, the trend towards fixed restraints being more beneficial was maintained, though it was still not significant.

As shown in Table 3, average disability in rear impacts was found to be 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. It is hard to see why, if this effect is real, it is not confirmed by the larger sample of females.

TABLE 3. **Average Disability vs Influencing Factors 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

In addition to the data displayed in Tables 2 and 3, the effects on average disability of seating position, while taking gender into account, have also been explored. Differences in average disabilities between the groups were generally small and the trends were not consistent, either across the three assessments or between the sexes. Other relationships tested have included disability against being more or less than 10cm from the head restraint for the sample subdivided by gender and "banded" impact speed. Again, no clear pattern emerged as to the benefit of being close to the restraint, with inconsistent trends and no significant differences.

The effects of restraint type and impact direction are further explored in Tables 4 (for males) and 5 (for females).

TABLE 4. **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 H/rest	2	**5.00**	1.00	0.00
	Fixed	4	**4.75**	1.25	0.25
	Adj	27	**2.59**	1.70	0.78
Not Rear	No H/rest	-	-	-	-
	Fixed	7	2.71	1.71	0.71
	Adj	24	2.92	2.46	1.67

TABLE 5. **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 H/rest	8	3.00	2.38	1.88
	Fixed	4	2.50	2.25	1.50
	Adj	43	3.63	2.58	1.67
Not Rear	No H/rest	4	4.25	2.50	1.00
	Fixed	4	2.50	2.25	1.25
	Adj	44	3.68	2.66	1.52

In Table 4, 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 4 and 5 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.

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).

As time goes on, the majority of people tend to recover from their injuries and move towards zero disability, or at least into the low disability group. Thus, one would expect to find the most significant differences between groups at the first assessment stage, where the numbers in the higher disability groups are highest. However, analysis of the initial disability scores did not reveal any significant differences between groups, even when the sample was subdivided by gender. Furthermore, the only factor which showed a clear, monotonic progression through the disability groups in all three samples was head restraint vertical distance, and the trend here was in the counterintuitive direction - the closer the centre of the restraint was to ear level, the greater was the disability. Tables 6 and 7 show the final disability figures for the whole sample and for the female subset, respectively.

TABLE 6. **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
Impact Speed (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
S/back height (cm)	57.8	152	56.4	16	58.0	1	57.6	169
H/rest height (cm)	76.4	137	74.6	16	77.0	1	76.2	154
%S/back height:Occ. Seated height	69.6	124	68.5	9	-	0	69.6	133

TABLE 7. **Final Disability vs Occupant/Vehicle Factors (Females Only)**

	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)	19.1	85	18.1	11	32.0	1	19.1	97
Impact Speed (km/hr)	19.4	75	21.8	11	16.0	1	19.7	87
H/rest Horiz. Dist.(cm)	9.5	48	5.4	7	-	0	9.0	55
H/rest Vert. Dist. (cm)	3.2	48	3.7	7	-	0	3.2	55
S/back height (cm)	57.3	92	56.3	12	58.0	1	57.2	105
H/rest height (cm)	76.0	79	73.9	12	77.0	1	75.7	92
%S/back height:Occ. Seated height	70.9	71	69.4	7	-	0	70.8	78

In Table 6, the medium disability group had a significantly smaller mean horizontal restraint distance than the low disability group (p=0.038). The female subset very nearly showed a significant difference between these groups, at p=0.051 (Table 7), but the male subset did not. No other significant differences were found. 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.

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 6 and 7 above, but with the sample split into "lumbar" and "non-lumbar" subsets. The three seat height parameters previously showed almost identical values across the disability groups so they were disregarded. 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 female subsets. To save space, only those male and female subsets where significant (better than 5%) differences were found are presented. 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.

THE MALE SUBSET: In Table 8, sensible horizontal distance to restraint trends were significant for the pure whiplash category (p=0.019), and very nearly significant for the lumbar category (p=0.057).

TABLE 8. **All states of Awareness, Frontal Impact: Males Only**

		Initial Disability Score					
		With Lumbar Injury			No Lumbar Injury		
		0 - 3	4 - 6	7 - 9	0 - 3	4 - 6	7 - 9
Seat Back Angle	mean	18.25	20.50	-	15.63	16.50	-
	n	4	2	0	8	2	0
Equivalent Speed	mean	23.75	13.00	-	27.33	27.50	-
	n	4	2	0	6	2	0
H/rest Hor. Dist.	mean	0.00	12.00	-	**5.67**	**14.00**	-
	n	2	2	0	6	2	0
H/rest Vert. Dist.	mean	4.50	4.50	-	8.00	12.00	-
	n	2	2	0	6	2	0

In Table 9, large seat back angle was significantly associated with high disability for the lumbar injury category (p=0.047). But large horizontal distance for the non-lumbar group was associated with low disability, although this was not significant (p=0.078).

TABLE 9. **All States of Awareness, Rear Impacts Only: Males Only**

		Initial Disability Score					
		With Lumbar Injury			No Lumbar Injury		
		0 - 3	4 - 6	7 - 9	0 - 3	4 - 6	7 - 9
Seat Back Angle	mean	**19.33**	**25.29**	-	18.15	19.25	20.00
	n	6	7	0	13	4	1
Equivalent Speed	mean	18.17	21.00	-	19.23	18.00	28.00
	n	6	4	0	13	4	1
H/rest Hor. Dist.	mean	12.80	14.20	-	13.10	4.00	-
	n	5	5	0	10	1	0
H/rest Vert. Dist.	mean	5.20	6.80	-	8.00	10.00	-
	n	5	5	0	10	1	0

THE FEMALE SUBSET: In Table 10, in the lumbar injury category, the average seat back angle of the low disability group was significantly higher than the other two ($p<0.01$). Several non-significant trends for females went counter-intuitively for seat back angle, and this seemed to be associated with being aware of the impending impact. Estimated speed for the high disability group was significantly higher than that of the other two ($p=0.036$).

TABLE 10. **Aware of Impending Impact, All Impact Directions: Females Only**

		Initial Disability Score					
		With Lumbar Injury			No Lumbar Injury		
		0 - 3	4 - 6	7 - 9	0 - 3	4 - 6	7 - 9
Seat Back Angle	mean	**25.62**	**16.25**	**16.67**	19.75	21.86	-
	n	8	4	3	16	7	0
Equivalent Speed	mean	**13.33**	**14.25**	**31.33**	17.50	23.17	-
	n	6	4	3	14	6	0
H/rest Hor. Dist.	mean	10.71	8.33	-	9.33	4.50	-
	n	7	3	0	6	4	0
H/rest Vert. Dist.	mean	3.14	1.67	-	3.50	3.25	-
	n	7	3	0	6	4	0

TABLE 11. **All States of Awareness, Rear Impacts: Females Only**

		Initial Disability Score					
		With Lumbar Injury			No Lumbar Injury		
		0 - 3	4 - 6	7 - 9	0 - 3	4 - 6	7 - 9
Seat Back Angle	mean	**15.79**	**19.50**	**30.00**	19.20	18.46	-
	n	14	10	1	10	13	0
Equivalent Speed	mean	24.38	18.33	21.00	16.77	21.18	14.00
	n	13	9	1	13	11	1
H/rest Hor. Dist.	mean	9.44	10.63	-	8.14	7.40	-
	n	9	8	0	7	5	0
H/rest Vert. Dist.	mean	5.78	3.00	-	3.00	2.80	-
	n	9	8	0	7	5	0

Here, for the lumbar injury category, the seat back angle for the high disability group was significantly higher than for the other two, although there was only one case in this group (p=0.033). The trend was in the "right", or sensible direction.

In Table 12, for the non-lumbar category, higher impact speed was significantly associated with higher disability (p=0.014).

TABLE 12. **Aware of Impending Impact, Rear Impact: Females Only**

		Initial Disability Score					
		With Lumbar Injury			No Lumbar Injury		
		0 - 3	4 - 6	7 - 9	0 - 3	4 - 6	7 - 9
Seat Back Angle	mean	20.00	16.67	-	20.50	22.50	-
	n	2	3	0	2	4	0
Equivalent Speed	mean	9.00	10.67	-	**11.00**	**24.67**	-
	n	1	3	0	2	3	0
H/rest Hor. Dist.	mean	10.50	8.50	-	9.00	7.50	-
	n	2	2	0	2	2	0
H/rest Vert. Dist.	mean	3.00	3.50	-	6.00	3.50	-
	n	2	2	0	2	2	0

TABLE 13. **Unaware of Impending Impact, Rear Impact: Females Only**

		Initial Disability Score					
		With Lumbar Injury			No Lumbar Injury		
		0 - 3	4 - 6	7 - 9	0 - 3	4 - 6	7 - 9
Seat Back Angle	mean	**15.89**	**20.71**	**30.00**	20.14	15.63	-
	n	9	7	1	7	8	0
Equivalent Speed	mean	28.44	22.60	21.00	18.75	19.29	-
	n	9	5	1	8	7	0
H/rest Hor. Dist.	mean	12.00	11.33	-	7.80	7.33	-
	n	4	6	0	5	3	0
H/rest Vert. Dist.	mean	8.75	2.83	-	1.80	2.33	-
	n	4	6	0	5	3	0

In Table 13, seat back angle was shown to be important for the lumbar injury category, although it was the single case at 30° which was significantly different from the others (p=0.047). Vertical distance to restraint for the lumbar group approached significance (p=0.079), but the trend was in the "wrong" direction.

SUMMARY FOR SEGREGATED LUMBAR INJURY CATEGORIES:

Seat back angle: Trends in the non-lumbar category were mixed, and none were significant, indicating that seat back angle is not of major importance in pure WAD cases. In the lumbar categories, several significant results were found in the overall (not shown), male and female subsets (Tables 9, 11, 13), and most of the trends were sensible, particularly for males. Reverse 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 (Table 10). All trends in the rear impact subset were sensible except for the "Female, Aware" group (Table 12).

Seat back angle is thus confirmed to be important for lumbar injury cases, especially in rear impacts. Awareness of impending impact, which has not been found to influence disability outcome, nevertheless has a confounding effect on the seat back angle trends for females.

Equivalent test speed: No clear difference emerged between the lumbar and non-lumbar categories, and trends were generally mixed. Significant trends in the "right" direction were associated with being aware of the impending impact, particularly for rear impact (Tables 10, 12). Reverse trends were associated with being unaware of the impending impact, again particularly for rear impact. One of these was significant, and one more approached significance (overall dataset, not shown).

Horizontal distance to head restraint: Two significant 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 (not shown), but when this was broken down into front and rear impacts, the frontal impact group remained significant and sensible (Table 8), while the rear impact group showed a reverse trend, which just failed to achieve significance (Table 9). Generally, in the pure whiplash subset, the horizontal distance trends were counterintuitive for all rear impact categories, 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.

Vertical distance to head restraint: No clear pattern emerged between lumbar and non-lumbar categories, and there were no significant results. Trends were mostly in the reverse direction, except for the male, non-lumbar category, where two sensible trends approached significance, mainly associated with being aware of the impending impact (not shown). However, lumbar injury females generally showed reverse trends, one of which approached significance, associated with being unaware of an impending rear impact (Table 13). 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.

THE HORIZONTAL DISTANCE TO HEAD RESTRAINT PROBLEM: In addition to the above analysis in terms of banded disability groups, strenuous efforts have been made to try to confirm the results obtained by Olsson *et al* (1990) regarding the 10cm horizontal distance threshold for the onset of long-term disability. 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* (1990). In only one 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.

CONCLUSIONS

The well-documented increasing incidence of neck strain injuries shows that current seat and head restraint designs are failing to have the desired effect in reduction of WAD incidence, and the conventional wisdom holds that this is, to a large extent, due to incorrect use of those items by vehicle occupants. Our study did not address WAD incidence, 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. 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. However, in the final analysis, one has no alternative but to take the word of the occupant at face value.

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 majority of the trends observed (non-significant as well as significant) to be reversed.

The findings of the study may be summarised as follows:

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 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.

The failure of this study to support the findings of Olsson *et al* (1990) and Eichberger *et al* (1996) regarding restraint adjustment deserves a closer examination. The former chose a sample which consisted entirely of Volvos which had been involved in rear impacts. The vehicles were therefore all of similar construction, with similar seats and all had fixed head restraints. The latter study was conducted under laboratory conditions, using specific vehicle seats in controlled sled (rear) impact tests. The WVS study covered 53 different makes and models of vehicles, ranging from a Zastava Yugo to a Mercedes 260 to a Porsche 944, and included front and side, as well as rear impacts (although the data allowed disaggregation by impact direction). The variation in seat and head restraint design, vehicle mass and vehicle structural design was therefore huge. It was not possible to segregate the data on the basis of vehicle type, as these other studies were able to do, since this would have led to very small groups (the most common vehicle in the WVS study was the Ford Fiesta, and there were only 29 of these, 17 of which were involved in rear impacts).

If head restraints are, in fact, beneficial then, even in the absence of significant results confirming this in a study such as ours, one would expect to find the majority of non-significant trends in the "right" direction. This was not the case in this study and, if our results are taken at face value then, as far as rear impact is concerned, one would have to recommend the removal of all head restraints from vehicles, or at least that they should be adjusted to be as far from the head as possible. The only way our results can be reconciled with the intuitive notion that head restraints must be beneficial is if variations in seat and head restraint design and in the crash pulse experienced by the occupants, which is determined by vehicle mass and structural design, were of such a magnitude as to have almost completely swamped the expected relationships between disability and restraint adjustment. Seat and vehicle design thus emerge as being of prime importance in reducing the whiplash "epidemic", rather than simply blaming the occupants of vehicles for not adjusting their restraints properly.

In particular, it is felt that rebound from the seat, and possibly differential rebound between the head and the torso caused by a mismatch between the force/deflection characteristics of the seat and the head restraint should be investigated further. Possible design modifications which could be investigated include the provision of plastic deformable elements in the seat back, or even allowing the whole seat to move backwards (to a limited extent) against an energy absorbing medium. The firing of belt pretensioners in rear impacts is also felt to be worth investigating. This would be more compatible with rear seat occupants than allowing the seat to move, but the belt would probably need to have a time-delayed tension release mechanism built in to avoid the likelihood of extreme discomfort, and possibly even (in an extreme case) suffocation of the occupant trapped between belt and seat back.

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