SOFT TISSUE INJURY OF THE CERVICAL SPINE IN REAR-END AND FRONTAL CAR COLLISIONS.

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ABSTRACT

Medical impairment associated with trauma to the neck is an increasing problem all over the world. In Sweden, neck injury AIS 1 resulting from traffic accidents has become the most common injury that causes medical impairment due to traffic accident. The injury as well as the injury mechanism are in many ways unknown. Preliminary studies indicate that the symptoms seem to be the same whether the car impact is a rear-end or frontal.

In the present study, real life data from insurance documentation and police records of accidents, as well as laboratory crash tests, were used. Insurance data on persons who sustained medical impairment from a neck injury AIS 1 and the correlation between the impairment and the impact direction of the car were investigated. The same data was used to analyze the structural damage of the car. Also, laboratory tests of dummy movements were analyzed. The paired comparison method was used to evaluate the influence of vehicle weight and car model as well as the age and sex of the occupants.
The laboratory crash tests indicated that similar body movements may occur in rear-end and frontal impacts. Also the acceleration pulse seem to have an influence on the occurence of neck injuries in rear-end collisions.

SOFT TISSUE INJURIES to the cervical spine (neck injuries AIS 1) , often called whiplash injuries, is an increasing problem. A Swedish study shows that the number of neck injuries AIS 1 with permanent disability has increased dramatically since the mid-seventies. These injuries account for almost 50% of all traffic injuries with long-term consequences (v Koch et al 1994).The problem has increased in other countries as well, especially after the enforcement of seat belt laws (Cameron, 1981; Thomas, 1990). The use of seat belt as a factor that increases the risk of acute neck sprain has been specifically mentioned by several authors (Krafft et al, 1989; Otremski et al, 1989; Larder et al, 1985). It has also been shown that there is an increased risk of soft tissue injury in a car model with four doors compared to the same car model with two doors, in rear-end collisions.The seat belt and the seat belt geometry is the only factor that is different between a two door and four door model (v Koch et al 1995).

The protective benefits of the head-restraints are small, typically 20% (O´Neill et al 1972; Nygren et al 1985). Also, the elastic rebound of the backrest in the front seat can aggravate the violence of the whiplash-motion and delay the contact between the head and the headrest (Svensson et al 1993).

Several authors have reported a considerably smaller risk of neck-injury AIS 1 in the rear-seat compared to the front seat for adult car occupants (States et al 1972; Carlsson et al 1985; Lövsund et al 1988). Also, neck injuries AIS1 have been reported to occur more frequently among females than males (Otremski et al 1989; Maag et al 1993; Schutt et al 1968).

Studies on the risk of sustaining a neck injury AIS 1, rarely distinguish between rear-end and frontal collisions.While the symptoms seem to be similar in different crash directions (Jónsson et al 1994), has yet to be documented.

The aim of this study was to:

- study the relationship between vehicle weightand the risk of neck injuries AIS 1
- study the differences in neck injury risk, AIS 1, between sexes
- study the differences of neck injury risk AIS 1, in the struck and striking car
- study the rebound effect of some different seat backs.

MATERIALS AND METHODS

The material can be divided in three parts: police records of accidents, insurance data and laboratory tests of car seats.

I. POLICE RECORDS- The neck injury risk, AIS 1, was calculated from matched accidents (Hägg et al 1992). The accidents were reported to the National Bureau of Statistics (SCB) in Sweden by the police during 1985-93. The injuries were classified as minor, severe or fatal. Of these reports, 8,049 accidents involving rear-end impacts can be identified where at least one driver was injured. Only minor injuries were selected, but, however, the specific injuries are not known. Based on earlier facts (v Koch, 1994; Larder, 1985; Nygren, 1984), almost all injuries classified as minor occurring in rear-end accidents are soft tissue neck injuries.

In order to normalize for exposure, the paired comparison method was used in analyzing the number of occupants of risk and the severity of the accident. The method was orginally used by Evans (1991) for occupants in one vehicle, but has been developed by Folksam for occupants in two vehicles. The method is known to give adequate consideration for variables in accident severity and was used in this study to analyze the influence of age, sex, car weight and car model. The method is based on the fact that the injury risk is a continuing function of accident severity.

In the paired comparison method, the numbers of injuries in the struck and the striking car were compared. Ideally, if the risk of injury was the same in both vehicles, the ratio of injuries is one-to-one, while any deviation from that ratio indicates a difference in risk.

II. INSURANCE DATA - The insurance data was used to analyse the correlation between impairment to the neck (AIS 1) and the impact direction. Also, the structural damage of the car was analyzed from photos. In Sweden, all injured traffic victims who sustain a disability are judged by medical specialists, according to a national impairment scale. Normally the degree of medical impairment is not permanently decided until three to five years after the accident. A preliminary degree is allocated about one year after the accident. This impairment scale is between 1% to 100% for each injury. The techniques used in determining the impairment degree have been described in more detail in another paper (v Koch et al 1994).
In this study, 113 persons diagnosed with a neck injury AIS 1 and who sustained a medical impairment , 10% or more, were analyzed by using information collected during claims settlement conducted between 1992 and1993 from all accidents in the area of Stockholm.

III. LABORATORY TESTS WITH FRONT SEATS - To determine if a rear-end collision generates any noticeable rebound velocity, laboratory tests were performed. The elastic properties of six seat backs were studied in a static test. Dynamic rebound velocity tests were also performed. All of the seats tested were front seats. The seats were all produced between 1987 and 1994.

In the static test the seat back was pulled back using a winch. The force was applied at both the top of the seat and approximately perpendicular to the seat back, the corresponding deflection was measured. The seat backs were pulled until they broke. In all, six different seats of different makes and models were tested.

The dynamic testing of the seats were performed on a sled.The sled was moving backwards in speeds ranging from about 15 km/h to about 35 km/h into a barrier. The stopping distance was typically 15-20 cm. A dummy (Hybrid II) was sitting in the seat. The rebound speed was measured using flashing light emitting diodes and video cameras (Ingemarsson 1992). The diodes were placed on the shoulder and on the head of the dummy. Since the head of the Hybrid II dummy is firmly fixed to the torso no major difference in rebound velocity was found when the two observation points were studied. For this reason only data from the shoulder point is used. The biofidelity in the head and torso movement of the Hybrid II dummy is low in this test type. In order to study rebound velocity the test set-up was essential. Both the pre-crash and rebound velocity of the dummy were measured. The relative rebound velocity was calculated as the quota between the pre-crash velocity towards the barrier and the maximum post-crash velocity of the dummy. In all ten seats of six models were tested. Since some of the seats collapsed during tests, giving no rebound velocity, measurements are presented for six tests.

RESULTS

I. POLICE RECORDS - RESULTS. In table 1, the relative risk of injury in the struck car in relation to the striking car is shown for different weight combinations in rear-end collisions. For cars of the same weight, the relative risk is up to twice as high in the struck car compared to the striking car. The same relative risk is reached when the striking car weighs on average 200 kg less than the struck car, indicating a change of velocity that is 15-20% higher in the striking car than the struck car. It is important to note that the injuries in the struck car almost always are soft tissue neck injuries, while there is a variety of injuries in the striking car. The injuries in the police reported accidents are only coded as minor injuries, the diagnoses are not known. The relative risk of neck injuries AIS 1 is, therefore, even more skewed than indicated by the figures presented in table 1. In the worst combinations, the relative risk is at least 4.2 times higher in the struck in relation to the striking car.

Table 1. The relative risk of injury to drivers in the struck car in relation to the striking car in rear-end collision.

	Striking car					
Struck car	900 kg (n)	1000 kg (n)	1100 kg (n)	1200 kg (n)	1300 kg (n)	1400 kg (n)
900 kg	1.46 (53)	1.37 (88)	2.50 (66)	4.00 (62)	4.16 (144)	3.13 (54)
1000 kg	1.43 (71)	1.61 (128)	2.37 (90)	3.03 (115)	4.17 (220)	3.21 (107)
1100 kg	1.09 (54)	1.27 (80)	1.83 (58)	2.20 (57)	2.54 (121)	3.37 (74)
1200 kg	0.83 (63)	1.02 (84)	2.27 (89)	2.32 (63)	2.25 (154)	2.44 (76)
1300 kg	0.90 (105)	1.03 (182)	1.09 (116)	1.30 (132)	1.51 (262)	2.02 (159)
1400 kg	0.60 (62)	1.05 (103)	0.98 (78)	1.59 (76)	1.48 (138)	1.81 (88)

n=number of rear-end collisions.

In table 2 the relative number of injuries in cars of different size, divided by sex is shown. The results show that for cars of given size the risk of injury is higher for females.

Table 2. The relative risk of injury for drivers, in rear-end collision, distuingished by sex.

Struck car	Striking car 900 kg (n)	1000 kg (n)	1100 kg (n)	1200kg (n)	1300 kg (n)	1400kg (n)
1300 kg men	0.63 (67)	0.89 (141)	1.00 (89)	1.09 (103)	1.37 (196)	1.88 (118)
1300 kg women	1.70 (37)	1.78 (38)	1.38 (26)	2.67 (29)	2.43 (61)	2.69 (40)

n=number of rear-end collisions.

In figure 1, the relative risk of injury in different car models is given in rear-end collisions. It can be seen that there are large differences between car models, even if they are in the same weight range. Among the largest cars, the differences are of the magnitude 1 to 1.5 (50% higher risk in the worst cars), while among smaller cars, the range is broader. The results indicate, that not only the weight of the car (that is, change of velocity), but also the construction of the car is of importance.

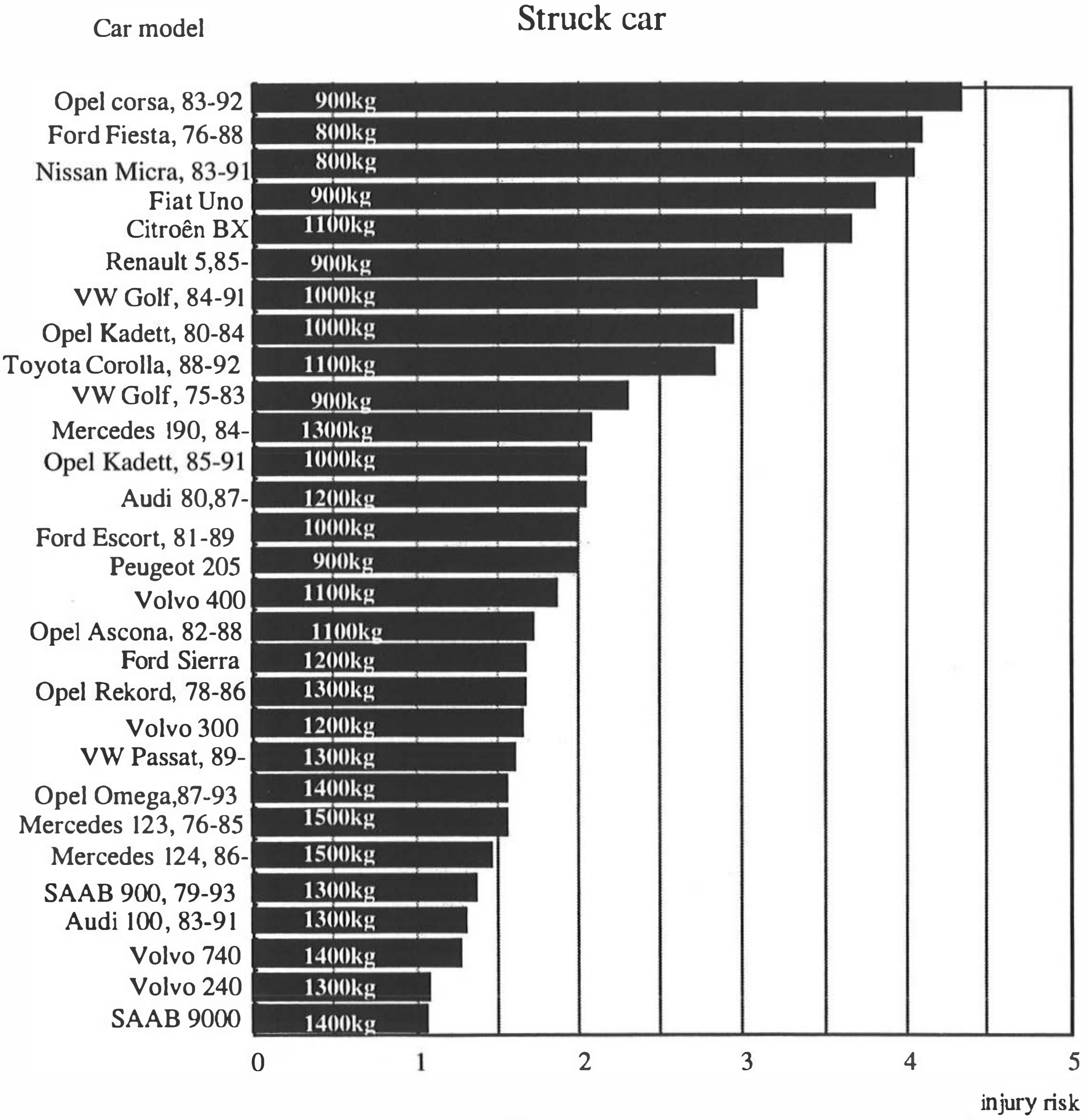

Figure 1. The relative risk of injury for different car models, in rear-end collisions, in the struck car.

In figure 2, the risk of causing an injury in an average car, struck by a specific car model, is shown. The paired comparison ratio between the striking and the struck car was normalized for the influence of the passive safety of the striking car, as well as the weight of the striking car. This was done by using the overall paired comparison ratio for all accident types. The figures used are therefore ideally only influenced by the construction and behaviour of the striking car, on the struck car. It is clearly shown that even among cars of identical weight, there is an important difference in the relative risk of injury. The result indicates that the construction of the striking car is also of importance.

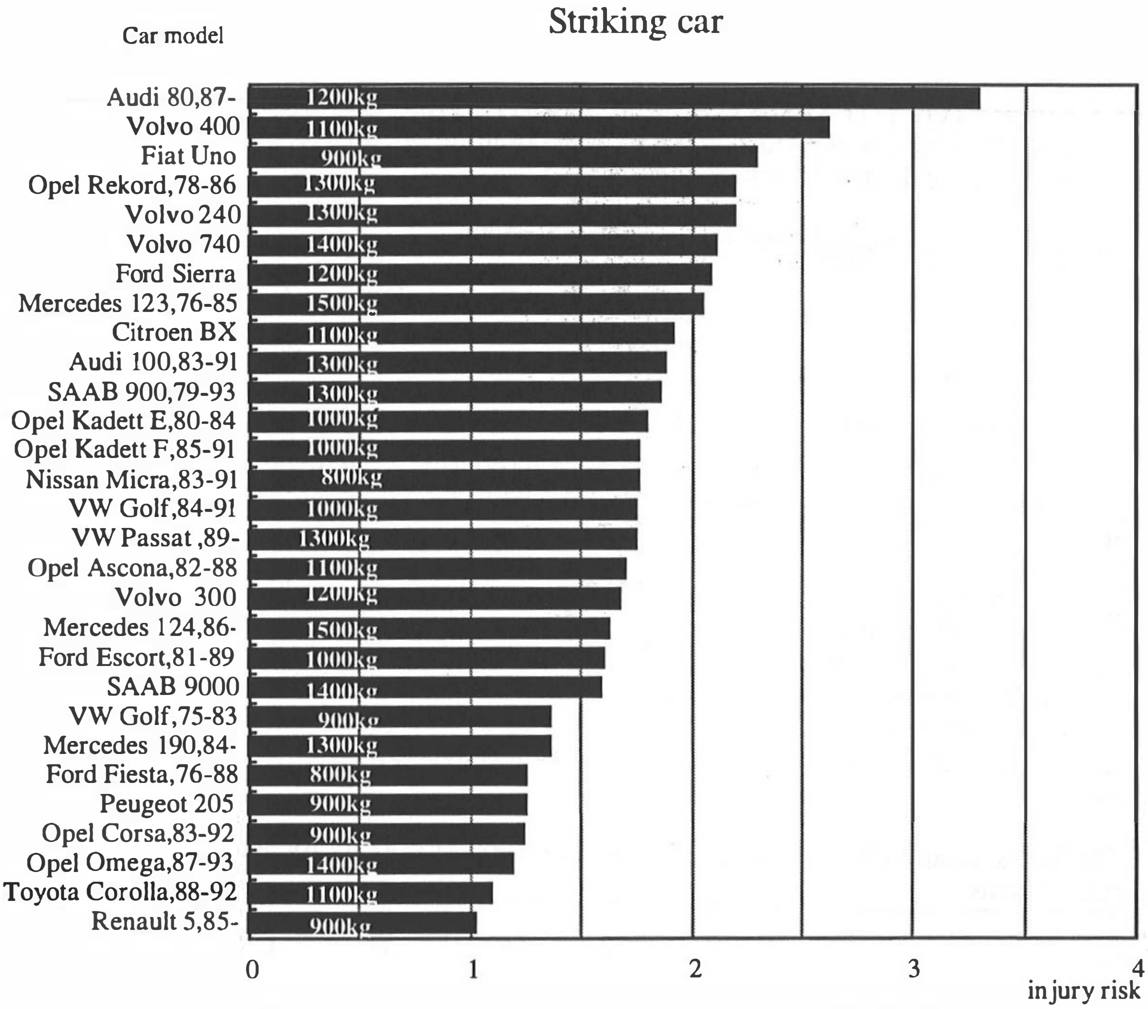

Figure 2. The risk of causing an injury in an average car, rear-end collision, by a specific car model (striking car).

II. INSURANCE DATA - RESULTS. When comparing the photos of the cars that were involved in an accident where at least one occupant in the car sustained an impairment (symptoms at least 1 year after the accident) from a soft tissue neck injury, generally, there were larger deformations in the frontal collisions compared to the rear-end impacts (see appendix). Table 3 shows the percentage of accidents resulting in impairments to the neck AIS 1 in different crash directions. Of the impairments to the neck, rear-end collisions were the most common direction at 64%, however, 23% occurred in frontal collisons.

Table 3. The relationship between persons that sustained an impairment to the neck, AIS 1, and the direction of the impact.

N=113

	N	%
Rear-end collision	72	63.7
Frontal collision	26	23.0
Side impact	10	8.8
Rollover	3	2.6
Unknown	2	1.8

III. LABORATORY TESTS WITH FRONT SEATS - RESULTS. Table 4 shows the stiffness coefficients, expressed as force to deflection, for six different seats. The coefficients were calculated from static tests.

Table 4. The stiffness coefficient for six different seats.

Seat	A	B	C	D	E	F
Stiffness coefficient (Nm/degree)	80	98	200	233	114	272

The stiffness coefficients had a large variation (80 to 272 Nm/degree). The stiffness coefficient varied with a factor of almost 1 to 3.5 between the weakest and the most rigid seat.

Table 5 shows the maximum relative rebound velocity for six different seats in six different tests. The maximum rebound velocity occurred, at approximately the same location for all seats, when the torso passed the pre-crash location and was leaving the seat back. The variation in relative rebound velocity is considerable between the different tests. It can also be foreseen that the relative rebound velocity will vary for the same seat if tested with different crash pulses (change of velocity, stopping distance, shape of the pulse etc.)

Table 5. The relation between impact speed and rebound velocity for six different seats.

Seat	A	B	C	D	E	F
Relative rebound velocity	0.80	0.85	0.85	1.10	0.90	1.30
Test speed (km/h)	17.6	15.3	19.1	16.8	18.4	20.1

In the tests the relative rebound velocity varied from 0.8 to 1.3. The tests show that a dummy can achieve a considerable higher speed out of the seat during a rear-end collision. In these tests the speed of the torso out of the seat back varied from 13km/h to 26km/h. By comparing the static and dynamic tests a certain correlation was found between the seat back stiffness and the relative rebound velocity.

DISCUSSION

Neck injuries (AIS 1) have been found to constitute a major problem in road traffic. Although this injury has been known for many years, there is no universally accepted explanation neither the mechanism nor the injury. The injury is often considered to be associated with rear-end collisions, however, as much as one quarter of the injuries are attributable to frontal impacts. It is also known, that neck injuries (AIS 1) have increased together with an increased seat belt use, though it is not known if this is associated with only frontal impacts or also with rear-end collisions.

The striking conclusion of earlier research is that the accident severity is so low, typically said to be in the region of less than 10 km/h to 20 km/h change of velocity (Kahane, 1982; Romilly et al 1989; Olsson et al 1990). In this study, it is found that the risks for injury are higher where there is a significant weight difference between the striking and the struck car, which could give us an idea that the lower limit given for where the injuries start to occur (10 km/h) can be too low. The elastic properties of cars in these low regions of impact severity might also produce a higher change of velocity than what has been previously anticipated (Romilly et al 1989). We are still left with the fact that the risk of an injury to the neck is far higher for a given change of velocity in the struck car than in the striking car (rear-end collision). In this paper, it is also found that the configuration of the striking car has an influence on the risk of injury in the struck car. The difference is probably because the crash pulse (acceleration time history) has some influence on the risk of a neck injury, and not simply due to the change of velocity.

In other writings on this subject, several possible injuries and injury mechanisms are said to be related to the symptoms called soft tissue neck injuries. Most of them are related to hyperextension, either in the rotation of the head over the seat back, or in the sequence where the torso is accelerated forward by the seat back. Other theories, related to the pressure in the spinal canal,or ramping effects, have been presented (Svensson et al 1989). The same symptoms seem to be found in both front and rear-end impacts (Jónsson et al 1994), but not with a common mechanism. It seems to be a more realistic question to pose, what kind of mechanism is present in both frontal and rear-end impacts, rather than to suggest that two different mechanisms lead to the same injury.
One such mechanism might be flexion of the head during the frontal movement of the occupant. This might be the mechanism in the frontal impact, and a possible mechanism for a flexion of the head in the rebound of a rear-end impact. Further research is necessary in order to accept or reject the hypothesis that neck injuries in rear-end impacts are mainly caused by rebound into the seat belt. Such research should focus on both empirical studies on neck injuries and seat belt use and also relation between neck injuries and the crash severity.

Several factors are involved conceming the rebounding velocity of an occupant in a rear-end impact: the stiffness of the seat back, the remaining deflexion of the seat back after the impact, the length of the crash pulse, the shape of the crash pulse, the weight and length of the occupant and the change of velocity. The tests of the stiffness of seat backs showed that the stiffness coefficient in some instances may vary at least by a factor of three times between different seat constructions.
When studying the results from table 4 and 5, a relation between stiffness of the seatback and rebound velocity can be seen. Some of the tested seats showed a remaining deflexion which means that energy had been absorbed by the seat. The remaining deflexion decreases the rebounding velocity. Seat "C" is an example of such a seat.
The measurements of the rebound velocity showed that it actually is possible to have a higher rebounding velocity than the impact velocity. That is possible if a combination of seat structure and crash pulse is fulfilled. The seat may load a certain amount of energy in a rear-end impact during the time of the crash pulse. When the impact is over, the seat back may rebound the occupant in a higher velocity than the impact velocity, since the seat back, depending on its stiffness, may in shorter time than the crash pulse was acting, push the occupant forward again. The possibility to release the loaded energy also depends of the shape and length of the crash pulse. The highest rebound velocity occurs if the seat back starts to push the occupant forward when the pulse is over. If the pulse is not over, the shape of the end of the pulse is influencing the rebound velocity.

For seat "F", several tests were performed at different velocities and with different stopping distances. These tests showed that the maximum rebound velocity occurs just before the seat back starts to collapse or starts to show signs of a permanent deflexion. The dummy used (Hybrid II) is not suitable for studying the kinematics and injury criteria for this type of test. Since the only factor that was investigated was the rebound velocity, it is not considered important.

This paper is presented in order to raise a hypothesis, that soft tissue neck injuries are a result of a common mechanism in both frontal and rear-end impacts, and that the use of seat belt is the decisive factor in both situations. The explanation for the large number of neck injuries AIS1 in rear-end impacts is that the impact severity is higher than what could be expected from only the change of velocity. The rebound velocity of the occupant in a rear-end impact may be up to 30% higher than the velocity to the vehicle. This leaves us with a corresponding frontal impact that is much more severe than could be expected from the initial accident severity. The seat-back is effectively acting as a spring which increases the velocity of the occupant significantly beyond the velocity of the striking car. The other circumstances that are different in the rear-end induced rebound and as opposed to a frontal impact that may result in a more severe neck injury. For example, the seat belt should act more stiff, as there are no forces acting on the vehicle from the frontal direction when the occupant rebounds into the seat belt. Also, the head might be in a more extended mode when the torso is stopped by the seat-belt compared to a frontal collision. Furthermore the stopping distance of the occupant is shorter than in a frontal collision, resulting in a more severe situation.

In summary, this paper suggests that the injury mechanism behind neck injuries both in frontal and rear-end impacts could be considered as a *frontal mechanism* for the occupant, where the relevant question is whether the impact from this perspective is a severe one or not. The following suggests that it is more likely that a severe one in the rear-end impact:

- The change of velocity for the struck car is probably higher than has been mentioned in earlier published literature.
- The forward rebound velocity for the occupant may be higher than the velocity of the car.
- The torso of the occupant, when rebounding, is exposed to a large slack in the seat belt.
- The stopping distance of the occupant in the rebounding forward movement is extremely small in a rear-end collision.

There might be several solutions to the problem, such as designing seats that are not elastic, to avoid the spring effect of the seat in the rebound, in a rear-end impact. Further study is required in order to overcome the problems associated with soft tissue injuries.

CONCLUSIONS

* The weight of the car, both struck and striking, is of importance of the occurrence of neck injuries in rear-end impacts.

* The construction of the striking car is of importance of the occurrence of neck injuries (AIS 1) in rear-end impacts.

* For cars of a given size the risk of neckinjury (AIS1) is higher for females.

* The rebound velocity of the occupant in a rear-end impact may be higher than the velocity to the vehicle.

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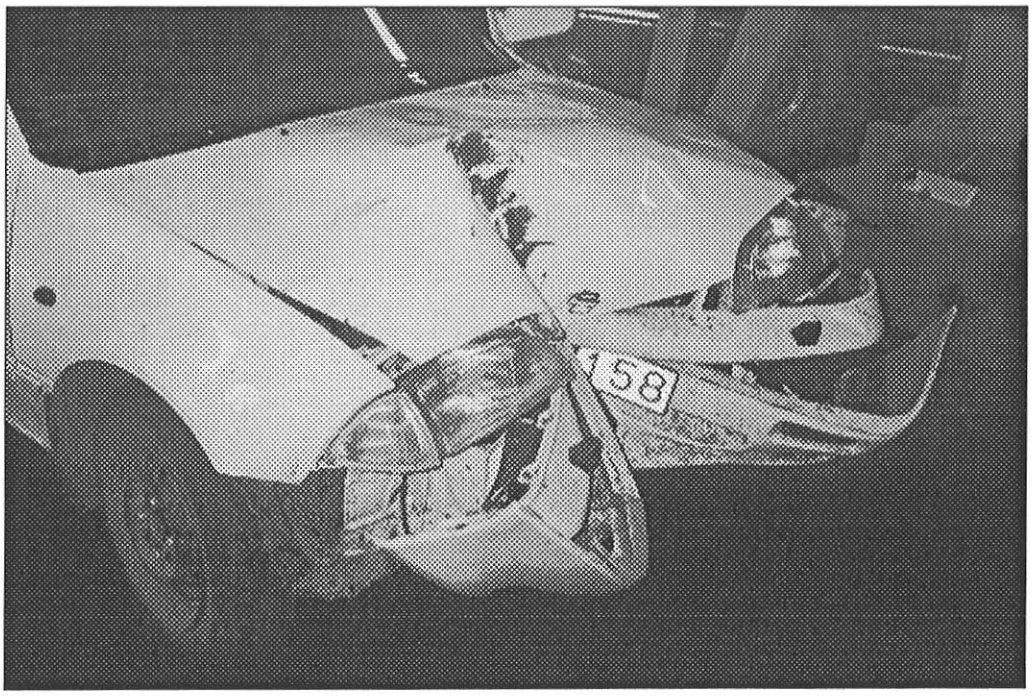
APPENDIX

A common deformation of a rear-end impact where the occupant/ occupants sustain an impairment to the neck AIS 1.



A common deformation of a frontal impact where the occupant/ occupants sustain an impairment to the neck AIS 1.