A COMPARISON OF SHORT- AND LONG-TERM CONSEQUENCES OF AIS 1 NECK INJURIES, IN REAR IMPACTS.

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ABSTRACT

Despite a good prognosis for individual victims, AIS 1 neck injuries causing long-term consequences are the most common disability injury in Sweden. This study compares the characteristics of rear impacts causing both short- and long-term disability neck injuries. Real life data from Swedish insurance material during 1990-1993 were used, where the resultant impact injuries to the neck were divided into two groups: occupants reporting initial symptoms shortly after the crash and a subgroup were the initial symptoms later developed into a long-term disability (chronic symptoms at least 1 year after the impact). The influence of change of velocity, crash pulse of the struck car, and the risk of long-term disability to the neck in different car models, were evaluated. The relative risk of neck injury in terms of initial disability was strongly influenced by the mass ratio between the struck and the striking car while other parameters such as crash pulse were an influencing factor in crashes causing long-term disability. Also, there was a 2.7 times higher risk of sustaining a long-term disabling neck injury in a vehicle manufactured in the end of the 1980s or beginning of the 90s than in one manufactured in the beginning of 1980. If one of the main reasons for the increasing number of long-term disabling neck injuries is associated with the influence of crash-pulse and factors related to newer car models, the situation will gradually become worse as the older car fleet is replaced. There is an increasing need for effective preventive measures, based on long-term disability data.

AIS1 NECK INJURIES are defined according to the Abbreviated Injury Scale, as neck strain with no fracture or dislocation. In England the incidence of neck injuries has been shown to have doubled over a ten-year period Morris and Thomas (1996). In Sweden most injuries have decreased in car crashes since the 70s, neck injuries have increased, von Koch et al (1994). These injuries have been found to have long-lasting and disabling effects, and account for almost 50% of all traffic injuries with long-term consequences Hopkin et al (1993), von Koch et al (1994).

INJURY MECHANISM AND IMPACT CLASSIFICATION - Since the injury mechanism is still unknown, even if different hypotheses exist, difficulties arise when new safety systems are constructed. Aldman (1986) proposed that the most harmful event occurs early on in the motion sequence, in the very early stages of head rotation, when the occupant's head is moving backwards relative to the shoulders. That the hyperextension would cause the injury has been questioned lately, mainly due to results from volunteer tests Mc Connell et al (1993). Recent results have shown that there is a compression of the cervical spine, a vertical motion, in the early stages of the impact that could be the cause of injury Ono and Kaneoka (1997).

Early clinical reports had suggested that injury was due to a forced flexion of the neck Gay and Abbot (1953). This belief was refuted based on contradictory results from computer models Mc Kenzie and Williams (1971); White and Panjabi (1978).
However, new results seem to support the flexion hypothesis Krafft et al (1996). These showes that there was a decreased risk of neck injury in a rear impact when the seat belt upper anchorage point (B-pillar) was placed further back. The investigation was based on 2 and 4 door car models of which the seat belt geometry were different, but the construction of the car being the same. In a rear impact the seat back of the 4-door car acted as a spring causing the torso to accelerate to a higher velocity before reaching the seat belt than it did in the 2-door car. This means that the mechanism behind neck injuries could be influenced by the rebounding forward movement of the occupant in a rear-end

collision. There is a need for a greater understanding of the interaction between vehicle, collision factors and occupant characteristics in the assessment of neck injuries before preventative measures can be adopted.

AIS 1 neck injuries, occur in all impact directions even though rear impacts are mostly mentioned. Galasko et al (1993) found that for drivers, 52% were injured in rear impacts, 27% in front impacts and 16% in side impacts. Morris and Thomas (1996) found that for occupants 38% sustained neck injury in rear impacts, 50% in frontal collisions and 25% in side impacts. However, Morris and Thomas based their study on vehicles that had been towed away which probably means that they represent more severe crashes where AIS 1 neck injuries occur and therefore such high frequency of frontal collisions.

HEAD RESTRAINT. - In rear impacts, head restraint effectivness was found by Nygren et al (1985) to be 25% (fixed restraint) and 15% (adjustable), compared to no restraint. Other estimates of effectivness have ranged from 63% Foret-Bruno et al (1991) to no detectable effect Morris and Thomas (1996). Boström et al (1997) found no correlation between a predictive neck injury-rating system based on the geometrical measurements of the head restraint and real life data. They suggested that other factors had more influence on the outcome.

SEAT YIELD - The risk of neck injury in rear impacts seems to decrease when the seat-back yields or collapses Foret-Bruno et al (1991), Thomson et al (1993), Parkin et al (1995). Boström et al (1997) showed that cars that were produced in the beginning of the 80s had a lower relative neck injury risk than newer models did. It may be that front seats have become stiffer to reduce the risk of ramping in severe rear impacts, which Viano et al (1992) concluded.

SHORT- AND LONG-TERM CONSEQUENCES - The main public-health problem concerning neck injuries are those leading to long-term consequences. Yet epidemiological studies and volunteer tests concerning AIS 1 neck injuries, mostly use data based on the injury outcome occurring shortly after the crash Eichberger et al (1996), Morris and Thomas (1996), Krafft et al (1995), Parkin et al (1995). Nygren (1984) showed that one out of ten occupants, after reporting neck injury to an insurance company, sustained long-term disability (determined at least 1 year after the collision). It is unknown whether crashes causing long-term disability to the neck, are a random sample of all crashes where occupants initially sustained disability, or whether they are characterised by other factors.

The aim of the current study was to determine whether the characteristics of rear impacts causing long-term AIS 1 neck injury disability (symptoms at least 1 year after the crash), correlate with those of rear impacts causing initial disability to the neck, where the injury may not necessarily lead to long-term disability.

The investigated variables were:
- influence of car weight and car model in struck and striking car
- influence of car pulse in struck car
- influence of year model of struck car.
- influence of age and gender distribution.

MATERIAL AND METHOD

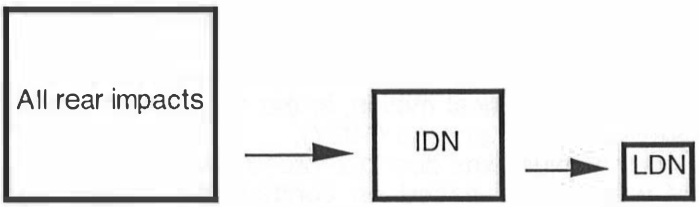

Figure 1. A schematic figure of different accident data.

In this paper the resultant impact injuries to the neck are divided into two groups, Initial Disabling Neck Injuries IDN and Long-term Disabling Neck Injuries LDN (Figure 1):

INITIAL DISABLING NECK INJURIES IDN (AIS 1) - Initial symptoms reported shortly after the crash, but not necessarily resulting in long-term disability. This means that both neck injuries causing short- or long-term consequences are included in this group.

Main study (I). During 1990-93, a random sample of 2 929 rear impacts were selected, where at least one occupant had reported a neck injury to the insurance company Folksam .

Sub study (II). In order to investigate the distribution of IDN for different crash directions, age, and position of the occupants, a random sample of car crashes were selected. The crashes occurred during 1990-93 where at least one occupant reported a neck injury to Folksam. This sample represented 1452 occupants.

Sub study (III). Data from an earlier study , Boström et al (1997) describing the relative IDN risk in the struck car for different car models was also used. This neck injury risk was calculated from matched two-car accidents Hägg et al (1992) reported by the police during 1991-95 in Sweden. All rear impacts (n=4 432) were selected during this time. In order to normalise for exposure, the paired comparison method was used in analysing the occupant injury risk and the severity of the accident, Hägg et al (1992); Krafft et al (1997).

LONG-TERM DISABLING NECK INJURIES LDN (AIS 1) - Initial symptoms reported shortly after the crash and which later developed into a long-term disability (symtoms persisted at least one year after the crash). This means that from the IDN group, short-term disabilites have been excluded.

All reported neck injuries to Folksam occuring during 1990-93 in a car crash, where at least one passanger sustained LDN, were seleced. They represented 1437 crashes and 1474 injured occupants, where 1283 answered a questionaire about the impact direction.

In Sweden all injuries that occur in car crashes where the victims require medical treatment are ranked according to a national disability scale (Medicinsk invaliditet 1981). The criteria for determining the extent of the LDN are related to loss of function, pain, and/or mental dysfunction. There is no relationship to the patient's occupation or social situation. Normally the degree of LDN is not established until three to five years after a crash. A preliminary estimation of the degree of disability is determined about one year after the crash.

TOW-BAR - In order to investigate the influence of tow-bar on neck injuries in rear impacts crash tests were performed with and without tow-bar. For the real-life data, information about the vehicles equipment of tow-bar were sampled from the National Swedish Vehicle Registry.

RESULTS

The percentage of accidents in different crash directions resulting in IDN or LDN, are shown in table 1. The impact direction did not seem to have any significant importance between the groups.

Table 1. The distribution of AIS 1neck injuries, resulting in a initial disabling neck injury IDN or a long-term disabling neck injury LDN for the occupants, in different impact directions.

Impact direction	IDN 1990-93* (random sample)		LDN 190-93				
	%	n	%	n	front-seat	rear-seat	un-known
Frontal	33.2	482	29.0	376	(341)	(26)	(9)
Side	9.6	140	11.6	148	(132)	(15)	(1)
Rear	47.9	696	51.1	652	(592)	(55)	(5)
Rollover	5.3	77	4.8	61	(51)	(10)	(2)
Unknown	3.9	57	3.5	46	(40)	(4)	(2)
Total	100	1452	100	1283			

* Material II.

IDN and LDN in REAR-END COLLISIONS, STRUCK CAR - Henceforth, only results concerning rear impacts are presented. For a given IDN, the results in Table 2 show that the risk of LDN is 44% higher for women than men. The risk of LDN is higher for the age group 41-60 than younger age groups. During 1990-93 no occupant under 15 years of age sustained long-term consequences to the neck (LDN).

Table 2. The gender and age distribution among occupants in rear impacts leading to a initilal disabling neck injury (IDN) and a long-term disabling neck injury (LDN).

Age, year	IDN* Male %	IDN* Female %	LDN Male %	LDN Female %
11-20	5	4	6	4
21-30	22	21	20	19
31-40	26	23	17	19
41-50	25	23	28	24
51-60	15	17	18	20
61-70	5	10	9	11
71-	2	2	2	3
*Material II	100	100	100	100
	n=678	n=723	n=257	n=395

The relative risk of LDN, in the struck car for different car models is shown in Figure 2. The risk varies widely between different car models, even if their weight is the same. The ratio between best and worst car is 1 to 5. The correlation between the weight of the struck car and the relative risk of IDN is shown in Figure 3. However, there is no such correlation in the relationship between relative LDN risk and car weight of the struck car (Figure 4). This indicates that the relative LDN risk does not increase in smaller lightweight cars compared to larger and heavier ones.

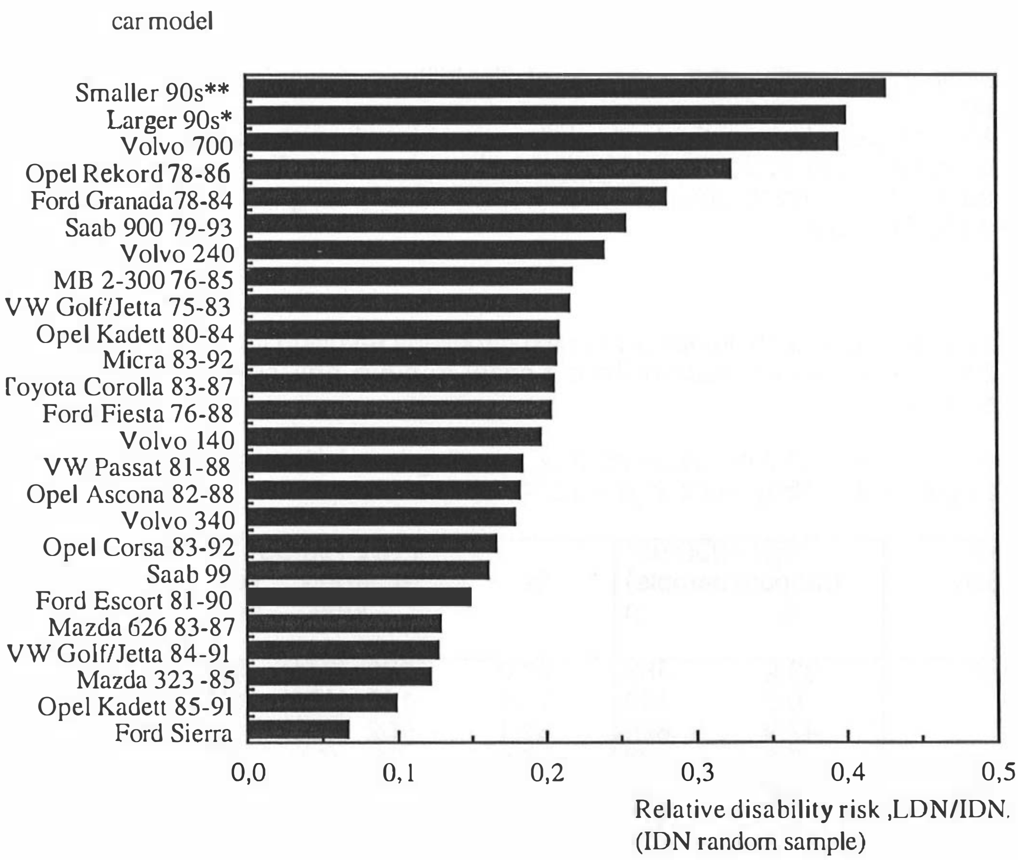

Figure 2. The relative long-term disability risk in rear impacts, to the neck in the struck car in different car models.

*smaller cars produced 1989 and later. See appendix

** Larger cars produced 1987 and later. See appendix.

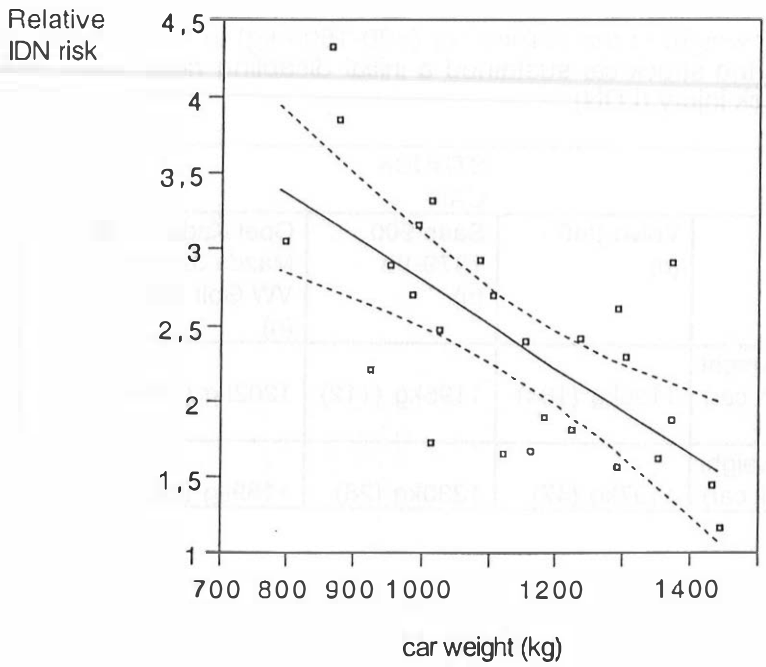

Figure 3. The correlation between car weight in the struck car and the relative initial disabling neck injury IDN risk.
Material III.

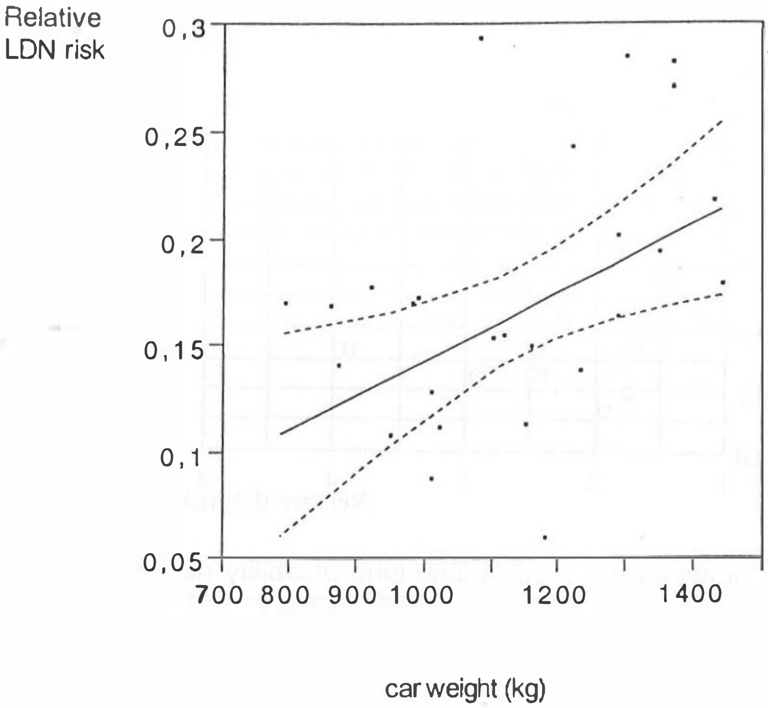

Figure 4. The correlation between car weight in the struck car and the relative long-term disability neck injury LDN risk.

In order to investigate whether the occupants sustaining LDN were exposed to a heavier striking car than in rear impacts causing IDN, the mean weight of the striking car (800-1500kg) was studied (Table 3). No differences in car weight of the striking car between the groups was found.

Table 3. The mean car weight of the striking car (800-1500 kg) in rear impacts where at least one occupant in the struck car sustained a initial disabling neck injury (IDN) or a long-term disabling neck injury (LDN).

STRUCK CAR			
	Volvo 240 (n)	Saab 900 1979-93 (n)	Opel Kadett E 85-91+ Mazda 323 81-85+ VW Golf 1984-91 (n)
Striking car weight (IDN* in struck car)	1196kg (184)	1195kg (112)	1202kg (189)
Striking car weight (LDN in struck car)	1197kg (47)	1230kg (28)	1189kg (23)

*material I.

In Figure 5 the relation between relative IDN risk (material III) and relative LDN risk for twenty-six different car models is shown.There was no correlation between relative initial and long-term disability risk to the neck. However, since the relative IDN risk is highly influenced by the car weight of the struck car (see figure 3), which is not the case for accidents causing LDN (see figure 4), the total car weight was compensated for different car models in the IDN-rating list (earlier presented Boström et al 1997). Thus only the construction of the car is rated and Figure 6 shows that there is no obvious correlation between relative LDN risk and compensated for the car weight relative IDN risk.

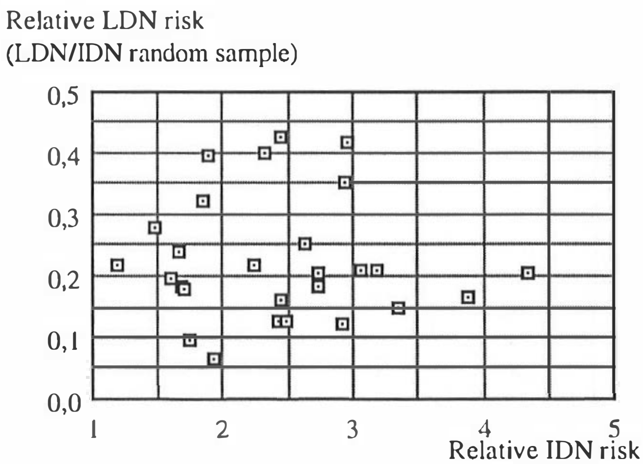

Figure 5. The relation between the relative long-term disability neck injury LDN risk and relative initial disability neck injury (IDN) risk, in different car models (struck car), in rear impacts.(IDN=material III)

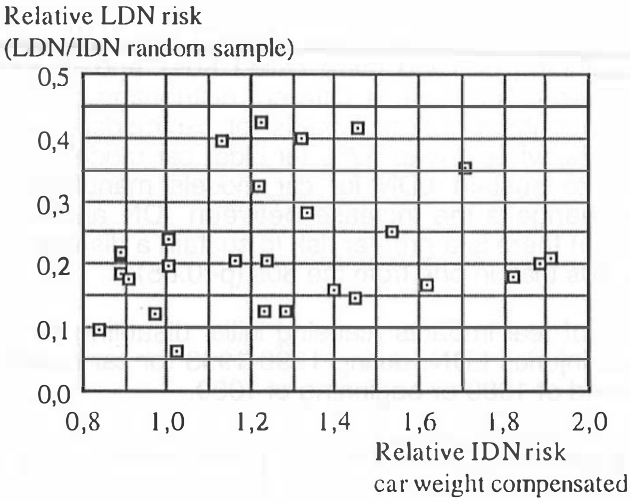

Figure 6. The relation between the relative long-term disabling neck injury (LDN) risk and relative initial disability neck injury (IDN) risk, compensating for car weight, in different car models (struck car), in rear impacts.IDN=material III.

In order to investigate the influence of the crash pulse, car models with and without a tow-bar were studied. First crash-tests were performed in a laboratory to establish whether a change of crash pulse duration occurs between the two alternatives. Two Volvo 240s with and without tow-bar were struck by a Volvo 240. In the car with a tow-bar, the peak acceleration was higher. The only dummy measurment taken was the lower neck which was higher than in the car without tow-bar both in rearward and forward (rebound) acceleration (see appendix). However, Meyer et al (1997) performed a rear impact in the laboratory with and without tow-bar and found no difference in change of velocity (10km/h) or mean acceleration (2.1g) between the cars.

Table 4 shows the influence of the tow-bar. To establish the average distribution of the tow-bar for the studied car model (struck car), data involving the same model as a striking car were used as a control group. It was assumed that the frequency of tow-bars among striking cars of a certain car model represents the average tow-bar distribution on the market for the concerned model. In total, for the car models shown in table 4 there was a 22% greater LDN risk in a car with a tow-bar than in one without (struck car). The statistical analysis was conducted on all three car models together (table 4). The difference in proportion tow-bar/no tow-bar was significant ($p<0.001$) between cars involved in rear impacts. There were no measurable differences between the control and IDN groups.

Table 4. The frequency of tow-bar for three different sample groups, in three different car models involved in rear impacts; long-term disabilty neck injury LDN (struck car), initial disability neck injury IDN (struck car), and a control group (striking car).

Tow-bar on different car models	Struck car LDN % (n)	Struck car IDN* % (n)	Striking car % (n)
Volvo 240	92 (37)	77 (120)	78 (228)
Volvo 700	87 (19)	70 (53)	74 (129)
Saab 900	79 (19)	62(60)	69 (69)

*material I

DIFFERENCE IN RISK CONCERNING CARS MANUFACTURED IN THE EARLY 80S AND 90S - When the car models are divided into two groups, car models manufactured in the beginning of 1980 (here called 80s) and in the end of 1980 or beginning of the 90s (here called 90s), a different distribution of impact direction was shown (Table 5).The percentage of rear impacts for car models from the 90s causing LDN represent nearly 70%, while it was 47% for older car models from the 80s. There were no increased risk to sustain LDN for car models manufactured from the 80s. However an important change is the increase between IDN and LDN for the 90s car models. This indicates that there is a greater risk to sustain a disability (LDN) to the neck in a car model from the 90s than in one from the 80s ($p<0.05$).

Table 5. The proportion of rear impacts causing initial disabling neck injuries IDN and long-term disabling neck injuries LDN, during 1990-1993 for car models produced at the beginning of 1980 and end of 1980 or beginning of 1990.

Car models	Rear impacts IDN**	Rear impacts LDN
80s*	49%	47%
90s*	54%	67%

*The car models are presented in the appendix.

**material II.

Cars that were produced in the beginning of the 80s had a lower LDN risk than did newer models (Table 6). Since the number of IDN are a random sample of all IDN during 1990-93, only the relationship between IDN and LDN can be studied. Given an initial injury, of the car models investigated, there was a 2.7 times higher long-term disability risk in cars produced round 1990 than in older models ($p<0.001$).

Table 6.The number of initial disabling neck injuries (IDN) (random sample) and long-term disabling neck injuries (LDN) among car models produced in the beginning of 1980 and the end of 1980 or beginning of 1990.

Neck injury AIS 1	Car models 80s* (n)	Car models 90s* (n)
IDN** (random sample 1990-93)	640	102
LDN (all 1990-93)	96	41
LDN/IDN	0.15	0.40

* the car models are presented in the appendix.

** material I

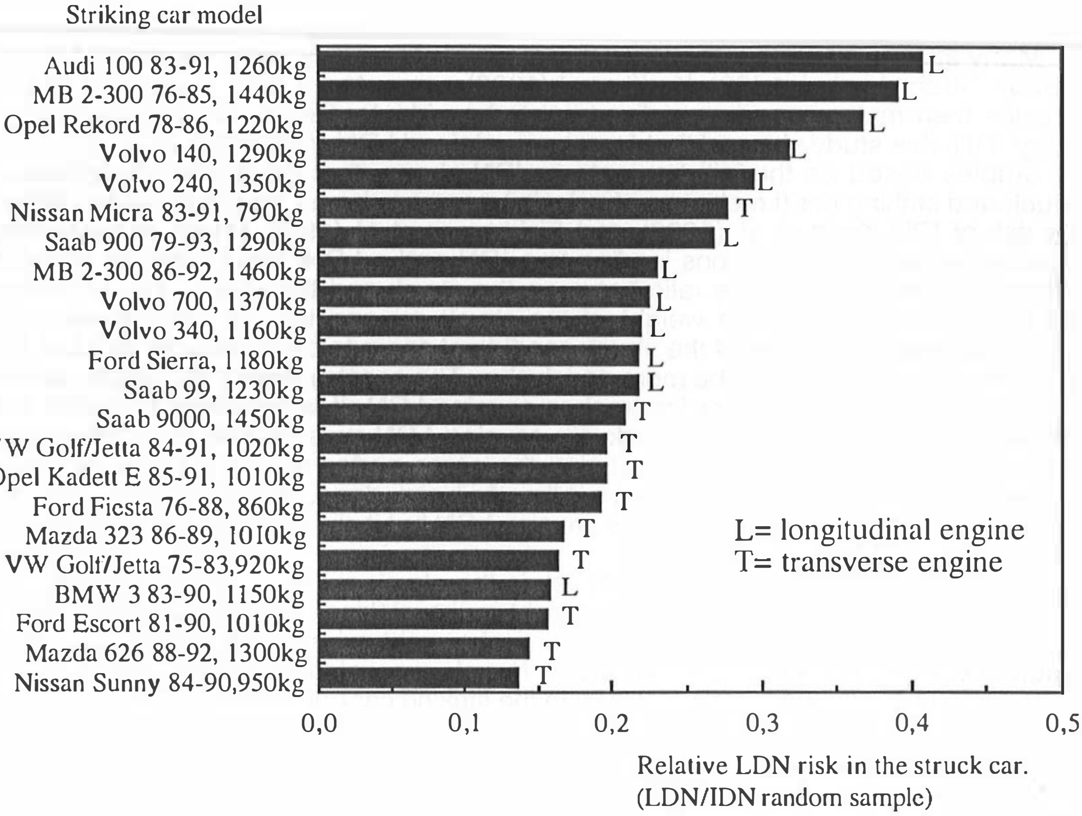

Figure 7. The risk of long-tem disability to the neck, LDN, caused to occupants in an average car struck by a specific car model (striking car) in a rear impact.

THE INFLUENCE OF THE STRIKING CAR ON THE STRUCK CAR - In Figure 7, the risk for LDN to occupants in an average car which is struck by a specific car model is shown. In general, a heavier car increases the risk of disability in the struck car. The average weight of the car models in the upper part of the figure is 1255 kg, and 1083 kg for the lower part. However, it is also shown in the figure that among cars of identical weight there is an important difference in the relative risk of disability to the neck. Also, car models with longitudinally mounted engines (L) cause a higher LDN risk in the struck car than car models with transverse mounted engines.

DISCUSSION

Most studies concerning AIS 1 neck injuries, are based on the initial symptoms that occur shortly after the collision. The main public-health problem however is that they are leading to long-term consequences. Therefore it is important to use injury criteria that are relevant to the long-term disability risk and not only to the initial symptoms. The injury as well as the mechanisms of whiplash have yet not been established. In order to better understand the phenomenon, accident data analysis are of importance. To gain more insight into the data based on the initial spectrum of symptoms, this study has separated crashes causing neck injury into two groups (IDN and LDN). Most occupants recover during the first 6 months Suissa et al (1995) after reporting a neck injury. In this study crashes causing LDN were treated separately, wheather they were characterised of other risk factors than IDN or not .

Since it is difficult to objectively determine the diagnosis of AIS 1 neck injury, the question is often raised about the credibility of these injuries. Even though the crashes causing short-term disability to the neck were excluded, there is no evidence that fraudulent claims exists among the group of final disabled. If neck injuries are the result of fraud, the disability risk would have been more or less the same for all car models, but it has been shown in this study that the relative LDN risk differs largely between different car models.

Many studies have shown that females are at higer IDN risk than males Maag et al (1993), Otremski et al (1989). Krafft et al (1996) presented a 56% higher risk of IDN for females than males based on police-reported accidents. Given an initial disabling neck injury IDN, this study showed that females sustained LDN more often (44%) than males.

Studies based on the initial symptoms IDN shows that the mass ratio between the struck and striking car (i.e change of velocity) seems to be an important factor influencing the risk of IDN Krafft et at (1996) and Eichberger et al (1996).When investigating the relationship between collisions leading to a IDN and a LDN, there were no measurable differences concerning mass ratio between the struck and the striking car. In contrast to the correlation between the weight of the struck car and the IDN risk, given an initial disabling injury the weight of the struck car did not seem to be a predictor of LDN (Figure 4), other factors seemed to be more conclusive. The construction of the struck car seems to be a more important factor for crashes causing LDN. It is important to notice that the influence of the weight of the struck car causing LDN was related to crashes causing IDN, and not with *all* rear impacts during the same period where also no neck injuries occured. A selection of crashes have allready been done. This suggests that delta-v could be a risk factor for rear impacts causing LDN but it did not increase the risk of LDN compared to IDN.

Another factor influencing the LDN risk in the struck car was the striking car. Even if there was a correlation between car weight in the striking car and disability risk in the struck car, there were also cars of identical weight where there was an important difference in relative LDN risk. Interesting to note was also that there seemed to be a correlation between the frontal structure in the striking car and LDN risk in the struck car. A transverse or a longitudinally mounted engine, which means a different architecture and stiffness of the car, seemed to influence the risk. The vehicles with a transversally mounted engine, seemed to cause less long-term disabilities to the neck for the occupants in the struck car. Low-speed crash tests are necessary to perform to verify the results in this study.

There was no correlation between the relative IDN risk and relative LDN risk for different car models studied. Even when the relative IDN risk compensated for car weight, and only the construction of the car was rated, there was no correlation. Also, there was a considerably larger dissolution among car models rated according to the relative LDN risk (ratio 1 to 5) than according to relative IDN risk after compensating for car weight (ratio 1to 2). Conclusively the relative IDN risk was mainly influenced by delta-v, since the difference between different car models strongly decreased after the weight compensation.

There was a higher LDN risk (22%) in a car with a tow-bar than without (same car model). The results indicate that the crash pulse is of importance, and could be one of the distinguishing factors between accidents causing IDN or LDN. Olsson et al (1990) brought up similar theories but could not verify them. According to sled test results for a given velocity change, the neck loads in the dummy increases with decreasing pulse duration Nilson et al (1994). However, further studies are necessary to better describe the influence.

It has been shown earlier that the relative neck injury risk, IDN, is lower for cars manufactured at the beginning of the 80s compared to car models produced round 1990, Boström et al (1997). This difference was considerably larger when the relative LDN risk was studied. There was a 2.7 times higher relative LDN risk in cars manufactured round 1990 than older models. A main reason could be that front seats have become stiffer due to the risk of ramping in severe rear impacts, Viano (1992). This could be a negative factor in low-speed collisions. Parkin et al (1995) showed that the plastic yielding of front-seat backs was beneficial in decreasing the risk of AIS 1 neck injuries occurring in rear impacts. Other results in this study seem to confirm the influence of the front-seat. Of all accidents causing LDN in car models produced round 1990, as many as 2/3 represented rear impacts. The corresponding share of rear impacts for models produced during the early 80s, was only 47%. This increased risk of long-term disability in rear impacts in newer models might be one reason why neck injuries AIS 1 have increased. Given that newer vehicles have a higher LDN risk, the number of long-term disabilities to the neck will continue to gradually increase as the older car fleet is replaced.

It is not possible to use accident data collected for the initial symptoms of neck injuries and then predict risk factors for long-term disabling neck injuries. The need of preventive measures, based on long-term disability outcome are therefore important.

CONCLUSIONS

Given an initial disabling AIS 1 neck injury,

- there was no correlation between car weight in the struck car and risk of long-term disability to the neck.
- the weight of the striking car did not increase the influence of the risk of long-term disability to the neck AIS 1, in the struck car.
- a tow-bar on the struck car increased the risk of risk of long-term disability by 22%.
- there was a 2.7 times higher risk to sustain a long-term disability to the neck in car models manufactured in the end of 1980 or beginning of the 90s than those of the beginning of 1980.
- females sustained long-term disability more often than males.

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APPENDIX

Car models “smaller 90s” and “larger 90s” in Figure 2.

	“Smaller 90s”	“Larger 90s”
Car models	Ford Escort 91- Honda Civic 92-96 Mazda 323 90-95 Mitsubishi Colt 89-92 Opel Astra 92- Renault Clio 91-97 Renault 19 90-95 Toyota Corolla 88-92 VW Golf/Vento 92-97 Volvo 440-460 89-95	Audi 80/90 87-95 BMW 5 88-95 Mazda 626 88-92 Mitsubishi Galant 88-92 Opel Vectra 89-95 Opel Omega 87-93 Toyota Camry 87-91 Toyota Camry 92- Toyota Carina 88-92 VW Passat 89-95

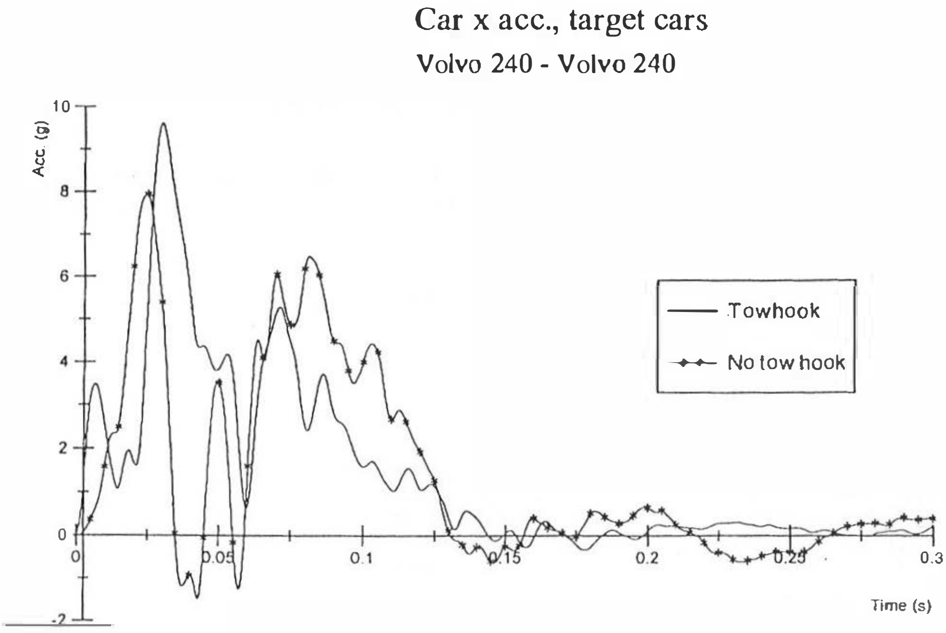
Car models “80s” and “90s” in Table 5.

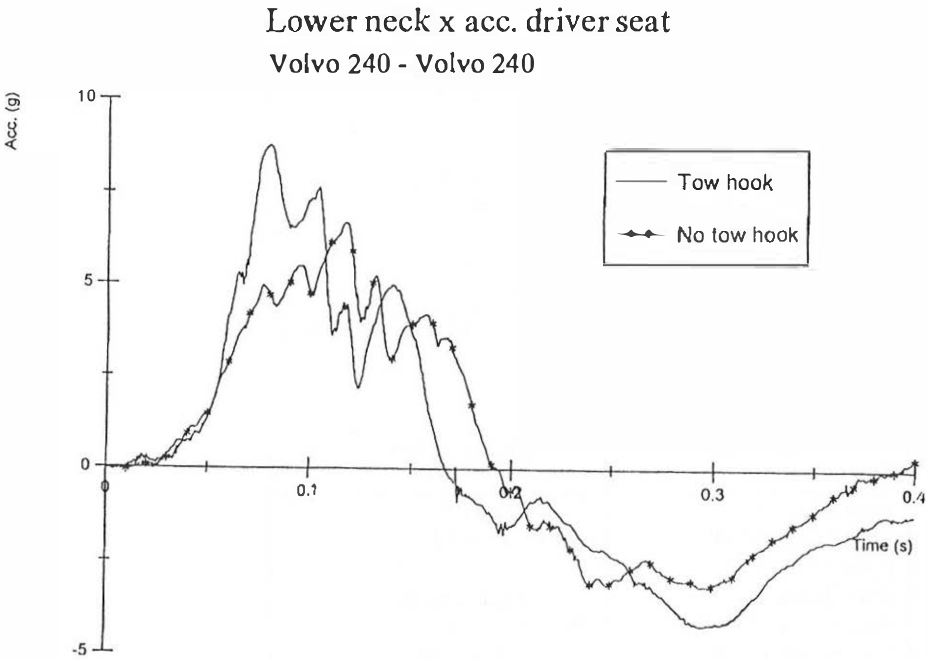
	Year of production 80s	Year of production 90s
Car models	Audi 100 83-91 Honda Civic 84-87 Mazda 323 86-89 Toyota Corolla 83-87 Toyota Camry 83-87	Audi 100 92-97 Ford Escort 90- Ford Mondeo Honda Civic 92-95 Mazda 626 92- Mazda 323 90-95 Opel Astra Toyota Camry 92- Toyota Corolla 93-96 Toyota Carina 92-95 VW Golf 92- VW Passat 89-95

(Only five different models representing the 80s since lack of information concerning crash direction for the IDN-group, material II)

Car models “80s” and “90s“ in Table 6.

	Year of production 80s	Year of production 90s
Car models	Audi 100 83-91 Ford Escort 81-89 Ford Scorpio Ford Sierra Honda Civic 84-87 Mazda 323 86-89 Mazda 626 83-87 Opel Kadett 85-91 Toyota Corolla 83-87 Toyota Camry 83-87 VW Golf 84-91 VW Passat 81-88	Audi 100 92-97 Ford Escort 90- Honda Civic 92-95 Mazda 626 92- Mazda 323 90-95 Opel Astra Toyota Camry 92-96 Toyota Carina 92-95 VW Golf 92-97 VW Passat 89-95


Car x acc., target cars
Volvo 240 - Volvo 240
Acc. (g)
10
8
6
4
2
0
-2
0
0.05
0.1
0.15
0.2
0.25
0.3
Time (s)
Towhook
No tow hook


Lower neck x acc. driver seat
Volvo 240 - Volvo 240
Acc. (g)
10
5
0
-5
0.1
0.2
0.3
0.4
Time (s)
Tow hook
No tow hook