PROTECTION AGAINST REAR-END ACCIDENTS

by

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After a presentation of a litterature review, a technical and medical survey on car accidents conducted by the Association Peugeot S.A./ Renault is presented.

LITERATURE REVIEW

Literature reviews dealing with rear-end impacts, cervical injuries and the effectiveness of head restraints have already been made by several authors (1)(2). Consequently, we shall only deal with the following subjects:

- frequency and severity of rear-end impact
- cervical hyperextension, nature of injuries and symptoms,
- effectiveness of head restraint,
- risk factors of cervical injury by hyperextension.

The percentage of fatalities due to rear-end impact is very low (around 3 %) in Europe (3) and in the United States (2). Fatal accidents described by C.J. Kahane (2) are essentially related to severe compartment collapse (trucks or fixed obstacles), to ejection or fire.

In fact, few people are very seriously injured in a rear-end impact. According to the American N.A.S.S. 1979 files, out of 1000 frontseat occupants involved in rear-end accidents, only one died and thirty are admitted to hospital. Among victims, 78 % sustained "whiplash" injuries.

Sudden cervical hyperextension pathology, without any head or neck contact is rather unknown for living persons. Results of researches made on animal reveal muscular and ligamentous tears, muscular hemorrhages and troubles coming from the encephalon or from the nervous system because of forces transmitted by the superior part of the spinal cord (4).

On the basis of "cineradiographic" analysis of cadavers, Nelson (5) pointed out abnormal modifications of the cervical spine due to soft cervical tissue injuries after hyperextension (or hyperflexion).

(*) Numbers in parentheses designate references at the end of paper.

There is a lack of objectivity and definition about "whiplash" injuries. This is the reason why medical technology uses words to qualify such injuries, taken from kinematic descriptions used by biomechanicians.

If the English term "whiplash" invented in 1928 by Crowe has often been discussed (6), it is the same for the French term "coup du lapin" which is even less pertinent.

There is also a problem with symptoms of injury (headaches, neck pains, perception disturbances, tingling sensations in hands) which are often delayed hours or days so that the injury is not evident at the scene of the accident (7). Kahane (2) points out that 55 % of whiplash injuries are not taken into account in police reports.

Besides, the author reports that, according to N.C.S.S. files, "whiplash" victims have four days of disability on an average.

This would be unimportant if victims did not still suffer from long term consequences several years after their accidents. Toussaint et Fabeck (8) describe a whole group of cervical-cephalic troubles including psychic symptoms which are similar to symptoms due to cerebral concussions.

Frequency of psychic problems prior to accident (30 % in Toussaint-Fabeck report) and the claiming tendency of these victims are frequently emphasized.

Braustein and Moore (6) conclude that the conscious or unconscious desire for gain on the part of patients may motivate them to exaggerate their injuries and disabilities. Gotten (9) reported a review of one hundred patients with neck injuries from rear-end impact car accidents in which 88 % recovered after litigation was settled. He stated that 85 % of them had psychosomatic complaints. According to Fournier (10), 90 % of cases of disability due to cervical spine injury disappear 18 months or 2 years later. The 10 % left are either cervical vertebra fractures consequences or psychosomatic cases.

Head restraints effectiveness for reducing whiplash cervical injuries was defined in 8 studies (Table 1). Effectiveness varies from - 22 to + 55 %. Such a disparity reveals uncontrolled bias which we shall study in

Table 1 - Head Restraints Effectiveness and Cervical Injuries Reduction

Data Sources	References	Effectiveness (%)
Sweden, 1973	12	55*
Los Angeles, 1970 Insurance Claims	13	18*
Rochester, 1972	1	15
Australia, 1979	11	10
North Carolina, 1972/73 ..	14	6
A.C.I.R.	16	0
M.D.A.I.	15	- 5
N.C.S.S.	3	- 22

(*) significant statistical tests

the next paragraph. Majority of studies points out that the beneficial effect

was more noticeable for female occupants than for male ones (1)(2)(11)(13). Some investigators report the less effectiveness of head restraints in the down position (respectively 17 % and 10 % for integral and adjustable restraints) (2). One of them points out that head restraints do not reduce death risk .

Finally, all the authors agree to say that whiplash injuries can occur with head restraint, even if it is properly adjusted. Head restraint can very rarely be the cause of cervical injuries (17)(18).

Majority of people involved in rear-end impacts does not suffer from cervical injury (1)(2)(11)(14). States (1) gave a list of factors which could change the risks. They are either human or technical.

Human factors: sex, age, height, cervical antecedents, seat position and attitude at the moment of the impact.

Technical factors: seat damage, reduction of the passenger compartment and head restraint.

Sex has a major influence over cervical injury frequency. The female injury rate is 1,5 (2) to twice (19) higher than the male injury one. On the basis of anthropometrical data, States (1) observed females have smaller necks relative to head size.

Other parameters have been studied with the following results:

- considering adult occupants: age, height and weight do not exert a detectable influence on cervical injury frequency (1)(19)
- front seat damages reduce cervical injury frequency by 27 % for drivers and by 8 % for front passengers (19).

Methodology and results hereafter try to point out the influence of technical factors (rear-end impacts description, crash violence, head restraint and seat damage influence) upon cervical injuries frequency.

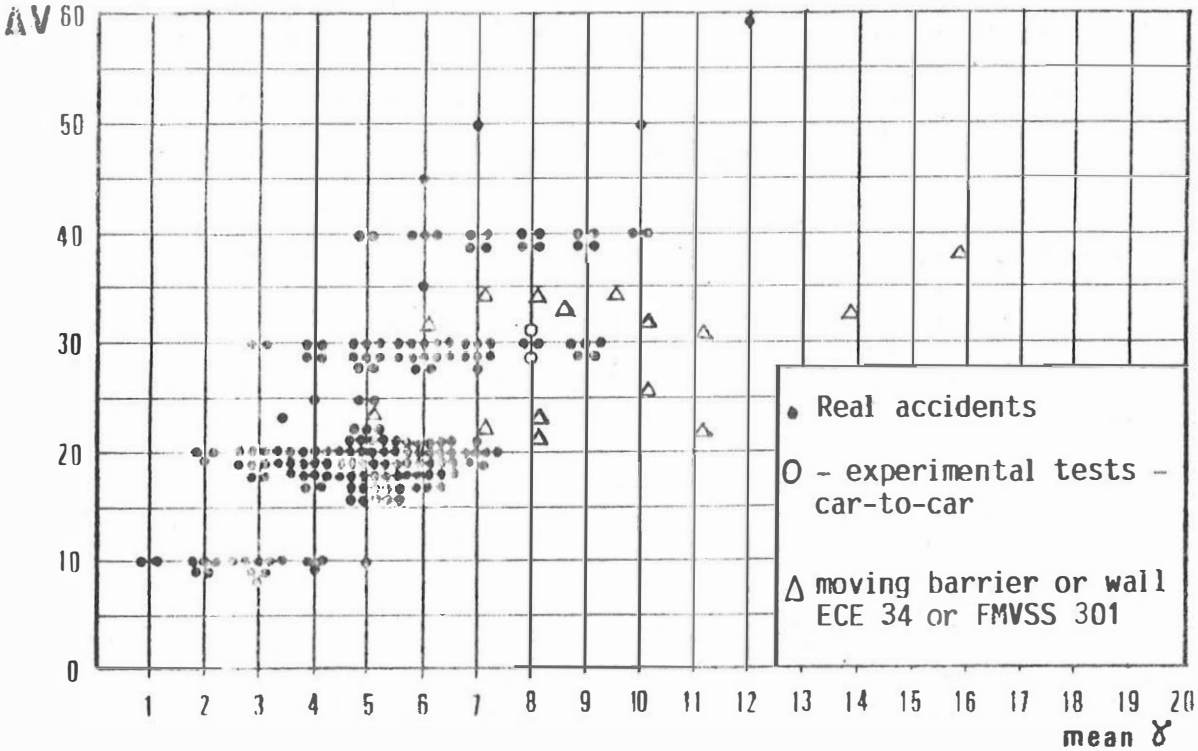
METHODOLOGY

Cases origin - The Peugeot S.A./Renault accident file contains 481 rear-end impact cases involving 759 front seats and 287 rear seats occupants, which occurred between 1970 and 1981. Car crash circumstances are described in police reports. Medical data are communicated by hospitals. A revision of the diagnostics is made two months after the accident.

Each car is examined by a specialist. Involved cars exterior deformations are photographied and analysed in order to evaluate the impact velocity. Passenger compartment examination reveals whether the occupants were restrained or not, if there were head restraint and seat damage after the impact.

Rear-end impact velocity - Estimation of impact velocity is calculated from occupant speed variation (ΔV) and from mean acceleration (mean γ) according to the method described by Tarrière (20) for frontal impact. Estimation of ΔV has been done for 172 car-to-car rear-end impacts and for 9 car-to-fixed-obstacles rear-end impacts. These cases are given in fig. 1 hereafter. The comparison with experimental impacts ECE 34 and FMVSS 301 highlights that average velocity in experimental tests is generally higher. The difference is due to the fact that experimental tests are fully distributed on the rear end of the car whereas the majority of real crashes are with offset.

Figure 1: Violence of Rear Collisions



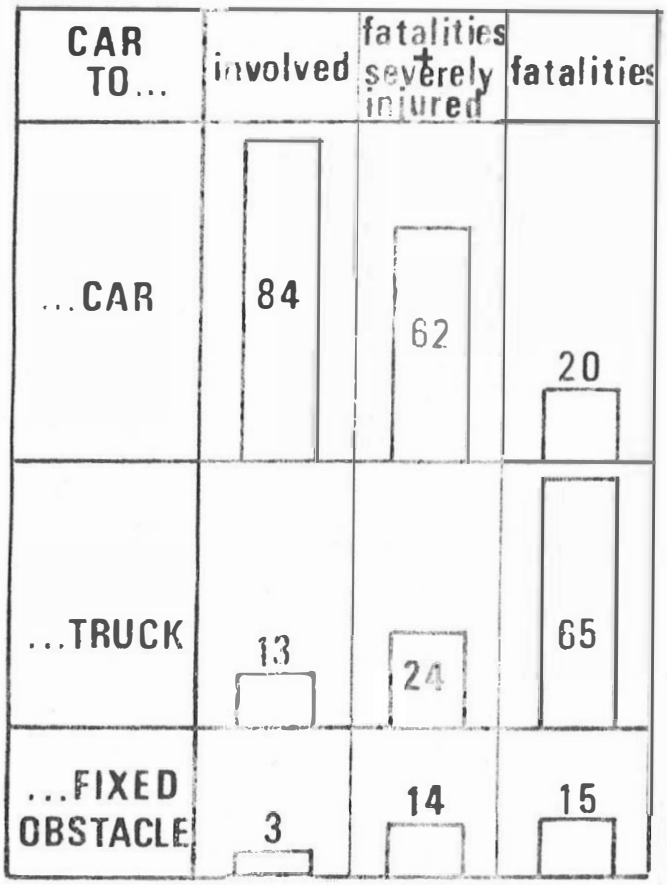


Figure 2: Distribution of injured occupants by type of obstacle.

RESULTS

1. Rear-end impacts characteristics

. Relative Frequency - In the APR sample, rear-end impact represents 7 % of involved, 3,8 % of seriously injured and 1,6 % of killed.

. Obstacles and Injury Severity (fig. 2) - For 84 %, the striking vehicle is another car but this type of collision represents only 20 % of fatal cases. But for two-thirds of the fatal rear-end impacts, the car is struck by a truck.

. Occupant injury severity and occupied seat - They are given in the following table:

	Uninjured	Slightly injured	Severely injured (1)	Killed (2)	Total (3)	(1)+(2)/(3)
. Front seats	290	447	18	13	768	4,0
. Rear seats	92	151	7	7	257	5,4
Total:	382	598	25	20	1025	

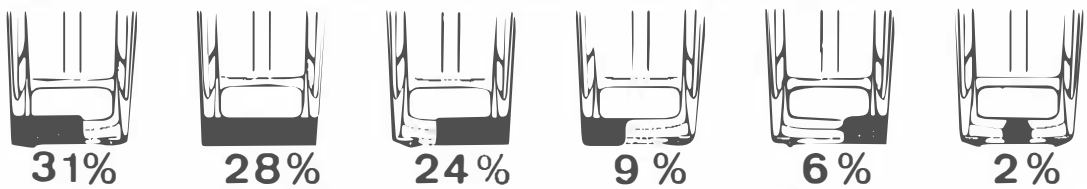
The gravity rate is higher for rear seats than for front ones, mainly because of intrusions of trucks in the rear-end compartment.

. Number of impacts - In the present sample, the rear-end impact was unique in 39 % of the whole cases. The over-representation of motorway accidents in our file can explain this percentage. Out of 297 cases among which the principal rear-end impact was associated with another impact, the first was the rear-end one for 248 cases (for 13 cases, the order is unknown). Rear-end impacts associated with secondary ones are thus included in this study because the position of almost all the front seat occupants is not influenced by the secondary impacts.

. Impact Direction - It is an axial one (6 o'clock for 83 % of the cases).

. Struck Area - The two thirds right and left rear-end areas represent 55 % of the cases (figure 3).

Figure 3 - Frequencies of deformation area of the car



Speed variation for the occupant (ΔV) - The distribution (in %)of ΔV is given hereafter (un km/h):

$\Delta V < 16$	ΔV 16-25	ΔV 26-35	ΔV 36-45	ΔV 46-55	ΔV 56-65	$\Delta V > 65$ km/h
26,6 %	45 %	19,4 %	7,8 %	0,9 %	0,3 %	0

It can be observed that more than 70 % of ΔV are inferior to 25 km/h.

2. Severity of Head and Neck Injuries - Head and neck are the most frequent body areas injured.

Head: The following table gives head injury severity in the AIS scale (21):

(*)	N	AIS head	0	1	2	3	4	5	
Front occupants	759		69	22	8,4	0,4	-	0,4	100%
Rear occupants ($\geqslant$12 years)	91		40	48	11	1	-	-	100%
Rear occupants ($<$12 years)	70		30	57	8,6	1,5	2,9	-	100%

- Front seat occupant: AIS $\geqslant$ 2 head injuries are observed in the most severe rear-end impacts, where seat damage (opening of seat back angle or seat track failure) occurs more frequently as we see in the following table:

(*)	N	ΔV known	% $\Delta V > 35$ km/h	Seat Damage frequency
. AIS Head: $\geqslant$ 3	7	7 cases	100 %	70 %
= 2	64	38 cases	47 %	60 %
Whole sample:	759	320 cases	9 %	45 %

Head AIS $\geqslant$ 3 are due to direct impact against the structure of the rear passenger compartment area which moved forward due to the intrusion effect.

Head trauma with loss of consciousness $<$ 15' (AIS 2) are observed in only 15 % of damaged seat cases. The majority of AIS 2 to head refers to these cases. Usually, they are due to head impacts against the bench seats or against the rear elements of the compartment.

Among the 64 injured who sustained AIS 2 to the head, 9 (14 %) had head restraints. These injuries are not only due to seat damages because seats remained intact 4 times out of 9.

- Rear seat occupants: rear seat occupants suffer more often head injuries than front seat's ones because they directly sustain the effects of intrusion.

(*) Killed persons non autopsied and rear seat occupants of unknown age are not taken into account.

Neck: the following table gives cervical injury by degree of AIS:

	N	AIS Neck	0	1	2	3	4	5	
Front occupants:	759		73	25,7	0,4	0,8	-	0,1	100%
Rear occupants (≥ 12 years)	91		68	31	1	-	-	-	100%
Rear occupants (< 12 years)	70		94	6	-	-	-	-	100%

Frequency of cervical injuries of AIS ≥ 2 for front seats occupants accounts for 1,3 % (10 cases). Fracture or luxation occur in 5 cases, contusion or sprain in 4 cases and burn in 1 case. AIS ≥ 2 cervical injuries are due to the following factors:

- cervical spine hyperextension: . with worsening factor (previous cervical fracture, arthrosis): 4 cases
  . Without worsening factor: 2 cases
- Head impact: 3 cases
- Burn: 1 case

One of these ten victims uses a head restraint. Head restraint as a countermeasure would have been effective in the case where the rear seat of a station-wagon driver could not open because there was a transversal bar situated between the B-pillars. The majority of occupants did not suffer from cervical injury, but neck pains frequency (neck AIS = 1) accounts for 25,7 %. This percentage is very high in comparison with the one observed in other types of accidents (6 to 8 %).

3. Neck AIS = 1 and prevailing factors.

Factors influencing neck injury frequency are either human or technical.

Human factors: the difference between cervical pains frequency for males (23 %) and for females (43 %) is highly significant. It is because female neck musculature is weaker than males' one. For adults, age, height and weight do not exert a detectable influence on neck AIS = 1 frequency.

Technical factors:

- Head restraint (fig. 4) - The repartition of the different head restraint types is: adjustable (56 %), integrated (25 %), fitted headrest with the seat-back (19 %). Among adjustable headrestraints, one fourth was in high position.

For males, neck AIS = 1 frequency without head restraint is equal to 22 % whereas it is equal to 27 % with head restraint. The difference is not statistically significant. For females, neck AIS = 1 frequency without head restraint is equal to 44 % and to 39 % with head restraint. The difference is not statistically significant.

- Seat damage (fig. 5) - Seat damage (seat back angle ≥ 140° or seat track failures) significantly reduces of 28 % AIS neck = 1 frequency for females. Cervical pains frequency for involved who did not sustain head impact accounts for 30 % (123/399). It accounts for only 20 % (48/233) for those who sustain a head impact. Despite the fact that seat damage provokes minor head contact, it has a positive effect in reducing the risk of cervical pain.

Fig. 4: frequency of AIS neck = 1
according to head restraints and sex.

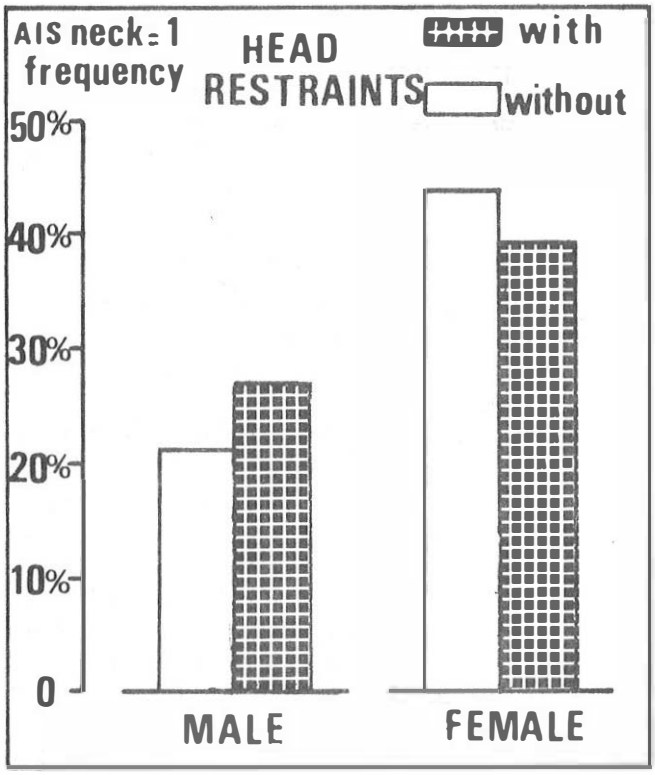
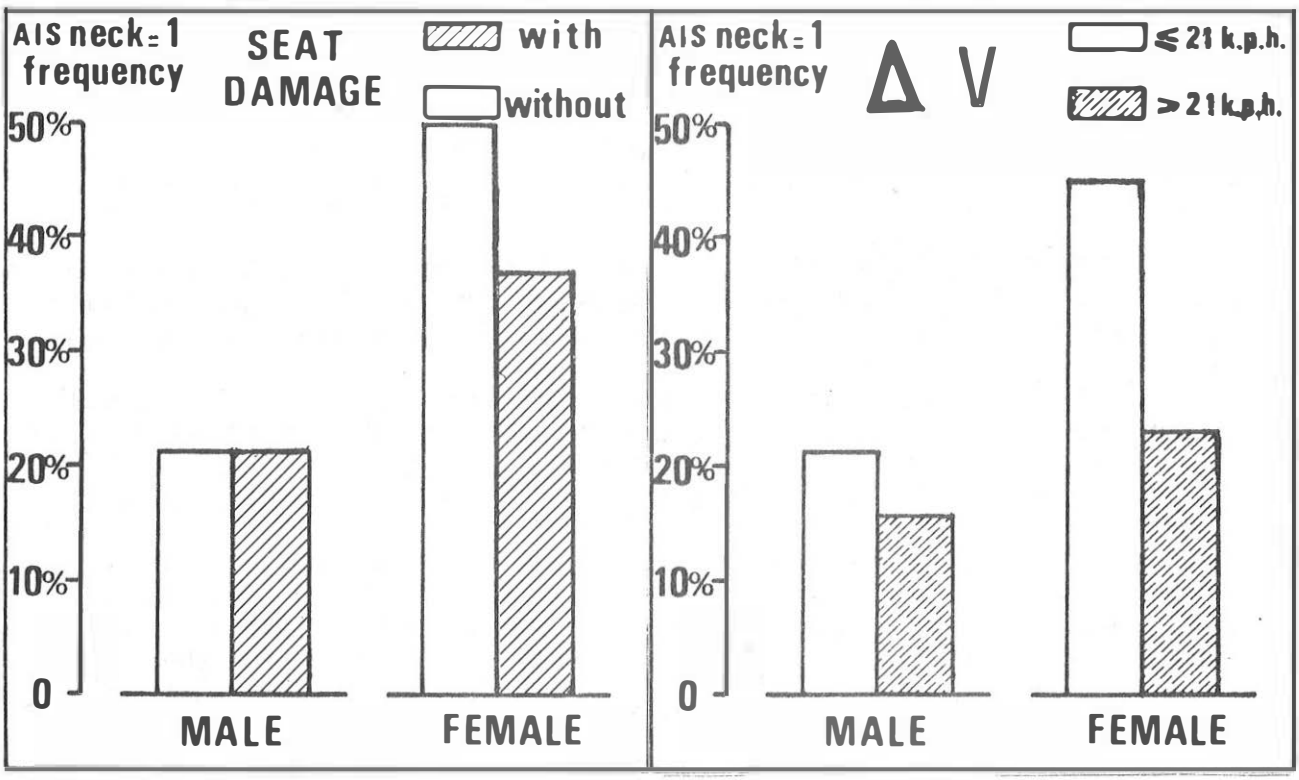


Fig. 5: Frequency of AIS neck = 1
according to seat damage and sex.

Fig. 6: Frequency of AIS neck = 1
according to V and sex.



- Rear-end impact velocity (ΔV) (see fig. 6) - The relative frequency of AIS 1 for females is lower at $\Delta V > 21$ than at $\Delta V \leq 21$. This tendency is significant.

As a conclusion, it could be said that technical factors do not exert a detectable influence on cervical injury risk for males. For females, the risk is mainly influenced by ΔV, seat damage and head restraint.

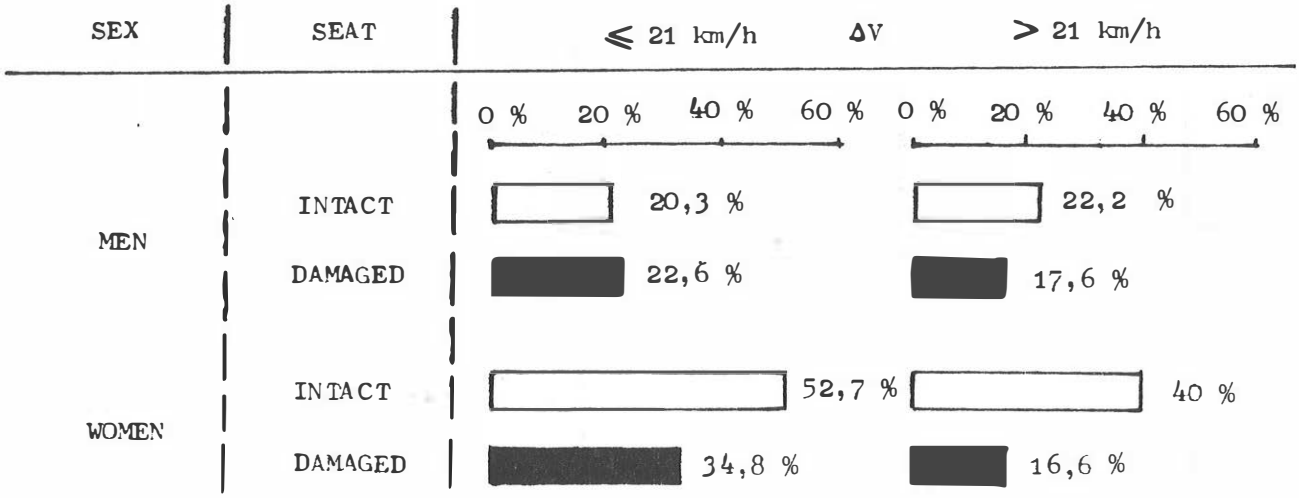
The two first technical factors "seat damage" and "ΔV" cannot be dissociated. They are correlated with the diminution of cervical injury risk.

4. Cervical injuries frequency and seat-damage according to sex and ΔV.

Figure 7 gives AIS neck = 1 frequency for 348 front seat occupants for which seat damage after impact, sex and ΔV are known.

Seat damage is effective for females only and reduce their neck injury risk by 45 %.

FREQUENCY OF AIS NECK=1 FOR 348 FRONT OCCUPANTS INVOLVED IN REAR IMPACT INFLUENCE OF SEAT DAMAGE , SEX AND ΔV (Fig. 7)



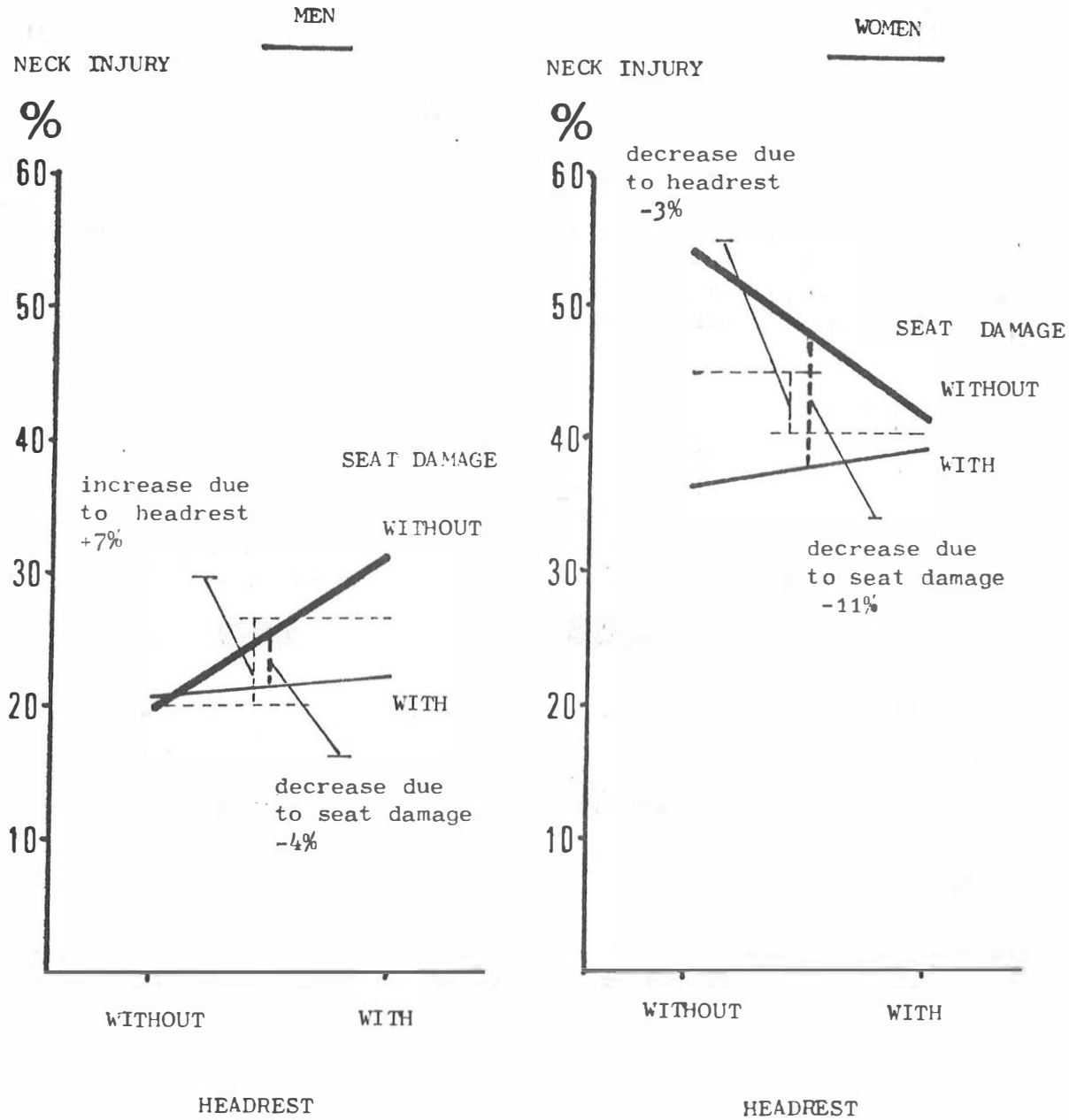
5. Comparative influences of neck restraint and of seat damage upon cervical pains frequency (fig. 8).

For males, seat damage reduces AIS neck = 1 of 4 % whereas head restraint is not effective. For females, reduction of cervical pain frequency is, on an average, equal to 11 % due to seat damage, and 3 % due to head restraint. It can be noticed that head restraint exerts a detectable influence mostly when cervical injury risk is great, that is to say when there is no seat damage, it principally occurs in rear-end impact with $\Delta V < 21$ km/h.

6. Long term disability.

All victims suffering from cervical pains received a mailing questionnaire. Out of 52 answers, 33 say that they do not suffer any more from any pain due to their accidents. Six years after the accident, 19 say that they have disabilities which are either stiffness of the back of the neck or mood troubles. The proportion of victims with previous cerebral or cervical troubles (past accidents, headaches, arthrosis) or who sustained a head impact

Figure 8
NECK INJURIES FREQUENCY FOR FRONT OCCUPANTS IN REAR IMPACTS
INFLUENCE OF HEADREST, SEX AND SEAT DAMAGE



during the accident is equal to 64 % (12/19) among people who have disability whereas the ratio is only equal to 21 % (7/33) for people who do not have any. It can be concluded that long term consequences are not only related to neck hyperextension. They can be observed with injured people who, before the accident, already had a fragile cervical spine, or who sustained a head impact. Medical literature on head trauma often describes subjective syndromes whose likeness with neck disability is obvious (22).

DISCUSSION

The poor head restraint effectiveness is probably due to the excessive vertical and mostly horizontal distance between the head and the restraint. The mispositioning of adjustable restraint is not a sufficient explanation because injured whose cars are equipped with "integral" seats still suffered from cervical pains. Beyond head restraint height, the horizontal distance between head and the restraint seems to be a pertinent factor. This distance is probably too important in most cases. Biomechanical tests could allow to evaluate the optimum distance for head restraint effectiveness.

Finally, the excessive stiffness of the seat, which prevents a more important bending of the seat-back, increases AIS neck = 1 risk for females. But, on the one hand, if seat damages reduce neck injury frequency, on the other hand, it could also increase minor head impact frequency, and, by the way, lessen the overall benefits. But such hypothesis would only occur in severe rear-end accidents.

The influence of the seat stiffness upon the neck injury risk must be taken into account in head restraint survey. In a recent NHTSA research (2), the head restraint effectiveness accounts for 10 to 17 % according to the various types. It may exist a bias due to the higher proportion of bench seats and split benchesin the sample without head rests. Considering that failures occur less frequently for benches than for bucket seats, the benefit attributed to head restraint instead of rearward bending of the seat back is questionable.

CONCLUSIONS

1. Rear-end impact represents 7 % of involved, 4 % of seriously injured and 1,6 % of killed people. Consequently, its importance is minor compared with frontal or side impacts.

2. Car-to-car crashes are the source of 84 % of rear-end impacts with injured occupants and of only 20 % of fatal rear-end accidents. Car-to-trucks account for 13 % of the overall cases, but for two-thirds of fatal rear-end impacts.

3. People involved in rear impacts whose ΔV is inferior or equal to 25 km/h account for 70 %.

4. Severe head and neck injuries (AIS $\geqslant$ 3) occur for less than 1 % of front seat occupants.

5. Cervical pains (AIS 1) in frontal occupants are four times more frequent (27 %) in rear-end impacts than in other types (7 %).

6. Women sustain AIS neck = 1 twice more frequently than men (respectively 43 % and 23 %).

7. Head restraint effectiveness is rather small. It reduces by 11 % (statistically not significant) the AIS neck = 1 for females. Whereas there is no reducing effect for males, the most obvious positive effect of head restraint is observed when, for females, cervical pain risk are high (seat is intact at low-speed impact).

8. Damaged seat-back or seat-track failure have a greater effectiveness than head restraint, considering cervical pains reduction. The highest seat damage frequency increases with ΔV and explains that, paradoxically, AIS neck = 1 are less often observed in rear impacts superior to 20 km/h of ΔV.

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