INFLUENCE OF AGE AND RESTRAINT FORCE VALUE ON THE SERIOUSNESS OF THORACIC INJURIES SUSTAINED BY BELTED OCCUPANTS IN REAL ACCIDENTS.

by

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Three studies published over recent years deal with the force at shoulder level of belted occupants in frontal collisions:

- L.M. Patrick (1)[x], following reconstitutions of real accidents using dummies, determines the tolerance threshold (50 % of occupants having an AIS 3) at 858 daN (1930 lbs) measured above the shoulder.

- N.H.T.S.A. (2), based on research investigations conducted with cadavers, has suggested a shoulder force limit of 534 daN (1200 lbs).

- J.Y. Foret-Bruno (3) has analysed 92 belted occupants involved in frontal collision, having a force limiting device between the shoulder and the upper anchorage point of the shoulder belt. He observes that the less than 30 year olds withstand a shoulder force of 740 daN with no thoracic injury, whereas beyond 50 years old, one belted occupant out of two risks one or more thoracic fractures at the 450 daN threshold. Finally, he verifies the under-estimation for living people by tests conducted with cadavers.

The present research investigation is also based on data acquired from observing force limiting devices fitted in Peugeot-Renault 3-point static belts. It incorporates 11 new cases. Stress is laid on those shoulder force thresholds where the first thoracic fracture appears, according to age.

Above all, the study attempts to quantify per age group the risk of thoracic fracture due to the belt for the front occupants involved in real frontal collisions, the violence of which is evaluated by the variation in velocity of the front occupant, and the mean deceleration of car mean γ.

The plan is as follows:

1 - Shoulder force values and assessment of thorax according to age,

2 - Shoulder force values according to violence of frontal collision (diagram ΔV, mean γ),

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(x) - Parentheses refer to the bibliography at end of paper.

3 - Risks, per age group, of going beyond the force threshold at which belt-induced rib fracture appears in real frontal collisions.

Verification on a sample of 227 belted occupants.

DEVELOPMENTS AND RESULTS

1. SHOULDER LOAD VALUES AND ASSESSMENT FOR THORAX ACCORDING TO AGE

Method: The shoulder load level for living subjects is supplied us from accidents involving wearers of static, 3-point belts as fitted to Peugeot and Renault standard production cars sold in France, from 1970 to 1977.

These belts have a load-limiting device located between the shoulder and the upper anchorage point.

Three different load-limiting systems were fitted successively to the cars as shown in the photos (figure 1), which exhibit them before and after the impact.

Type A - Load limiter with 5 different lengths of band: the mean load values from 1st. to 5th. bands are as follows:

Band No	1st	2nd	3rd	4th	5th
Breaking load (in daN)	210	385	325	400	440

Type B - Load limiter with 5 bands of equal length: the mean values are considerably higher:

Band No	1st	2nd	3rd	4th	5th
Breaking load (in daN)	740	720	750	800	800

Type C - Tear webbing: triggering peak: 550 daN.

Important remark: when all the shock-absorbing material has been used (5 broken bands for types A and B, completely ripped tear webbing for type C), the load undergone by the shoulder was at least equal to the maximum value stated for the type of load-limiting device in question. The load value taken into account is not the exact value but a "threshold" value.

LOAD MEASUREMENT for a belted occupant in an accident is conducted taking account of the above-mentioned values. The values shown henceforth in this study are corrected in accordance with occupant mass, in compliance with the equation suggested by Eppinger (4) and which we would state once again:

$$F_{\text{corrected shoulder}} = F_{\text{measured shoulder}} \left(\frac{75\ \text{kg}}{\text{occupant mass}}\right)^{2/3}$$

103 belted occupants involved in frontal collisions had their shoulder forces determined. The following conditions were satisfied:
- at least one band broken, whether it was a type A or B load limiter, or beginning of tearing of type C limiter,
- age and weight known,

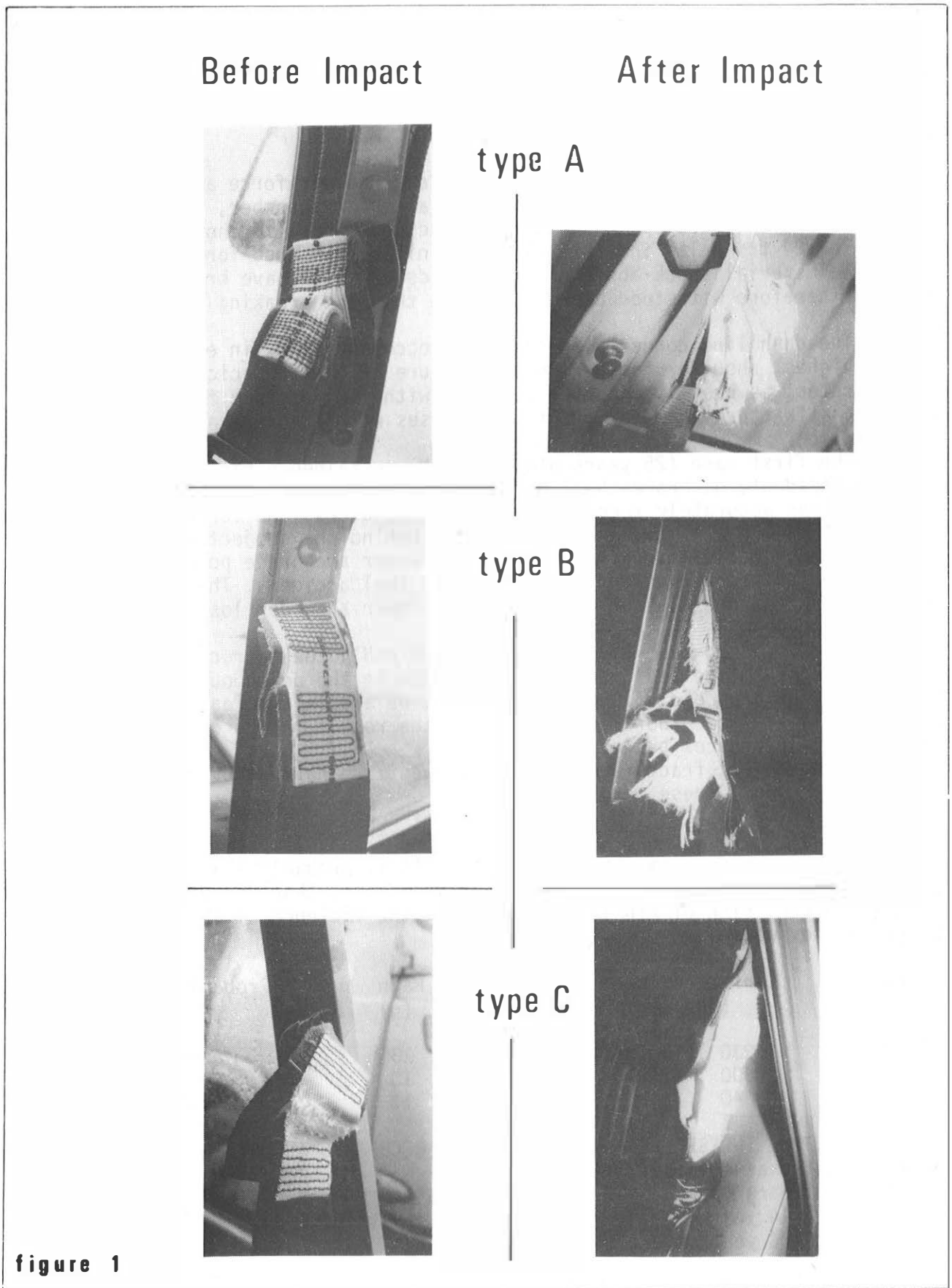


figure 1

- no thorax contact with an element other than the belt itself for occupants suffering thorax injuries.

Collating the force value sustained by the occupant and the assessment of thorax injuries if there are any according to the age enables the rib fracture risk threshold to be defined per age group.

RESULTS - Figure 2 shows the corrected shoulder force according to age for the 103 belted occupants having a material shock-absorber, involved in a frontal collision. Possible cases of rib fractures are also shown.

The 24 triangles indicate that the initial measured force value is caused by the material shock-absorber the 5 bands of which have broken. These belts have therefore withstood a greater force than the breaking load of the 5th. band.

The dash line connects those belted occupants who, in each age group, have the highest shoulder force with no fracture of the thoracic segment. This line separates, as best it can, the 11 cases with rib fracture from the 92 cases with no fracture. However, 2 of the 4 cases with fracture are situated below this line.

The first case (25 years old, 840 daN) sustained 5 rib fractures. In the real accident, he broke the 5 material shock-absorber bands (type A). This collision was accurately reconstituted using cadavers. The corrected shoulder load was 840 daN. However, the cadaver seated behind the subject was not so heavy as in the real accident. Deformation of the upper anchorage point was less considerable in the reconstitution than in the real accident. These indications make us think that the load of 840 daN is the lower shoulder load limit effectively withstood by this young belted occupant.

In the second case (54 years old - 440 daN), the corrected load is exact. The case of the belted occupant of same age in the neighbourhood of this observation (54 years old, 470 daN) shows that we are in an area where, for similar age and loads, the thoracic response is the result, among others, of the difference in tolerances between individuals.

Among the 11 fracture cases, 5 underwent the harmful overload of the rear adult occupant. These were:

- the 3 belted occupants under 45 years of age,
- 2 cases of flail chest, the victims being 75 and 42 years old.

It will be seen in what follows that it is probable that with no overloading due to the rear occupant, the 3 victims less than 45 years old would not have run the risk of rib fracture, seeing the violence of the collisions in which they were involved.

Age	Corrected load (daN)	ΔV (km/hr)	γ Mean (g)	Probable load area[x] (daN)
21	930) lower	53	13	650 - 900
24	800) limit	53	13	650 - 900
42	840	40	11	500 - 650

FRACTURE THRESHOLDS FOR LIVE, BELTED OCCUPANTS ACCORDING TO AGE - They can be situated as follows:

- $<$ 35 years old: 900 daN
- 35 to 44 years old: 650 daN
- 45 to 54 years old: 500 daN
- 55 to 64 years old: 350 daN
- $\geqslant$ 65 years old: 250 daN

(x) see figure 3

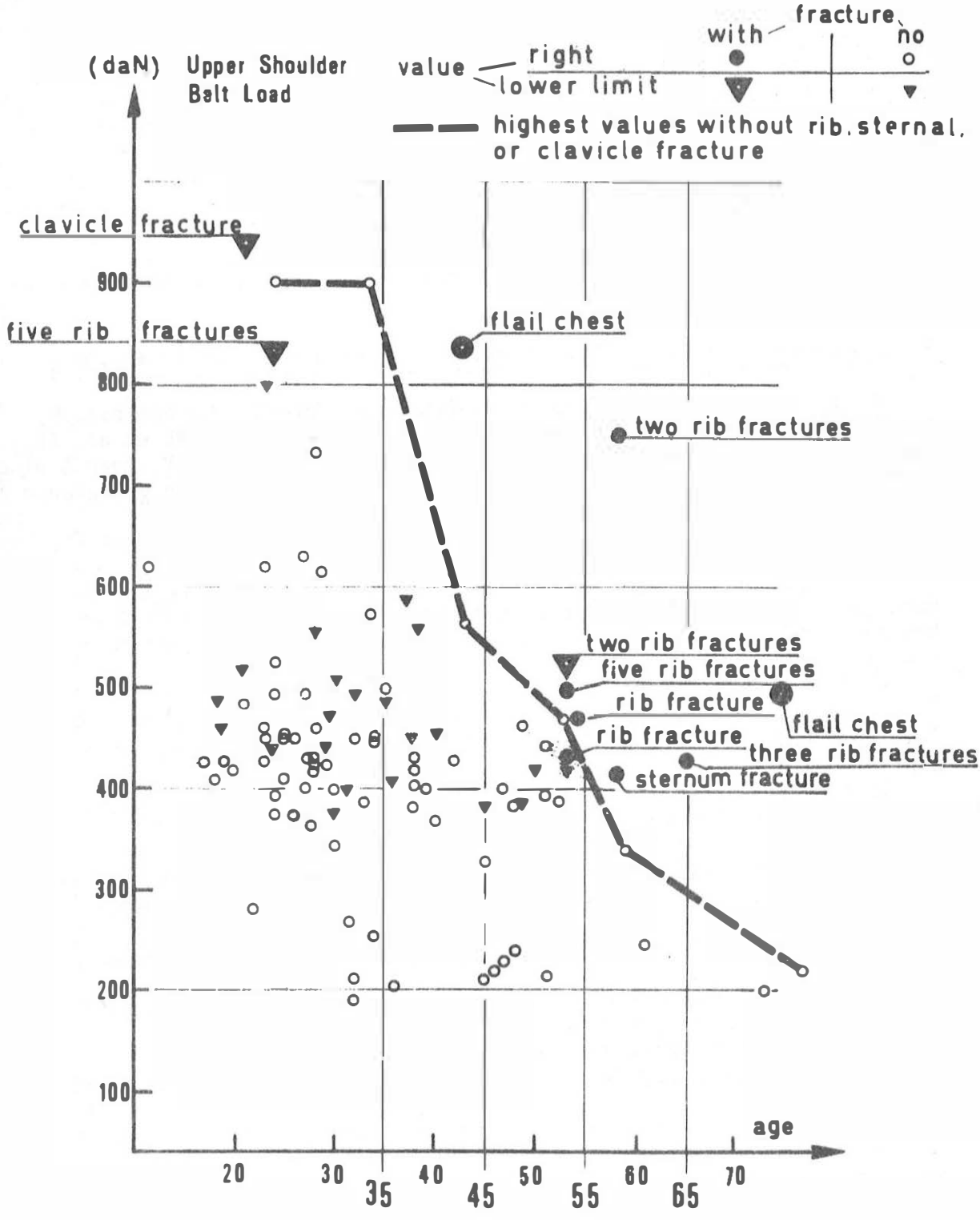


FIG. 2 SHOULDER BELT LOAD VERSUS AGE FOR 103 OCCUPANTS INVOLVED IN FRONTAL COLLISIONS

APR 5 79

The reliability of such an estimate resides in the number of observations in the neighbourhood of the load threshold suggested for a given age group. The highest uncertainty is for the 35-44 years old age group.

One must be careful of the fact that they are thresholds for the appearance of just one rib fracture and not flail chest (at least 3 consecutive double rib fractures), which situates the real limit of thoracic tolerance. For information, we would mention that Foret-Bruno (3), based on Eppinger's (4) results obtained with cadavers, shows how wide the difference in load is between the moment 1st. and 7th. rib fractures appear depending on age. The difference is 370 daN for 35 year-old, 290 daN for 45 year-old, 240 daN for 55 year-old and 180 daN dor 65 year-old.

Let us now see to what collision violences correspond the load thresholds per age group.

2. SHOULDER LOAD VALUES VERSUS FRONTAL COLLISION VIOLENCE (DIAGRAM ΔV, MEAN γ)

Method: The frontal collision violence parameters (ΔV and mean γ) are estimated in accordance with a method already stated (TARRIERE et al. (5)). We now want to find at what collision violences shown in the ΔV, mean γ diagram correspond the different shoulder load values related to the appearance of rib fracture for each of the age groups under consideration.

To draw up such a graph requires each observation used to satisfy further conditions.

- The measured value must be exact. We must therefore reject those belted occupants for which all the breaking capacity of the material shock absorber has been used, and who may have sustained a load greater than the maximum breaking threshold.
- ΔV and mean γ must be known.
- The belted occupants under consideration should not have suffered overloading due to rear occupant, sub-marining, wearing a manifestly too-loose static belt.

These conditions reduce from 103 to 29 the number of belted occupants that can be used for the graph.

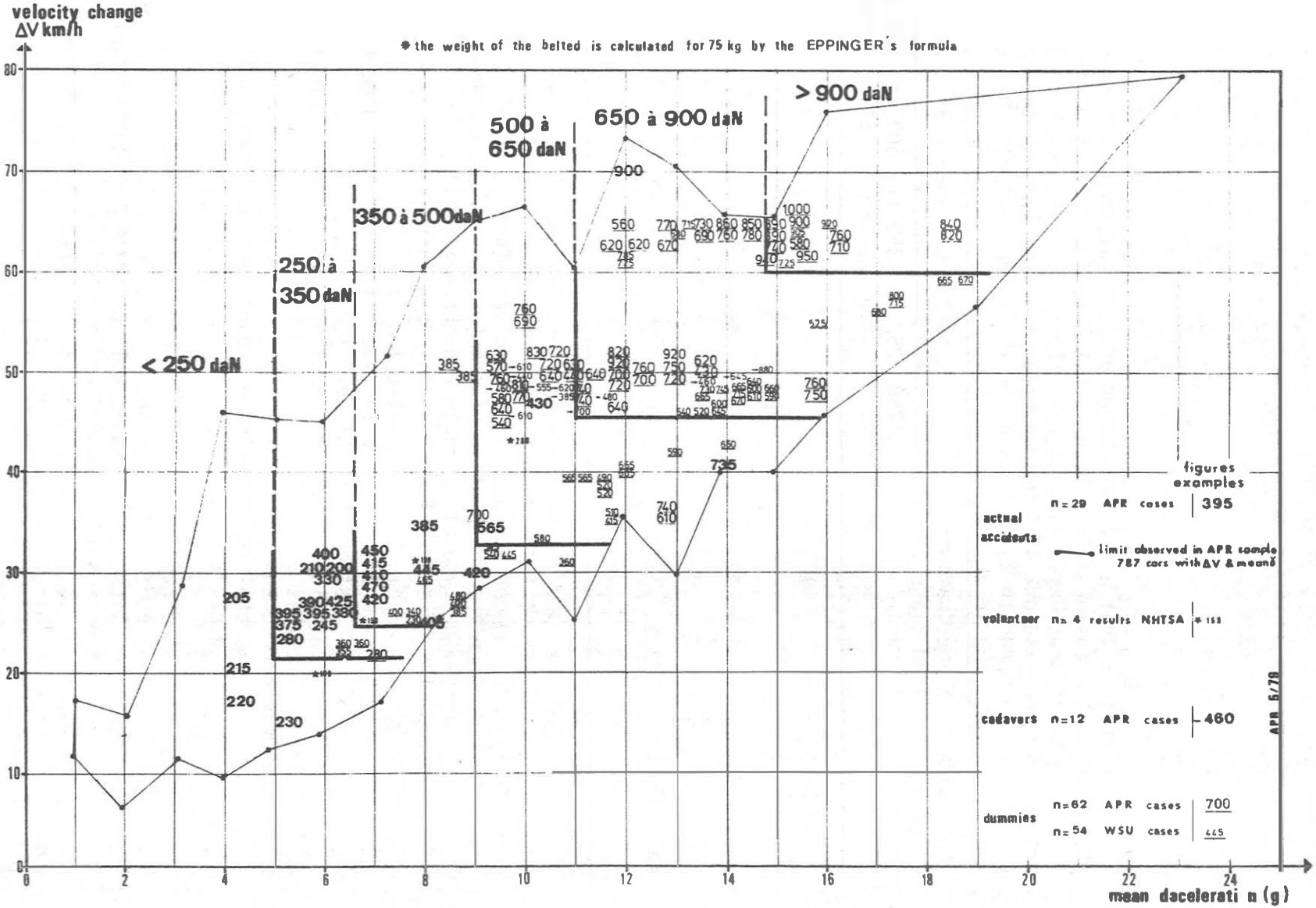
Taking account of the end we are working towards, it has become necessary to resort to similar results acquired in experiments provided that the violence of the collisions is comparable to that observed in real accidents. The following were used:

- 12 cadavers stemming from collisions conducted by the Peugeot-Renault (6) Laboratory,
- 62 dummies stemming from collisions conducted by the Renault and Peugeot test departments (not published),
- 54 dummies stemming from tests conducted by Patrick (1),
- 4 results acquired from an American volunteer with no belt pre-tensioning (7).

The estimation of the collision violence shown in the ΔV, mean γ diagram, and corresponding to the different shoulder load limits per age group, is in short effected on a sample of 161 belted occupants.

RESULTS - Figure 3, "ΔV, mean γ" diagram shows the shoulder load (corrected values) for the 161 belted occupants. The violence of the previously stated load thresholds is as follows:

fig.3: CORRECTED* SHOULDER BELT LOAD VERSUS "DELTA V" & MEAN GAMMA



Load threshold (daN)	Mean collision violence ΔV(km/hr)	γ (g)
900	⩾ 60	⩾ 14.7
650	⩾ 45	⩾ 11
500	⩾ 34	⩾ 9
350	⩾ 25	⩾ 6.5
250	⩾ 22	⩾ 5

It is obvious that a greater number of observations would have been preferable and that, consequently, these results should be regarded cautiously.

In spite of considerable scattering about the class, each load class counts practically one case out of two among the belted occupants, the shoulder load of which corresponds to this class as shown in the following table:

Load class (daN)	Number satisfying load class (N=161)	Number per load class (daN)					
		250	250 to 349	350 to 499	500 to 649	650 to 899	900
250	11	5	3	3	0	0	0
250 to 349	5	0	3	1	1	0	0
350 to 499	38	0	10	18	7	3	0
500 to 649	40	0	0	2	21	16	1
650 to 899	58	0	0	0	13	37	8
900	9	0	0	0	0	3	6

Scattering observed on the corrected shoulder load value can be explained here by four series of factors that it has not been possible to take into account up till now in our accident investigation. They concern:

- the car: deceleration profile of car (which varies furthermore depending on the type of obstacle and the velocity),
  the geometry of belt anchorage points,
- the classic "3-point" belt (static/reel):
  . how well belt is worn (even if considered correct) (importance of "belted occupant/car" loop);
  . technical characteristics of belt (stretch, dynamic response curves).
- the belted occupant:
  . morphology of belted occupant (weight being equal),
  . thorax strength.
- the obstacle:
  . strength of obstacle (already stated since it is taken into account in the car deceleration profile),
  . collision angle (and angle of belted occupant displacement-thorax sliding under shoulder belt).

The overload due to the rear occupants, "submarining" and intrusion phenomena also affect shoulder load, but these cases have been excluded from the present analysis.

Let us now examine the risks of going beyond the load thresholds (for rib fracture) in real accidents per age group.

3. RISKS PER AGE GROUP OF EXCEEDING THE LOAD THRESHOLD AT WHICH BELT-INDUCED RIB FRACTURE APPEARS IN REAL FRONTAL COLLISION.

Method: for each age group, the probability is calculated of exceeding the risk of a simple rib fracture by referring to the occupant accident frequency (in each age group) having a greater or lower violence than that which causes the critical restraint load for the age group they belong to.

For this evaluation, we have 1134 front occupants at our disposal (whose ages are known) involved in frontal collision and classified in ΔV, mean γ. The cases issue from the multipurpose investigation conducted since 1970 by the Peugeot-Renault Association (8).

This risk estimation is verified on the sub-sample of 227 belted occupants who have suffered neither notable intrusion nor rear occupant overload.

The thresholds of initial rib fracture per age group in the "ΔV, mean γ" diagram were defined in the previous chapter for belted occupants weighing 75kg. These thresholds must be corrected to take account of the real average weight of the front occupants per age group (correction made using the 2402 front occupants in our investigation, of whom we know the age and weight).

The shoulder load correction is made by applying the Eppinger equation.

Finally, the new thresholds are defined in the "ΔV, mean γ" diagram by interpolating with relation to the results obtained for 75 kg.

The results are shown in the following table:

Age group (years)	Average weight (kg)	Shoulder load (daN) 75 kg	for average weight	Threshold in "ΔV, mean γ"	
< 35	62,8	900	800	55	13,5
35 - 44	66,1	650	600	42	10,5
45 - 54	67,3	500	465	32	8,5
55 - 64	68,3	350	330	24	6,2
≥ 65	67,5	250	235	21	4,9

It can be seen, for example, that in a real frontal collision, the ΔV limit 55 km/hr, and mean deceleration 13.5 g is a limit not to be exceeded for young people less than 35 without running the risk of a belt-induced rib fracture.

We are now trying to find the theoretical frequency of the belt-induced rib fracture risk per age group for those involved in real frontal collision.

RESULTS - The Peugeot-Renault "accident" investigation includes 1134 front seat occupants, whether belted or not, whose age and frontal collision violence (ΔV, mean γ) are known.

The situation of each of the 1134 occupants is compared with regard to age and frontal collision violence, with the limit of violence (related to age) corresponding to initial, belt induced rib fracture.

The results are shown in the following table:

Age Group (years)	Percentage involved	Relationship between those exceeding the threshold (of initial belt-induced rib fracture) with all those involved.	
		- Involved -	- Percentage -
< 35	59 %	24/666	4 %
35 - 44	18 %	20/198	10 %
45 - 54	13 %	38/151	25 %
55 - 64	6 %	22/70	31 %
≥ 65	4 %	28/49	57 %
Total:	100 %	132/1134	12 %

It appears that 88 % of front occupants involved in a frontal collision do not run the risk of belt-induced thorax fracture. This risk varies considerably depending on age.

The risk is only 4 % for front occupants less than 35, who represent 60 % of front seat occupants. Over 65, one occupant out of two risks one or more thoracic fractures. Luckily, they represent only 4 % of front occupants.

One must be careful of the fact that too-low a shoulder load limitation obtained by increasing the stopping distance would penalize the more tolerant belted occupants. The latter, who are by far the greatest number, would then be exposed to more frequent impacts with the passenger compartment units.

Sub-sample of belted occupants and their own - The risk of rib fracture is verified versus age group for the 227 belted front occupants having sustained no considerable intrusion, no rear occupant overload, and involved in a frontal collision classified as "ΔV, mean δ ".

The following table gives the results of this analysis.

Belted occupants involved in a frontal collision less violent than threshold			. Age group . Corrected load threshold for average mass of age group . Limit in diagram ΔV, mean δ .	Belted occupants involved in frontal collision above threshold		
No of cases with fracture	No of involved	(%)		No of cases with fracture	No of involved	(%)
3	124	2 %	< 35, 800 daN, 55 km/hr 13,5 g	1	5	20 %
2	40	5 %	35-44, 600 daN, 42 km/hr, 10,5 g	0	4	0 %
4	31	13 %	45-54, 465 daN, 32 km/hr, 8,5 g	5	8	63%
1	9	11 %	55-64, 330 daN, 24 km/hr, 6,2 g	7	8	88%
0	7	0 %	≥ 65, 235 daN, 21 km/hr 4,9 g	3	7	43%
10	211	5 %	TOTAL	16	32	50%

Out of the 227 belted occupants, only 26 (i.e. 11 %) sustained one or more thoracic fractures. Although women represent only 35 % of those involved in front seats, and although, on an average, they weigh less than men, we observe that they are over-represented among the 26 belted occupants sustaining rib fracture (16/26, i.e. 62 %). Belted occupants involved in collisions less violent than the thresholds corresponding to their age, have one or more rib fractures in the proportion 10/211 (i.e. 5 %).

On the other hand, when the threshold is exceeded, the proportion rises to 16/32 (i.e. 50 %).

The ideal theoretical proportions from 0 to 100 %, depending on whether the defined threshold is exceeded or not, are not obviously verified.

There is no need for concern in as much as scattering is caused by:

- small sample size,
- differences in weight with relation to the average weight of each age group,
- a probable smaller tolerance for women,
- restraint because of knee contact.

This partly explains why 8 belted occupants out of 9 aged less than 45 suffered no rib fracture although the corresponding threshold for their age was exceeded.

Only two cases of flail chest were recorded out of the 227 belted occupants studied (i.e. 1 %). These were two belted occupants over 55 involved in serious collisions (40 km/hr - 11 g for one, 60 km/hr, 15 g for the other).

DISCUSSION

1 - Specifying a correct parameter for the thorax is an important problem for biomechanics. All occupant protection systems in frontal collisions, whether they be safety belts, air-bags, steering wheel or dash-board, apply forces directly to the thorax. If the head doesn't hit anything, the critical part is the thorax.

Specialists agree on one point. It is desirable for the thorax protection criteria to be measured on the dummy itself and to be independant of the restraint system used.

This is not the case for shoulder load (or load at upper belt anchorage point) which is closely related to 3-point belt technology (static or reel), having a 5 to 6 cm wide shoulder belt.

The results related to the shoulder force are not applicable to wide or inflatable shoulder belts, and even less to air-bags. As they are "pretension" belts, only those data relating to the shoulder loads corresponding to the initial thoracic fracture thresholds according to age remain valid (figure 1). Pretension belts lower the level of shoulder load for a given set of violence and weight conditions.

Shoulder load, or upper belt anchorage point load, is related to the 3-point belt technology. Not being measured on the dummy, this parameter cannot be retained as a thorax protection criterion.

It remains with biomechanics to define the parameter which most accurately reflects human response, taking into account the observations for live belted occupants. The present proposals concern the total load, the load per unit area, the deflection or any index derived from the deceleration/time curve recorded with an accelerometer located in dummy thorax.

Reconstituting real accidents using dummies and cadavers, plus the work conducted on characterizing the cadaver bone condition, should enable the required correspondences between the thoracic responses of live occupants, cada-

vers and dummies to be established.

2 - Stating injuries using the Abbreviated Injury Scale (9) exagerates the seriousness of a large number of cases by assigning a degree 3 to 3 rib fractures (or sternum or clavicle fractures). Out of 22 belted occupants showing only one or two thoracic fractures and coded AIS 3, 9 were not admitted to hospital, 12 were admitted to hospital for less than 9 days and 1 stayed in hospital for 18 days. The arithmetical mean is 3 days in hospital. The injuries, from the standpoint of seriousness expressed by AIS, showed the same severeness of injury as those who suffered head injury with displaced fracture of the skull, the therapeutic difficulties of which we know of, as well as the risk of after-effects. This lack of consistency means general overestimation of the seriousness of one or two rib fractures. It is proposed to review this point and to replace it with the following scale:

Allowable levels:	AIS 1 - One or two rib fractures
	AIS 2 - From 3 to 7 rib fractures, or fracture of the sternum or the clavicle, associated or not with a number of ribs lower than 4.
Levels at which protection is sought:	AIS 3 - Flail chest with no displacement. At least 3 consecutive double rib fractures or more than 7 rib fractures.
	AIS 4 - Flail chest with displacement.
	AIS 5 - Flail chest requiring respiratory aid.

CONCLUSIONS

1 - The limit shoulder load withstood by the belts corresponding to the absence of thoracic fracture (fitted with classic "3-point" belts) varies depending on age. The estimate of the limit load (corrected for a weight of 75kg) per age group is as follows: $<$35 years old: 900 daN, 35 to 44: 650 daN, 45 to 54: 500 daN, 55 to 64: 350 daN, $\geq$ 65: 250 daN.

2 - Seeing the average weight per age group, we can estimate that the risk of initial, belt-induced thoracic fractureoccurs, at the present time, at the following (ΔV, mean γ) violence thresholds: $<$ 35 years old: 55 km/hr and 13,5 g, 35 to 44: 42 km/hr and 10,5 g, 45 to 54: 32 km/hr and 8,5 g, 55 to 64: 24 km/hr and 6,2 g, $\geq$ 65: 21 km/hr and 4,9 g.

3 - The percentage of front occupants involved in frontal collision per age group is as follows: $<$35 years old: 59 %, 35 to 44: 18 %, 45 to 54: 13 %, 55 to 64: 6 %, $\geq$65: 4 %.

4 - 88 % of front occupants, whether belted or not, are involved in frontal collisions the violence of which is lower than the different thresholds (related to age) of initial, belt induced thoracic fracture (in the absence of overloading by rear occupant).

It should be underlined that front occupants less than 35 years old not attaining the threshold of initial rib fracture (800 daN for 62,8 kg, or again 900 daN for 75 kg, i.e. 55 km/hr, 13.5 g) represent on their own 55 % of all front occupants involved in frontal collisions.

5 - The risk of one or more belt-induced thoracic fractures varies considerably depending on age. The probability is 4 % for the less than 35 year olds, 10 % from 33 to 44, 25 % from 45 to 54, 31 % from 55 to 64, 57 % for the 65 year olds and more.

6 - Belt-induced flail chest is rare (1%). Out of 227 belted front seat occupants involved in frontal collisions rated as " ΔV, mean γ " and not ha-

ving suffered any notable intrusion or overloading by rear passenger, only two cases of flail chest were observed for persons age more than 55.

7 - An injury criterion based on "shoulder force or upper belt anchorage point force" is closely related to the technology of 3-point belts having a 5 to 6 cm wide shoulder belt. Such a criterion is not applicable to the other restraint systems. Direct measurement on dummy should be preferred as a criterion.

8 - Reconstituting real accidents using dummies and cadavers, plus the work conducted on characterizing the cadaver bone condition, should enable the required correspondences between the thoracic responses of live occupants, cadavers and dummies to be established.

9 - Stating thoracic bone injury with the Abbreviated Injury Scale exagerates the seriousness of a large number of cases by assigning a degree 3 to 3 rib fractures. A scale is proposed whereby degree 3 would be attained for flail chest without displacement or more than 7 rib fractures.

ALL IN ALL, the risk of rib fracture by the shoulder belt is low, in the region of 12 %. The risk is only 1 % for these injuries to be serious enough to achieve flail chest which alone shows any real character of seriousness.

Flail chest is sustained by old people whose tolerance is three times less than for young people (measurement of shoulder load). To protect would require very low shoulder load levels, which would benefit in no way the large majority of belts as young people withstand the impact much better.

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