INTERACTION OF CAR PASSENGERS IN FRONTAL, SIDE AND REAR COLLISIONS

by

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Abstract

With rising shortage of energy resources and higher fuel prices it is expected that the passenger rate per car will rise in the future.

Based on earlier observations at the test facility of the Federal Highway Research Institute (BASt) a project about interaction of car passengers was conducted. The project is supported by the EEC Biomechanics Program, Phase 2. 30 Tests were conducted for frontal, side and rear collisions from end 1979 till June 1980. The aim of this paper is to report and discuss these results and to present conclusions. It is expected that the project will be continued within the EEC Biomechanics Program, Phase 3.

1. Introduction

With rising shortage of energy resources and higher fuel prices it is expected that the passenger rate per car - today at about 1,8 - will rise in the future. Since the end of 1979 the increase of "car pooling" is encouraged by the German Government. To reduce the risk of being hurt or fatally injured in car accidents, all passenger cars registered in the Federal Republic of Germany after May 1978 have to be equipped with restraint systems (at least lap belts) on the rear seats. Further regulations to fit older cars with rear seat belts are in progress.

In previous research conducted at the test facility of the Federal Highway Research Institute (BASt) was observed that in frontal impacts belted front seat passengers were additionally loaded by unbelted rear seat passengers. Rear seat passengers were hit by front seat passengers in high velocity rear impacts because the front seat back support often broke and the occupant moved backwards.

The aim of this study is to evaluate and quantify the influence of interaction of car passengers in impacts. The project was started in phase two of the EEC Biomechanics Research Program* at the end of 1979 and will be accomplished at the end of phase three in 1981. It is planned to conduct a total number of about 70 car tests. In the first phase of the project 30 impact tests were conducted at the crash test facility of the BASt.

Only in a very small number of research studies reported in the literature effects of interaction are quantified mostly these effects are described

*Under Contract G 3 between Commission of the European Communities and the BASt

qualitatively. In some studies which delt with other subjects injuries or dummy loads could be identified to be caused by interaction, f.i. SEIFFERT /¯1_7. Furthermore these effects are difficult to discover especially in accident analysis. Therefore we suppose that interaction loadings are underestimated in the field of biomechanics.

WALZ et al. /¯2_7 evaluated from accident analysis that in frontal collisions the front seat occupants are overloaded by the impacting unbelted rear occupants. The additional loadings generate lesions of the thorax and abdomen induced by the restraint system and injuries to head and neck because the frontal passenger is pushed against steering wheel and dashboard.

In dummy tests SEIFFERT /¯3_7 measured doubled loadings in the frontal occupant if he is impacted by an unbelted rear seat dummy.

In lateral impacts CESARI et al. /¯4_7 accentuated two effects:

- on one hand an increased frequency and severity of injuries found in the occupant sitting on the impacted side caused by compression due to the loading by the other occupant
- and on the other hand a certain minor injury risk of the offside passenger who strikes the nearside passenger and who is partially or nearly totally prevented to hit the car's side structures.

WALZ et al. /¯2_7 and HUELKE /¯5_7 evaluated distinct figures of injury hazard in frontal and rear impacts. They estimated an injury rate of about 20% for front respectively rear seat passengers caused by occupant-occupant contact.

2. Test Method

The test method fixed before the program was only slightly modified if it seemed to be inevitable. As test car types were selected VW Golf, VW Passat and FORD Tanus. The selection parameters of car type were:

- easy and cheap to buy
- today in production
- high share in traffic (for 1978: Golf 9,4%, Passat 5,8%, Taunus 4,6%)
- subcompact/compact size.

The test cars were bought from the used car market. They were all in a normal technical condition corresponding to their age (age mean 4,5 - 5 years)in traffic. All front seats were furnished with head rests and three point automatic seat belts. The head rest types were integrated head rests provided by the car manufacturer and extended seat backs. The cars were impacted by a rigid moving barrier attached with the "contoured surface" according to SAE J 972a. Barrier masses were 1100 and 1800 kg with an axle load distribution of 60/40 percent (front/rear axle).

For this reported first phase impact angles were fixed to 0^0, 90^0 and 180^0. For each angle two collision speeds were settled. Each of the 6 configurations were repeated 5 times.

During the tests the cars were stationary with their own brakes fully activated, additionally the lowest gear was engaged. To controll the motion of the test vehicles during and after crash, the moving barrier's brakes were activated after primary impacts. The braking system had to be released shortly before impact to afford that full braking force was available at 1 - 1,2 m behind initial contact point.

The applied dummies were two new bought 50% male Sierra 292-1650 type calibrated by Sierra (Transaero Inc.) according to PART 572 (Hybrid II) specification. The joint characteristics of the dummies were adjusted before each test. For studying effects of greater distance between dummies in side collisions two 5% female dummies Sierra 592-805 were additionally inserted in the test car. The seating positions of the dummies were controlled and kept constant in the different test configurations.

The Hybrid II and 1 female dummy were equiped with triaxial accelerometers in head, thorax and pelvis. Longitudinal forces were measured in the femurs. If applied 4 belt forces were measured; 2 each in shoulder and lap belts. The motions of the dummies were filmed by 2 high speed cameras attached to the test car and 2 high speed cameras stationary on the ground.

2.1 Frontal Collision

The selected car type was FORD Tanus with four doors. The test cars weighted 1150 ± 15 kg. The mass of the moving barrier was 1800 kg. Impact velocities and ΔV were measured (via double integration) within the range of:

29,4 - 30,2 km/h and 18,2 - 18,9 km/h for the 30 km/h tests,
59,4 - 59,8 km/h and 36,4 - 37,4 km/h for the 60 km/h tests.

The average side displacements of the test cars after crash were less than 20 cm in the 30 km/h tests and less than 40 cm in the 60 km/h tests. Therefore it was assumed that the impact load on the car was longitudinal. One Hybrid II dummy was seated on driver seat the other on seating position behind him. The frontal occupant was belted.

2.2 Side Collision

The type of car was Volkswagen Golf with two doors. The test car weighted 1045 ± 5 kg. The mass of the moving barrier was 1100 kg. Impact velocities and ΔV were measured within the range of:

29,5 - 30,1 km/h and 15,1 - 15,3 km/h for the 30 km/h tests,
44,3 - 45,3 km/h and 23,0 - 26,5 km/h for the 45 km/h tests.

It was observed a fairly low resultant side displacement and resultant rotation. As evaluated from high speed filming both movements were generated for the greatest part after the crash pulse was finished. Therefore it was assumed that the impact load on the test car was mainly rectangular.
Two Hybrid II dummies were positioned on the front seats. Additionally two 5% female dummies (1 equiped with accelerometers) were positioned on the rear seats. The frontal passengers were belted.

2.3 Rear Collision

The selected car type was Volkswagen Passat with four doors. The test cars weighted 1075 ± 20 kg. The mass of the moving barrier was 1800 kg. Impact velocities and ΔV were measured within the range of:

29,0 - 30,5 km/h and 18,7 - 21,1 km/h for the 30 km/h tests,
59,6 - 60,4 km/h and 34,7 - 37,4 km/h for the 60 km/h tests.

The average side displacements of the test cars were about 30 cm in 30 km/h tests and 55 cm in 60 km/h tests. The side displacement of the Passat was caused among others by the stiffness of the spare wheel which is placed in the luggage compartment. This low amount of sideward motion was mainly generated after the crash pulse was finished when the car was slipping on the ground; therefore it was assumed, that the impact load on the test car was mainly longitudinal. Two unbelted Hybrid II dummies were positioned on the right seats of the car.

3. Test Results

No high velocity head impacts were measured (in the test program HIC was measured lower than 500). Interaction effects however were observed in the following measuring parameters:

- frontal collision
    - frontal passenger: accelerations of thorax and pelvis, forces in shoulder/lap belts and in the femurs
    - rear seat passenger: accelerations of thorax and pelvis, femur forces
- side collision
    - nearside and offside passengers: accelerations of thorax and pelvis
- rear collision
    - frontal passenger: accelerations of thorax and pelvis
    - rear passenger: femur forces.

Complete quantitative evaluation of additional loadings caused by interaction is quite difficult because up to now no tests under the same configuration but without occupant-occupant contacts have been conducted in this program.

Furthermore the test results have to be interpreted carefully because Hybrid II dummy response is not in all aspects optimal for studying interaction effects:

- in longitudinal collisions the knees of the rear seat dummy impact the back of the front seat dummy. Due to the construction of the thorax spine (it consits of a metal box with ribs attached to) the back of the dummy is very stiff. High contact forces and accelerations with short durations are resulting
- the well known poor kinematic response of the Hybrid II in side collisions is primarily caused by its unelastic shoulder region. In consequence of this, fairly low shoulder and thorax deformations as well as head motions can be observed with poor fidelity in comparison with human response.

The significant evaluated effect of interaction is the change of direction of acceleration in the additionally loaded occupant, because the interaction forces are effective in the opposite direction of the primary impact forces. If interaction happens after the primary impact pulse is finished high peak to peak acceleration levels with a considerable extension of acceleration pulse duration are the consequence. If interaction happens when the primary impact is not yet finished the primary impact acceleration level is diminished by the opposing force and the secondary acceleration level is lower too. In consequence of this high compression forces occur in the additionally loaded occupant.
The compression forces cannot be measured directly but estimated indirectly with regard to the measuring values of the impacting passenger.

For the estimation of higher injury risk of car occupants caused by interaction are up to now no protection criteria available concerning compression forces and adversal accelerations with high peak to peak levels. It is shure however that interaction can produce a higher injury risk and should be observed in future safety research.

3.1 Results of Frontal Collisions

In frontal collisions the unbelted rear occupant moves forward relatively to the car. He hits the front seat back and bends it with his knees. After further forward motion he hits the belted frontal occupant and loads him with this mass forces via legs and thorax.

In 30 km/h tests interaction occured when the primary impact - observed preferably in the belt forces - of the frontal occupant was settled. All measured loadings of the frontal occupant remained fairly low. The maximum femur forces of the impacting occupant were in the range of 265 to 390 daN, about 100 to 150 daN were caused by the retaining forces of the frontal seat back.

The thorax accelerations of the frontal occupant induced by the seat belts amounted to 13 - 25 g, the interaction accelerations induced by the rear occupant's femur forces amounted to 18 - 33 g in opposite direction. Peak to peak values of thorax accelerations lay between 28 and 48 g. Normal acceleration pulse duration was doubled by interaction, because the impact of the whole body of the rear seat occupant lengthened the forward acceleration pulse which was primarily generated by the rear seat passenger's femur forces.

In three 60 km/h tests the front seat adjustment mechanism failed and the seat was pushed forward by the rear seat occupant. In all tests the frontal passenger hit the dashboard with his legs and the steering wheel with his thorax. In 2 tests maximum femur forces were measured to 480 and 895 daN, in the remaining 3 tests the femur forces reached 1100 to 2050 daN (protection criteria 1000 daN). The femur forces of the rear occupant emerged when the primary impact on the frontal occupant was not yet finished. These forces reached values between 775 and 1696 daN. In 1 test the maximum femur forces remained below the protection criteria 1000 daN. In all tests the protection criteria of the femur was exceeded in at least one dummy. About 150 to 195 daN femur force of the rear occupant was caused by reaction force of the front seat back.

In the phase when the belt forces were decreasing the rear occupant hit the back of the frontal occupant (first with his knees than with his trunk) and generated belt forces. These additional belt forces are estimated to amount to 50 to 120% of belt forces without interaction, furthermore the duration of the forces is extended by 60 to 80%. It was necessary to estimate the interaction forces because the primary impact was not yet finished when they became effective.

The thorax and the pelvis of the frontal occupant were decelerated by the seat belts like in accidents without interaction. When the legs of the rear seat passenger impacted the back of the frontal passenger he was accelerated forward. The forward acceleration pulses reached high peak values at short duration . But only 2 thorax and 1 pelvis accelerations slightly exceeded the respective protection criteria (60 g/ 3 ms and 80 g/ 3 ms). The peak to peak accelerations however were measured to 65 - 134 g for the thorax and 67 - 122 g for the pelvis. The thorax impact of the frontal occupant on the steering wheel had a low severity.

Figures 1 - 3 illustrate the decribed findings.

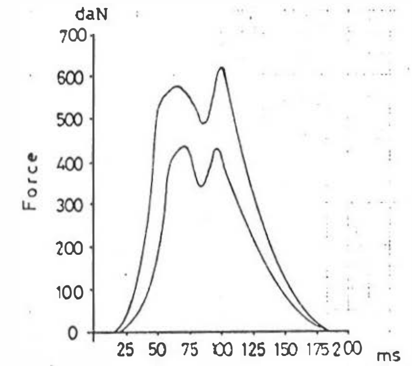

Fig. 1: Belt forces shoulder and lap, frontal occupant, test nr. 28, 60 km/h, frontal collision

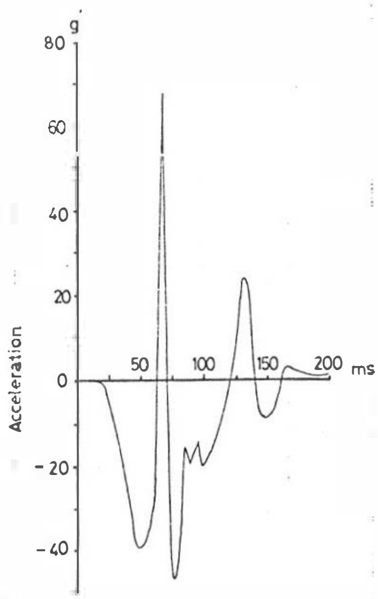

Fig. 2: Thorax acceleration, frontal occupant, test nr. 28, 60 km/h frontal collision

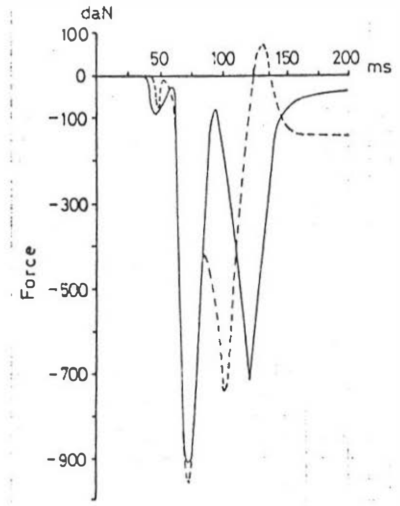

Fig. 3: Femur forces left and right, rear occupant, test nr. 28, 60 km/h, frontal collision

3.2 Results of Lateral Collisions

In lateral impacts the dummy sitting at the impact side (nearside) of the car was thrown to the middle of the compartment where he hit the dummy who was sitting opposite (offside) to him. In the 30 and 45 km/h tests interaction occured when the primary impact produced by intrusion of the car side structure was nearly finished. This primary impact pulse had high peak accelerations with short durations.

The occupant-occupant contacts generated dummy loads which reached nearly the same level in each of the interacting body regions. As evidently the interaction loads were remarkably lower than those measured in the primary impacts. But the total pulse duration was nearly doubled by interaction.

In 30 km/h tests the maximum primary impact accelerations were measured in the nearside front passenger to 60 - 120 g for the thorax and 64 - 98 g for the pelvis. The maximum acceleration levels caused by interaction were measured to 38 - 55 g for the thorax and 10 - 20 g for the pelvis. The average peak to peak values were evaluated to 134 g (+89 g, -45g) for the thorax and 93 g (+83 g,

-16 g) for the pelvis.

The acceleration levels measured in the 45 km/h test were considerably higher: in primary impacts 149 - 158 g for the thorax and 150 - 166 g for the pelvis. The maximum acceleration levels caused by interaction were measured to 58 - 152 g for the thorax and 35 to 160 g. The average peak to peak values were evaluated to 254 g (+154 g, -100 g) for the thorax and 205 g (+157 g, -48 g) for the pelvis.

For the purpose of studying effects of greater space between dummies two 5% female dummies were positioned on the rear seats. The respective accelerations of the nearside passenger were fairly lower. Thorax accelerations of all 45 km/h collision tests are shown in figures 4 and 5.

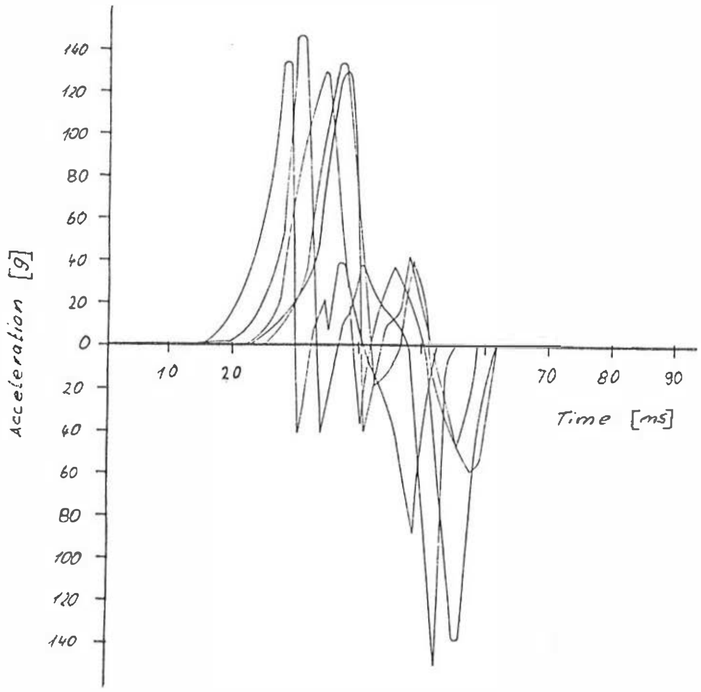

Fig. 4: Thorax acceleration, nearside occupant, 45 km/h, all side collisions

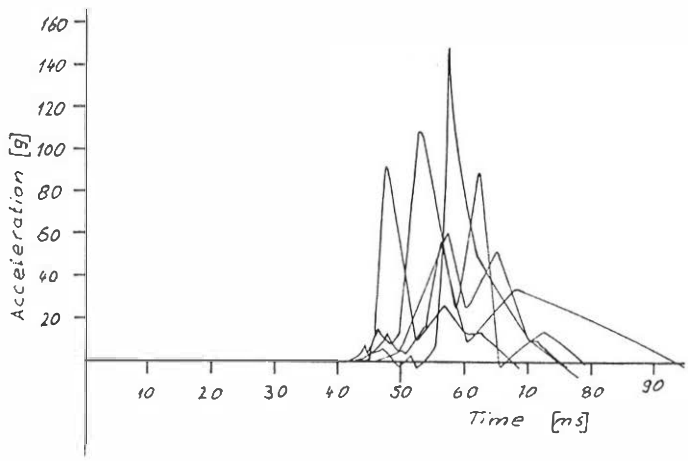

Fig. 5: Thorax acceleration, offside occupant, 45 km/h, all side collisions

3.3 Results of Rear Collisions

In rear collisions interaction was observed mainly in the thorax of the frontal passenger and in the femur forces of the rear passenger. The mass forces of the frontal occupant bended his seatback rearward till it hit the knees of the rear seat occupant. Because common seat backs - the seat back of the seat type used in this tests too - do not produce considerable damping forces under concentrated load as caused by the knees of a rear seat occupant, the femur forces were nearly completely applied to the back of the frontal occupant. The maximum damping forces were measured between 30 and 120 daN.

In 30 km/h tests the thorax of the frontal occupant was accelerated forward by his seat and seat back at a level of about 6 - 10 g. The maximum forward acceleration caused by femur forces of 225 - 455 daN of the rear occupant amounted to 19 - 32 g.

In 60 km/h tests forces and accelerations caused by interaction were considerably higher. The thorax accelerations induced by the seat back lay between 10 and 12 g. Femur forces of 1185 - 1600 daN caused forward accelerations in the thorax of the frontal occupant from 37 to 88 g.

The pelvis accelerations of the rear seat passenger showed high peak to peak values (74 to 156 g), which were generated first by the low damping of the back of the rear bench and then by the transmission of high femur forces in the opposite direction. Figures 6- 8 illustrate the described findings.

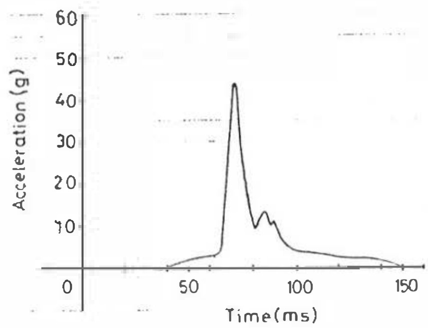

Fig. 6: Thorax acceleration, frontal occupant, test nr. 8, 60 km/h, rear collision

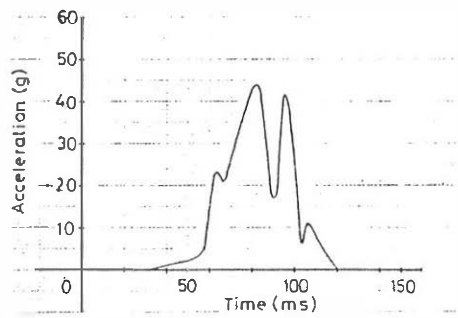

Fig. 7: Pelvis acceleration, frontal occupant, test nr. 8, 60 km/h, rear collision

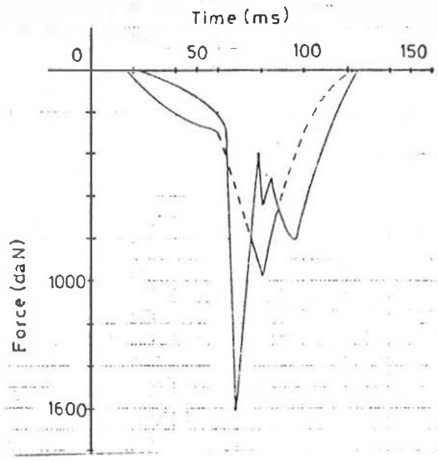

Fig. 8: Femur forces left and right, rear occupant, test nr. 8, 60 km/h, rear collision

4. Conclusions

- It is not sufficient to look only at the established protection criteria in order to classify occupant loadings and estimate unfavourable injury potential caused by interaction of car passengers. It is rather necessary to examine the different variables in detail especially those of the dummy who generates additional loadings on the other dummy.
- The requirements of ECE 17 and 25* concerning car seats and head rests are considered to be too low.
- It is usefull and necessary to integrate the different countermeasures mentioned below within a comprehensive safety system to avoid or to diminish interaction effects.
- For frontal impacts should be required: obligatory seat belt wearing on rear seats, because additional loadings of car passenger caused by interaction would then become insignificant. This is relevant for front and rear seat occupants.
- If a certain share of unbelted rear seat occupants is taken in account respective unavoidable, for frontal collisions could be required:
    - reduction of additional belt loads on the frontal occupant (belt forces not higher than 800 daN)
        - by resistance of seat adjusting mechanism to forces of about 1000 daN
        - by resistance of seat back adjusting mechanism to a moment of about 150 to 200 daN
    - reduction of thorax accelerations of the frontal occupant and reduction of femur forces of the rear occupant
        - by padding of the front seat back, f.i. by a steel sheet covered with plastic foam attached to the seat back at the height of the rear seat occupant's knees
    - the head rest should be prevented to leave its mounting, f.i., by a shape locked stop at maximum height adjustment.
- For developing sufficient countermeasures in side collisions it is necessary to evaluate the two different interaction effects observed: compression forces and high peak to peak accelerations in the respective body region of the nearside occupant. For both effects no protection criteria are applicable up to now.
- Reduction of compression forces on the nearside passenger could be achieved:
    - by increasing space between the nearside and opposite passenger. The offside passenger should hit the nearside passenger when the primary impact pulse is decreased or finished. From our 45 km/h tests a distance

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*most important requirements of ECE 17 and 25: seat rail and adjusting mechanism of the seat: 20 g acceleration on seat alone; seat back adjusting mechanism: moment of 53 daNm round h-point transmitted to seat back; head rest especially height adjustment mechanism: impact of a dummy block with given mass, angle and velocity between offside and nearside passenger of roughly 25 cm ascertains no compression forces (estimation: car intrusion 26 - 30 cm plus car displacement 8 - 10 cm minus interior deformation 3 - 5 cm and minus distance between shoulder and side structure 9 cm)

- by retention of the offside passenger via
  - seat back: a support shaped around passenger's shoulders avoids the thorax to slip down and enables a certain padding effect. On the basis of our 45 km/h tests a seat back of front and rear seats should withstand an sideward acceleration pulse of about 10 g with 70 ms duration, allowing a side displacement of the shoulder of an occupant of not more than 20 - 22 cm
  - shoulder belt: mayor effects of shoulder belts can be afforded by retracting the belt during impact and positioning the outward arm of the passenger in a more horizontal bearing. In this way the arm can "hook" around the shoulder belt. This position could be supported by interior car shape.

- Reduction of peak to peak thorax accelerations of the nearside passenger is possible
  - by the above mentioned retention of the offside passenger
  - by padding of the space between two opposite car passengers.
- For safety improvements in rear collisions a reduction of thorax accelerations of the frontal occupants and a reduction of femur forces of the rear seat occupants should be required. Generally the same countermeasures deduced from frontal collision tests for padding and stiffening the frontal seat backs are effective.

5. References

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