Effects of Belt Restraint Systems on Occupant Protection Performance in Side Impact Crashes

Nobuyoshi Shimoda, Yousuke Nishida, and Akihiko Akiyama,
Honda R&D Co., Ltd.

Abstract

Currently, belt restraint systems are among the most effective occupant protection devices now available and mandatory usage laws are spreading among the world's nations. Accordingly, the belt usage ratio is also increasing annually. Following the implementation of the FMVSS 208 Passive Restraint Regulation in the United States, a diversity of belt restraint systems has come to be offered on the automotive market.

This implies that an increasing number of belt-restrained occupants may be involved in side impact traffic accidents in the future.

Considering such a situation, in this paper, we focused attention on occupant head behavior in a side impact crash, and investigated the effects of several belt restraint systems on occupant head behavior and impact protection performance in side impact crashes.

For this purpose, we conducted 10 full-scale side impact crash tests according to the National Highway Traffic Safety Administration (NHTSA) test procedure using one model of a Honda subcompact car.

In half of these test cars, two '88 improved-type Side Impact Dummies (SID) were placed one behind the other on the near-side.

In the other half, two SID's were placed side by side in the front seats.

Five different restraint conditions were tested in both seating configurations, i.e., lap belts only, 2 point automatic shoulder belts (2P/A), 3 point automatic belts (3P/A), 3 point manual belts (3P/M) and no-restraints.

Based on these test results, we compared and analyzed whether SID head behavior and SID torso region accelerations were affected by differences of condition such as occupant restraints, seating positions and presence of a side occupant, and discussed the effectiveness of the belt restraint systems tested on side impact occupant protection.

Introduction

The most popular belt restraint system now in use is 3P/M, a combination of lap and shoulder belts. But in a side impact crash, it has been argued, this belt system is mainly effective in protecting the far-side occupant and precluding the ejection of occupants. (1)*

This lack of effectiveness for the near-side occupant may be because the effective buffer distance from the outmost side of the vehicle body to the near side occupant is so short, compared with the distance from the front end of the vehicle to the occupant, that he may be more directly exposed to an impact from a striking car.

Nearly half the deaths in side impact crashes are related to head injuries. (2, 3 and 4) Yet, passenger car occupants, if in a proper seating position, seldom receive fatal head injuries from the initial direct impact in a car side crash. Presumably, the injuries are caused by the secondary contacts with the interior of their own car, or with outside objects during the moments immediately following the crash. Even if we exclude the consequences of occupants' ejection from the car, the incidence of head injuries in side impact crashes is by no means negligible. (5)

Ideally, it would be desirable if belt restraint systems offered occupant protection for secondary impacts in side crashes as well as in head-on collisions.

In this context, it can be argued that belt restraints are effective in mitigating injuries to near-side occupants.

But, in practice, experience shows that near-side occupants with 3P/M sometimes get serious head injuries in side impact crashes.

To date, the head injury mechanism of side-impact has not yet been fully clarified.

An analysis of traffic accident statistics indicates that in about half of all head injury cases, head contact points are "unknown". (3)

So, in order to provide satisfactory protection against head injuries in side-impact, it would be useful to clarify the behavior of the belt-restrained occupants' head.

As the first step in such research activities, this paper tries to find out how the heads of belt-restrained occupants behave, how they are affected by alternative belt restraints and conditions, and whether belt restraints can be used effectively for the occupants' head protection in side impact crashes.

A series of full-scale side impact tests were carried out according to the NHTSA test procedure (6) on 10 examples of sections of a generic model of a subcompact passenger car (Honda Quint Integra 3 door).

As shown in figure 1, each of 10 test cars had different SID seating configurations or restraint conditions.

During the tests, SID head behaviors and torso accelerations were observed to investigate the effects of the restraint systems in each SID seating position.

The NHTSA side impact test procedure has not yet been fully developed as a side impact test. Also the SID is not satisfactory with respect to some specific items to be measured nor do its responses have fully reliable biofidelity.

However, we decided to adopt the test procedure and the dummy as an interim means of comparison in this series of tests.

The occupant protection performance of each belt restraint system was measured at two different stages of side impact resulting in occupant injuries. One is the initial

*Numbers in parentheses designate references at end of paper.

occupant impact stage (IOIS), a relatively early stage (within some 50 ms) of a crash in which the near-side occupant could be hit directly by the inside of the vehicle pressed inward by the striking car. The other is the secondary occupant impact stage (SOIS), in which the near-side occupant could be hurled by the rebound of IOIS or by the inertial force of the occupants' own body against the cabin interior, outside objects or another occupant.

Test Procedure

Figure 1 provides an overview of the test vehicle conditions and number of tests.

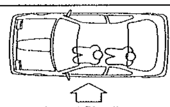
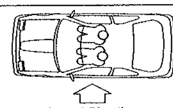
Condition of Occupant Position / Restraint Condition	 Impact Direction		 Impact Direction	
	Near Side Front Occupant	Near Side Rear Occupant	Near Side Front Occupant	Far Side Front Occupant
No Restraint	1	2	1	1
Lap Belt	1	–	1	1
2P. Automatic Shoulder Belt	1	–	1	1
3P. Automatic Belt	1	–	1	1
3P. Manual Belt	1	3	1	1

Figure 1. Matrix of SID seating configurations and restraint conditions.

Ten full scale side impact tests according to NHTSA test procedures were conducted on these test vehicles to measure the accelerations of the SID torso regions and observe the SID head trajectories with two (or three) vehicle-mounted high speed cameras.

Figures 2 and 3 show the front and side views of a test vehicle before the test, and figure 4 shows the moving deformable barrier used in the tests.

Figure 2. The front view of a test vehicle before the test.

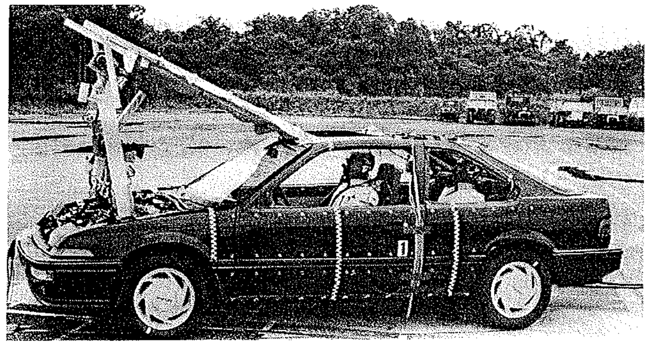


Figure 3. The side view of a test vehicle before the test.

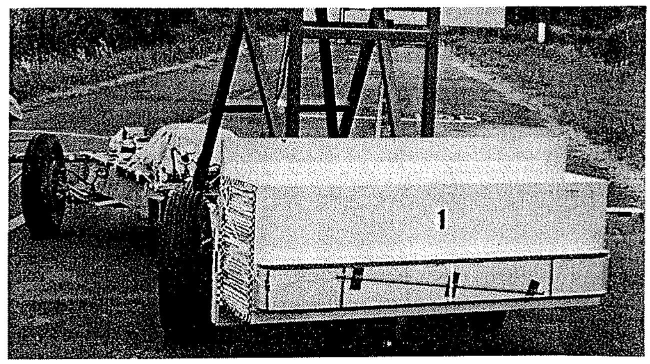


Figure 4. The moving deformable barrier.

Test conditions

NHTSA Prescribed Side Impact Test

- NHTSA-specified side impact moving barrier (1,360kg)
- Crab angle: 27°
- NHTSA-specified MDB
- Projected impact speed: 53.6 km/h

Side Impact Dummy (SID)

- SID incorporated with 1988 retrofit kit. (Made by Alderson Research Laboratory).

(Measuring channels are filtered with SAE J 211 b for the head and SAE J 211 b + FIR for all other regions.)

Belt restraint condition

Figure 5 provides the anchorage points of the belt restraint systems tested. Referenced to the SID hip point, each of the restraint system anchorage positions were set to reproduce the similar dimensions to the relating points of production cars.

Test results

The SID head (the forehead center) trajectories for five different restraint conditions in three kinds of SID seating configurations, i.e., the front near-side (without far-side SID), the front near-side (with far-side SID) and the front far-side are shown in figures 6, 7 and 8.

(Rear Seat SID head trajectories could not be observed.)

The acceleration time histories in three regions of the SID torso are shown in figures 9 through 16.

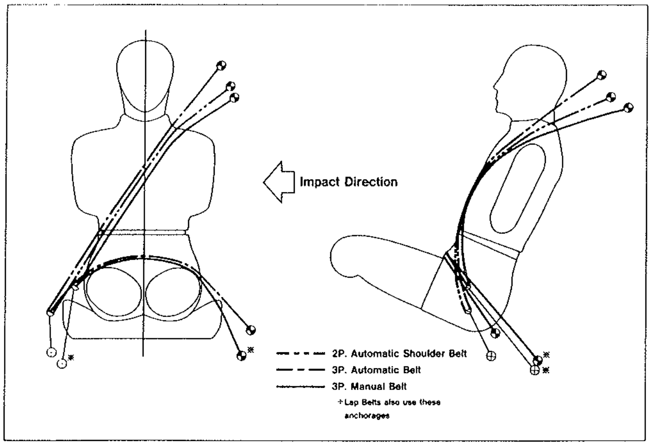


Figure 5. The anchorage positions of tested belt restraint systems.

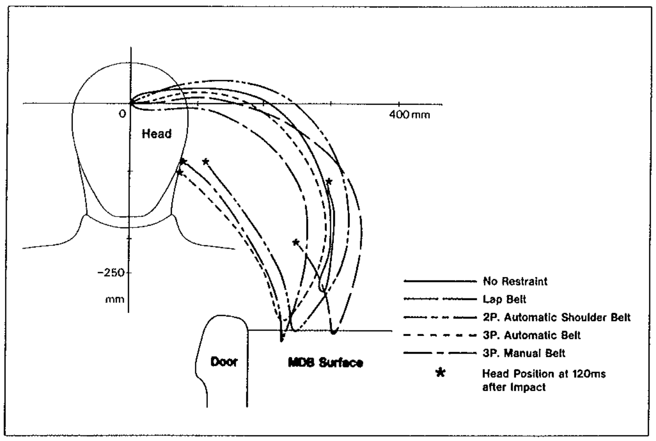


Figure 6. Head trajectories of front near-side SID (without far-side SID).

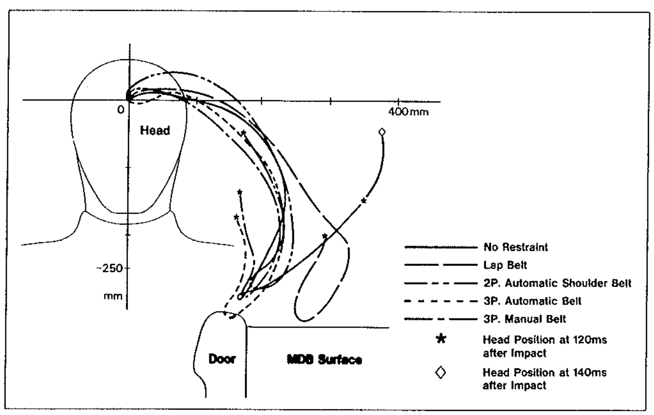


Figure 7. Head trajectories of front near-side SID (with far-side SID).

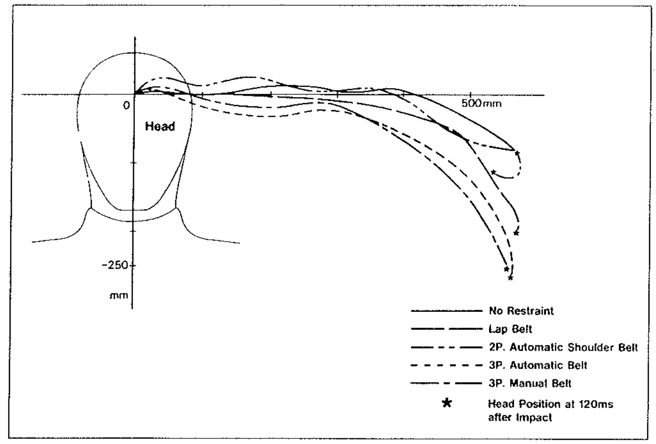


Figure 8. Head trajectories of front far-side SID (with near-side SID).

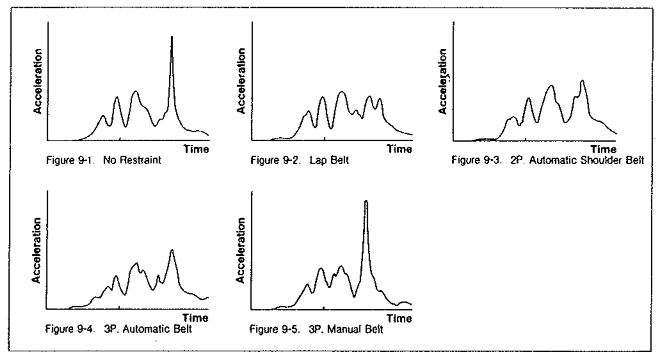


Figure 9. Head response of front near-side SID (without far-side SID) in five different restraint conditions (resultant acceleration).

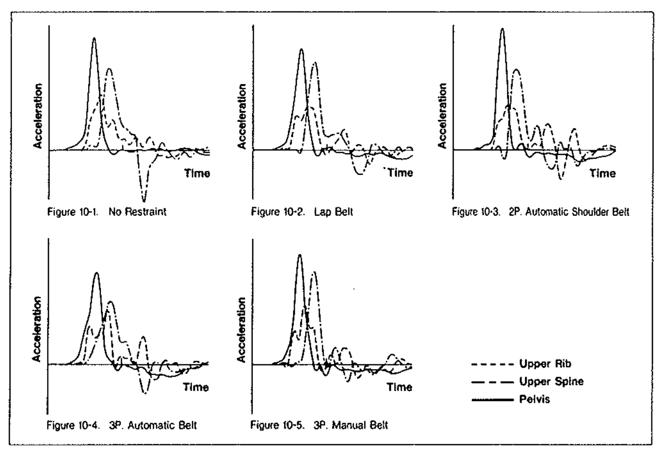


Figure 10. Torso response of front near-side SID (without far-side SID) in five different restraint conditions.

Front near-side SID (without far-side SID)

SID Acceleration (figures 9 and 10).—The peak acceleration of the SID torso regions occurred within 50 ms during which the SID remained almost motionless. This suggests that belt restraints may not be so effective for occupant protection at the IOIS.

Head Trajectory (figure 6).—At around 80 ms after the MDB contacted the test vehicle, the head/face of the SID, whether restrained or not, came in contact with the MDB or the upper edge of the vehicle door, and also the acceleration of the head reached its peak at this moment (figure 8). It may be argued from these findings and for the test conditions used that belt restraints provide not so effective occupant protection at the SOIS.

Note that all of the SID heads did not come in contact with any other part of the vehicle body.

As is apparent from the head trajectories in figure 6,

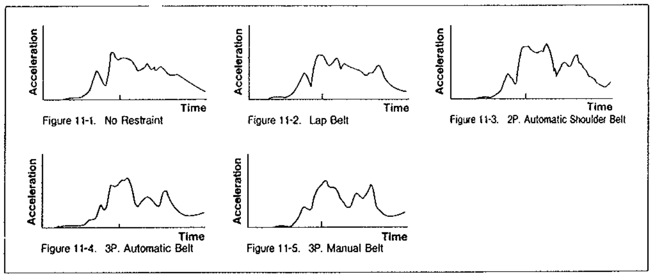


Figure 11. Head response of front near-side SID (with far-side SID) in five different restraint conditions (resultant acceleration).

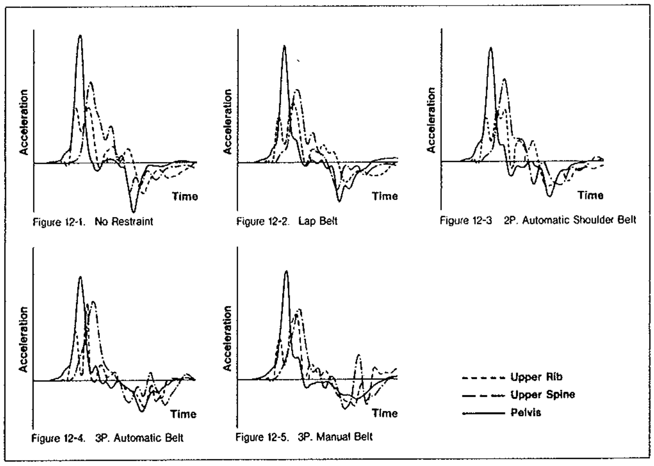


Figure 12. Torso response of front near-side SID (with far-side SID) in five different restraint conditions.

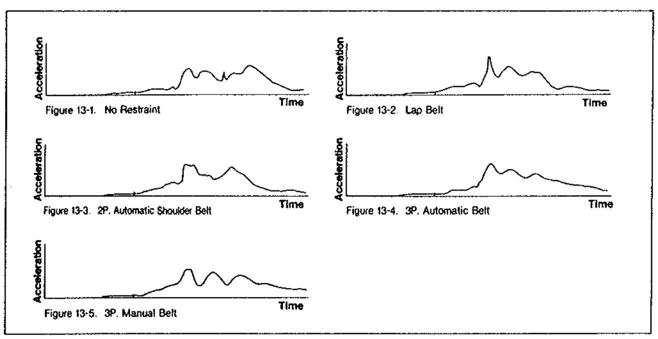


Figure 13. Head response of front far-side SID (with near-side SID) in five different restraint conditions (resultant acceleration).

however, the SID head, after hitting against the MDB, was pulled back toward the inside of the cabin by the restraint system, especially when it had a shoulder belt. This suggests that partial ejection of the near-side occupant's head at the SOIS may be mitigated with a belt restraint system.

Compared with the no restraint case, the head trajectory of the 2P/A restrained SID extended a little farther upward and outward, and that of the lap belt restrained SID, although staying below the unrestrained SID at the initial stage of impact, went farthest out at the latter stage.

These phenomena give a typical example of functional differences between the shoulder and lap belts during side impact. The 2P/A cannot effectively restrain the upward movement of the SID because it has no lap belt, but its

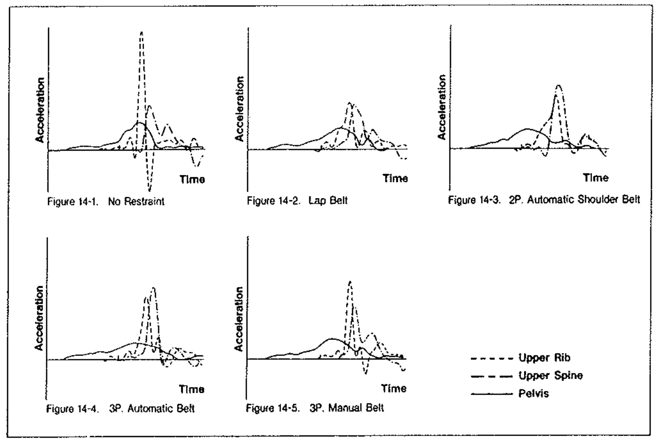


Figure 14. Torso response of front far-side SID (with near-side SID) in five different restraint conditions.

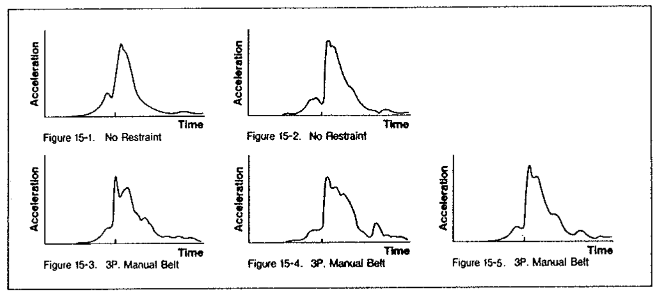


Figure 15. Head response of rear near-side SID in two different restraint conditions (resultant acceleration).

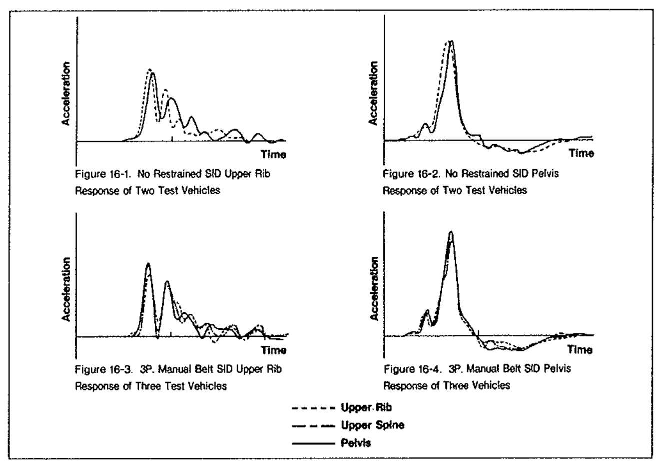


Figure 16. Torso response of rear near-side SID in two different restraint conditions.

shoulder belt checks the outward movement of the dummy. The lap belt, on the other hand, restrains the upward movement of the SID but fails to check its outward movement.

The head trajectory of the 2P/A restrained SID went farther outward than that of the no-restraint SID, probably because, at the IOIS, the pelvis of the latter moved away toward the far side of the vehicle and its torso was pulled back toward the inner part of the cabin, making the ejection of the head that much less. By comparison, the head of the 2P/A restrained SID moved farther outward in this example as its pelvis was restrained by the lower part of the shoulder belt from moving away toward the far side.

The head trajectories of both 3P/A and 3P/M restrained SIDs stayed within that of the no-restraint SID. This was probably because the lap and shoulder belts of these restraint systems checked the upward and outward movements of the SIDs.

Compared with the 3P/M, the 3P/A slackened somewhat, perhaps because the lap and shoulder ELRs, attached to the door, were displaced a little farther inward by the crash than the anchorage of the 3P/M which was attached to the side sill.

Apparently, this was why the head trajectory of the 3P/A restrained SID moved outside that of the 3P/M restrained SID.

Front near-side SID (with far-side SID)

SID Acceleration (figures 11 and 12).—Up to about 50 ms after the MDB contacted the test vehicle, the accelerations of the front near-side SID with the far-side SID present were similar to those recorded without far-side SID present. Apparently, the presence of the far-side SID had little influence on the behavior of the near-side SID in this respect.

After more than 50 ms from the contact, the near-side SID contacted the far-side SID, but the torso acceleration of the former was significantly lower than the latter. This test result may be attributed to the asymmetric structure of the current SID design.

Accordingly, it would be desirable if a two directional SID were developed to facilitate research efforts in this area.

Head Trajectory (figure 7).—The head/face of the near-side SID, whether belt-restrained or not, hit against the MDB or the upper edge of the door with the far-side SID present. It did not come in contact with any other part of the vehicle body.

In all of the tests with the far-side SID present, the outward range of the head trajectories were shorter than those recorded without the far-side SID. This is probably due to the near-side SID coming in contact with the far-side one at an early stage of side impact, and its pelvis and upper torso were held between the collapsing door and the far-side SID, resulting in a head trajectory more closely centered on the neck.

The head trajectories of the lap belt-restrained and the no-restraint near-side SIDs moved farther outward when the far-side SID was present. In particular, the head of the no-restraint near-side SID jutted considerably out of the cabin in the later stages because its motion was left unchecked in these examples.

These findings suggest that belt restraints may influence the behavior of the near-side occupants in the SOIS.

But, in mitigating the partial ejection of the head, the shoulder belt is more effective than the lap belt.

Front far-side SID (with near-side SID)

SID Acceleration (figures 13 and 14).—In all of the example restraint conditions examined, the far-side SID hit against the near-side SID and the acceleration reached its peak more than 50 ms after the MDB Contact.

The peak acceleration of the unrestrained far-side SID was higher and occurred sooner than with any of the belt-restrained SIDs. This may have come from a combination of the near-side SID's rebound and the far-side SID's inertial motion.

Apparently, the effects of belt restraints were reflected in this phenomenon, indicating the potential usefulness of these restraint systems in protecting far-side occupants at the SOIS.

Head Trajectory (figure 8)—The amplitude of the head motion of the far-side SID remained virtually unchanged for all restraint conditions, because it contacted the near-side SIDs.

At an early stage of side impact, the head of a no-restraint far-side SID rotated almost horizontally, but after its torso hit against the near-side SID, its head trajectory shifted upward because its pelvis lifted slightly as it moved against the other dummy.

The common type of shoulder belt with its lower anchorage fixed on the cabin center was less effective in these tests in checking the upward motion of the far-side SID, as the belt tended to slip off the dummy shoulder at an early stage of side impact.

It was found that the head trajectory of the 2P/A restrained SID extended as far upward as that of the no-restraint SID.

The lowest head trajectories were achieved by the 3P/A and the 3P/M.

These findings illustrate differences among the belt systems in occupant restraint capability.

A combination of these observations and the SID acceleration data indicate that belt-restraint systems provide effective protection for far-side occupants at the SOIS.

Rear near-side SID

The acceleration time responses for the rear near-side SIDs are shown in figures 15 and 16.

These SIDs, whether belt-restrained or not, showed roughly the same acceleration wave form. This indicates that for the particular impact used, and the resulting cabin and SID accelerations and other motions, the example belt restraints do not make a significant difference in the effective occupant motions at the IOIS. Of course other example impact trajectories, kinematics, and impact points may have produced different results.

These diagrams, also suggest that this series of tests had good reproducibility in the absence of configuration effects.

Summary and Conclusions

A series of full-scale side impact tests were carried out according to NHTSA specified test procedure at a 27° crab angle, a crash speed of 53.6 km/h and with an NHTSA-specified MDB. Ten passenger car examples of one model were used, prepared in five different restraint configurations, i.e., lap belt only, 2P/A, 3P/A, 3P/M and no-restraint. One test car from each of these five groups had two SIDs placed in tandem, one in the front seat and the other in the rear on the near-side, and the other car had two SIDs placed side by side in the front seats on the near and far-sides.

The head trajectories of the SIDs and their accelerations at several different regions were measured to examine the effects of varying seating positions and belt restraint systems. The findings for these examples may be summarized as follows:

1. In none of the restraint conditions, did the head of the front SID hit the upper part of the vehicle structure, such as the front pillar, center pillar or roof side rail, but instead the head, did strike the MDB or the upper edge of the vehicle door in some cases due to partial ejection of the SID.

If the biofidelity of the SID's sideways behavior can be relied upon, it can be assumed that head injuries of belt-restrained near-side occupants during side impact crashes are mostly caused by head partial ejection against the door upper edge or some external object. We believe occupants' heads seldom hit against any other structure in the car under these types of impact conditions.

2. At the IOIS, all of the belt-restraint systems used in the example tests were not so effective in protecting near-side occupants.

3. Belt restraints had some influence on the head trajectories of front near-side SIDs (without far-side SID) at the SOIS, but none of the restraint systems precluded the SID heads from hitting against the MDB or the vehicle door upper edge for the test conditions used.

4. The head trajectories at the SOIS of front near-side SIDs (with far-side SID present) differed significantly with belt-restraint configurations. It was found that the shoulder belt was more effective than the lap belt in mitigating the partial ejection of the head, but did not preclude the SID head from hitting against the door top in these example tests.

5. Belt restraints appeared to offer effective protection at the SOIS for the far-side SID (with near-side SID).

These findings indicate that the head trajectories of occupants, except in the case of near-side SIDs at the IOIS, are more or less influenced by belt restraints during side impact collisions. A possible way of reducing the incidence of head injuries due to partial head ejection could be to prevent the occupants' heads from translating out the side window during side impact.

However, there is no known side window that combines such occupant restraint capability with the function and performance of existing windows.

Further research efforts would have to be made on a technique to mitigate head partial ejection, possibly by restraining occupants' torsos more tightly.

Of course, the more firmly the torso is restrained, the greater the bending angle of the neck to the torso may become. Opinions (7 and 8) are divided on the subject and no definite assessment has yet been made on the effects of this phenomenon on the incidence of neck injuries in side impact.

These trade-offs must be borne in mind in developing any new restraint system to hold the torso more satisfactorily.

References

(1) National Transportation Safety Board, Bureau of Safety Programs, "Performance of Lap/Shoulder Belts in 167 Motor Vehicle Crashes (Volume 1)", Report No. NTSB/SS–88/02 U.S. Department of Commerce PB88–917002, Mar. 1, 1988.

(2) Department of Transportation, National Highway Traffic Safety Administration, 49 CFR PART 571 (Docket No. 88–06, Notice 3), Federal Motor Vehicle Safety Standards; Side Impact Protection—Passenger Cars Federal Register/Vol. 53, No. 161/Friday, August 19, 1988/ Proposed Rules.

(3) S.W. Rouhana, M.E. Foster, "Lateral Impact—An Analysis of The Statistics in The NCSS", SAE Technical Paper No. 851727, 1985.

(4) F. Hartemann, C. Thomas, J.Y. Foret-Bruno, C. Henry, A. Fayon, C. Tarrier, "Occupant Protection in Lateral Impacts", Proceedings of Twentieth Stapp Car Crash Conference, SAE Technical Paper No. 760806, 1976.

(5) S.C. Partyka, S.E. Rezabek, "Occupant Injury Patterns in Side Impacts—A Coordinated Industry/ Government Accident Data Analysis" Proceedings of International Congress & Exposition, SAE Technical Paper No. 830459, 1983.

(6) Department of Transportation, National Highway Traffic Safety Administration, 49 CFR PART 571 (Docket No. 88–06, Notice 1) Federal Motor Vehicle Safety Standards; Side Impact Protection, Federal Register/Vol. 53, No. 17/Wednesday, January 27, 1988, Proposed Rule.

(7) F.H. Walz, P.F. Niederer, C. Thomas, F. Hartemann, "Frequency and Significance of Seat Belt Induced Neck Injuries in Lateral Collisions", Proceedings of The Twenty-Fifth Stapp Car Crash Conference; September 28–30, 1981.

(8) D.J. Dalmotas, "Injury Mechanisms to Occupants Restrained by Three-point Seat Belts in Side Impact", Proceedings of International Congress & Exposition 1983, SAE Technical Paper No. 830462 1983.