SAE TECHNICAL PAPER SERIES

2002-01-0020

Human Occupant Kinematics in Low Speed Side Impacts

Thomas F. Fugger, Jr., Bryan C. Randles and Jesse L. Wobrock
Accident Research and Biomechanics, Inc.

Judson B. Welcher and Daniel P. Voss
Biomechanical Research and Testing, LLC

Jerry J. Eubanks
Automobile Collision Cause Analysis

Reprinted From: Impact Biomechanics (SP–1665)

The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL

SAE 2002 World Congress
Detroit, Michigan
March 4-7, 2002

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760

ISSN 0148-7191

Printed in USA

2002-01-0020

Human Occupant Kinematics in Low Speed Side Impacts

Thomas F. Fugger, Jr., Bryan C. Randles and Jesse L. Wobrock
Accident Research and Biomechanics, Inc.

Judson B. Welcher and Daniel P. Voss
Biomechanical Research and Testing, LLC

Jerry J. Eubanks
Automobile Collision Cause Analysis

ABSTRACT

A search of the automotive collision trauma literature reveals that over the last 35 years shows that there have been less than ten published Society of Automotive Engineers (SAE) articles describing the collision effects and resulting human occupant kinematics in low speed side impact collisions. The aim of this study was to quantify the occupant response for both male and female occupants for a battery of low-speed side impacts with various impact speeds and configurations.

Eight volunteers were used in a series of twenty-five staged side impact collisions with impact speeds ranging from approximately 2 km/h to 10 km/h and impact configurations to the front, middle and rear side portions of the vehicle. A NHTSA FMVSS 301 moving barrier was used as the impacting vehicle. A stiff bumper was constructed to fit the front of the barrier and was attached at a normal passenger vehicle bumper height. Occupant and vehicle responses were monitored by accelerometers and high-speed video. Occupant kinematic severity was found to have a positive correlation with increasing lateral Delta V.

INTRODUCTION

Lateral impact studies have traditionally concentrated on higher speed impacts that generally result in severe or fatal injuries [1,2,3]. Many of these studies assess the crashworthiness of vehicle side structures and occupant survivability using crash data from various reporting sources, such as the National Accident Sampling System (NASS), Fatal Accident Reporting System (FARS), Transport Canada and others [4-11]. Early research regarding side impacts utilized cadavers and primates in an effort to determine injury threshold values for the development of anthropomorphic test dummies suitable for side impacts [12-13]. The use of biomechanically based mathematical models and anthropomorphic test devices (ATD's) have become prominent in side impact research [14-15]. Increased implementation of side impact airbags and supplemental inflatable restraints for the occupant head have spawned the development of improved side impact ATD's and protocols for side impact testing that are more representative of real world crashes. However, government compliance testing and independent agency testing is almost exclusively performed at relatively high closing speeds of 50 km/h or greater.

Approximately 50% of side impacts reported in the National Automotive Sampling System (NASS) and Crashworthiness Database System (CDS) for both vehicle-to-vehicle and narrow object near side collisions occurred at delta-V's less than 24 km/h (15 mph). Of these near side impacts, 11% of the vehicle-to-vehicle impacts resulted in an MAIS 3+ compared to 25% in narrow object crashes [11]. Side impacts have been shown to result in more severe injuries for near side occupants compared to far side occupants for the same impact speeds and relative configurations [9]. Recent years have seen a rise in injury claims resulting from low-speed lateral impacts. A review of the current literature yielded only a handful of published studies that address the severity and occupant kinematics of human subjects in low-speed side impacts [16-22]. This study was undertaken to quantify the occupant kinematics of both near side and far side occupants in lateral impacts with differing resulting speed changes.

LITERATURE REVIEW

SEVERITY OF IMPACT – A search of the accident reconstruction literature found two papers that concentrated on the quantification of low-speed side impacts. Bailey *et al* used a momentum-energy-restitution model to predict the change in linear and angular velocity for the target vehicle [16]. This model also predicted the linear velocity change for the bullet vehicle and the energy absorbed during the impact. Toor *et al* proposed a methodology for quantifying sideswipe collisions that is also applicable to low-speed side impacts [17]. This model utilizes the principles of the CRASH 3 algorithm along with several other calculated parameters, including: contact forces, longitudinal acceleration rates, relative sliding distance and contact duration. Users of these models, as well as users of the CRASH 3 and SMAC algorithms, must apply these models with appropriate care given to the evaluation of the input parameters. Side impact crush coefficient data from government testing is not available for many vehicle makes and models. Additionally, side impacts that include involvement of the axle add an increased stiffness component that is not accounted for in most FMVSS 214 testing.

HUMAN SUBJECT TESTING – In the mid-1960s, a series of lateral impact tests on human subjects was performed by the United States Air Force [18,19]. The first series of tests used a controllable lateral deceleration device with lap belted subjects [18]. The occupant kinematic data, physiologic data and associated symptoms were reported for the subjects for each of the impacts. Subjects experienced average impact decelerations of 3.25 to 9.02 G and impact durations of 0.3 to 0.1 seconds. This study found that no permanent physiological changes were found at exposure to an average deceleration of 9.02 G with a 0.1 second duration for this population. Minor physical complaints were noted for approximately 50% of the subjects at an average deceleration of 6.25 G or above. Physical complaints generally consisted of minor to moderate headache lasting a few minutes and up to a couple of hours and cervical pain lasting a few minutes with possible stiffness up to a couple of days. In a follow-up study, the same controllable deceleration device was used in conjunction with a lap belt and a shoulder harness consisting of two over the shoulder harness straps [19]. In this battery of tests, subjects were exposed to average decelerations of 4.47 to 11.59 G and durations of 0.22 to 0.09 seconds, respectively. Individual physical complaints were not reported; however, it was reported that no permanent physiological changes occurred in this population of young, healthy males. Minor complaints, such as neck muscle soreness, were reported in 60% of the exposures at an average deceleration of 8.8 G and above.

The Naval Aerospace Medical Research Laboratory studied a quantification of the dynamic response of the head and neck to lateral accelerations in the late 1970s [20]. Five volunteers were exposed to sled acceleration profiles ranging from 2 to 11 G, in 1 G increments. Various rates of onset and duration of acceleration were tested. It was determined that increased peak accelerations at the first thoracic vertebrae (T_1) resulted in increased head angular acceleration. Peak T_1 acceleration was the major determinant of peak head angular acceleration and velocity. Time profiles for the acceleration duration was found to be significantly related to T_1 and head linear accelerations and to head angular accelerations. Additional work looked at the effects of initial positioning of the head using the same basic sled test setup [21]. Peak accelerations ranged from 2 to 7 G, with the rate of onset increasing with the peak acceleration. Different time durations were not tested in this study. Four different seating positions were tested as the initial condition and were defined as follows: neck up/chin up, head tilted left, head tilted right and head down. A peak acceleration of 5 G was the highest acceleration at which all conditions were analyzed. The conclusions of the study determined that, for this population, the initial lateral bending of the head in the direction of the induced acceleration reduces the peak angular acceleration and velocity of the head but increases the head linear acceleration. The effects of initial lateral flexion in the direction of the induced acceleration were found to be greater than in the direction contrary to the induced acceleration. It was also determined that lateral bending of the head in general significantly reduced the peak head angular acceleration and velocity. Forward flexion of the cervical spine increases the angular acceleration and velocity of the head put this after lateral bending discussion. No physical symptoms were reported in these studies, however, it was indicated in the head down (flexed) condition that subjects who had struck their chin against the right shoulder or right shoulder restraint at 5 G were not run at 6 G and no head down conditions were run at 7 G.

Matsushita *et al* studied human neck motion using cineradiographic techniques and accelerometry in low-speed rear-end, frontal and lateral impacts [22]. Only three tests were performed laterally at delta V's of 3.4, 3.4, and 4.2 km/h. The use of electromyography (EMG) permitted the reporting of relaxed or tensed muscle activity in the neck prior to and immediately after impact. All three subjects were reported as relaxed at the time of impact. One male subject was unbelted and the other male subject and female subject were both lap-shoulder belted at the time of impact. No physical complaints were documented and it was noted that severe cervical lateral flexion did not occur because of the lack of a side structure to restrict the movement of the torso.

Low speed vehicle-to-vehicle lateral impact testing with human volunteers was performed by Bailey *et al* [16]. The five tests had a delta V range of 0.7 to 6.8 km/h with a peak vehicle acceleration of 4.8 G. The vehicle motion was described as lateral with no significant rotational displacement. Occupant kinematic data were not reported. The male occupants were seated as far side passengers and the volunteers did not strike anything in the vehicle interior. No physical symptoms were reported by any of the volunteers.

METHODS

COORDINATE SYSTEM - All acceleration axis systems were in accordance with SAE J211/1 Recommended Practice and SAE J1733 Information Report with the positive X, Y and Z axes forward, rightward and downward, respectively [23,24]. The SAE sign convention dictated that lateral flexion of the spine was positive going from left to right (+Y axis directed mediolaterally from L to R).

HUMAN SUBJECTS – Four male (28.8 ± 7.5 years, 179 ± 1.5 cm, 83 ± 2.9 kg) and four female (22.3 ± 3.5 years, 167.6 ± 3.7 cm, 61.1 ± 4.1 kg) volunteers were subjected to six impacts. Basic anthropometric data for each subject can be found in Table 1. Each of the male subjects were directly involved in the research and the female subjects were previously known to the researchers. For each of the impacts, the male subject was seated as the near side front passenger and the female subject as the far side front passenger. The volunteers were adequately informed of the aims, methods, anticipated benefits and potential hazards of the study. Each participant was informed that they were at liberty to abstain from participation and free to withdraw consent for participation at any time. The subjects submitted informed consent in writing according to the Declaration of Helsinki [25].

Subject	Seating Position	Age	Height (cm)	Weight (kg)
F1	far side	26	163.8	61.4
M1	near side	24	177.8	86.4
F2	far side	24	165.1	55.9
M2	near side	25	180.3	81.8
F3	far side	18	171.5	65.9
M3	near side	26	180.3	79.5
F4	far side	21	170.2	61.4
M4	near side	40	177.8	84.1

Table 1 – Anthropometric data and seating position for vehicle occupants

Head accelerations for both the near side and far side occupants were obtained via a single triaxial block of IC Sensors 3031-050 (50 g) accelerometers affixed to the center of the forehead via a lightweight headband. The headband was made of rubber which, when tightly fastened to the subject's head, formed a secure bond.

Thorax and lumbar accelerations were also obtained for the far side (female) occupants. A specially developed low profile (<1 cm) triaxial block of accelerometers was constructed using two Entran EGAXT-50 accelerometers and one IC Sensors 3031-050 accelerometer. This was affixed to the occupant with medical adhesive at the approximate level of C7-T1 on the anterior torso. A lightweight uniaxial IC Sensors 3031-050 accelerometer was affixed with medical adhesive to the base of the subject's lumbar spine at the approximate location of L5-S1.

VEHICLES – A Federal Motor Vehicle Safety Standard (FMVSS) 301 rigid moving barrier was used as the bullet vehicle. Photographs of the FMVSS 301 barrier used can be found in Appendix A. A rigid bumper was attached to the face of the barrier at a normal bumper height. The target vehicles were two 1989 Ford Escort GT's. Neither of the vehicles were modified other than removal of the center console and carpeting for sensor placement. Vehicle and barrier data for the tests can be found in Table 2.

Year	Make	Model	VIN	Wf (kg)	Wr (kg)	Wt (kg)
1989	Ford	Escort GT	1FAPP93J1KWxxxxxx	663.2	404.5	1067.7
1989	Ford	Escort GT	1FAPP93J0KWxxxxxx	664.1	404.1	1068.2
N/A	FMVSS	301 Barrier	N/A	1250	627.3	1877.3

Table 2 – Vehicle and barrier information

Figure 1 - Barrier/vehicle exemplar orientation

The barrier was accelerated down an inclined roadway and was assisted by the researchers for the higher speed impacts. The barrier was perpendicular to the target vehicle for all impacts. Figure 1 shows the impact configuration for the tests to the front side portion of the vehicle. Each portion of the vehicle's side (front, door/middle, rear) were impacted twice; once at an approximate damage onset threshold (approximately 2 to 4½ km/h) and a second time at a damage producing speed (approximately 6 to 10 km/h). A time trap (DTS Timer Interval Meter) triggered by pressure sensitive tape switches (Tape Switch Corporation Type 102A) and an optical time trap (Farmtek, Inc.) recorded the bullet vehicle's velocity immediately prior to impact. A triaxial array of accelerometers (IC Sensors 3031-050) was affixed to the target vehicle's approximate static center of gravity. The accelerometer placement was approximately equal to the longitudinal (X-axis) position of the normal seating position of the occupants. The acceleration data were used to determine the kinematic response of the center of gravity of the target vehicle. The target vehicle was in neutral with the driver's foot on the brake pedal prior to impact.

TEST PROTOCOL – Six impacts were performed to each side of the vehicles. The first three impacts were at the damage onset threshold speed and the second series at the higher damage producing speed. Each series of three side impacts started with an impact to the front, followed by an impact to the door structure and then an impact to the rear section of the vehicle.

The volunteers were given no specific instruction regarding seating position, and were simply told to adopt a normal driving or seating position. The volunteers adjusted the seat fore-aft position and seat back angle to whatever position they determined was comfortable. Standard lap and shoulder belt were worn for all tests. The only instruction given to the occupants was to maintain their normal seating position and to look forward prior to impact. Figure 2 represents a basic schematic of the test impact configurations relating the barrier position to the vehicle.

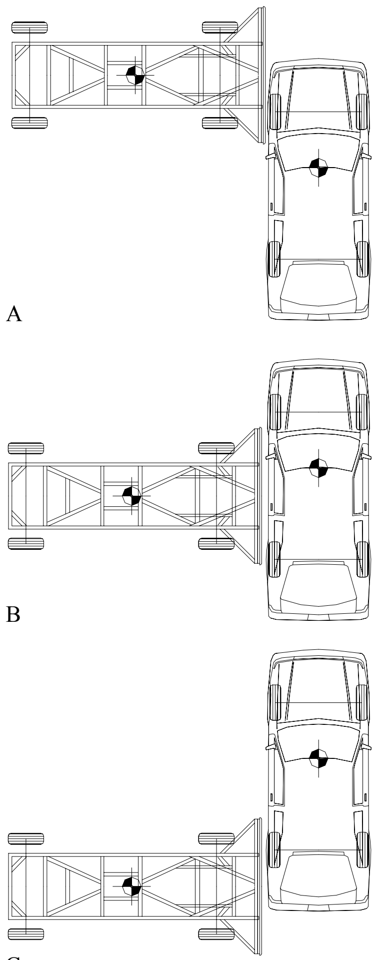

Figure 2 - Barrier/vehicle impact orientation to (A) front, (B) door area/middle and (C) rear

DATA ACQUISITION AND POST PROCESSING - All data were collected following the general theory of SAE Recommended Practice: Instrumentation for Impact Test - J211/1 Mar95 [23]. All accelerometer data were collected at 1000 Hz. Vehicle changes in velocity were calculated from vehicle acceleration data filtered with an SAE Class 180 filter. Occupant acceleration data were filtered with an SAE Class 60 filter in accordance with previous research [26].

RESULTS

The lateral acceleration were collected from the target vehicle and used to determine the Delta V (change in velocity of the struck vehicle). In addition, the lateral displacement of the front and rear tires of the target vehicle were measured immediately post impact. The relevant peak values are shown in Table 3.

Test	Area of target contact	Peak Y-Axis Accel.	Lateral Delta V (km/h)	Front wheel Y disp. (mm)	Rear wheel Y disp. (mm)
Right Sided Impacts					
8	front	-3.9	-2.5	-102	0
9	door	-2.5	-2.0	-102	-32
10	rear	-1.6	-1.3	-76	-279
11	front	-9.7	-5.4	-356	-25
12	door	-17.0	-6.4	-368	-343
13	rear	-5.0	-3.6	-152	-579
14	front	-4.4	-3.2	-203	0
15	door	-5.2	-3.9	-83	-127
16	rear	-1.2	-2.2	-254	-533
17	front	-18.3	-5.8	-991	-203
18	door	-14.8	-9.8	-686	-673
19	rear	-7.0	-4.0	-2083	-1727
Left Sided Impacts					
1	front	3.2	1.7	133	13
3	door	5.1	3.7	76	146
4	rear	2.7	2.0	0	292
5	front	8.8	5.3	57	140
6	door	4.8	5.8	273	413
7	rear	6.0	3.5	203	129
20	front	12.8	3.0	216	0
21	door	5.4	4.3	114	152
22	rear	1.6	1.8	91	699
23	front	22.0	6.7	1308	451
24	door	18.6	7.5	508	762
25	rear	6.8	4.0	1378	2870

Table 3 - Peak Y-axis vehicle parameters

Lateral occupant accelerations were recorded for both near and far side occupants. More acceleration measures were collected from the female occupant in all tests due to their under representation in the human subject testing literature. Relative acceleration between the thorax and lumbar region was also considered as an indicator of possibly deleterious occupant motion. Table 4 shows the peak values of the selected quantities. Note that, as with the vehicle parameters, the occupant parameters are reported in accordance with the SAE J211 sign convention. Thus, the peak value of interest is typically of opposite sign for left vs. right-sided impacts.

Minor physical complaints were noted immediately after five of the twenty-five impacts. The complaints were generally a transient complaint of pain in the back or a slight headache that lasted only a few minutes. All of these came after the higher velocity impacts. Physical complaints were noted/experienced within the one to three days following testing in four of the eight subjects. They consisted of minor neck or shoulder soreness that lasted a day in three of the subjects and a maximum of three days in one of the subjects. All symptoms resolved without treatment and no permanent physiological changes were noted. Occupant information including answers to the post-impact questionnaire for each test and a follow-up regarding any physical symptoms are reported in Appendices B and C.

Test	Near Side Head (Y) G	Far Side Head (Y) G	Far Side Thorax (Y) G	Far Side Lumbar (Y) G	Far Side Thorax relative to Lumbar (Y) G
Right Side Impacts					
8	-1.0	dl	dl	dl	dl
9	-1.4	-0.9	-0.6	-1.6	-1.6
10	-1.2	-1.4	-1.3	-2.1	-2.1
11	-2.2	-1.7	-1.6	-3.6	-3.6
12	-2.2	-1.9	-2.7	-1.5	-1.5
13	-2.4	-2.6	-5.6	-5.7	-5.7
14	-1.4	-1.0	-1.2	-1.8	-1.8
15	-1.5	-1.3	-2.1	-3.0	-2.5
16	-1.3	-1.3	-1.7	-2.1	-1.9
17	-2.4	-2.8	-2.2	-2.6	-2.8
18	-7.1	-3.8	-6.4	-5.3	-6.7
19	-6.1	-2.5	-4.3	-4.9	-6.2
Left Side Impacts					
1	1.5	0.7	0.7	1.3	1.4
3	2.5	2.4	2.2	3.4	3.4
4	1.7	1.4	1.6	2.2	2.0
5	2.5	0.8	2.0	2.3	1.9
6	4.3	3.4	5.2	4.5	6.2
7	4.5	dl	dl	dl	dl
20	2.1	0.7	0.7	1.6	1.5
21	1.7	1.3	1.4	0.5	1.1
22	1.4	1.4	1.6	2.0	1.9
23	2.7	1.5	3.0	2.4	2.4
24	8.8	4.1	7.7	6.5	5.8
25	8.4	4.9	5.9	6.2	6.5

Table 4 - Peak Y-axis occupant parameters

DISCUSSION

The results indicate that there was a clear difference between near and far sided occupants with respect to peak head lateral acceleration. Near sided occupants typically had higher peak accelerations and shorter duration acceleration curves. This was most pronounced in impacts where the near side occupant reported body contact (i.e. arm, shoulder, head) with the interior structure of the door; however, the condition still persisted where no contact was reported. A representative comparison is shown in Figure 3. This result would appear to be similar to what Matsushita [22] found in that the far side occupant's lateral motion is not restricted by occupant interior contact. There may also be effects from the stature differences between the near and far sided occupants (typically the far side occupant was 8-15 cm shorter).

In addition, a time shift of acceleration onset for different portions of the occupant was clearly represented for both near and far side occupants. The lumbar region acceleration was most tightly coupled with the vehicle acceleration. The thorax acceleration lagged behind the lumbar acceleration and almost always had a lower peak. Likewise, the onset of significant head acceleration did not occur until after the vehicle acceleration pulse had already subsided and was generally lower than both the lumbar and thorax accelerations. This is similar to the trend seen in antero-posterior (X-axis) direction acceleration pulses seen in rear end collisions with the exception that the head accelerations in rear end impacts tend to be higher due to head-to-head restraint contact. An example of this phenomenon is shown in Figure 4.

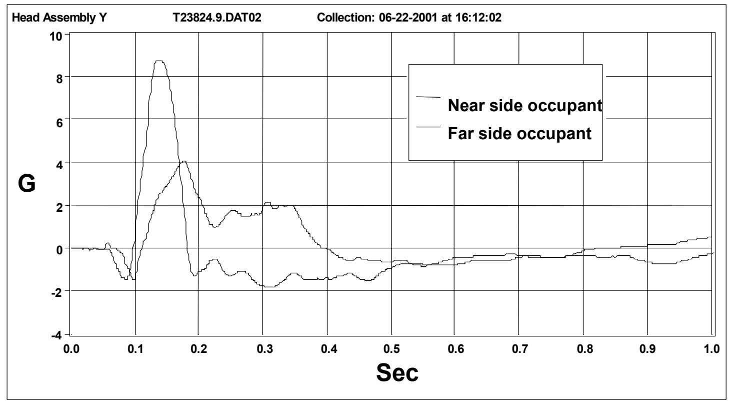

Figure 3 - Head acceleration comparison of near side to far side occupant for a driver's side impact

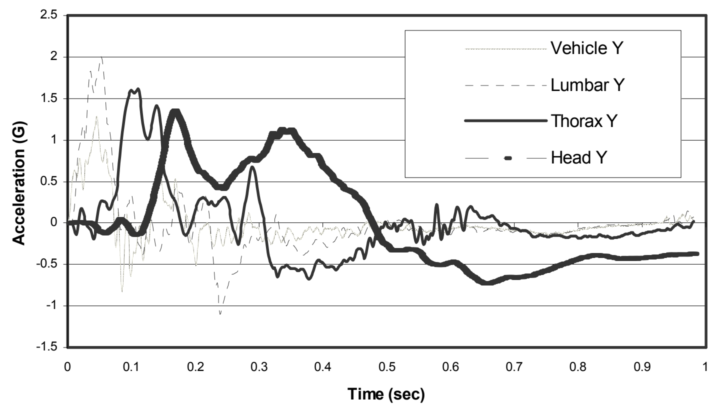

Figure 4 - Comparison of acceleration profiles for the lumbar, thoracic and head mounted accelerometers

Finally, there was weak but significant ($p<0.05$) correlation between the measured target vehicle lateral Delta V and the relevant lateral occupant acceleration measures.

Physical complaints immediately after impact were noted in only five out of the 50 exposures (10%). Of these complaints, 60% were reported by the far side (female) occupant and all were transient in nature. Care should be used when attempting to extend this result to an occupant involved in a single impact as each human subject in this test series was exposed to a total of six impacts. Multiple exposures in the subject study may have resulted in an increased prevalence of complaints. Post-test interviews with the subjects revealed that three of the subjects that had experienced physical complaints immediately following a test, experienced symptoms consisting of minor muscle soreness in the back or neck region of not more than 24 hours in duration. One of the female subjects who did not experience any symptoms the day of or day after testing had minor muscle soreness two days after the series of tests. This soreness lasted only one day and was similar to the phenomenon of delayed onset muscle soreness (DOMS).

CONCLUSION

A series of 24 lateral impact tests were performed resulting Delta V's of the struck vehicle of 1.3-9.8 km/h. Acceleration measurements were recorded from eight human occupants (4 female, 4 male) with particular emphasis on the far side, or female, occupant. Each occupant underwent six impacts. The data indicated a tight coupling between the lumbar region of the occupant and the vehicle (likely due to lap belt use and frictional effects of the seat). In addition, statistical analysis showed an increase in occupant kinematic severity with increasing lateral Delta V measured at the center of gravity of the target vehicle.

ACKNOWLEDGMENTS

The authors would like to thank the volunteers for their participation in this study.

REFERENCES

1. Severy, D., Mathewson, J. and Siegel, A. Automobile side-impact collisions. Society of Automotive Engineers 600470, Warrendale, PA, 1960.
2. Severy, D., Mathewson, J. and Siegel, A. Automobile side-impact collisions – Series II. Society of Automotive Engineers 620149, Warrendale, PA, 1962.
3. Shaw, L. and Clark, C. Side impact restraint development and evaluation techniques. Society of Automotive Engineers 806052, Warrendale, PA, 1980.
4. O'Day, J. and Kaplan, R. The FARS data and side-impact collisions. Society of Automotive Engineers 790736, Warrendale, PA, 1979.
5. Melvin, J., O'Day, J., Campbell, K., Robbins, D. and Huelke, D. Side impacts: a comparison of laboratory experiments and NCSS crashes. Society of Automotive Engineers 800176, Warrendale, PA, 1980.
6. Partyka, S. and Rezabek, S. Occupant injury patterns in side impacts – a coordinated industry/government accident data analysis. Society of Automotive Engineers 830459, Warrendale, PA, 1983.
7. Dalmotas, D. Injury mechanisms to occupants restrained by three-point seat belts in side impacts. Society of Automotive Engineers 830462, Warrendale, PA, 1983.
8. Hobbs, C. and Mills, P. Injury probability for car occupants in frontal and side impacts. Transport and Road Research Laboratory Report 1124. 1984,
9. Miltner, E. and Salwender, H. J. Injury severity of restrained front seat occupants in car-to-car side impacts. Accid. Anal. and Prev. 27(1), 105-110, 1995.
10. Augenstein, J., Bowen, J., Perdeck, E., Singer, M., Stratton, J., Horton, T., Rao, A., Digges, K., Malliaris, A. and Steps, J. Injury patterns in near-side collisions. Society of Automotive Engineers 2000-01-0634, Warrendale, PA, 2000.
11. Zaouk, A., Eigen, A. and Diggs, K. Occupant injury patterns in side crashes. Society of Automotive Engineers 2001-01-0723, Warrendale, PA, 2001.
12. Stalnaker, R., Roberts, V. and McElhaney, J. Side impact tolerance to blunt trauma. Society of Automotive Engineers 730979, Warrendale, PA, 1973.
13. Morgan, R., Marcus, J. and Eppinger, R. Correlation of side impact dummy/cadaver tests. Society of Automotive Engineers 811008, Warrendale, PA, 1981.
14. Payne, A. and Hopton, J. Comparison study of EuroSID, USSID, and BioSID performance using MIRA's new M-SIS side impact simulation technique. Society of Automotive Engineers 960103, Warrendale, PA, 1996.
15. Ahn, C. and Bae, H. Development of finite element US-SID and Euro-SID model. Society of Automotive Engineers 2000-01-0160, Warrendale, PA, 2000.
16. Bailey, M., Wong, B. and Lawrence, J. Data and methods for estimating the severity of minor impacts. Society of Automotive Engineers 950352, Warrendale, PA, 1995.
17. Toor, A., Roenitz, E., Johal, R., Overgaard, R., Happer, A. and Araszewski, M. Practical analysis technique for quantifying sideswipe collisions. Society of Automotive Engineers 1999-01-0094, Warrendale, PA, 1999.
18. Zaborowski, A. Human tolerance to lateral impact with lap belt only. Proceedings of the 8th Stapp Car Crash Conference, 1964.
19. Zaborowski, A. Lateral impact studies: lap belt shoulder harness investigations. Proceedings of the 9th Stapp Car Crash Conference, 1965.
20. Ewing, C., Thomas, D., Lustik, L., Muzzy, W., Willems, G. and Majewski, P. Dynamic response of the human head and neck to +Gy impact acceleration. SAE 770928. Proceedings of the 21st Stapp Car Crash Conference, 1977.
21. Ewing, C., Thomas, D., Lustik, L., Muzzy, W., Willems, G. and Majewski, P. Effect of initial position on the human head and neck to +Y impact acceleration. SAE 780888. Proceedings of the 22nd Stapp Car Crash Conference, 1978.
22. Matsushita, T., Sato, T., Hirabayashi, K., Fujimura, S., Asazuma, T. and Takatori, T. X-ray study of the human neck motion due to head inertia loading. SAE 942208. Proceedings of the 38th Stapp Car Crash Conference, 1994.
23. SAE: "Surface Vehicle Recommended Practice: (R) Instrumentation for impact test – Part 1 – Electronic instrumentation – SAE J211-1", Society of Automotive Engineers, J211-1, 1995.
24. SAE: "Surface Vehicle Information Report: Sign Convention for Crash Testing - SAE J1733", Society of Automotive Engineers, J1733, 1994.

25. “Recommendations Guiding Medical Doctors in Biomedical Research Involving Human Subjects”, 41st World Medical Assembly, World Medical Assembly Declaration of Helsinki, September, 1989.
26. Szabo, T.J. and Welcher, J.B.: “Human Subject Responses to Various Acceleration Fields”, in Low Speed Collision TOPTEC, Society of Automotive Engineers, Richmond, BC, 1996.

CONTACT

Thomas F. Fugger, Jr., P.E.
Accident Research and Biomechanics, Inc.
27811 Avenue Hopkins, Suite 1
Valencia, CA 91354
arb@accidentresearch.com

Judson B. Welcher
Biomechanical Research and Testing, LLC
1827 Ximeno Avenue, #2
Long Beach, CA 90815
welcher@scf.usc.edu

APPENDIX

Appendix A - NHTSA FMVSS 301 rigid moving barrier photos

Appendix B – Post-test follow-up interview summary

Subject	Day of test	1 day post	1 week post	2 weeks post	3 weeks post	1 month post	2 months post	3 months post	4 months post	5 months post	6 months post
F1	reduced movement of neck and slight headache after test 4	left subscapular, subclavicular neck stiffness 1 day duration	none	none	none	none	none	none	none	none	none
M1	slightly light-headed after test 7	none	none	none	none	none	none	none	none	none	none
F2	none	none	minor neck stiffness 1 day duration, less than working out, 2 to 3 days post testing	none	none	none	none	none	none	none	none
M2	none	none	none	none	none	none	none	none	none	none	none
F3	slight headache after test 18 and small cut on ankle some upper back stiffness 3 hours post	mid to lower back stiffness only 1 day	rear-ended at approx 20 mph while driving (no additional soreness attributable to testing)	none	none	none	none	none	none	none	none
M3	none	none	none	none	none	none	none	none	none	none	none
F4	slight pain in thoracic (T7) area following test 24	none	none	none	none	none	none	none	none	none	none
M4	slight dizziness after last impact test 25	exacerbation of previous soft-tissue complaints in left shoulder	none	none	none	none	none	none	none	none	none

Appendix C – Post-impact questionnaire responses.

Responses following right-sided impacts

Test #	Subject	Perceived body motion	Impact vehicle interior	Hands remain on steering wheel	Foot remain on brake	Vehicle pushed lateral	Relaxed/not anticipating	Rate impact to 1st	Seatbelt engage	Physical Complaints
8	M2	Right	Yes - upper arm hit door	N/A	N/A	No	Yes	Normal	No	No
	F2	Left	No	Yes	Yes	Yes - couple of inches	Yes	Very light	No	No
9	M2	Right	Yes - upper arm hit door	N/A	N/A	No	Yes	Less Severe	No	No
	F2	Josselled	No	Yes	Yes	No	Yes	Less Severe	No	No
10	M2	Right	No	N/A	N/A	Yes - 10" at rear	Yes	About the same	No	No
	F2	Left	No	Yes	Yes	Yes - 5"	No	More Severe, strong	No	No
11	M2	Right	Yes - upper arm hit door, head hit edge of roof	N/A	N/A	Yes - 20" at front, 4" at rear	Yes	More severe	No	No
	F2	Left	No	No	Yes	Yes - 2'	Yes	Much more severe	No	No
12	M2	Right	Yes - upper arm hit door	N/A	N/A	Yes - 6" total	Yes	More severe	No	No
	F2	Left	Yes - right ankle hit center console mount	Yes	No	Yes - 2'	Yes	More severe	Yes	No
13	M2	Right	Yes - upper arm hit door, head hit edge of roof, knee hit window crank	N/A	N/A	Yes - 5' at rear, 1.5' at front	Yes	More severe	No	No
	F2	Left	Yes - left shoulder hit side door	Yes	Yes	Yes - 4' at the rear	Yes	More severe	Yes	No
14	M3	Left	No	N/A	N/A	Yes - 6"	Yes	Minor impact	Yes	No
	F3	Right	No	Yes	Yes	Yes - 3"	Yes	N/A	No	No
15	M3	Right	No	N/A	N/A	Yes - 1'	Yes	Less Rotation	No	No
	F3	Left	No	Yes	Yes	Yes - 6"	Yes	About the same	No	No
16	M3	Right	No	N/A	N/A	Yes - 1.5' at rear	Yes	A little worse	No	No
	F3	Right	No	Yes	Yes	Yes - 2'	Yes	More severe	No	No
17	M3	Right	Yes - upper arm hit door, right knee hit door	N/A	N/A	Yes - 2' in the front	Yes - but saw it coming	More severe	No	No
	F3	Left	No	No	Don't know	Yes - 3' at the front	Yes	More severe	No	No
18	M3	Right	Yes - upper arm hit door, right knee hit door	N/A	N/A	Yes - 2'	Yes	More severe	No	No
	F3	Right	Yes - left leg hit door, right ankle hit center console brace	Yes	No	Yes - 2'	Yes	More severe	No	Yes - tension headache, small cut on right ankle
19	M3	Right	Don't know	N/A	N/A	Yes - 5' at rear, 1' at front	Yes	More severe	Yes	No
	F3	Right	No	Yes	Yes	Yes - 6' at rear, 2' at front	Yes	More severe, much worse	No	No

Responses following left-sided impacts

Test #	Subject	Perceived body motion	Impact vehicle interior	Hands remain on steering wheel	Foot remain on brake	Vehicle pushed lateral	Relaxed/not anticipating	Rate impact to 1st	Seatbelt engage	Physical Complaints
1	M1	Right	No	Yes	Yes	Yes - 1'	Yes	Severe/Forceful	No	No
	F1	Right	No	N/A	N/A	Yes - 6"	Yes - eyes closed	Harder than expected	No	No
3	M1	Left to Right	No	Yes	No	Yes - 4"	Yes	Not as sharp	N/A	No
	F1	Right	No	N/A	N/A	Yes - < 6"	Yes	Harder	No	No
4	M1	Right	No	Yes	Don't know	Yes - 1'	Yes	Similar	N/A	No
	F1	Right	No	N/A	N/A	Yes - 1' at rear	Yes	More Severe, very hard	No	Yes - Reduced/painful neck movements, headache
5	M1	Right	No	Yes	No	Yes - 1.5'	Yes	Harder	N/A	No
	F1	Slightly to the right	No	N/A	N/A	Yes - 2' at front	Yes	Harder impact, body felt it less	No	No
6	M1	Dramatically to right	No	Yes	No	Yes - 1'	Yes	Stronger	N/A	No
	F1	Right	No	N/A	N/A	Yes - 1.5'	Yes	More Severe/Very hard	No	No
7	M1	Strongly to the right	Yes - shoulder hit door	Yes	No	Yes - it rotated 4'	Yes	Stronger	N/A	Yes - A little lightheaded, not very severe
	F1	Don't know	No	N/A	N/A	Yes - 5'	Yes	More Severe, hardest	No	No
20	M4	Left	No	Yes	Yes	Yes - 1'	Yes	Minor, loud	No	No
	F4	Right then left	No	N/A	N/A	Yes - 1'	Yes	Loud, small jolt	Yes	No
21	M4	Left	No	Yes	Yes	Yes - 1'	Yes	More severe	No	No
	F4	Left	No	N/A	N/A	Yes - 1'	Yes	More severe	No	No
22	M4	Right	No	Yes	Yes	Yes - 1.5' at rear	Yes	Less severe	No	No
	F4	Left	No	N/A	N/A	Yes - 2' at rear	Yes	Less severe	No	No
23	M4	Left	Yes - left knee bumped the door	Yes	Yes	Yes - 3' at the front	Yes	More severe	No	No
	F4	Left	No	N/A	N/A	Yes - 4' at the front	Yes	More severe	No	No
24	M4	Left	Yes - left shoulder hit side door	Yes	Yes	Yes - 4'	Yes	More severe	No	No
	F4	Left then right	Yes - right elbow hit door	N/A	N/A	Yes - 1'	Yes	More severe	Yes	Felt pain immediately after in thoracic, ~ T7
25	M4	Left	Yes - left shoulder hit side door	No	Don't know	Yes - 5' at the rear	Yes	More severe, not as severe as straight broadside	No	Yes - dizziness and unsteadiness
	F4	Forward left	No	N/A	N/A	Yes - 5' at the rear		More severe	Yes	No