IMPROVING SIDE IMPACT PROTECTION: RESPONSE OF THE ES-2RE AND WORLDSID IN A PROPOSED HARMONIZED POLE TEST

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ABSTRACT

The paper reports on the foundational research conducted by Transport Canada in support of a harmonized pole impact test procedure. Field data from Asia-Pacific, Europe and North America were analyzed to identify the type of motor vehicle occupant at greatest risk of serious injury in narrow object crashes and to describe the pattern of injuries most frequently associated with these types of collisions. Laboratory crash testing was subsequently carried out to evaluate the responses of the ES-2re and WorldSID dummies. Oblique pole tests were conducted with five paired tests of vehicles ranging in size from small passenger cars to mid-size SUV's at impact velocities of 32 km/h.

Keywords: ES-2re, harmonization, pole test, side impact, WorldSID

IN RESPONSE TO THE NEED FOR WORLDWIDE HARMONIZATION in side crash protection and a request from the European Experimental Vehicle Committee (EEVC), the International Harmonized Research Activities (IHRA) steering committee approved a Side Impact Working Group (WG) in June 1998 to coordinate side impact research activities. Working group members from the U.S., Canada, the European Union, and Japan under the chairmanship of Australia first met in the fall of 1998 and together worked to develop a harmonized side impact procedure until September of 2004 (Seyer, K., 2003). The tasks undertaken by various members included:

1. A review of world side impact crash data to determine representative crash configurations, target populations and injury patterns;
2. The evaluation of moving deformable barrier variants;
3. A comparison of oblique and perpendicular pole impacts and
4. A comparison of ES-2, ES-2re and WorldSID responses in full-scale vehicle crash tests.

The working group proposed a moving deformable barrier (MDB)- to- vehicle test to address side impact protection needs of small female drivers and a vehicle- to- pole test to improve protection for mid-size male drivers involved in collisions with narrow objects (Newland, C. et. al., 2005). Though it was not within the working group's mandate to recommend an anthropometric dummy, the evaluation of the ES-2, ES-2re and WorldSID anthropometric test devices (ATD) became an integral part of the research conducted to evaluate pole test configurations by necessity.

The ES-2re is an ES-2 with a modified rib assembly proposed by the NHTSA to eliminate the risk of back plate interaction with the seat back or seat back gouging by the back plate. The ribs are extended to reduce the discontinuity that was present between the ribs and the back plate (Sutterfield et al. 2005). The WorldSID is a new harmonized side impact dummy released in March 2004. The ISO TR 9790 biofidelity rating is 4.3 for ES-2re and 7.6 for WorldSID (Hautmann, E., 2003).

The world crash data review combined with an updated description of the North American side impact experience summarized in this paper supports the working group recommendations and highlights the importance of protecting the head and chest for the population of drivers. In 2005 Transport Canada presented the results of three paired oblique and perpendicular pole impacts conducted with the 50^{th} percentile WorldSID (Tylko, S. Dalmotas, D., 2005). Preliminary results were also presented for two additional paired oblique pole tests, to compare the response of the WorldSID and ES-2re in oblique pole testing conditions. This paper presents additional analysis of these comparisons and introduces 3 additional paired tests conducted to further the comparison of the ES-2re and WorldSID ATD's in oblique pole impacts.

WORLD DATA REVIEW

ASIA-PACIFIC Japan reports approximately 4560 fatalities among occupants of passenger cars or mini trucks involved in traffic collisions. Almost 25% of these fatalities are the result of lateral collisions. Front-seated occupants account for approximately 93% of fatalities observed in lateral crashes. Struck side occupants account for approximately 65% of front seated fatalities in lateral crashes and the body regions most frequently injured are the head, followed by the thorax and abdomen. Head injuries are particularly prevalent among fatally injured occupants (~50% of fatal injuries), but far less so among non-fatal seriously injured occupants (~12%). In the case of seriously injured non-fatal cases, the body region most frequently injured is the thorax (~31%).

Single vehicle side crashes account for approximately 38% of fatalities and 21% of non-fatal seriously injured occupants. Collectively, impacts with narrow vertical structures, in the form of telephone poles and sign posts account for close to 25% of fatal single vehicle side crashes. A further examination of a sample of case studies of vehicle-to-pole crashes resulting in serious or fatal injury indicated that structures of the order of 35 to 40 cm in diameter were most common. This was also the widest pole diameter grouping considered in the analysis and accounted for close to 40% of the case studies. The second most common grouping (18%) consisted of structures 30 cm to 35 cm in diameter. Virtually all of the structures in these two size groupings were telephone posts. Compared with earlier Canadian and European findings, surprisingly few of the narrow vertical rigid structures took the form of trees in the Japanese sample (~13% of cases in the Japanese sample involved trees).

EUROPE Data on the magnitude and nature of the side impact problem in Europe, reported to the working group, were obtained from two reports prepared for the European Commission. The first of these, prepared by the Transport Research Laboratory (TRL), examined field collision data gathered in the United Kingdom, Sweden, Germany and the Netherlands in support of a review of possible changes to the European frontal and side impact directives. The second report, prepared by Bundesanstalt fuer Stassenwesen (BASt), examined field collision data gathered in France, Sweden, Germany and the United Kingdom as part of a broader research effort in support of the SID2000 project.

Single event side impacts accounted for approximately 25% of all seriously or fatally injured car occupants. Of these 43 to 55% were car-to-car impacts while 12% to 16% involved narrow vertical fixed object collisions (poles, trees, etc.). Vehicle-to-vehicle impacts involving bullet vehicles other than a car (e.g. trucks, buses, etc.) typically accounted for 14% to 19% of the casualties. In terms of impact direction, perpendicular impacts and oblique impacts from the forward direction (nominally 60 degrees) were the most common and were equally represented in severe-to-fatal collisions.

Occupants seated adjacent to the damaged side of the vehicle represented just over two-thirds of fatally or seriously injured casualties. The body regions most frequently injured in side impacts at the AIS$\geq$ 3 level were the chest and head, followed by the lower extremities, the abdomen and the pelvis.

AUSTRALIA Crash data was obtained from the Federal Office of Road Safety (FORS), the Crashed Vehicle File (CVF) and the Australian Harm database assembled by the Monash University Accident Research Centre (MUARC). Almost three-quarters of occupants of cars and light vehicles (vans, light trucks, sport utility vehicles) injured in side impacts sustain their injuries in vehicle-to-vehicle impacts while just over a quarter sustain their injuries in single vehicle collisions, the vast majority being related to narrow object collisions (poles or trees). In terms of impact direction, there is little difference in frequency between impact configurations described as "perpendicular" and those described as "oblique".

Female occupants account for 52% of fatalities or seriously injured in side crashes. Among occupants seated adjacent to the side of the vehicle impacted, the most frequently injured body region in vehicle-to-vehicle impacts was the thorax whereas in vehicle-to-narrow object impacts the most frequently injured body region was the head.

UNITED STATES Over the past decade (1995-2004), analysis of the Fatality Analysis Reporting System (FARS) database indicates that approximately 32,000 occupants of passenger vehicles were killed annually in US road-related crashes. Approximately 24% of the fatalities were associated with collisions wherein a perpendicular type side impact (3 or 9 o'clock directions) was judged to be the most harmful event. Of these, approximately one third involved narrow object collisions and accounted for 18 % of side related fatalities. Two thirds involved vehicle-to-vehicle impacts and accounted for 56% of all passenger side related fatalities.

In narrow object impacts, the representation of males ranged from a low of 65% in the case of restrained fatalities in passenger cars to a high of 82% in the case of unrestrained fatalities in LTVs. The mean ages of the casualties were 27.3 years for unrestrained male occupants of passenger cars and 32.9 years for restrained female occupants of LTVs.

Females accounted for the majority (56.1%) of restrained passenger car occupants killed in two-vehicle side crashes. Regardless of restraint status or gender, the casualties in two-vehicle side crashes were older than the populations represented in narrow object collisions. The mean ages of the casualties in two vehicle crashes were 40.2 years for unrestrained male occupants of passenger cars and 50.7 years for restrained female occupants of passenger cars. Restrained female passenger car occupants showed the highest two-vehicle to single vehicle narrow object fatality ratio at 8.3. The highest representation of restrained females was in LTV-to-car side crashes where they accounted for 56.9% of restrained car fatalities. The most frequently injured body regions were the chest and head, collectively, the two body regions accounted for over 50% of injuries rated AIS 3 or greater.

CANADA Over the past decade (1995-2004), the Traffic Accident Information Database (TRAID) managed by Transport Canada indicates that approximately 2,150 occupants of passenger vehicles have been fatally injured annually in Canada in road-related crashes. Of the approximately 950 passenger vehicle occupants killed annually in side-related crashes, approximately 100 (~10%) are killed in single narrow object collisions, while approximately 525 (~55%) are killed in vehicle-to-vehicle impacts.

The trends in terms of gender and age variations observed in the FARS dataset were also reflected in the Canadian data. The populations killed in narrow object impacts and vehicle-to-vehicle crashes are skewed both with respect to age and gender. Males for example, account for approximately 75% of occupants killed in single vehicle narrow object impacts. This representation ranges from a low of 71 % among restrained passenger car occupants to a high of 86 % for unrestrained LTV occupants. The mean age of occupants killed in single vehicle narrow object impacts is 30.1 years and varies little as a function of gender, 29.5 years and 32.0 years for males and females, respectively. In contrast, 48% of occupants killed in vehicle-to-vehicle side crashes are females, with the representation of females reaching a high of 51% in the case of restrained passenger car occupants. The mean age of the casualties is 44.0 years with little variation as a function of gender, 44.3 years and 43.8 years for females and males, respectively.

In addition to the continuous monitoring of TRAID data, Transport Canada conducts field accident investigations to obtain a detailed assessment of injury mechanisms, to detect serious detrimental effects of safety systems that may not be detectable in large databases and to provide case studies suitable for reconstructions and crash dummy validation studies.

Single-vehicle crashes with narrow fixed objects such as poles and trees involving late model vehicles (last 10 years) form a subset of the side impact crash investigations. To be included in the sample, a case vehicle must have included an occupant seated adjacent to the area of impact, have undergone a principal direction of force within plus or minus 45 degrees of the normal to the struck surface, and present a CDC extent zone (SAE J224 MAR80) between 2 and 4. Key parameters used to categorize narrow object crashes such as, impact location, principal direction of force (impact angle) and crush are difficult to estimate accurately in the field.

Figure 1 illustrates the extent of exterior damage and intrusion into the occupant compartment of two typical case studies where the injury outcomes are completely different, despite seemingly comparable measurements. In the first case, the left side of the Sunfire impacted a utility pole while in a clockwise rotation. The maximum crush to the left-front door was 720 mm, located immediately ahead of the B-pillar (09LPAN4). The driver was a 19-year-old male with a height of 168 cm and a mass of 59 kg. He was fully restrained with his seat positioned in the middle of its adjustment range. He received a concussion, an abrasion to the right temple, lacerations to the scalp and left arm (MAIS 2). The second case involved a 2001 Honda S2000 convertible, which impacted a non-frangible light standard. The maximum crush to the left-front door was 660 mm, with the damage extending from the sill to the convertible's soft roof, just ahead of the B-pillar (09LPAN4). The driver, a 39-year-old, male, was unrestrained, with his seat adjusted fully rearwards. He sustained a fatal head injury, hemorrhagic shock, and an open, unstable, pelvic fracture (MAIS 5).

Figure 1 Two case studies with equal crush but different injury outcomes.

Biofidelic and reliable anthropometric crash test dummies are necessary to quantify the dynamic events of a crash. Post crash measurements alone are not sufficient. The dummy and its associated instrumentation must be capable of detecting differences in the vehicle safety systems specifically in the regions of the head thorax and abdomen, the regions most frequently injured at the AIS 3 level.

Table 1: Test matrix of pole tests conducted by Transport Canada in support of IHRA

	Perpendicular		**15 º Oblique**	
A			WS 50th	ES-2re
F F		WS 50th	WS 50th	ES-2re
T C		WS 50th	WS 50th	ES-2re
H A			WS 50th	ES-2re
H S			WS 50th	ES-2re
S L			WS 50th	ES-2re
V T		WS 50th	WS 50th	

LABORATORY CRASH TESTS: METHODOLOGY

TEST MATRIX Vehicles were selected on the basis of model size and available side airbag technology. Two identical models were purchased for each dummy and test configuration comparison. A total of 16 tests were conducted as defined in Table 1. Paired tests had previously been carried out to compare WorldSID responses in oblique and perpendicular pole impacts with three vehicle models. Additional tests were also conducted to carry out a preliminary assessment of the ES-2re and WorldSID dummy responses in oblique pole impacts with two vehicle models (Tylko, S., Dalmotas, D. 2005). These tests are identified in the shaded cells of Table 1. In more recent testing, additional oblique tests were carried out to expand on the comparison between the ES-2re and the WorldSID and to investigate whether shifting the impact point forward would result in similar responses to those obtained during oblique pole tests.

TEST SET-UP To assure an accuracy of ± 3 mm of the target impact point and ± 0.5 km/h of the target impact velocity, the vehicle was towed by an electrical propulsion system and guided with dual trolleys to within 0.5 meter of the pole. The fore and aft trolleys were linked to the vehicle by way of steel cables anchored to the understructure of the vehicle, near the suspension.

The vehicle steering was fixed, but the suspension was left intact. The wheels were replaced by caster wheels to limit friction and permit crabbed motion of the vehicle. The vehicles were instrumented with a tri-axial accelerometers mounted at the vehicle CG while 4 uni-axial accelerometers were installed under the rocker panels near the level of the A and B pillar, in the driver door at points coincident with the H-point, shoulder and knee of the 50th percentile dummy driver. An additional 4 accelerometers were mounted underneath the rocker panels beneath each door.

Airbag systems and the interior trim encapsulating the curtains were not modified or interfered with. A fine gauge wire was placed across the anticipated opening to record airbag opening times. Tests were conducted with the driver side window in the full down position to enhance camera views. Perpendicular impacts were conducted with the vehicle aligned with the dummy head CG. In the case of shifted impact tests, the vehicle was aligned with a point that was of the order of 100 mm forward of shoulder location in the oblique condition. The 15º oblique impacts are aligned with a series of points defined by a plane drawn through the driver's head CG at 15º and projected to the surface of the door. Vehicles were launched at 32 km/h for the oblique condition.

The ES-2re and WorldSID dummies were both positioned in the driver seat of left hand drive vehicles by following the University of Michigan Transportation Research Institute (UMTRI) procedure, referred to as the IIHS/UMTRI seating procedure Version IV (Reed et al., 2001). A Faro® arm was used to match H-point and head CG placement to within ± 5 mm and ± 2 mm respectively for dummies being placed in paired vehicles. Vertical coordinates; particularly for the head CG could not be matched due to differences in dummy posture and anthropometry.

Instrumentation and Filtering The ES-2re and WorldSID dummies were instrumented with the following instrumentation: tri-axial accelerometers at the head CG, a 6-axis load cell at the upper and lower neck; a three axis load cell at the shoulder and displacement sensors at each of the three thoracic ribs; tri-axial accelerometers at the upper and lower spine and pelvis; uni-axial accelerometers at each rib and on the spine box opposite each rib. The WorldSID was further instrumented with deflection sensors at the shoulder and the two abdominal ribs. The ES-2re had three uni-axial load cells in the fore, mid and rear regions of the abdomen and a back-plate load cell. All data recording and filtering was performed in accordance with SAE J211 with the exception of the shoulder load cells. Table 2 describes the sign convention applied for the ES-2re and WorldSID shoulders.

Table 2: Sign convention applied for the shoulders of ES-2re and WorldSID

	ES-2re	WorldSID
Compression of the shoulder	+	+
Rearward displacement of the left arm relative to thorax	+	-
Upward displacement of the left arm relative to thorax	+	-

LABORATORY CRASH TESTS: RESULTS

VEHICLE RESPONSE Range of crush at shoulder and thorax level, averaged 375 mm and 396 mm respectively for the complete sample of oblique tests carried out with WorldSID or ES-2re as a driver. Figure 2 compares the intrusion measured on the door at approximately the level of the shoulder for paired vehicles. Oblique impacts resulted in greater deformation than perpendicular while shifting the impact point forward to coincide with the approximate location of the impact line for an oblique test caused a deformation that was comparable to the oblique tests.

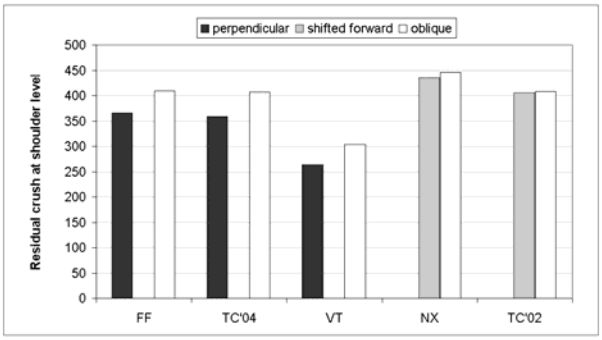

Figure 2: Residual crush of doors at shoulder level as a function of impact configuration.

Oblique tests resulted in a greater rotational component post impact. This rotation was observed to begin, on average between 50 and 60 ms into the event, after the large majority of peak responses of the dummies had occurred. Peak dummy responses were noted to occur as much as 10 ms earlier in perpendicular configurations when compared to the oblique. Peak responses in the shifted configuration occurred approximately 4 ms later than the oblique condition.

PLACEMENT The anthropometry and posture of the WorldSID and ES-2re dummies are different. WorldSID was designed to the UMTRI seating posture and is more reclined than the ES-2re. The head of the WorldSID displays a more slouched posture as the chin is tilted more towards the chest than ES-2re head. Differences in femur length and pelvis shape also influence how the dummy is seated in the seat. While great care was taken to match the H-point and head CG locations in the fore aft and lateral planes little could be done to match the vertical placement. Comparisons of the two dummy outlines are shown in Figure 3 for three of the vehicles included in the test sample. The head CG and shoulder is consistently higher for ES-2re while the WorldSID shoulder and arm placement are always closer to the door shown for the paired vehicles to the right of each dummy outline. The higher head and shoulder placement of the ES-2re influence dummy kinematics and response as will be seen in the comparison of head and thorax responses.

The exterior and interior door trim outlines are perfectly aligned and thus confirm that the reference axes used for measurements in the paired vehicles were equal. The post-test measurements of the exterior door and interior door trim are located within the outline of the dummy illustrating the extent of intrusion that occurred within the original occupant space. To differentiate between the two dummies WorldSID post-test door outlines are identified by stars while the ES-2re outlines are identified by rings. There appears to be a difference in the intrusion and displacement pattern of the interior trim both as a function of dummy and vehicle. The vehicles were all equipped with seat mounted thorax bags.

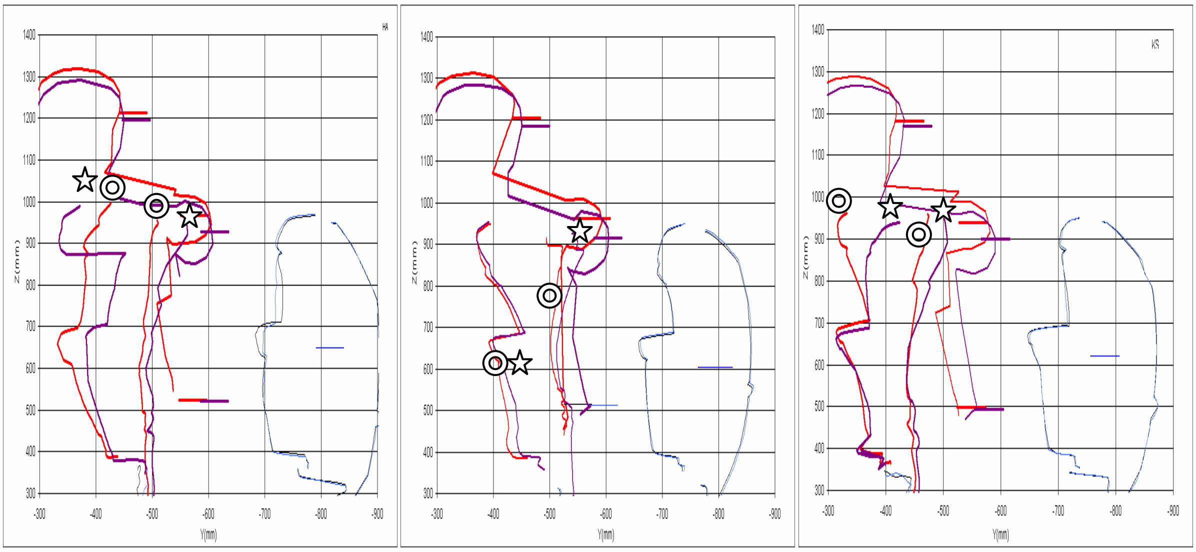

Figure 3: Outline of dummy placement relative to the door structure in the Y - Z plane in three vehicles.

SHOULDER forces were used for comparison of the ES-2re and WorldSID, since there is no shoulder deflection measurement in the ES-2re. The fore aft and lateral components of shoulder forces for the 5-paired vehicles are shown in Figure 4. The WorldSID shoulder traces are initiated earlier and appear to respond more rapidly than the ES-2re though the lateral peak force in the ES-2re typically occurs earlier in time relative to the WorldSID peak lateral load. The WorldSID shoulder displays a principal direction of force that is almost purely lateral while the ES-2re shoulder, displays a combined loading shared between the fore-aft and lateral directions. The magnitude of the amplitude and width of the lateral force curve is greater for WorldSID in all but one vehicle model.

In all but the FF vehicle model, the WorldSID shoulder is characterized by a very small and short duration positive fore-aft load component of the order of 200 N coincident in time with side airbag opening and corresponding to a forward arm displacement. This is then followed by a small negative fore-aft component of longer duration and is consistent with a rearward motion of the shoulder. Fore-aft response trace in the WorldSID shoulder is initiated at the same time as the principal lateral load response trace. In the ES-2re there occasionally appears to be a 2 to 4 ms delay in fore-aft response beyond the initiation of lateral load. Initial forward motion of the shoulder, at airbag opening, is typically not noticeable with the ES-2re.

THORAX time history traces for the WorldSID and ES-2re rib responses are presented in Figure 5. The corresponding time history traces of the lateral shoulder forces, upper spine acceleration and back plate forces are presented in Figure 6 for each of the five paired vehicle models. The intention here is not to illustrate a comparison of performance across vehicle models but rather, to highlight differences in dummy responses. The scales for the side-by-side graphs have been individually set to enhance this visualization.

The WorldSID ribs consistently respond earlier than the ES-2re and exhibit greater deflections and greater energy than the ES-2re. The order of the ribs attaining the greatest deflections, and thus the rib most frequently responsible for the peak thoracic deflection, differs between the two dummies. For example, with WorldSID, in 4 out of 5 vehicles tested, the highest deflections recorded is for rib 1, whereas the ES-2re rib 1 displays maximum deflection in 3 of the five models tested. The WorldSID ribs exhibit a wide range of deflections and each individual rib displays a diversity of contours. The ES-2re deflection traces in contrast, are more homogenous with amplitudes that are more tightly grouped together. The WorldSID ribs appear to be more responsive to airbag inflation as seen in the fourth deflection trace of figure 5.

Lateral back plate loads were generally of the order of 500 N and peaked midway through the shoulder force period. This occured between 4 to 10 ms after the lateral shoulder force peak, or at approximately 45 ms, as shown in the series of figures labeled Figure 6. The negative polarity of the back plate load signifies that the ribs were being displaced in-board relative to the back plate.

Back plate loads of the order of 500 N did not typically correlate to a reduction in thoracic rib deflection in the ES-2re. Peak back plate loads were actually attained before peak rib deflection and displayed no discontinuity in relation to rib response. Fore-aft peak back plate loads for all but one model lagged behind the peak shoulder fore-aft load by 5 to 10 ms. A lateral load as high as 1100 N was recorded for one vehicle model and did indicate that an interaction between the back plate and the seat back had occurred. In this particular vehicle the first or upper rib appeared to be the most affected with a deflection that was approximately 50 % less than the deflection measured in WorldSID, the second or middle rib was reduced by 30% while the lowest or third rib deflection in the ES-2re was reduced by 20 %. Both lateral and fore-aft peak shoulder loads for this model coincided in time with the peak back plate lateral force of 4000 + N and a fore-aft peak back plate load of 3200 N.

Upper rib deflections in the ES-2re tended to be lower than the corresponding WorldSID rib 1 deflections in models where elevated fore-aft shoulder forces were recorded. In fact as the peak fore-aft shoulder load approached 50 % of the concurrent lateral load in the ES-2re, the difference between the magnitude of the ES-2re upper rib and WorldSID rib 1 deflections attained 9 mm.

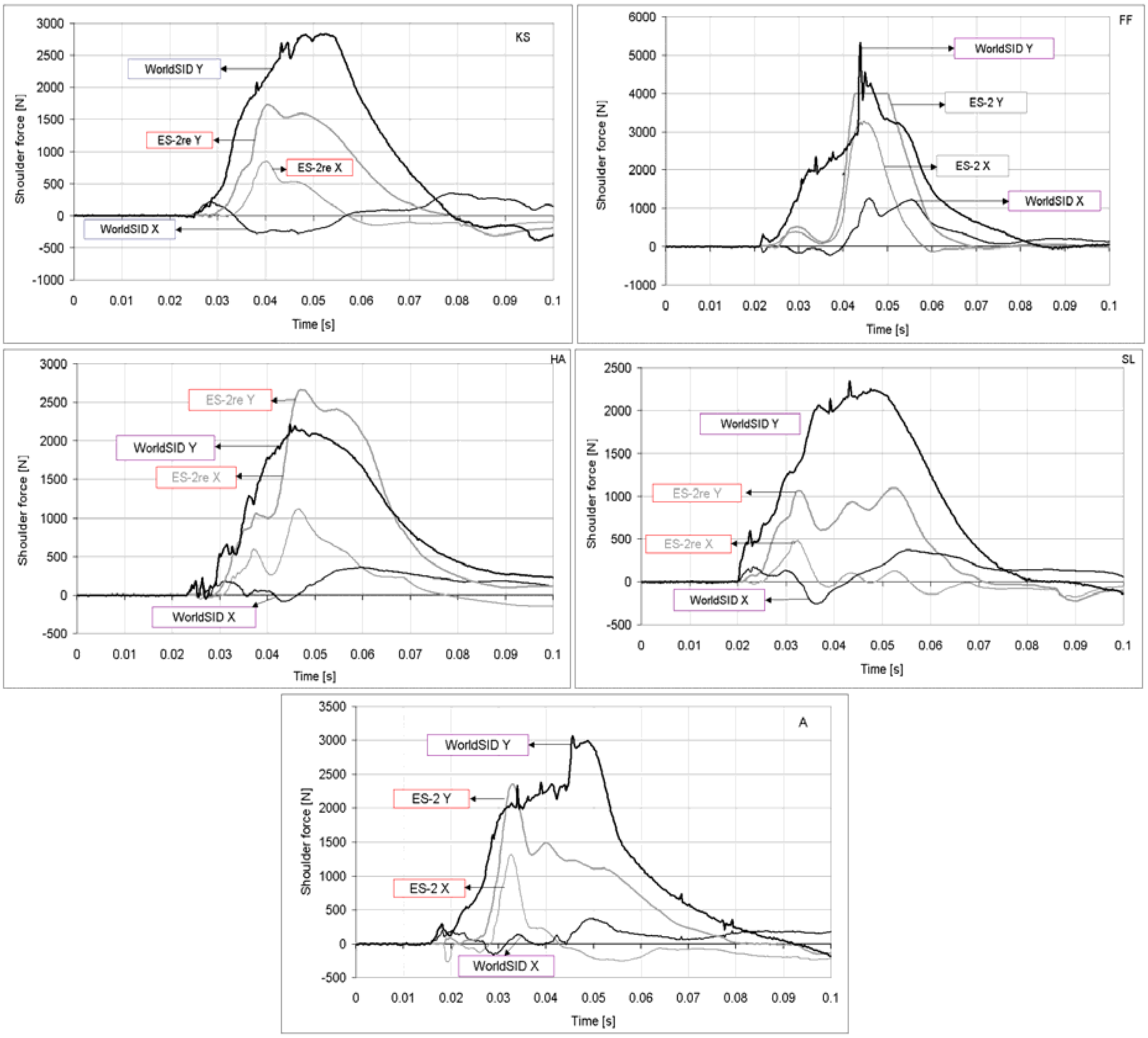

Figure 4: Shoulder force components for WorldSID and ES-2re.

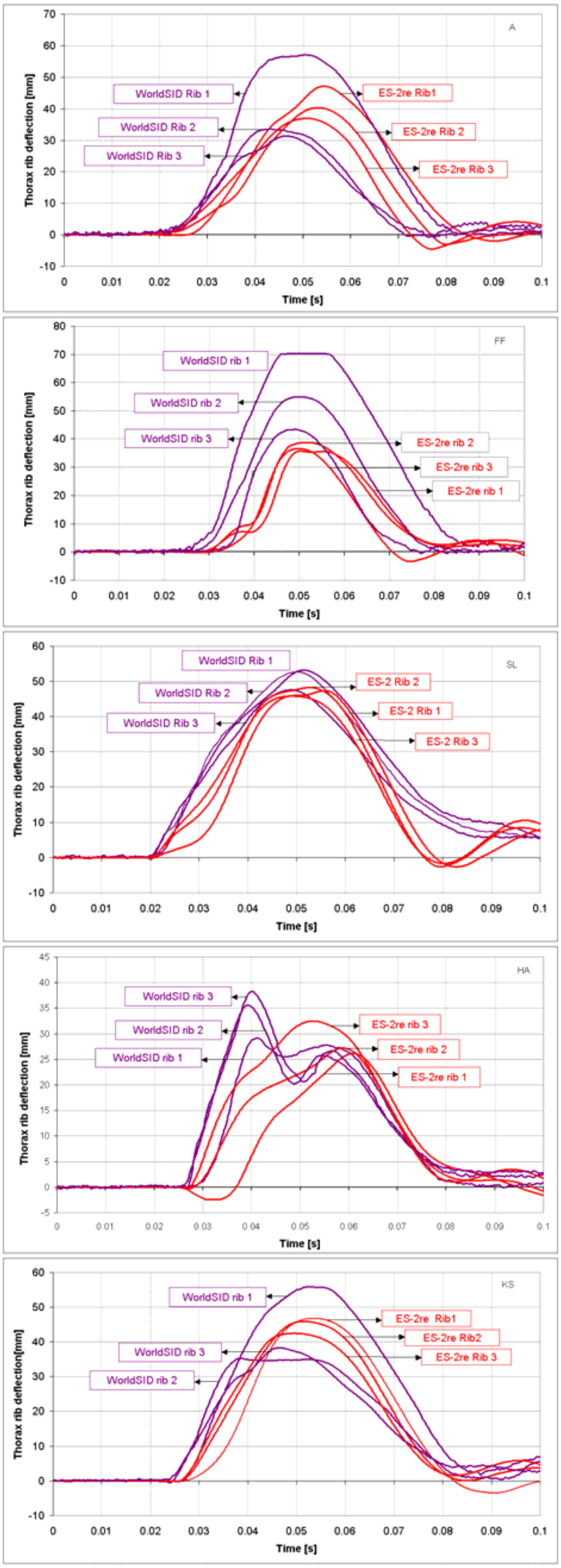

Figure 5: Comparison of thoracic deflections for ES-2re and WorldSID in oblique pole tests.

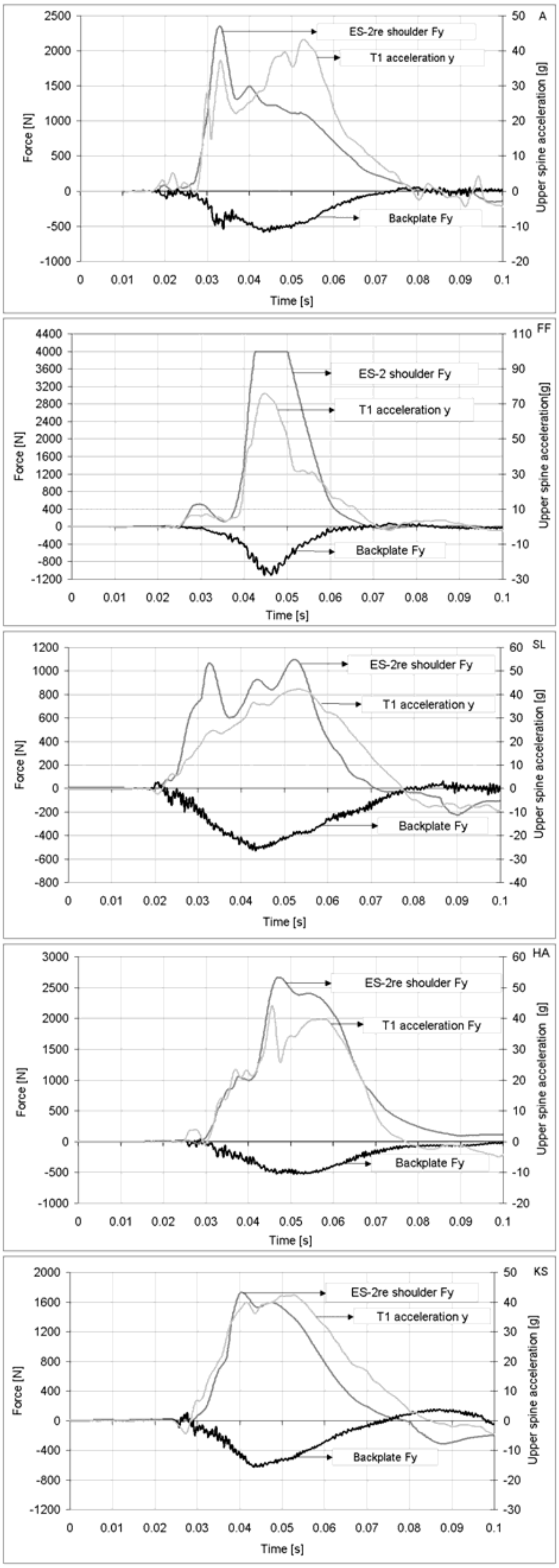

Figure 6: Comparison of shoulder force, T1 acceleration and back plate force for the ES-2re in corresponding tests.

ABDOMEN The abdominal injury risk assessment value for the ES-2re is based on the sum of three load cells located in the front, middle and rear region of the lower abdomen. Current proposed requirements are that the peak sum of these three loads, in time, remains below 2500 N. The abdominal injury criterion for WorldSID is based on the peak deflection of two abdominal ribs located immediately below the third thoracic rib. The abdominal ribs are located higher on the abdomen compared to the load plates of the ES-2re, and as such, are more in-line or more exposed to the armrest. Responses for the two dummies were normalized using the respective limits of 2500 N for the ES-2re and 42 mm of deflection for WorldSID. The results of the comparison, including the two vehicle models that were previously tested, are shown in Figure 7. The WorldSID abdominal rib deflection criterion was exceeded in 3 of 5 vehicles whereas the ES-2re load plates exceeded the limit value in only 1 of the 5 models tested.

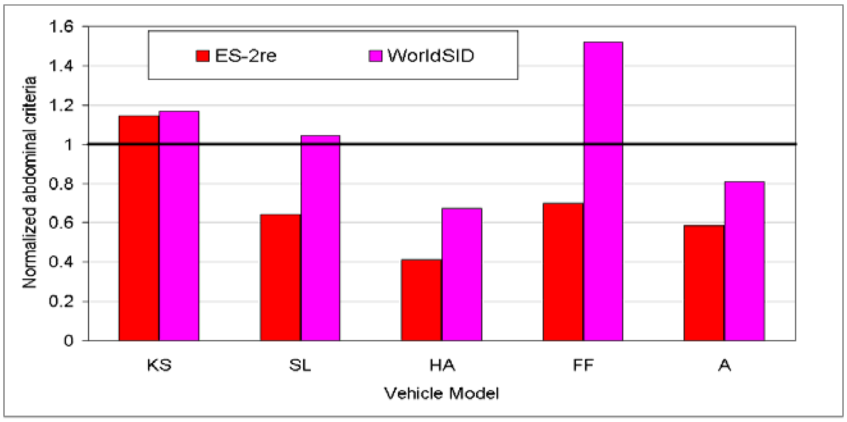

Figure 7: Normalized abdominal responses for five vehicle models.

DISCUSSION

The accident studies worldwide suggest the need for improvements in head, thorax and abdominal protection for both male and female occupants. The increased incidence of serious to fatal injuries among young male drivers involved in narrow object impacts and the concurrent large proportion of female occupants seriously or fatally injured in vehicle-to-vehicle side impact collisions in many jurisdictions, offers the opportunity to develop a comprehensive test methodology that potentially addresses differing kinematics, impact zones and injury tolerances with two test configurations: a moving deformable barrier test performed with a small female side impact dummy seated forward of the mid seat track position and a pole impact test performed with a mid size male side impact dummy seated at or rearward of the mid seat track position.

The accident databases do not have sufficient detail to confirm the relevance of pole impact angle in the field and so it becomes necessary to base the decision of impact configuration on scientific evidence. Normally one could conduct a limited series of tests to determine which test condition presents the greatest opportunity for evaluating and eventually improving the safety of a vehicle. However, such a scenario assumes that there exists a single ATD with confirmed biofidelity and well-understood and quantified responses for the applications of intended use. The crashworthiness research community has at its disposal an ES-2 designed for pure lateral impacts, an ES-2re with a modified rib cage to eliminate load paths from very specific and unique test conditions and a new harmonized side impact dummy with a new anthropometry, new posture, improved biofidelity and significantly more measurement capabilities. The test matrix has become unmanageable and the required scientific evidence very costly to obtain as we must rely on multiple dummy comparisons for guidance.

Perpendicular pole impacts appear to result in somewhat lower peak head and thorax responses yet are associated with more rapid onsets and more rapid peak response times. In contrast, oblique test conditions are characterized by greater magnitudes but later onsets and peak responses. Testing in a perpendicular orientation may challenge sensors and airbag deployments to a greater extent then testing in oblique since the permissible window of opportunity for intervention is reduced by approximately 10 ms.

Depending on the seating procedure used and the vehicle interior design, the ES-2 or ES-2re may lead to less than accurate assessment of head injury risk if during impact the trajectory of the head is diverted or its velocity slowed by a roof liner. The WorldSID stature combined with a more humanlike de-coupling of the upper and lower torso allows the head to follow an uninterrupted trajectory and attain peak velocity prior to impact with the curtain or exterior object.

The shoulder design influences the kinematics, load transfers and rib deformation patterns since in several vehicles the shoulder serves as the primary load path. Because the ES-2/ES-2re shoulder is designed to rotate forward and in-board, any off-axis load applied will cause a displacement of the shoulder complex and result in a redistribution of the load in all three axes. This redistribution of the loads is observed to occur very early on in the event. The fore-aft load appears approximately 4 ms after the onset of the lateral load. Not surprisingly, the more energy is redirected in the fore-aft direction, the less lateral energy is available for the displacement of the ribs. In this study, vehicles where the fore-aft load is 50% that of the lateral peak load are associated with rib deflections that are reduced by 9 mm relative to the WorldSID deflections. The freedom of motion towards the front, inherent in the ES-2 shoulder design, may explain why deflection response of the upper rib is reduced relative to the WorldSID and why the ES-2re is less able to detect airbag opening. Cadaveric studies conducted at ±15° and 0° reported increased shoulder compliance when the loads forced the shoulder rearward and greater resistance when the load forced the shoulder forward (Compigne et al., 2004). This is opposite to what is observed in the ES-2re. The authors also identified shoulder deflection as a better predictor of AIS 2+ shoulder and clavicle injuries than shoulder force. The WorldSID shoulder is symmetrical about the coronal plane, compresses in a manner that is comparable to what has been observed in cadaver tests, does not alter the load path and is sufficiently sensitive to track the motion of the arm throughout the event, displaying forward arm displacement that is coincident with airbag opening.

Observation of the traces indicate that the WorldSID ribs tend to respond independently of each other contributing to a wider range of deflections and time history contours. This is a vital attribute to permit the evaluation of interior door designs and airbag technologies. The responses obtained in this study suggest that the ES-2re ribs respond in unison and are therefore; less capable of detecting localized regions associated with potentially elevated injury risks.

The source of the low-level back plate loads (500 N) observed in all but one vehicle is not clear. Since the loads do not coincide with rib activity, this load may be a combination of inertial loading and/ or load transmissions to the spine from other regions of the dummy. However, since the rib extensions extend well beyond the rib boundary of the human chest and that of WorldSID, it is also possible that these low level loads represent interaction between the seat structure and the rib extensions. Additional impact tests, with and without seat back interaction, would need to be conducted to fully understand the relationship between dummy loads and the back plate response.

Furthermore, based on the results of the one vehicle where high back plate loads were recorded it would appear that the rib extensions (ES-2re), designed to alleviate interference between the dummy back plate and seat back have not solved the problem. Elevated lateral back plate loads are generated when the displacement of the back plate is restricted. This occurs when the seat back cushion traps the back plate and the ribs are displaced laterally relative to the back plate. The energy that should have deflected the ribs is dissipated instead, in the displacing the back plate into the seat back. Clearly this type of loading condition is not humanlike and thus renders the dummy responses less reliable.

The two comparative tests conducted in 2005 indicated that in one vehicle the ES-2re missed the identification of a potentially injurious abdominal loading. In the three subsequent tests carried out in this study two further vehicles were identified. In these vehicles the armrest comes into contact with a region of the ES-2re that is void of instrumentation as the abdominal load plates are located just below this zone of impact. In the case of the WorldSID, the location of the two abdominal ribs is such that it provides an uninterrupted region of measurement rendering it very difficult if not impossible to bypass the dummy's monitoring capabilities.

CONCLUSION

The world accident data defines clear opportunities for improvements in side impact protection for both women and men. The merits of a pole test with a mid-size male ATD capable of monitoring head, chest, and abdominal injury risks are clearly supported by the world accident data.

This study presented results of identically paired oblique pole crash tests conducted to compare the capability of the ES-2re and WorldSID dummies. The ES-2re produces erroneous responses when subjected to crash test conditions where the loads are not applied precisely to the central axis of the shoulder. In the oblique pole test configuration, the load to the shoulder is redistributed early in the event, generating proportionately high fore-aft components of force. This response reduces the rib displacement response of the ES-2re as well as its ability to detect airbag opening.

The ES-2re lacks the capability of measuring shoulder deflection, identified by other researchers as being a good predictor of shoulder and clavicle injuries. The homogeneity in response of the three ES-2re thorax ribs suggests a reduced sensitivity. This, combined with the absence of instrumentation in a region of the abdomen that is frequently adjacent to prominent sections of armrests, indicate that the dummy is less capable of detecting localized regions of injury risk than the WorldSID. Finally, the introduction of the rib extension has not eliminated the interaction between the back plate and the seat back but has instead added one additional level of complexity in the interpretation of results.

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