ASSESSMENT OF OCCUPANT PROTECTION SYSTEMS IN VEHICLE-TO-POLE LATERAL IMPACT USING ES-2 AND WORLDSID

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ABSTRACT

A series of vehicle-to-pole lateral impact tests were conducted using ES-2 and WorldSID dummies. Pure lateral (90°) and oblique (75°) impacts were included in the test series and the level of protection offered by the head protecting side airbag was assessed under each condition.

The head injury risks predicted by the ES-2 and WorldSID dummies under the same oblique pole test conditions were dramatically different, with the ES-2 indicating a low risk of head injury and the WorldSID indicating a very high risk of head injury. Sled tests were used to investigate the kinematics of the ES-2 shoulder, the consequent influence of shoulder load on head / neck kinematics, and the ability of this dummy to discriminate the level of head protection offered by head protecting side airbags. The head, neck, and shoulder kinematics and peak shoulder loads of the ES-2 were found to be highly sensitive to the direction of loading to the shoulder resulting from each pole impact angle.

INTRODUCTION

The EuroSID 2 (ES-2) dummy was originally developed for mobile deformable barrier side impact testing, and is the current regulatory dummy specified in UNECE R95 (Protection of Occupants in the Event of a Lateral Collision). The WorldSID dummy was developed as part of a collaborative project to develop a world harmonized side impact dummy with superior biofidelity to earlier generations of side impact dummies. Like all anthropomorphic crash test devices, these dummies are essentially an assembly of mechanical components and instruments, the purpose of which is to simulate a human biomechanical response and measure injury risks.

The ES-2 shoulder assembly (see Figure 1) consists of an arm clavicle mounted between two metal plates, and an elastic cord which is used to hold the shoulder in position. This design allows transverse adduction of the shoulder, but does not allow significant other movements of the shoulder. A tri-axial load cell is used to measure shoulder loads. The WorldSID shoulder consists of a mounting bracket and a shoulder rib. The shoulder bracket allows some transverse adduction of the shoulder, and the shoulder rib permits medial deflection of the upper arm / shoulder. A tri-axial load cell is used to measure shoulder loads, and an IRTRACC (see Figure 3) is used to measure shoulder rib deflection.

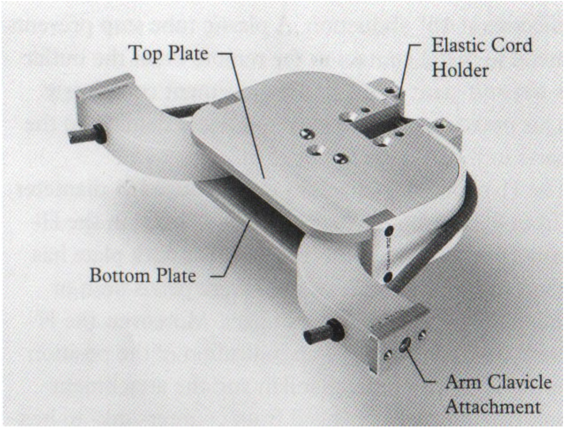

Figure 1. ES-2 shoulder assembly (note: arms are attached to each clavicle attachment).

The ES-2 has three rectangular thorax ribs (see Figure 2). These ribs are mounted to a spring slide and hydraulic damper assembly, and are capable of purely lateral deflection from one side only. ES-2 rib deflections are measured by linear potentiometers. The WorldSID has three circular thorax ribs mounted either side of a central spine box (see Figure 2 and Figure 3). These ribs are capable of deflection in all directions, and from both sides. An IRTRACC is used to measure the lateral component of rib deflection. It is not practical to package sufficient instrumentation to simultaneously measure deflections on each rib on both sides of the dummy.

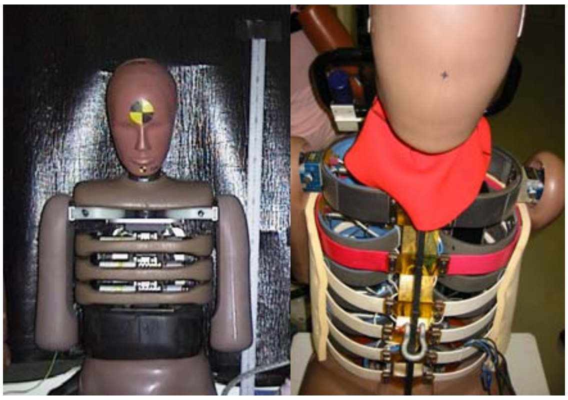

Figure 2. ES-2 (left) and WorldSID (right) shoulder, thorax, and abdomen design.

The ES-2 abdomen (see Figure 2) consists of a load cell element. Load cells are used to measure front, middle, and rear abdomen loads. In contrast, the WorldSID has two circular abdomen ribs mounted either side of its central spine box. An IRTRACC is also used to measure the lateral component of abdomen rib deflection.

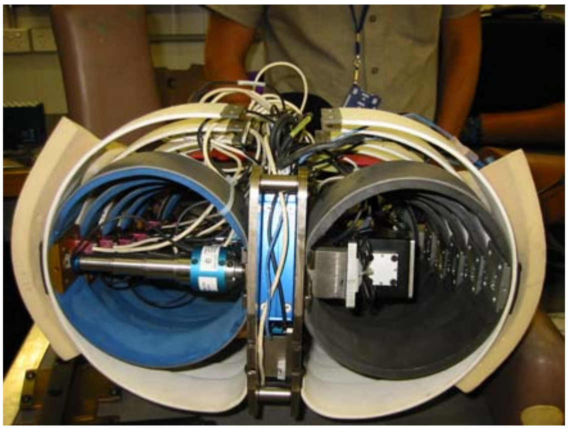

Figure 3. WorldSID thorax rib assembly (including IRTRACC and rib accelerometer instrumentation).

The suitability of the ES-2 and WorldSID dummies for lateral impact testing is therefore determined by the capacity of each mechanical component / sensor to measure the types of impact loadings that occur in lateral impact. It is also determined by the capacity of each dummy to simulate a human biomechanical response to side impact conditions.

In this study, results obtained from a series of vehicle-to-pole side impact tests, are used to analyse the crash responses of ES-2 and WorldSID. Results obtained from a series of pole sled tests are then used to further investigate the kinematics of the ES-2 shoulder, neck, and head.

METHOD

Vehicle Pole Test Series

A series of 3 full scale vehicle-to-pole side impact tests were conducted using ES-2 and WorldSID dummies (see Table 1). The vehicle model chosen for this series of tests was a 2004 model, right hand drive, 5 door mid-sized SUV, with curtain and seat mounted thorax (front row) side airbags. This vehicle model was popular in the Australian market, and was used for each test in this series.

Table 1 summarises test conditions for each full scale vehicle pole side impact test. A perpendicular pole test was conducted using an ES-2 dummy situated in the drivers seating position. Two oblique pole tests were also conducted; one with an ES-2 driver's side dummy, and the other with a WorldSID dummy in each front row seating position. WorldSID dummy sensor data is therefore available for both the struck side and non-struck side occupant. Interactions occurred between the two WorldSID dummies; however, this paper will focus on struck side injuries. It is important to recognise that results show dummy interaction responses to be separate events to struck side injuries. Therefore the presence of a front passenger dummy does not affect the assessment of struck side injuries.

Table 1.
Test Matrix
(Vehicle Pole Test Series)

Impact Angle (Degrees)	Impact Speed (km/h)	Driver Dummy	Front Passenger Dummy	Side Airbags
90	28.8	ES-2	-	Thorax Curtain
75	32.2	ES-2	-	Thorax * Curtain
75	32.0	WS	WS	Thorax * Curtain

* Airbag failed to deploy correctly / deployed inside the drivers seat

The seatback angle was set to achieve a manufacturer specified torso angle of 21º and the seat was locked in the mid track seating position. A 3-D H-point machine was used in accordance with the requirements of EuroNCAP pole side impact testing protocol (version 4.1) [1] to determine the H-point of the driver's seat. For the tests conducted using an ES-2 dummy, a FARO arm was used to match, as closely as possible, the dummy with the seating reference point determined with the 3-D H-point machine. A FARO arm was also used to measure and match the location of the head centre of gravity for each ES-2 test. The ES-2 dummy has a more upright seating posture than the WorldSID. It is therefore not possible to match both the H-point and head centre of gravity of each dummy. The WorldSID dummy was therefore positioned using the same seating track position and seat back angle, and a FARO arm used to accurately match the dummy head centre of gravity location (x-coordinate) to those recorded for the previous ES-2 tests. This ensured that the pole was aimed at the same location on the vehicle for each oblique pole test.

Each pole side impact test was conducted with either a perpendicular (90º) or oblique (75º) angle between the direction of travel and the vehicle longitudinal centreline / axis (see Figure 4 and Figure 5). For each test, a laser was used to align the pole with the dummy head centre of gravity, and a carrier sled was used to impact the vehicle with the pole. The pole used was in accordance with the specifications of EuroNCAP pole side impact testing protocol (version 4.1) [1].

Figure 4. Overhead view of 90 degree (perpendicular) pole side impact test.

Figure 5. Overhead view of 75 degree (oblique) pole side impact test.

The perpendicular pole test was conducted with a targeted impact speed of 29 km/h. For the oblique pole tests, the targeted impact speed was 32 km/h. In all cases, the actual impact speed was within ± 0.2 km/h of the targeted impact speed. For each full scale vehicle test, the actual impact alignment was within 4 mm of the intended impact alignment.

Pole Sled Test Series

A series of pole sled tests were conducted to further investigate the biomechanical response (i.e. head, neck, shoulder) of the ES-2 dummy (see Table 2). In this series of tests, a UNECE R16 hard seat was mounted to a crash sled, and a head curtain airbag (from one of the earlier full scale vehicle tests) was pre-inflated to a constant regulated pressure (approx 45 kPa) and secured against the pole by a fabricated test fixture (see Figure 6 and Figure 7). A stepped pole fixture was used in one of the tests to simulate shoulder deflection for an ES-2 dummy (see Figure 8). The stepped portion of the pole was positioned to interact with the dummy head, but not the dummy shoulder.

The curtain airbag was able to be moved relative to the pole, using the fabricated test fixture. This made it possible to simulate different head impact locations with the curtain airbag. Four head impact locations were tested. Three of these locations were chosen to match the head to airbag impact locations for each full scale vehicle test. The remaining head impact location was chosen to approximate an estimated WorldSID head impact location for a perpendicular pole test.

Table 2.
Test Matrix
(Pole Sled Test Series)

Dummy Angle (Degrees)	Impact Speed (km/h)	Pole Step (mm)	Head / Airbag Impact Location	Right Arm Angle (Degrees)
90	22	0	ES-2 / 90	0
90	22	0	WS / 90	0
75	22	0	WS / 75	40
75	22	0	ES-2 / 75	40
75	22	50	ES-2 / 75	40

Each pole sled test was conducted with the ES-2 dummy midsagittal plane oriented at either a perpendicular (90º) or oblique (75º) angle to the direction of motion. Foam block padding was used to ensure the correct pre-impact orientation of the dummy. For each test, the centre of the pole was aligned with the dummy head centre of gravity.

The right arm was set to a 0º (horizontal) or 40º angle depending on the dummy / pole impact angle being simulated. For the perpendicular tests, the dummy arm was set to a horizontal position prior to impact; this was done to simulate the position of the arm following successful deployment of the thorax airbag. For the oblique pole sled tests the dummy arm was lowered by 40º; this was done to simulate the lower arm positions observed, when the thorax airbag fails to deploy successfully.

Each pole sled test was conducted with a 22 km/h impact speed. This impact speed was selected following an initial investigation of dummy head acceleration. This initial investigation involved the conduct of some experimental tests, the purpose of which was to determine a set of test conditions (including test speed) which would give marginal head contact with the pole through the airbag. This enabled further investigation of the effect of pole test variables on ES-2 head, neck, and shoulder responses.

Figure 6. Onboard view of pole sled test (at maximum head acceleration).

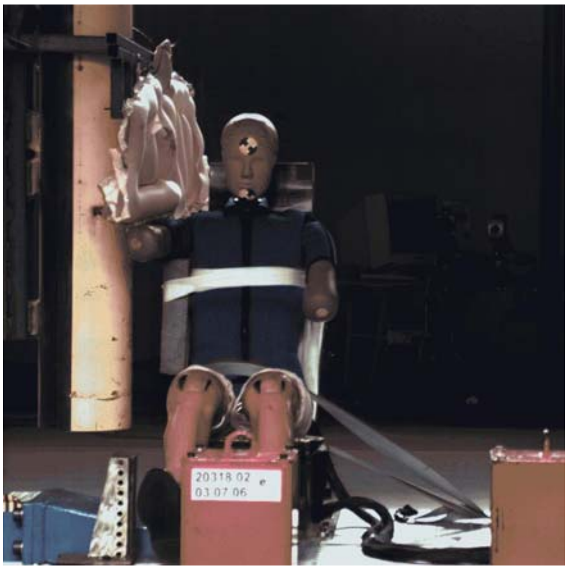

Figure 7. Front view of pole sled test (approx. 10-15 ms prior to impact).

A 70 mm foam block was used to improve the simulation of dummy thorax interaction with the pole. A webbing strap located around the pelvis and anchored to the sled, was used in each test to restrain the pelvis and upper legs of the dummy. A metal fixture was used to limit / restrain the motion of the lower legs (see Figure 7).

Figure 8. Stepped pole test fixture.

Data Acquisition

All dummy and vehicle sensor channel data was collected at a 20 kHz sampling frequency. All data presented in this paper is in accordance with the filtering and sign conventions specified by SAE J211-1 (December 2003) [2].

RESULTS

Vehicle Pole Test Series

Table 3 shows struck side 3 ms head acceleration and HIC 36 results for each vehicle-to-pole side impact test. The ES-2 dummy head avoided hard contact with the pole for each pole impact condition. In contrast, the WorldSID head was observed to bottom out the curtain airbag, making hard contact with the pole. Consequently, for oblique pole impact, WorldSID indicated a higher head injury risk (i.e. HIC 36) than ES-2. Figure 9 shows resultant head acceleration for each test. Two separate head acceleration spikes were recorded for the oblique pole test conducted using the WorldSID. The first of these acceleration spikes was co-incident with the dummy head-to-pole collision; the second was co-incident with a collision of the driver and front passenger dummy heads (not discussed in this paper).

Table 3.
Head Acceleration / HIC 36

Impact Angle (Degrees)	Impact Speed (km/h)	Driver Dummy	3 ms Head Acc. (g)	HIC 36
90	28.8	ES-2	60.89	352.7
75	32.2	ES-2	80.43	809.1
75	32.0	WS	65.92	2941.6

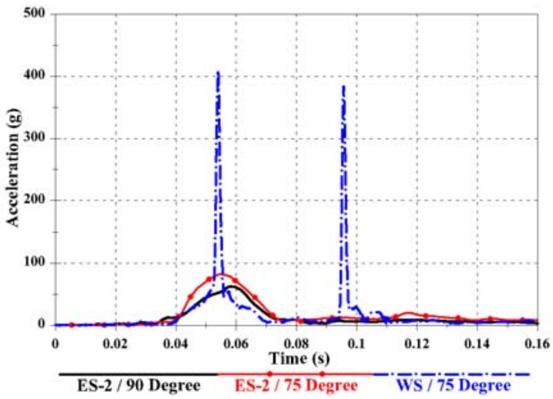

Figure 9. Resultant head acceleration.

Figure 10 shows longitudinal (x-axis in dummy coordinate system) head acceleration for each vehicle-to-pole side impact test. For the ES-2 dummy, oblique pole impact produced an earlier and larger longitudinal head acceleration response, than perpendicular impact. This increase in ES-2 longitudinal head acceleration is due to the longitudinal component of impact velocity; it is also a product of the longitudinal components of shoulder load, upper spine acceleration, and upper neck load. The WorldSID longitudinal head acceleration response shows the occurrence of a dummy head-to-pole collision (t ≈ 54 ms). However, in the period immediately following impact and preceding this head collision (i.e. between t = 0 and t ≈ 51 ms), WorldSID longitudinal head acceleration was substantially lower than that of ES-2.

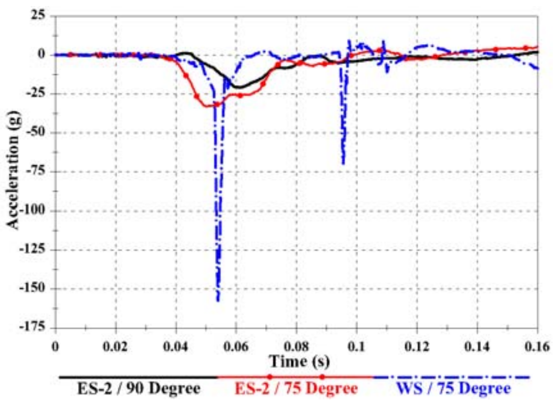

Figure 10. Longitudinal head acceleration (Ax).

Figure 11 shows lateral (y-axis in dummy coordinate system) head acceleration for each vehicle-to-pole side impact test. For the ES-2 dummy, oblique impact also produced more lateral head acceleration than perpendicular impact. This increase is likely to have been caused by a combination of factors, including a small increase in the lateral component of vehicle impact velocity, and a substantially larger lateral shoulder load (see Figure 13). The lateral head acceleration recorded during the oblique WorldSID test was initially similar to that recorded during the perpendicular ES-2 test (i.e. up until the occurrence of the head-to-pole collision). This suggests that the ES-2 dummy head came very close to colliding with the pole for each pole impact condition. For the oblique pole test conducted using ES-2, there was just enough initial head acceleration to prevent hard impact from occurring between the head and pole through the airbag.

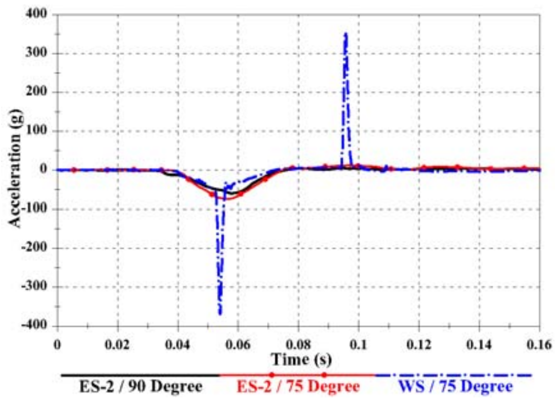

Figure 11. Lateral head acceleration (Ay).

Figure 12 shows struck side longitudinal shoulder load for each vehicle-to-pole side impact test. For the ES-2 dummy, oblique pole impact produced substantially more longitudinal shoulder load than perpendicular impact. This relatively large longitudinal shoulder load acts in an anterior direction (i.e. pushes shoulder back relative to chest), and is a result of the longitudinal component of oblique pole test impact velocity. Under these conditions, the relative stiffness of the ES-2 shoulder is likely to prevent any substantial relative transverse lateral, longitudinal, or vertical motion between the shoulder and upper spine, as the shoulder is pushed onto its limit stops. For the oblique pole test condition, WorldSID recorded substantially less longitudinal shoulder load than ES-2.

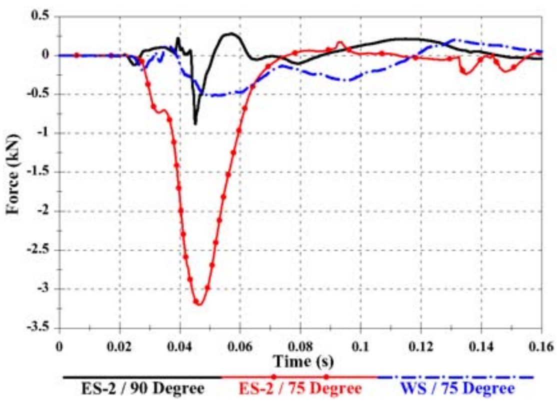

Figure 12. Longitudinal shoulder force (Fx).

Figure 13 shows lateral shoulder load for each vehicle-to-pole side impact test. For the ES-2 dummy, oblique pole impact produced substantially more lateral shoulder load than perpendicular impact. For this dummy and oblique pole impact condition, a large longitudinal shoulder load coincided with a large lateral shoulder load. Under these conditions, there is a direct lateral load / energy transfer path from the ES-2 shoulder to the upper spine and neck. In oblique impact, the WorldSID struck side shoulder rib deflected 51.5 mm. The WorldSID shoulder rib therefore stored / absorbed energy during impact. As a result, under oblique impact conditions, WorldSID recorded a smaller peak lateral shoulder load than ES-2.

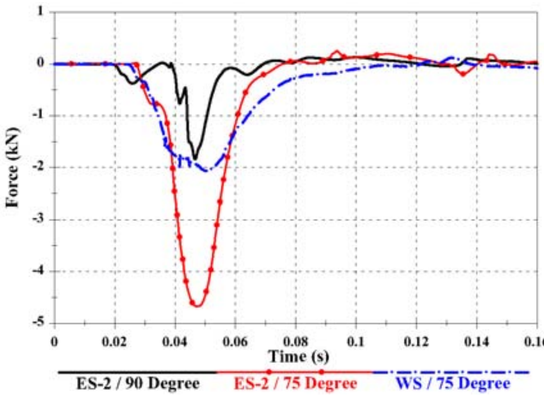

Figure 13. Lateral shoulder force (Fy).

Figure 14 shows vertical shoulder load for each vehicle-to-pole side impact test. For the ES-2 dummy, oblique pole impact produced substantially more vertical shoulder load than perpendicular impact. For both impact conditions, the ES-2 shoulder was initially pushed upwards (negative load) by the intruding door at the window line. In the case of perpendicular impact, successful thorax airbag deployment caused the ES-2 shoulder and arm to rise above the intruding door, and the vertical shoulder load to change from negative (upward acting) to positive (downward acting). For the oblique pole test condition, WorldSID recorded substantially less vertical shoulder load than ES-2.

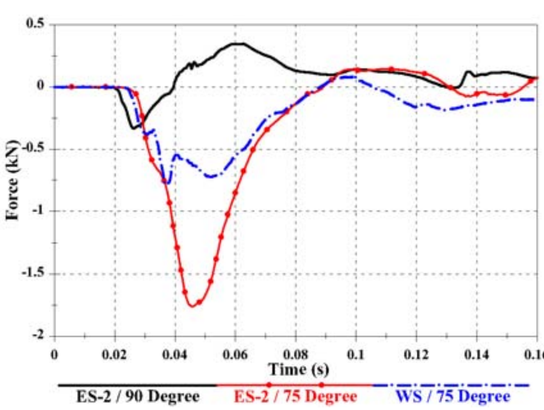

Figure 14. Vertical shoulder force (Fz).

During the perpendicular pole test, the ES-2 arm and shoulder were able to move both forward and inboard (see Figure 15). This movement of the shoulder / arm was assisted by the successful deployment of the thorax airbag. In contrast, during the ES-2 oblique pole test, the thorax airbag failed to deploy correctly, the arm was jammed between the intruding pole and the thorax, and the shoulder was unable to move substantially forward or inboard relative to the upper spine (see Figure 16). In oblique impact, the WorldSID shoulder was deflected inwards and the arm was jammed between the intruding pole and the thorax (see Figure 17). This medial shoulder deflection reduces the distance between the intruding pole and the base of the neck. This increases the likelihood of dummy head-to-pole hard contact through the airbag.

Figure 15. ES-2 arm and shoulder position approximately 75 ms after time-zero (perpendicular impact condition).

Figure 18 and Figure 19 show the longitudinal and lateral components of upper spine acceleration for each vehicle-to-pole side impact test. For each dummy and pole impact condition, there is a correlation between the corresponding components of shoulder load and upper spine acceleration (see Figure 12 and Figure 13). All else being equal, higher shoulder loads will increase acceleration of the upper spine, head, and thorax. For the ES-2 dummy, oblique impact produced higher peak longitudinal and lateral upper spine accelerations than perpendicular impact. For oblique impact, WorldSID longitudinal and lateral upper spine accelerations peaked at lower levels than ES-2 (note: the WorldSID upper spine acceleration response includes interaction with front passenger occupant at t ≈ 95 ms). Also notable is the later occurrence (approx. 10 ms) of WorldSID peak inboard and backward upper spine accelerations compared with ES-2.

Figure 16. ES-2 arm and shoulder position approximately 75 ms after time-zero (oblique impact condition).

Figure 17. WorldSID arm and shoulder position approximately 75 ms after time-zero (oblique impact condition).

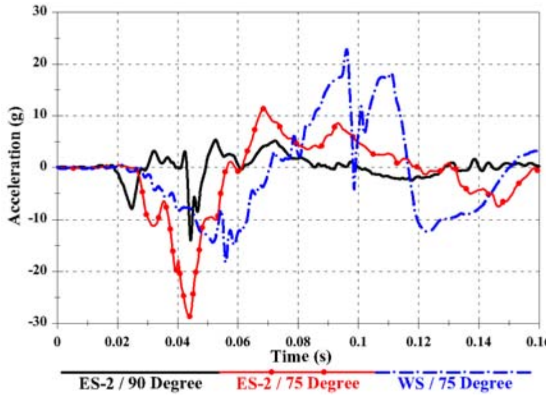

Figure 18. Longitudinal upper spine acceleration (Ax).

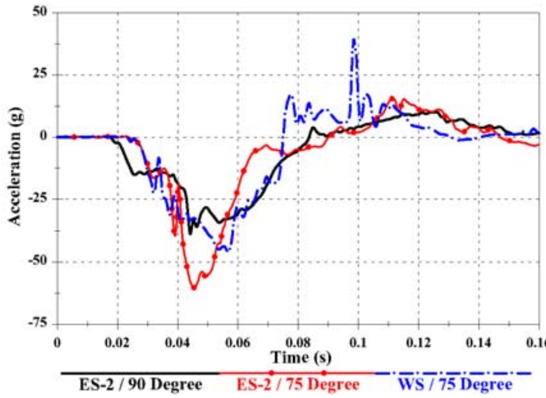

Figure 19. Lateral upper spine acceleration (Ay).

Figure 20 shows longitudinal upper neck load for each vehicle-to-pole side impact test. For the ES-2 dummy, oblique pole impact produced substantially more longitudinal upper neck load than perpendicular impact. In oblique impact, ES-2 longitudinal upper neck load is predominantly negative. This indicates forward movement of the head relative to the chest. It is also noteworthy that peak (negative polarity) longitudinal upper neck load occurred at approximately the same time as peak (negative polarity) longitudinal shoulder load (see Figure 12). This suggests that the ES-2 dummy head is pulled / accelerated rearward of the pole by load transferred through the shoulder and upper neck. For the oblique pole impact condition, WorldSID longitudinal head acceleration rapidly changed from negative to positive. This polarity change was coincident with dummy hard head contact with the pole, and indicates rearward movement of the head relative to the chest (i.e. pole pushed dummy head back relative to chest).

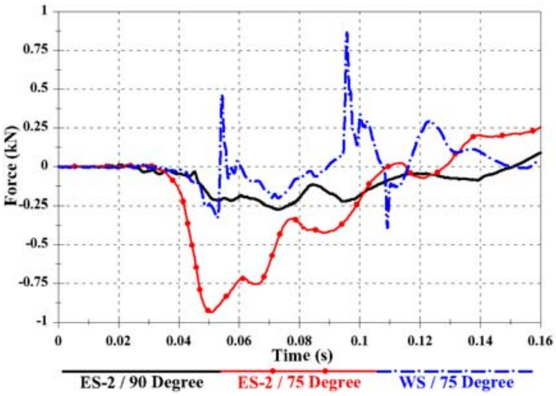

Figure 20. Longitudinal upper neck force (Fx).

Figure 21 shows lateral upper neck load for each vehicle-to-pole side impact test. For the perpendicular pole test, ES-2 lateral upper neck load is predominantly positive. This means the head moves leftward (inboard) relative to the chest. For the oblique impact condition, the ES-2 lateral upper neck load is initially negative (i.e. head moves right relative to chest). This negative lateral upper neck load pulls the upper neck towards the pole, and an equal and opposite (i.e. positive) resistive load pulls the head away from the pole. For the ES-2 dummy and oblique impact condition, peak (negative polarity) lateral upper neck load occurred at approximately the same time as peak (negative polarity) lateral shoulder load (see Figure 13). This suggests that the ES-2 dummy head is pulled / accelerated away (inboard) from the pole by relatively large (negative polarity) lateral upper neck and shoulder loads. For the oblique pole impact condition, WorldSID lateral upper neck load was also initially negative. However, the peak magnitude and the duration of negative lateral upper neck load were considerably less for the WorldSID. For this dummy, lateral upper neck load changed polarity immediately prior to hard head-to-pole contact. Therefore, in contrast to ES-2, the WorldSID head was pushed inboard relative to the chest, during head interaction with the curtain airbag / pole.

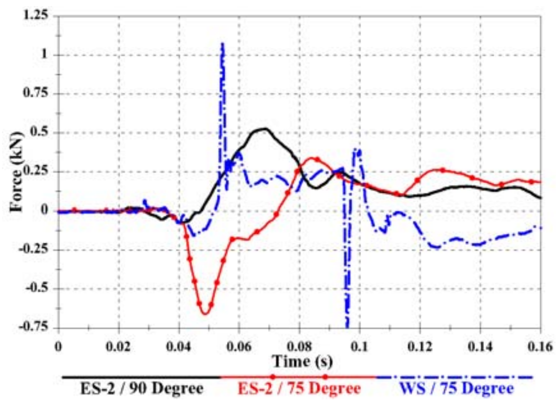

Figure 21. Lateral upper neck force (Fy).

Figures 22 to 24 show upper, middle, and lower thorax rib deflection for each vehicle-to-pole side impact test. For the ES-2 dummy, perpendicular impact produced more upper and middle rib deflection, than oblique impact. This is despite the fact that the thorax airbag failed to deploy successfully during oblique impact. For the oblique impact condition, the location of maximum rib deflection (i.e. upper, middle, or lower rib) varied depending on the dummy used. WorldSID predicted greatest injury risk (i.e. highest rib deflection) at the upper thorax, while ES-2 predicted greatest injury risk at the lower thorax. This is likely to be attributable to a range of factors, including differences in the seating posture, and biomechanical response of each dummy. The capacity of each dummy to detect oblique (i.e. not purely lateral) rib loads may also be a factor. It should be noted that the ES-2 rib is only capable of lateral rib deflection, and the WorldSID is only capable of measuring the lateral component of rib deflection. Furthermore, under oblique impact, friction in each dummy's linear rib deflection sensor could potentially provide resistance to rib deflection. As a result, it is possible that either dummy could have failed to detect some oblique rib loading.

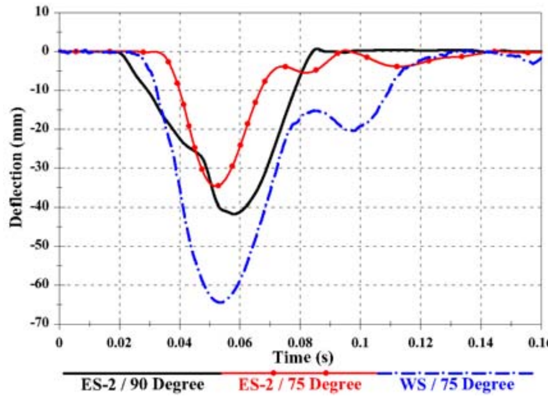

Figure 22. Upper thorax rib deflection.

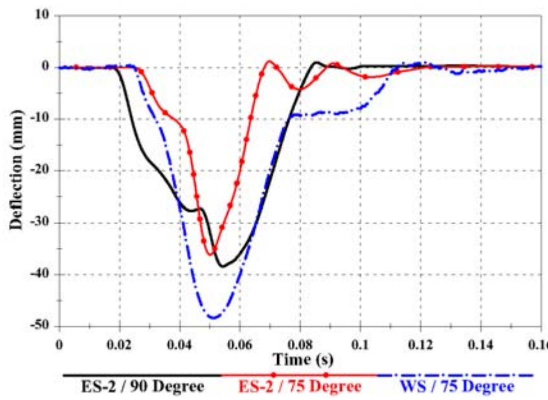

Figure 23. Middle thorax rib deflection.

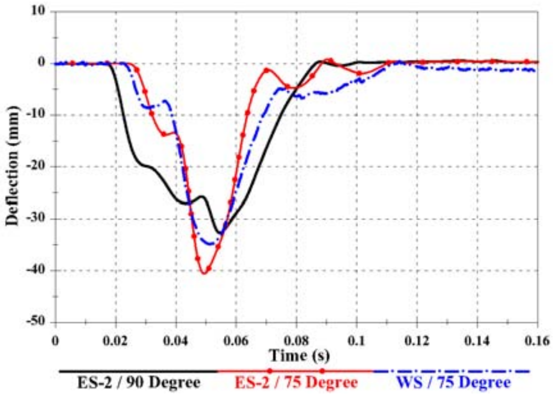

Figure 24. Lower thorax rib deflection.

Pole Sled Test Series

Table 4 includes dummy head, neck, shoulder, and upper spine results for each pole sled test. Each test was conducted with an ES-2 dummy at a 22 km/h impact speed. This impact speed was selected to achieve marginal head contact with the pole. A 40º arm angle was used for oblique impact, and a 0º (horizontal) arm angle was used for perpendicular impact. The test variables investigated were pole impact angle, head impact location, and shoulder deflection (simulated by a stepped pole). The purpose of these tests was to investigate the relative influence of each test variable on dummy head, neck, and shoulder response.

Oblique and perpendicular pole impact conditions were simulated by altering the dummy orientation relative to the seat and pole. Results show dummy impact angle (i.e. pole impact angle) to have a greater effect on shoulder load, upper neck load, and upper spine acceleration, than any other test variable. Similar to results obtained from the full scale vehicle-to-pole tests, peak longitudinal and lateral components of shoulder load and upper spine acceleration were all greatest for the oblique impact condition. Other similarities between these results and those obtained from the full scale vehicle tests include, increased HIC 36 for oblique impact, and reversal of peak upper neck load polarities for each impact angle. In this series of tests, peak longitudinal / lateral upper neck loads were negative for oblique impact, and positive for perpendicular impact.

Head impact location was controlled by moving the head curtain airbag relative to the pole. Four head impact locations were tested. These were chosen to match ES-2 and WorldSID head-to-airbag impact locations from full scale vehicle-to-pole oblique and perpendicular impact tests. Of all the test variables investigated, head-to-airbag impact location had by far the least effect on dummy head, neck, shoulder, and upper spine results.

The ES-2 shoulder design does not allow pure lateral deflection of the shoulder relative to the upper spine. In contrast, the WorldSID shoulder is able to deflect inwards, thereby reducing the lateral distance between the point of the shoulder / pole and the side of the head. In this series of tests, pure lateral deflection of the ES-2 shoulder was simulated by conducting a pole sled test with a stepped pole fixture. This stepped pole was used to reduce the lateral distance between the pole and the head, during shoulder interaction with the pole. The simulated shoulder deflection condition (test 5) produced a substantially greater HIC 36 than any other test condition. Therefore, of the test variables investigated, shoulder rib deflection / design appears to have the greatest influence on 3 ms head acceleration and HIC 36 results. This relationship between shoulder rib deflection and 3 ms head acceleration / HIC 36 could be further substantiated by conducting similar pole sled tests using a WorldSID. This work is part of further planned research.

Table 4.
Pole Sled Test Results

Test	Dummy Angle (Degrees)	Pole Step (mm)	Head / Airbag Impact Location	Right Arm Angle (Degrees)	3 ms Head Acc. (g)	HIC 36	Peak Upper Neck Load X (kN)	Peak Upper Neck Load Y (kN)	Peak Upper Spine Acc. X (g)	Peak Upper Spine Acc. Y (g)	Peak Shoulder Load X (kN)	Peak Shoulder Load Y (kN)
1	90	0	ES-2 /	0	40.2	155	0.13	0.42	17.7	-30.8	-2.00	-2.88
2	90	0	WS / 90	0	40.4	153	0.13	0.46	17.0	-29.1	-1.97	-2.77
3	75	0	WS / 75	40	43.0	218	-0.38	-0.58	-16.7	-50.3	-3.43	-3.70
4	75	0	ES-2 /	40	46.5	242	-0.44	-0.72	-16.8	-52.4	-3.92	-4.46
5	75	50	ES-2 /	40	56.9	1009	-0.52	-0.66	-18.6	-50.7	-3.86	-4.56

CONCLUSION

Under oblique vehicle-to-pole lateral impact test conditions using the same vehicle model, ES-2 and WorldSID dummies predicted very different levels of head injury protection provided by a head protecting curtain airbag. The test data suggest that these differences are a result of the design and mechanical response of the shoulders of the ES-2 and WorldSID dummies.

Perpendicular and oblique vehicle-to-pole lateral impact tests using ES-2 show a significant difference in shoulder behaviour between these test conditions. Dummy to pole sled tests confirmed the influence of ES-2 shoulder behaviour on head kinematics and consequently on the ability of this dummy to discriminate the level of head protection offered by head protecting side airbags. The head, neck, and shoulder kinematics and peak shoulder loads of the ES-2 were found to be highly sensitive to the direction of loading to the shoulder resulting from each pole impact angle.

These results suggest that ES-2 may not be an appropriate test tool for evaluation of side impact head protection systems in vehicle-to-pole lateral impact tests.

REFERENCES

[1] European New Car Assessment Programme (EuroNCAP) Pole Side Impact Testing Protocol (Version 4.1), EuroNCAP (www.euroncap.com), March, 2004.

[2] SAE J211-1, SAE International, December, 2003.

ACKNOWLEDGEMENTS

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