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Biofidelity evaluation of WorldSID and ES-2re under side impact conditions with and without airbag

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ABSTRACT

This study evaluated the biofidelity of the WorldSID and the ES-2re under whole-body side impact conditions with and without a side airbag using the biomechanical cadaveric response data generated from 4.3 m/s whole-body side impact tests. Impact forces, spinal kinematics, and chest deflections were considered in the biofidelity evaluation. Average responses and response corridors of PMHS were created using a time-alignment technique to reduce variability of the PMHS responses while maintaining the sum of the time shifts to be zero for each response. Biofidelity of the two dummies was compared using a correlation and analysis (CORA) method. The WorldSID demonstrated better biofidelity than the ES-2re in terms of CORA ratings in the conditions with airbag (0.53 vs. 0.46) and without an airbag (0.57 vs. 0.49). Lastly, the kinematic analysis of the two dummies indicated an overly compliant shoulder response of the WorldSID and excessive forward rotation of the ES-2re relative to the PMHS.

1. Introduction

Thirty-two percent of serious injuries to occupants in non-rollover tow-away crashes in the US are side impacts (Samaha and Elliott, 2003). The high severity of side impact crashes was identified in the study by Bedard et al. (2002) who found that side impact crashes are twice as likely to result in a fatality as frontal impact crashes. Occupants in side impact crashes exhibit a higher rate of serious thoracic injuries than occupants involved frontal impact crashes, regardless of the age or gender of the occupants (Rhule et al., 2011). Although substantial advances in countermeasure development have been made during the past thirty years of side impact research, further advances in the biofidelity and injury prediction of dummies may be necessary to develop and evaluate improved side impact protection (Yoganandan and Pintar, 2005).

The EuroSID-2 with rib extension crash dummy (ES-2re) is currently being used as a surrogate for evaluating occupant protection during side impact crash tests for regulation and consumer information programs (NHTSA, 2012; European new car assessment programme, 2016). A more advanced side impact surrogate, the 50th percentile male WorldSID, has been developed as a potential replacement for the 50th percentile male ES-2re. The WorldSID and the ES-2re have been evaluated under various impact conditions, and the WorldSID has shown improved biofidelity relative to the ES-2re (Rhule et al., 2009). Compigne et al. (2004) evaluated the biofidelity of the WorldSID and the ES-2 in detail, including spine kinematics, using photo analysis under blunt impact conditions (Compigne et al., 2004). Beyond studies with impactors, it was deemed beneficial to analyze the spinal kinematics under a whole-body lateral impact condition to evaluate the biofidelity of the side impact dummies. While studies have evaluated the biofidelity of the WorldSID and/or ES-2re under whole-body lateral impact conditions using various bucks (Yoganandan and Pintar, 2005; Scherer et al., 2009; Rupp et al., 2011; Pintar et al., 2007; Damm et al., 2006), the PMHS experienced numerous bone fractures due to the severity of the loading conditions, which obfuscated comparisons with dummies. Although Yoganandan et al. (2007) indicated that the effect of side airbags on the elderly population needs to be investigated (Yoganandan et al., 2007), no study has evaluated the biofidelity of the WorldSID and the ES-2re under a whole-body side impact test with an airbag.

(Lessley et al. (2010) and Shaw et al. (2014) have recently conducted cadaveric whole-body pure lateral impact tests without and with a side airbag, respectively, in which significant informa-

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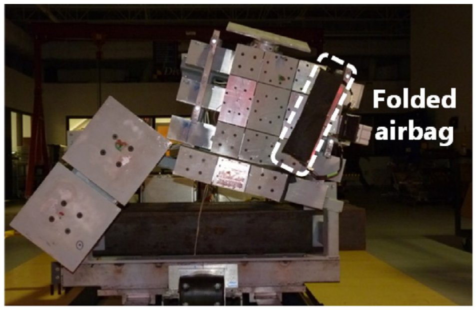
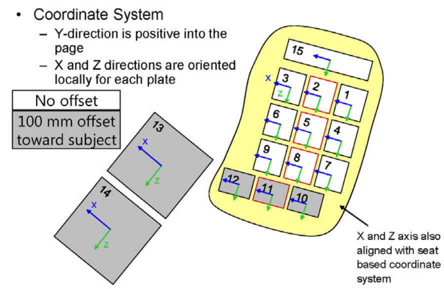
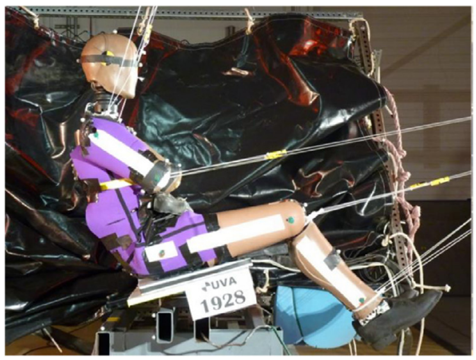
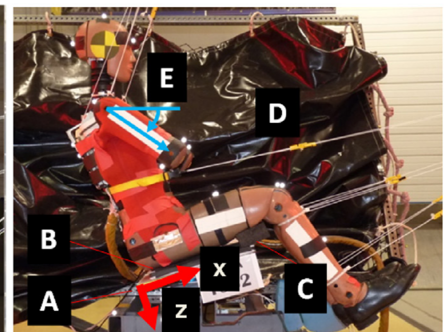




(a) Wall with airbag mounted (b) plate numbers and coordinate systems of the wall buck





(c) WorldSID dummy with straps (d) ES-2re dummy with straps

Fig. 1. Test set-up—(A) Seat coordinate system, (B) Lightweight rigid foam seat pad with (C) additional pad under the distal thigh to achieve the target femur angle, and (D) catcher to protect the dummy after a main event (E) upper arm angle.

tion about the occupant response was measured. Six (three with side airbag and three without) approximately 50th-percentile adult male PMHS were subjected to right-side pure lateral impacts at 4.3 ± 0.1 m/s using a rigid wall mounted to a rail- mounted sled. The initial impact speed was selected from a review of previous PMHS tests with rigid and padded sleds, (Pintar et al., 1997; Tarriere et al., 1979) as well as simulations, in an effort to identify a velocity that was expected to produce substantial subject responses without causing extensive damage to the specimens. Specifically, an impact velocity of 4.3 m/s was used for the PMHS tests reported by both Lessley et al. (2010) and Shaw et al. (2014). Since the tests were conducted at conditions representing the onset of injury, and the subject impact response was comprehensively measured, these tests provide an ideal basis to assess the fidelity of the dummies or computational models in predicting human response and potential for injury. While Park et al. (2014) evaluated the biofidelity of computational surrogates in side impact, no evaluation of the biofidelity of the ES-2 and WorldSID physical dummies has been performed using either Lessley et al. (2010) or (Shaw et al. (2014) PMHS data.

The goal of this study is to evaluate and to compare the biofidelity of the WorldSID and the ES-2re relative to PMHS under a full body side impact condition with and without a side airbag. The external biofidelity was evaluated using the applied forces from the wall to the dummy, and the internal biofidelity was evaluated by comparing the acceleration of the spine, spinal kinematics, and chest deflections of the two dummies to those of the PMHS.

2. Method

2.1. Test condition

The biomechanical responses of the WorldSID and the ES-2re were recorded during an impact event that involved a wall striking the stationary seated dummy's right side. The wall consisted of fifteen separate plates mounted on six-axis load-cells was used to impact test dummies (Fig. 1a–b) (Lessley et al., 2010; Shaw et al., 2014). The plates were adjusted anterior/posterior so that the shoulder joint center and lateral torso aligned with the approximate centers of Plate 2, 5, and 8. Note that the plates for the pelvis and lower extremities (Plates 10–14) were positioned 10 cm closer to the subject to approximate the typical geometry of a door panel intruding during a side impact. Plate 11 was aligned with the H-point of dummy, and Plate 15 was tilted away from the dummy such that head contact occurred after the maximum torso deformation. Tethers were attached to each dummy's head, arms, torso, knees, and ankles in order to achieve the pre-impact seated posture (Fig. 1c–d). The upper arm angle measured from the horizontal plane was 35° for both dummies (Fig. 1d). The average upper arm angles of the PMHS was 34° for the no airbag condition and 40° for the airbag condition. Approximately 10 ms prior to the airbag or the wall contacting the dummy, tension on the tether suspension system holding the dummy in position was released. For the airbag condition, a custom 60 L (330 mm (D) × 320 mm (W) × 590 mm (H)) dual inflator side airbag, which was developed by the CENIT ADAPTA project (2008–2011) (Park et al., 2013; Luzon-Narro and Arregui-Dalmases, 2012), was deployed approximately 17 ms prior to contact with the dummy, which allowed for full inflation prior to loading of the thorax. The deploying airbag contacted the right arm prior to contact with the thorax. The airbag/wall loaded the dummy and displaced the dummy to the left and into an energy-absorbing "catcher" consisting of fabric restrained by ropes that pulled through friction eyes (Fig. 1c–d). The upper surface of the seat and the lower surface of the seat pad were covered with Teflon to provide a coefficient of friction of 0.239 (static: 0.255 and dynamic: 0.223) (Lessley et al., 2010).

2.2. Instrumentation

Measurements included wall impact forces, dummy accelerations and displacements, and chest deflections (Table 1). The