

The Hybrid III Dummy Family Subject to Loading by a Motorized Shoulder Belt Tensioner

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ABSTRACT

Motorized shoulder belt tensioning is a new automotive seatbelt technology which has shown promise to reduce automotive crash injuries. The current study was conducted to determine if the Hybrid III family of dummies is an appropriate biofidelic surrogate for studying motorized shoulder belt tensioning. The objective was to measure torso retraction time, torso position, torso velocity, internal resistive moment, changes in torso curvature and the center of rotation of torso extension during seatbelt tensioning for the Hybrid III family.

A previous study developed a protocol and test fixture to measure the biomechanics of volunteers subject to quasi-static loading by a motorized shoulder belt tensioner. A fixture supported the occupant leaning forward and applied shoulder belt tension. Kinematics were quantified by analyzing the motion of reflective markers on the dummy using an eight camera digital video system. A three axis load cell measured internal resistance to extension. This test method was applied to the 6-year-old, the 5th female and 50th male Hybrid III dummies.

Peak shoulder belt loads of 131–141 N were applied to the dummies causing torso deflections of 8°–13° in 0.42–0.57 seconds. The data was compared to the responses of human volunteers. Peak shoulder belt loads of 82 N–92 N were applied to volunteers causing torso deflections of 42°–58° in 0.78–0.95 seconds. The center of rotation for the Hybrid III torso was further from the H-point than observed in volunteer studies. The out-of-plane belt-side shoulder drop and twist was much less for the dummies than observed for the volunteers. The dummy biofidelity was limited in this environment. They were found to be poor human surrogates for motorized shoulder belt tensioning of out-of-position occupants.

The stiff lumbar spine and molded seated pelvis lacked the mobility observed in relaxed volunteers.

INTRODUCTION

Motorized pre-crash shoulder belt tensioning is a new occupant protection technology that can improve occupant kinematics prior to a crash and reduce automotive crash injuries (Hearon et al. 1982; Haland and Skanberg 1989; Bauberger and Schaper 1996; Zellmer et al. 1998; Lorenz et al. 2001; Tobata et al. 2001; Schöneburg et al. 2003; Tobata et al. 2004; Otte and Krettek 2005; Anon. 2006a; Pack et al. 2006; Parenteau 2006a). A motorized shoulder belt tensioner can reposition an out-of-position occupant prior to impact or snug the belt on a properly positioned occupant increasing the restraint ride-down during impact (Hearon et al. 1982; Haland and Skanberg 1989; Bauberger and Schaper 1996; Zellmer et al. 1998; Tobata et al. 2001; Schöneburg et al. 2003; Tobata et al. 2004). Shoulder belt tensioning can also control occupant kinematics in high acceleration and pre-crash vehicle motions such as violent swerving, braking and yaw (Zuppichini et al. 1997; Kumpfbeck et al. 1999).

The Hybrid III anthropometric test device (ATD) (Mertz 1993) and its entire crash test dummy family is used worldwide in the development and regulation (Anon. 2006c) of automotive occupant protection systems. This dummy design was originally developed as a biofidelic human surrogate for frontal impact typical of a 48 km/h (30 mph) barrier crash (Backaitis and Mertz 1994). However, it has become widely used in other applications where the biofidelity of the dummy may not be completely proven.

The objective of this study was to measure the response of the Hybrid III 6-year-old child, the Hybrid III 5th percentile female and the Hybrid III 50th percentile male

dummy subject to quasi-static motorized shoulder belt tensioning. The variables studied were torso retraction time, torso position, torso velocity, occupant resistive moment, changes in spinal curvature and the center of rotation of torso extension. Good et al. (in press) previously developed a methodology to study the effects of motorized shoulder belt tensioning on a population of volunteers (5th percentile female, 50th percentile male, 95th percentile male). The same methodology was applied to the Hybrid III dummies and the results were compared to data collected in the volunteer study. The current study was conducted to determine whether the Hybrid III family of dummies is an appropriate biofidelic surrogate for studying motorized shoulder belt tensioning.

Other researchers have investigated the benefits of motorized shoulder belt tensioning for occupant protection in frontal collisions using the Hybrid III dummy. Tobata et al. (2001; 2004) and Takagi and Pal (2004) conducted computer simulations using the MADYMO model of the Hybrid III 50th percentile male and conducted sled tests with the Hybrid III 50th percentile male. They found motorized shoulder belt tensioning increased ride down, reduced chest acceleration and decreased forward excursion during impact. However, the biofidelity of the Hybrid III compared to humans may be poor during the early low-g phase of pre-crash tensioning. Morris (2004) conducted a study of 49 volunteers and the Hybrid III 5th female, 50th male and 95th male crash test dummies as passengers in straight line pre-impact braking and other pre-impact scenarios. They found ATDs appeared to bear little similarities to the human volunteers. The ATDs were reported to have very stiff spines that limited biofidelic motion and the lack of neck musculature frequently positioned the head in the wrong location and attitude.

McCoy and Balavich (2005) investigated the lateral motion of Hybrid III dummies prior to roll using a deceleration rollover sled. The pre-roll dummy kinematics were compared using conventional seatbelts and pre-crash activated motorized shoulder belt tensioners. They reported motorized shoulder belt tensioning had an indistinguishable effect on dummy kinematics. In contrast, Parenteau (2006a) studied upper torso kinematics of volunteers with and without 100 mm of added shoulder belt slack in lateral pre-roll conditions. Without slack, two of three far side occupants showed reduced head excursion and all showed reduced shoulder excursion. Near side occupants showed little improvement. Parenteau concluded that slack removal technologies such as motorized shoulder belt tensioning seem beneficial for reducing occupant excursion in lateral pre-roll conditions and the benefit would be higher for far-side occupants. Parenteau also studied Hybrid III dummies in the same pre-roll conditions. The dummies were found to reach peak excursion faster and have lower peak excursion compared to the volunteers under the same conditions. The study questioned the usability of the Hybrid III

dummy in low-g, pre-roll conditions. Praxl et al. (2004) also identified biofidelity issues with dummies compared to volunteers where the dummies tipped over sooner and lacked the upper body bending capabilities of humans in lateral pre-roll conditions. Other investigators (Parenteau et al. 2002; Yamaguchi et al. 2005; Parenteau 2006b) have studied the response of the Hybrid III compared to volunteers in low-g events and identified differences in occupant kinematics.

METHODS

Previously, Good et al. (in press) developed a protocol to measure the biomechanics of volunteers subjected to loading by a motorized shoulder belt tensioner. A Hybrid III 6-year-old child dummy (Serial #052, Denton ATD, Milan OH), a Hybrid III 5th percentile female (Serial #0500-0122, Denton ATD, Milan OH) and a Hybrid III 50th percentile male (Serial #0200-350, Denton ATD, Milan OH) dummy were tested using a similar protocol. Table 1 shows the gross properties of the Hybrid III dummy family tested.

	Hybrid III Anthropometric Test Device		
	6-year-old Child	5 th Female	50 th Male
Mass [kg]	23	49	78
Seated Height [cm]	64	79	88
Height (Theoretical) [cm]	115	150	175

Table 1 Geometric properties of the Hybrid III dummies tested

TEST FIXTURE - Figure 1 shows the custom test facility and data acquisition equipment designed to apply motorized shoulder belt tensioning and measure the response of volunteers and surrogates. A complete description and the specifications of the apparatus is presented in the volunteer study (Good et al. in press). A brief overview is presented here.

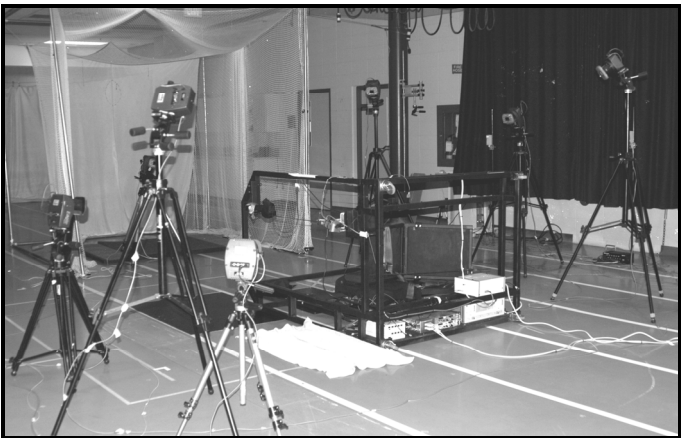


Figure 1 Test Facility and Motion Capture System

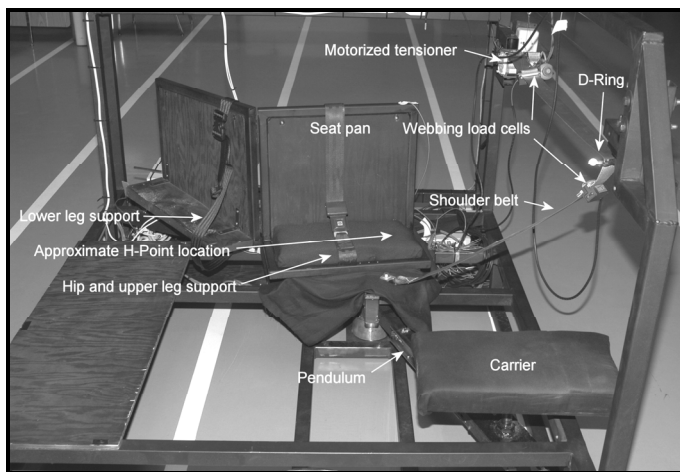


Figure 2 - Test Fixture

Figure 2 shows the test fixture and Figure 3 shows the Hybrid III 5th female dummy installed in the fixture. The volunteers and the dummies were tested lying on their sides to remove the effects of gravity, and to remove uncertainties associated with locating the subject's center of mass. The installation of the 50th male was similar. For the 6-year-old child a 7.5 cm spacer was placed under the buttocks to simulate a belt positioning booster seat. The National Highway Traffic Safety Administration (NHTSA) recommends a belt positioning booster seat be used by children over 18 kg (40 lb) until they are 8 years old or 145 cm (57 inches) tall (Anon. 2006b). The Hybrid III 6-year-old child falls in this range.

The test fixture supported the occupant on their side. The legs and pelvis were held and strapped to the fixture. The subject's torso was supported by a padded carrier on a horizontal cantilevered pendulum. The center of rotation of the pendulum was attached to the test fixture by a bearing approximately in line with the H-Point of the occupant. The H-Point is defined as the pivot center between the torso and the thigh (Anon. 1995b). The fixture facilitated low friction movement of the subject's torso in the sagittal plane while immobilizing the lower extremities.

A prototype motorized shoulder belt tensioner and belt system was fixed to the test fixture. The shoulder belt tensioner, webbing and D-ring were positioned in a manner similar to an automotive environment. The motorized shoulder belt tensioner could generate a maximum webbing tension of approximately 225 N. Less webbing tension was available when webbing was being retracted. The same prototype webbing tensioner used in the volunteer study was used in this investigation. Between studies, the motorized retractor was overhauled (a bearing was replaced) and the power supply was switched. The peak available webbing tension force was approximately 25 N higher post-overhaul. In the volunteer study, the motorized shoulder belt tensioner was able to reposition the torso of a relaxed, forward leaning occupant rearward by 42°-58° in 0.78-0.95 seconds. The average retraction velocity of the shoulder belt was 46-50 cm/s.

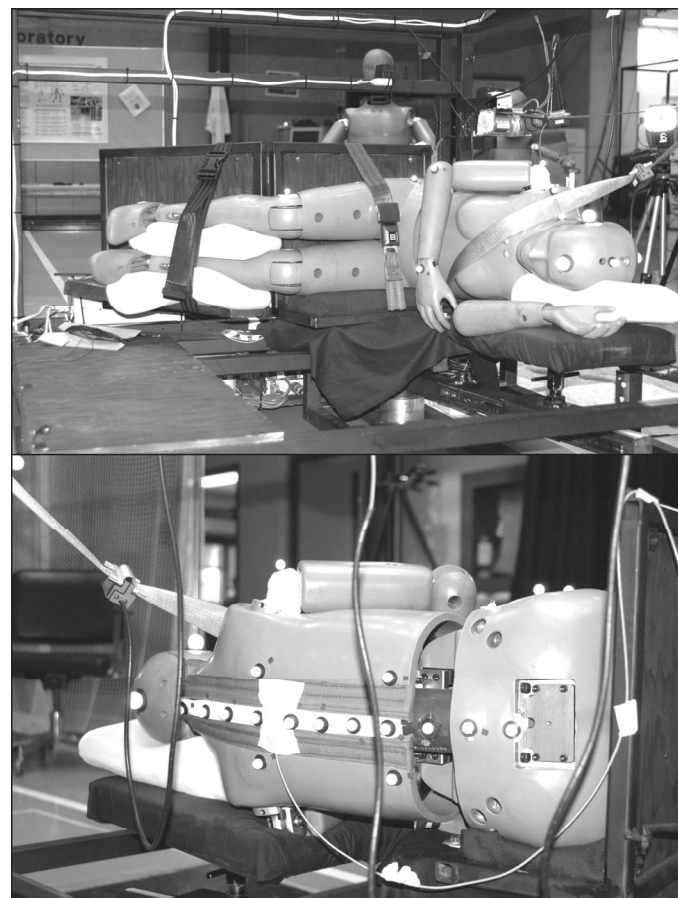


Figure 3 Hybrid III 5th Female in test fixture. Shoulder belt over right shoulder. Upper torso supported on pivoting carrier. Markers on anatomical landmarks.

INSTRUMENTATION - The same instrumentation used in the volunteer study (Good et al. in press) was utilized in this study. Twenty-nine reflective spherical markers were attached to the dummies at various anatomical landmarks as specified in the volunteer study (see Figure 3). Markers were fixed to the spinous process of the vertebra from C7 to S4 in addition to the head, right shoulder, elbow, wrist, H-point, knee, scapula and ribs. The anatomical structures, which were easily palpated in the volunteer experiments, had to be estimated on the dummies in many cases. Reflective markers were also placed on the fixture to identify the D-ring axis. During the tensioning experiments, an eight-camera Eagle digital video system (Motion Analysis Corporation, Santa Rosa, California) was used to record the positions of the reflective markers. The cameras orientations are visible in Figure 1.

A three-axis load cell was mounted beneath the lower extremity support of the fixture to measure reaction forces in the sagittal plane. Since the lower extremity and pelvis were stationary during the experiments, the sagittal plane moment measured by the load cell could be related to the subject's internal reaction moment about the H-Point during tensioning. Shoulder belt tension was measured by two Robert A. Denton (Rochester Hills, MI) Model 6375 load cells. One load

cell was located immediately adjacent to the occupant's shoulder and the other next to the seatbelt retractor. A Celesco PT-101 (Chattworth, CA) cable extension position transducer measured webbing retraction.

EXPERIMENTAL TASKS - Pilot testing with the dummies revealed the seated pelvis prevented the dummy from being manipulated into the full forward or half forward leaning positions of the volunteer experiments. The molded flesh of the seated pelvis would not allow hip flexion beyond approximately 90°-100°. An attempt was made to pull and hold the dummies in a forward leaning position using a rope. The rope obtained further forward flexion of the dummy through flexion of the lumbar spine element. However, the use of a rope required the simultaneous release of the rope and the initiation of shoulder belt tensioning. This operation had to be performed manually. When the dummy was pulled forward with the rope and the rope released, the dummy would unnaturally spring back to a neutral position. This was clearly not an acceptable test configuration. Consequently, only the maximum static forward lean of the dummy was tested.

Each dummy was subjected to 12 tensioning tests. The torso of the dummy was manually manipulated to lean forward as much as possible to the extent the dummy would stay in position without external assistance. Data acquisition was triggered with the activation of the motorized shoulder belt tensioner. The same data acquisition system and post-processing routines utilized in the volunteer experiments were used. Six repeat tensioning tests were performed with the dummy as designed. An additional six repeat tests were performed with the abdomen of the dummy removed to investigate the contribution of the abdomen to torso biomechanics. Figure 4 shows the 5th female dummy with the abdomen removed. The relative angle defined by the knee, the H-point and a line tangent to the torso at the T8 level was used as a measure of torso position (θ) in the sagittal plane identical to Good et al. (in press) (Figure 5). Torso deflection was calculated as the change in angle from the initial position when belt tensioning was initiated ($\theta - \theta_0$). The sagittal center of rotation of the torso was calculated from the eleven trajectories of the spine markers using the method of Halvorsen (2003). The method was adapted for use in two dimensions.

Outcome dependent variables were identified from the experimental results. A repeated measure, two-way (3 by 2) analysis of variance (ANOVA) statistical analysis was performed on each variable. The independent variables were dummy type (6-year-old child, 5th female, 50th male) and abdomen condition (full dummy as-designed and dummy with no-abdomen). Where significant dummy effects were found, Tukey HSD comparison tests were used to identify significant differences between specific populations. Statistical significance was determined with $p < 0.05$.

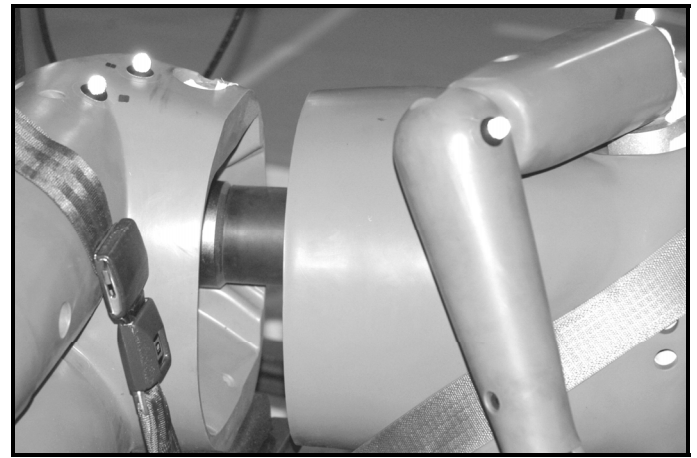


Figure 4 Hybrid III 5th female with abdomen removed

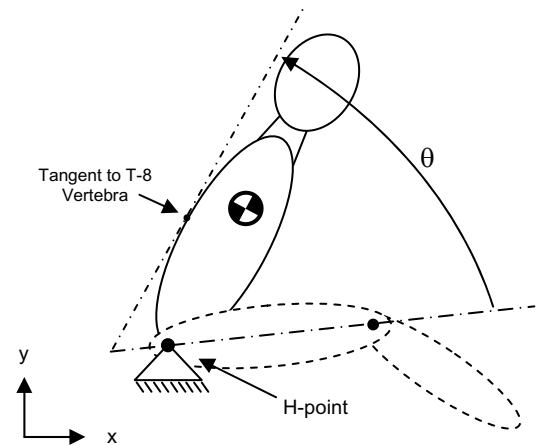


Figure 5 Torso position measurement

RESULTS

Figure 6 shows a representative trajectory of the spine markers for each of the dummies during motorized shoulder belt tensioning. The H-point and the center of rotation of the spine markers are shown. Table 2 shows the distance from the calculated center of rotation to the H-point for the dummies. The center of rotation for the 50th male was much closer to the H-point than the 6-year-old and the 5th female. Differences between the dummy as designed and without the abdomen were small (< 4 mm).

There was little change in the curvature of the dummy's spine during tensioning. This was expected as the upper torso of the dummy is constructed with rigid steel components. The 6-year-old child and 5th female dummies did not show the typical human lordosis and kyphosis curvature of the spine. This curvature can be seen in the 50th male dummy trajectory. In the representative data shown in Figure 6, the total torso deflection of the 5th female dummy was the smallest and the 6-year-old child was the largest. This trend was also found for average torso deflection measuring 13.2° for the 6-year-old child, 8.4° for the 5th female and 10.8° for the 50th male (see also Table 4).