MODELING BIOMECHANICS OF VOLUNTEERS SUBJECT TO LOADING BY A MOTORIZED SHOULDER BELT TENSIONER

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ABSTRACT

Motorized shoulder belt tensioning is an occupant protection technology that has potential to reduce collision injuries. There is not a biofidelic model of shoulder belt tensioning that has been validated against experimental data. A lumped-mass model was developed and validated characterizing the biomechanical response of volunteers during motorized shoulder belt tensioning. The 5th percentile female, 50th percentile male and 95th percentile male population groups were studied.

Keywords: Biomechanics, Models, Occupants, Restraint Systems, Safety Belts, Volunteers

PRE-CRASH SHOULDER BELT TENSIONING is a technology that has shown promise to reduce automotive crash injuries of belt wearers (Bauberger and Schaper 1996; Zellmer et al. 1998; Lorenz et al. 2001; Tobata et al. 2001; Tobata et al. 2004; Otte and Krettek 2005; Anon. 2006; Pack et al. 2006; Parenteau 2006).

The objective of this study was to develop and validate a mechanical model to characterize the biomechanical response of forward leaning volunteers during motorized shoulder belt tensioning. A previous study, Good et al. (2007), measured the upper torso biomechanics of three populations of forward leaning adult volunteers (5th percentile female, 50th percentile male, 95th percentile male) during motorized shoulder belt tensioning. The volunteer study concluded that the development of a population-specific, mechanical model was feasible to predict occupant response for shoulder belt tensioning. The model was developed based on findings from the volunteer study. Volunteer data from the study was used to test the validity of the mechanical model.

METHODS

Figure 1 shows the lumped mass model of an occupant subject to shoulder belt tensioning. Lumped mass models have been successfully implemented in biomechanical studies by many researchers (Lobdell et al. 1973; Huang 1983; Mertz 1984; Viano 2003).

In the 2-dimensional model proposed here, the upper torso and head are represented by a single rigid body connected to the inertial reference frame by a revolute joint located at the H-point. Moments acting on the occupant include M_b, the shoulder belt tension moment, and M_{hp}, the internal moment resisting extension (muscle activation and passive resistance). The effects of the gravitational force and the acceleration field applied by pre-crash maneuvers were not included in the model. The model was formulated to be representative of the volunteer experiments to facilitate validation.

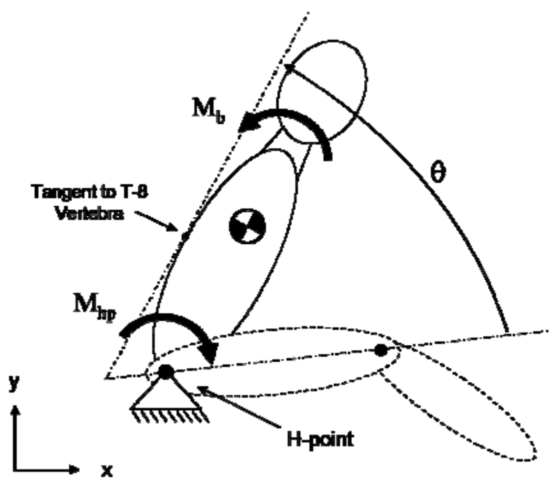

Figure 1 Free body diagram of occupant model. X-direction is posterior-anterior, Y-direction is inferior-superior.

The forward leaning occupant model of shoulder belt tensioning was based on the following assumptions: (1) changes in spinal curvature are small, (2) the centre of rotation of the torso is the H-Point and (3) the transverse twisting of the occupant is small. These assumptions are consistent with data from the volunteer experiments (Good 2007).

MODEL INPUTS Shoulder belt webbing tension was the input for occupant pullback. The shoulder belt moment (M_b), applied to the occupant is a function of the shoulder belt webbing tension vector (F_b) and the point of application relative to the H-point (r_{hp}) as shown in Equation 1. Only the sagittal component of M_b was utilized. The shoulder belt webbing tension, line of action and point of application to the occupant were measured directly in the volunteer experiments. M_{hp} was also measured directly in the volunteer study (Good et al. 2007).

$$M_b = r_{hp} \times F_b \quad (1)$$

Figure 2 shows mean M_b measured in the volunteer experiments for the three population groups. Towards the end of the tensioning movement, the moment applied to the occupant decreased since the belt force moment arm decreased as the occupant was pulled rearward and shoulder belt tension remained roughly constant. The variability in the belt force moment increased as the occupant was pulled back. The peak moments were 35.6 N·m for the 5th female, 39.3 N·m for the 50th male, and 46.1 N·m for the 95th male. The mean distance from the H-point to the shoulder, measured for each volunteer sitting upright, was 48.0 cm for the 5th female, 53.8 cm for the 50th male and 57.1 cm for the 95th male.

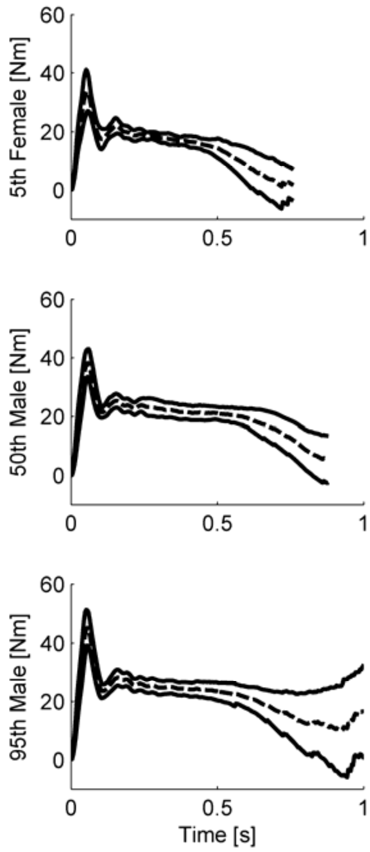

Figure 2 - Mean moment (M_b) applied to volunteer occupant populations by shoulder belt tensioner. Corridors show ±1 standard deviation.

ANALYSIS PROCEDURES For the model shown in Figure 1, the equation of motion is:

$$M_b - M_{hp} = I_{hp} \frac{d^2\theta}{dt^2} \quad (2)$$

M_b and M_{hp} were determined from volunteer experiments for each population. I_{hp} is the moment of inertia of the occupant about the H-point. Torso deflection was defined as the change in torso position (θ) as measured from the initial torso position (θ_o).

$$\text{Torso Deflection} = \theta - \theta_o \quad (3)$$

Equation 2 can be numerically integrated in time to yield the time history of torso deflection given the initial conditions for torso position and velocity. The initial condition for torso position was set to zero, i.e., $\theta(0) - \theta_o = 0$. The initial condition for torso velocity was the average volunteer torso velocity at the initiation of tensioning.

OCCUPANT INERTIA PROPERTIES Table 1 shows the moment of inertia I_{hp}, calculated about the H-point for each subject and averaged for each population group from the volunteer experiments. The total moment of inertia is the sum of the moment of inertia of the occupant plus the moment of inertia of the test fixture supporting the occupant's torso. The test fixture moved with the occupant and is described elsewhere (Good et al. 2007). The moment of inertia of the fixture was calculated based on its mechanical properties. The fixture could be adjusted to accommodate different occupant sizes; adjusting the fixture changed its moment of inertia. A procedure was also developed to remove the

		5th Female	50th Male	95th Male
Number of Subjects		6	11	9
Mass of Torso	[kg]	28.8 (1.65)	43.9 (4.31)	57.7 (3.70)
Moment of Inertia of Torso about H-point	[kg m^2]	4.49 (0.281)	7.98 (1.36)	11.3 (1.09)
Moment of Inertia of Test Fixture Pendulum	[kg m^2]	2.51 (0.227)	2.60 (0.231)	2.71 (0.241)
Total Moment of Inertia about H-point	[kg m2]	7.00 (0.312)	10.6 (1.46)	14.0 (1.24)

Standard deviation in parentheses

Table 1 - Inertial Properties of torso for volunteer populations

effects of the test fixture inertia on the occupant response (Good 2007).

The subject-specific inertial properties were calculated using the regression equations of de Leva (1996a; 1996b). These were selected since subject-specific inertial properties could be estimated with a low degree of error using easily measured anthropometrics from the volunteer subjects. The de Leva procedures were based on data collected by Zatsiorsky and Seluyanov (1983; 1986; 1990).

VALIDATION CRITERIA Thunnissen et al. (1995) proposed that the magnitude of response variables predicted by a computer model be within the mean ±1 standard deviation of the mean response as measured from tests with volunteers. This validation criterion was used to examine the model proposed here.

RESULTS

Figure 3 shows the response of the dynamic model for the three populations studied against the experimental corridors from the occupant leaning fully forward (Good et al. 2007). The torso deflection (or angular displacement θ-θ_o) and torso velocity are shown. The experimental corridors show the mean response ±1 standard deviation of the volunteer population. The response of the model shows good agreement with the experiments. In most cases, it is within ±1 standard deviation of the experimental response at the position and the velocity level as required by the proposed validation criteria. As a general trend, the position response of the model slightly under-predicts the position response of the mean experimental population.

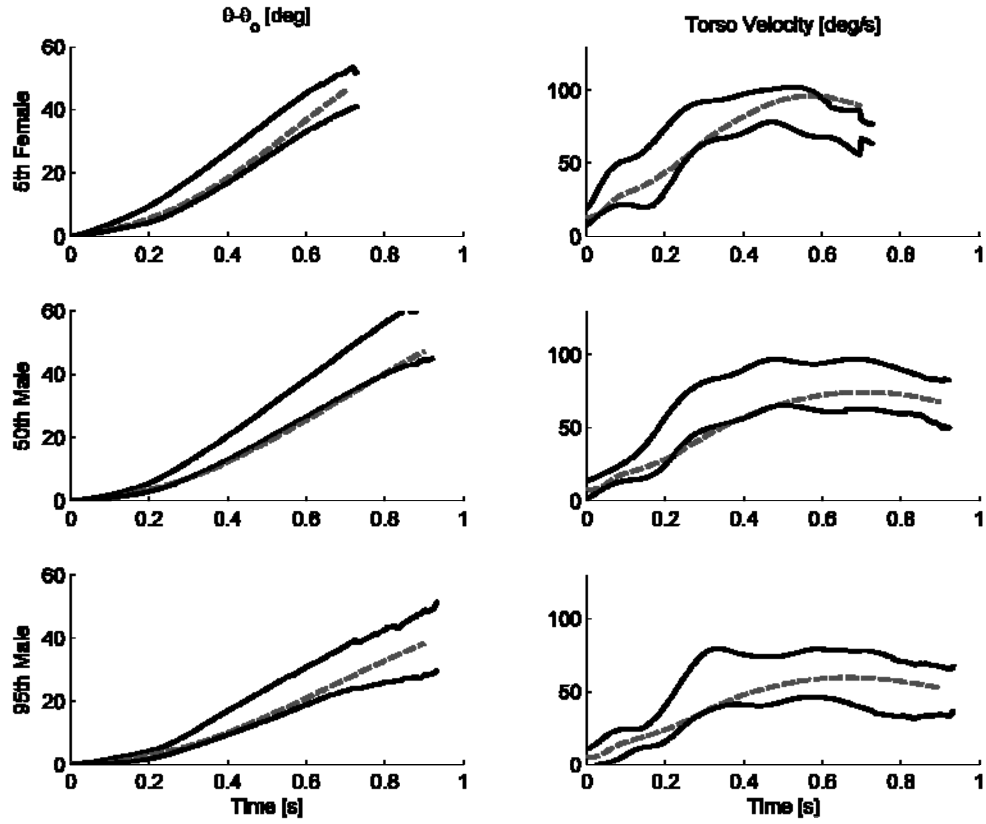

Figure 3 Response of occupant model for all populations (dashed line) for torso deflection (θ-θ_o) and torso velocity against experimental corridors (±1 standard deviation) from volunteer experiments (solid lines)

DISCUSSION

The proposed occupant pullback model of Figure 1 has been validated against the experimental data for the 5th percentile female, 50th percentile male, and 95th percentile male populations. The model was validated against data from forward leaning volunteer experiments.

The validation study performed here is the first step in the development of in-vehicle models to predict occupant torso motion for a wide range of occupants in pre-crash situations subject to motorized shoulder belt tensioning. Further refinements will be required to introduce the effects of pre-impact maneuvers and mechanical tensioner dynamics on the occupant response.

MODEL LIMITATIONS The input data used in the validation tests is only applicable to the range of occupant motion and retraction speeds studied in the volunteer tests. The validity of the model outside this range is not known. Additionally, model results are dependent on the strength of the modeling assumptions outlined previously.

CONCLUSIONS

A biofidelic model of shoulder belt tensioning has been validated against experimental data from volunteer subjects. The model has wide application in the further development of restraint systems with shoulder belt tensioning.

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