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Occupant Responses to Moderate Frontal Impacts Vary with Seat Belt Slack and Anchor Location

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ABSTRACT

Both seat belt slack and anchor location are known to affect occupant excursion during high speed frontal collisions, but their effects have not been studied at moderate collision severities. The goal of this study was to explore how seat belt slack and anchor location affects occupant kinematics and kinetics in moderate frontal collisions. A Hybrid III dummy was seated on a programmable sled and exposed to frontal collisions with a speed change of 17.5 km/h. The seat belt was adjusted either snugly or with 10 cm slack (distributed 60/40 between the shoulder and lap portions) and the anchor location was varied by adjusting the seat position either fully forward or aft (seat travel = 13 cm). Accelerations and displacements of the head, T1, and pelvis were measured in the sagittal plane. Upper neck loads and knee excursions were also measured. Five trials were performed for each of the four combinations of belt adjustment (snug, slack) and anchor location (seat forward, seat aft). For each trial, kinematic and kinetic response peaks were determined and the combined data were compared using repeated-measures ANOVAs. Peak excursions, accelerations and loads varied significantly with both seat belt slack and anchor location. Seat belt slack affected more parameters and had a larger affect than anchor location on most peak dummy response parameters. Head excursions increased a similar amount between the snug/slack belt conditions and the aft/forward anchor locations. Overall, horizontal head excursions increased from 23 cm in the snug-belt, rearward-anchor configuration to 33 cm in the slack-belt, forward-anchor configuration. These results showed that analyses of occupant excursion need to consider potential sources for seat belt slack and account for differences in seat belt anchor locations.

INTRODUCTION

Seat belts decrease automobile-related fatalities and injuries (Campbell, 1987; Evans, 1996). They achieve this benefit by reducing the peak loads applied to the occupants, applying these loads to anatomical structures able to handle high loads, and limiting occupant excursion within the vehicle, thus reducing the probability of contact with structures inside the vehicle.

Seat belts function optimally when worn snugly. Slack in the seat belt has been shown to increase the excursion of the head, chest, hips and knees in frontal impacts (Hontschik et al., 1977; Viano et al., 1980; Biss, 1988). Slack can be initially introduced by poor seat belt adjustment, bulky clothing, or tension-relieving devices incorporated into some emergency locking retractors, and dynamically introduced through tightening of the webbing on the spool after the retractor locks (Bacon, 1989). Seat belt slack therefore increases both the potential for occupant contact with interior vehicle structures and the severity of any contacts that occur even with a snug belt.

The location of the seat belt anchor points also affects the occupant dynamics in frontal collisions (Hontschik et al., 1977). Moving the shoulder belt anchor point down has produced larger head excursions and head speeds (Freeman and Bacon, 1988). Alternatively, moving the lap belt anchor location rearward decreases hip excursion, but increases the potential for submarining (Armstrong and Waters, 1969). Seat belt anchor points vary from vehicle to vehicle, and even within a specific vehicle, anchor locations can vary horizontally with fore/aft seat position and vertically if a shoulder belt anchor adjustment is present.

All of these experiments examining the effect of seat belt slack and anchor location have been conducted at collision speed changes of 35 km/h or higher. Most real collisions, however, occur at speed changes less than 25 km/h (Farmer, 2003), and the magnitude of these slack and anchor-location effects at lower speed changes have not been previously reported. The goal of this study was to quantify the effect of seat belt slack and seat belt anchor location on occupant response during moderate speed frontal impacts. Based on previous studies at higher severities, we hypothesized that seat belt slack and a forward anchor location would increase peak occupant kinematics and kinetics.

METHODS

Instrumentation

A 50th percentile male Hybrid III dummy (First Technology Safety Systems, Plymouth,MI) was instrumented to measure head, T1, and pelvis kinematics and upper neck kinetics in the sagittal plane. An array of five linear accelerometers (ROTAC-2D5/200, TNO, The Netherlands) was mounted inside the head to measure sagittal plane linear accelerations (a_x, a_z) and angular accelerations (α_y). A six-axis, low-capacity upper neck load cell (IF-207, First Technology Safety Systems, Plymouth, MI) was installed, but only the sagittal plane responses (R_x, R_z, and M_y) were recorded. Linear accelerations at T1 and in the pelvis were measured using pairs of orthogonally-mounted uni-axial accelerometers (7264B-2000, Endevco, San Juan Capistrano, CA). Angular velocity about the mediolateral axis (ω_y) at T1 was measured using a uni-axial angular rate sensor (ARS-04E, ATA Sensors, Albuquerque, NM).

Horizontal sled acceleration was measured using a uni-axial linear accelerometer (Sensotec JTF3629-05, Columbus, OH). Transducer data were acquired for 2 seconds at 10 kHz using a 12-bit, simultaneous-sample-and-hold Win30 DAQ card (United Electronics Incorporated, Watertown, MA). All data channels conformed to SAE J211 Channel Class 1000 (SAE, 1989), except for the sled acceleration channel, which was Channel Class 180.

Digital video of the sagittal plane motion was captured using an OmniSpeed HS motion capture system (Speed Vision Technologies, Solana Beach, CA) and high-speed camera (JCLabs 250; 512 x 216 lines resolution, Mountain View, CA). Video data were recorded at 250 frames per second using a shutter speed of 1/1000 s. Reflective targets were applied to the sled, seat and dummy (Figure 1) and subsequently digitized. The digitized video data had an accuracy of ± 2 mm at the vertical plane containing the seat centerline. Synchronization was achieved by simultaneously triggering the data acquisition and video systems. The initial position of the dummy was measured using a three-dimensional digitizer (FaroArm B08-02, Lake Mary, FL; single-point accuracy of ±0.30 mm) and the resulting RMS error for the initial vertical and horizontal positions of the head center of mass, rear T1 target and H-point was less than 3 mm.

Figure 1:   Lateral view of the dummy on the sled with the seat fully rearward and thus the outboard seat belt anchor points (not visible) in the forward condition. The inboard lap anchor (visible) moves with the seat.

Test Procedures

The Hybrid III dummy was placed in a front passenger seat of a 1991 Honda Accord LX 4-door sedan. The H-point was located 88 ± 4 mm forward and 101 ± 3 mm above the seat hinge. The seat was mounted to a feedback-controlled linear sled and the seat back angle was set to 27 degrees from the vertical. A stock seat belt assembly from the same vehicle was installed on the sled with the anchor mounts at the same relative positions present in the vehicle. The D-ring anchor was fixed at a height equivalent to one notch below the uppermost of four positions in the vehicle. The seat belt consisted of a continuous loop of webbing from a fixed lap-belt anchor, through a plastic-lined sliding latch plate, up to a plastic-lined D-ring, and down to a vehicle-sensitive and webbing-sensitive emergency locking retractor (ELR). The lap anchor, D-ring and retractor were fastened to the sled on the outboard side of the seat and did not move with the seat. The buckle was fastened to the inboard side of the seat frame and moved with the seat. The seat belt was fully

extracted from the retractor between tests to ensure similar webbing wind-up on the spool during each test.

The independent variables in this study were seat belt slack (snug, 10 cm slack) and seat belt anchor location (forward, rearward). The snug seat belt condition was achieved by pulling firmly upward on the shoulder portion of the belt prior to each test and then allowing the system to relax. The seat belt slack condition was achieved by extracting an additional 10 cm of webbing and placing a clip on the webbing at the D-ring to counter the retractor spool tension. Four centimeters of slack was initially placed in the lap belt and 6 cm of slack was initially placed in the shoulder belt, although the sliding latch plate allowed the proportion of slack between the lap and shoulder belts to change during a test. The two conditions for seat belt anchor location were achieved by moving the seat between the front and back of the seat rails (Table 1). With the seat in the forward position, the positions of the outboard lap anchor and the D-ring anchor relative to the seat were 128 mm rearward and 17 mm below their positions when the seat was in its rearward position. The total length of the seat belt webbing was 302 cm. The length of the webbing from the outboard lap anchor bolt to the retractor housing was 210 cm with a snug belt in the forward anchor condition and 235 cm with a slack belt in the rearward anchor condition. Thus the change in anchor location produced a 15 cm change in the amount of webbing extracted from the retractor.
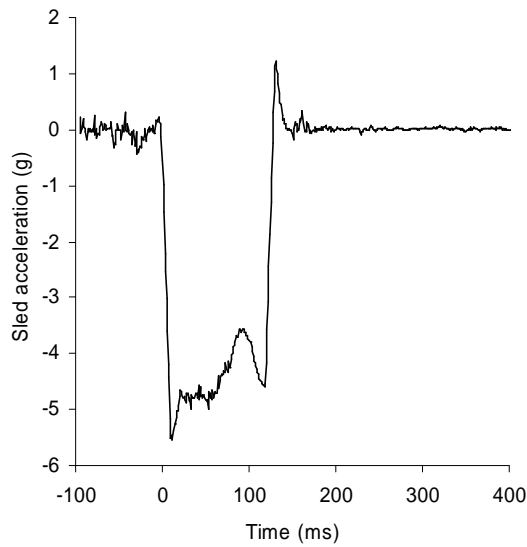

Figure 2:   Acceleration v. time of sled pulse.

Table 1. Seat Belt Anchor Locations Relative To An Origin Located Along The Seat Hinge Axis At The Seat Centerline
(X-axis horizontal, +ve forward; Y-axis horizontal, +ve right; Z-axis vertical, +ve down).

Anchor point	Anchor Forward			Anchor Rearward		
	X (mm)	Y (mm)	Z (mm)	X (mm)	Y (mm)	Z (mm)
Inboard lap anchor	29	-306	196	29	-306	196
Outboard lap anchor	-67	367	114	-195	367	131
D-ring anchor	-123	244	-702	-251	244	-685

For all tests, the sled was accelerated rearward (-x) to rest from an initial forward speed of 17.5 km/h over 120 ms at an average acceleration of -4.0g (Figure 2). The dummy experienced five repetitions of all four test conditions. Tests were conducted in five blocks of 4 tests, with all four test conditions randomly presented within each block.

Data Reduction

Accelerations were determined from the transducer data and displacements were determined from the high speed video data. All dummy accelerations and loads were reported in local head, T1, and pelvis coordinates and all displacements were reported in global coordinates. The x-axis was oriented positive forward, the z-axis positive down, and angular motion about the y-axis was positive in extension. The sagittal plane moment measured by the upper neck load cell was corrected to the atlanto-occipital (AO) joint pin, and load cell data were reported as forces and moments applied to the head by the neck. Angular rate data were digitally-compensated to reduce the sensor's high-pass frequency to 0.002 Hz (Laughlin, 1998), and angular accelerations were then computed using a moving average (16 ms window). All signals were zeroed based on their pre-impact values.

Peak values for the linear and angular accelerations and displacements of the head, linear accelerations of the T1 vertebra and the pelvis, and linear displacements of the knees were determined from the time-varying transducer signals (Figure 3). Peak resultant accelerations of the head, T1 and pelvis were determined from the vector sum of the component transducer signals. The peak neck forces and moment were determined from the upper neck load cell signals (Figure 3). In addition to these peak kinematic and kinetic values, two normalized neck injury criteria were also computed. Peak normalized neck injury criterion N_{ij} was calculated from the neck axial force (F_z) and the neck moment (M_y) using the intercept values for the Hybrid III mid-sized male (tension/compression 4500 N, flexion 310 Nm, extension 125 Nm; Eppinger et al., 1999; 2000). The normalized neck injury criterion N_{km} was calculated from the neck shear force (F_x) and the neck moment (M_y) using the intercept values for the Hybrid III mid-sized male (anterior/posterior shear 845 N, flexion 88.1 Nm, extension 47.5 Nm; Schmitt et al., 2001).

Statistical Analysis

A two-way, repeated-measures analysis of variance (ANOVA) was performed for each of the peak values extracted from the data (Figure 3). All analyses were conducted using Statistica (v.6.0, Statsoft, Tulsa, OK) and a significance level of 0.01.

RESULTS

Ten centimeters of seat belt slack produced significant changes in the magnitude of 21 of the 22 peak dummy responses examined, whereas moving the seat belt anchor location forward 13 cm only produced significant changes in twelve of the peak responses (Table 2). Resultant accelerations of the head, T1, and pelvis increased an average of 30% with the additional seat belt webbing, but only increased an average of 10% with moving the anchor position forward. Likewise, neck loads and moments increased by an average of 33% with seat belt slack compared to an average increase of only 11% with the forward anchor location. In contrast, increases in forward head excursion were similar for both the addition of seat belt slack (21% increase) and moving the anchor location forward (18% increase), and increases in knee excursions were about twice as large with the addition of seat belt slack (35%) than with the forward shift in seat belt anchor location (18%).
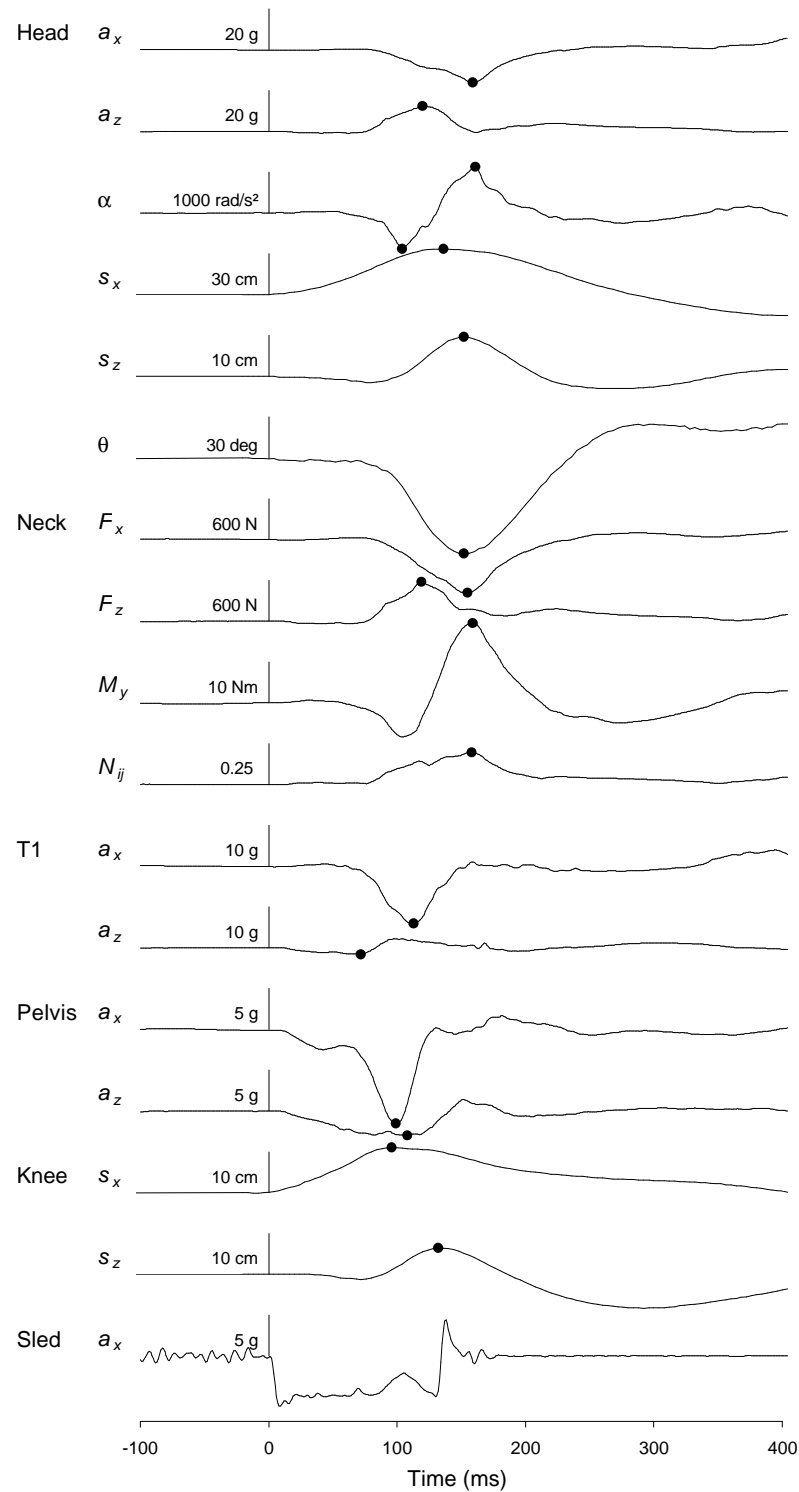
Figure 3: Sample data for the Hybrid III dummy exposed to a frontal collision with the seat belt in the slack condition and the anchor in the forward location. Black circles represent peak responses used as dependent variables. *a*, linear acceleration; α, angular acceleration; *s*, linear displacement; θ, angular displacement; *F*, force; *M*, moment; N_{ij}, normalized neck injury criterion; subscripts *x* and *z*, horizontal and vertical axes.
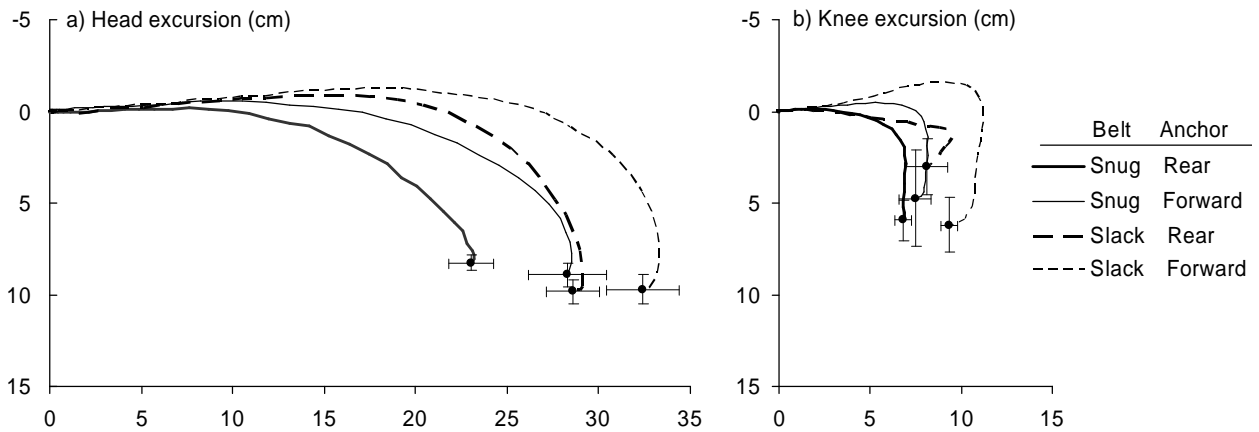
Figure 4: Horizontal and vertical excursions of the head centre of mass (a) and knee joint (b) for the snug and slack belt conditions and the rearward and forward seat belt anchor locations. Plots terminated at the peak downward excursion for clarity (peak forward excursion always occurred before peak downward excursion). Data represent the average of five trials; standard deviation bars shown for the end point only.

Table 2. Average (SD) Of The Dependent Variables For The Four Conditions And The Results Of The 2-Way Analyses Of Variance. Bolded Values ≤ 0.01.

			Anchor Rearward		Anchor Forward		ANOVA p-values		
			Snug	Slack	Snug	Slack	Belt	Anchor	Interaction
Head	a_x	g	-9.6 (0.3)	-13.0 (0.8)	-10.8 (0.9)	-14.2 (0.7)	**0.0000**	**0.0023**	0.9687
	a_z	g	6.4 (0.5)	10.8 (0.6)	8.7 (1.4)	12.2 (1.1)	**0.0000**	**0.0007**	0.3161
	a_{xz}	g	10.1 (0.2)	13.1 (0.6)	12.0 (1.1)	14.7 (0.9)	**0.0000**	**0.0002**	0.6505
	s_x	cm	23.2 (1.1)	29.2 (1.4)	28.5 (1.8)	33.2 (1.8)	**0.0000**	**0.0000**	0.3587
	s_z	cm	8.3 (0.4)	9.9 (0.6)	9.1 (0.6)	9.7 (0.7)	**0.0006**	0.2387	0.0801
	$\alpha_{y\ min}$	rad/s²	-541 (69)	-846 (57)	-573 (115)	-849 (76)	**0.0000**	0.6403	0.6974
	$\alpha_{y\ max}$	rad/s²	690 (50)	993 (80)	783 (57)	1,028 (95)	**0.0000**	0.0680	0.3804
	$\Delta\omega$	rad/s	30.5 (1.1)	38.7 (1.6)	34.2 (2.6)	41.0 (1.6)	**0.0000**	**0.0018**	0.4042
	θ	deg	-56 (3)	-67 (2)	-64 (3)	-69 (3)	**0.0000**	**0.0004**	0.0348
Neck	F_x	N	-579 (26)	-730 (36)	-621 (36)	-765 (28)	**0.0000**	0.0164	0.8218
	F_z	N	285 (27)	479 (34)	381 (64)	536 (59)	**0.0000**	**0.0029**	0.3707
	M_y	Nm	14.1 (0.6)	17.3 (0.9)	15.3 (0.8)	18.1 (1.0)	**0.0000**	0.0228	0.5426
	N_{ij}	-	0.134 (.006)	0.171 (.011)	0.151 (.010)	0.182 (.013)	**0.0000**	**0.0065**	0.5563
	N_{km}	-	0.97 (0.04)	1.21 (0.06)	1.05 (0.06)	1.28 (0.05)	**0.0000**	**0.0052**	0.6619
T1	a_x	g	-9.7 (0.5)	-13.4 (0.5)	-10.2 (0.9)	-13.8 (0.6)	**0.0000**	0.1191	0.6851
	a_z	g	0.83 (0.10)	2.03 (0.20)	1.22 (0.28)	1.80 (0.54)	**0.0000**	0.5700	0.0506
	a_{xz}	g	9.7 (0.4)	13.5 (0.5)	10.3 (0.9)	13.9 (0.7)	**0.0000**	0.1225	0.7131
Pelvis	a_x	g	-8.0 (0.2)	-10.8 (0.6)	-8.8 (0.4)	-11.7 (0.6)	**0.0000**	**0.0019**	0.7620
	a_z	g	-4.1 (0.4)	-3.1 (0.1)	-4.0 (0.4)	-3.4 (0.3)	**0.0001**	0.5055	0.2763
	a_{xz}	g	8.7 (0.2)	11.1 (0.7)	9.5 (0.6)	12.1 (0.6)	**0.0000**	**0.0016**	0.6764
Knee	s_x	cm	7.0 (0.3)	9.5 (0.6)	8.2 (1.0)	11.2 (0.9)	**0.0000**	**0.0006**	0.5050
	s_z	cm	6.5 (1.5)	5.7 (4.3)	6.0 (2.0)	7.6 (1.0)	0.7355	0.5720	0.3106

Peak forward head excursion increased from a minimum of 23.2 ± 1.1 mm in the snug belt, rear anchor condition to a maximum of 33.2 ± 1.8 mm in the slack belt, forward anchor condition (Figure 4). Minimum and maximum knee excursions also occurred in the snug belt, rear anchor and slack belt, forward anchor conditions respectively.

DISCUSSION

The results of this study show that adding seat belt slack and moving the seat belt anchor location forward generally increase the peak kinematic and kinetic responses of an occupant during a moderate frontal impact. Of the two independent variables studied, seat belt slack affected more peak response parameters than moving the outboard lap and shoulder anchor points, and within the subset of response parameters affected by both seat belt slack and anchor location changes, seat belt slack always had a larger effect than anchor location changes on the peak responses.

All but two of the peak responses assessed in the current study increased significantly with the addition of the 10 cm of webbing slack. Both unaffected response parameters were in the vertical direction: peak downward knee excursion varied considerably between trials and was not significantly different between conditions, whereas peak vertical pelvis acceleration was significantly lower in the slack condition (albeit the resultant pelvis acceleration was significantly larger). Amongst the other response parameters, the resultant accelerations, neck kinetics and horizontal excursions increased an average of 31% in the slack condition. These changes were large given that 10 cm represents a 4 to 5 percent increase in the length of the extracted webbing (ignoring the webbing remaining on the spool). Moreover, 10 cm of slack has previously been shown to produce no increase in head excursion, although increases in chest and hip kinematics were observed (Viano et al., 1980). The reason for the difference in these head excursion findings may be related to the lower speed (17.5 vs. 35 km/h), seat belt configuration (retractor vs. fixed belts), dummies (Hybrid III vs. Part 572), or other factors such as seat construction, seat belt anchor locations or webbing material.

Moving the outboard lap and shoulder belt anchors forward by 13 cm increased the magnitude of peak responses in all twelve parameters significantly affected by this variable. Since the change in anchor location was achieved by moving the seat from its most forward position to its most rearward position, some of the benefit derived from having the seat as far back from the dash is eliminated by the simultaneous change in anchor location. For instance, the 13 cm of additional head space available with the seat in the rearmost position is reduced to 7 cm because head excursion increased by 5 cm due to the change in seat belt anchor locations.

The snug condition results in the current study compare well with previous data acquired at similar collision severities (Table 3). Viano and Culver (1981) reported similar head excursions, but higher head accelerations, possibly due to the fixed belts they used. Chandler and Christian (1970) observed slightly larger average head excursions at higher speed changes and accelerations using pre-tensed human subjects. Their knee excursions were similar to those observed in the current study, although their subjects used a foot rest whereas the feet of the Hybrid III used in the current study were not initially supported against a toe pan. Head excursion data reported by Herbert et al. (1975) was also similar to that observed here.

In addition to the effects of seat belt slack and anchor location observed in the current study, peak occupant responses have also been shown to vary with seat cushion properties (Herbert et al., 1975), total seat belt webbing length (Bacon, 1989), collision pulse shape and amplitude (Armstrong and Waters, 1969), impact angle (Horsch, 1980; Herbert et al., 1975) and muscular pre-tension (Armstrong et al., 1968; Mertz and Patrick, 1971). These factors need to be considered when applying the currents results – obtained with a single seat, seat belt and collision pulse – to collision conditions other than those tested here.

Table 3. Comparison Of Selected Peak Response Variables With Previous Studies.

Study	Subjects (N)	Speed change	Acceleration	Horizontal head excursion	Horizontal head acceleration	Horizontal knee excursion
Viano and Culver (1981)	Part 572 (2 tests)	17 km/h	6 g	26-30 cm	16 g	12.7 cm*
Chandler and Christian (1970)	Human subjects (19)	23.4 km/h	11.8 g	31.4 ± 8.2 cm	-	7.6 ± 1.5 cm
Herbert et al. (1975)	Ogle-MIPA (3 tests)	18.7-21.5 km/h	13.5-15.4 g	26.5-30.6 cm	-	-
Current study	Hybrid III (5 trials/group)	17.5 km/h	5.5 g	23.2 ± 1.1 cm** / 28.5 ± 1.8 cm	9.6 ± 0.3 g** / 10.8 ± 0.9 g	7.0 ± 0.3 cm** / 8.2 ± 1.0 cm

* hip displacement; ** rearward and forward anchor locations respectively

Although Hybrid III dummies have been shown to underestimate the excursions observed in cadavers during high speed collisions (Kallieris et al., 1982), the Hybrid III neck response corridors were developed from tests of a pre-tensed human subject at collision severities between 14 and 24 km/h with peak accelerations of 5.7g to 14.0g (Mertz and Patrick, 1971; Culver et al., 1972). The collision severity used in the current study is within this range and therefore the head and neck responses in the current study are within the design limits of the Hybrid III neck. Mertz and Patrick (1971) also reported lower head angular excursions and higher moments at the occipital condyles with pre-tensed neck muscles compared to initially relaxed neck muscles; however, the effect of muscle tension on other peak response parameters has not been documented.

CONCLUSIONS

The results of this study showed that a 10 cm change in seat belt slack and a 13 cm change in seat belt anchor location alter the peak kinematic and kinetic responses of an occupant exposed to a 17.5 km/h frontal speed change. Adding 10 cm of seat belt slack increased the peak amplitude of 20 of the 22 response parameters measured at the head, neck, T1, pelvis, and knees, whereas moving the outboard seat belt anchor points forward by 13 cm increased only 12 of the 22 measured response parameters.

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REFERENCES

ARMSTRONG, R. W. and WATERS, H. P. (1969). Testing programs and research on restraint systems (690247). Society of Automotive Engineers, Warrendale, PA.

ARMSTRONG, R. W., WATERS, H. P., and STAPP, J. P. (1968). Human muscular restraint during sled deceleration (680793). Proc. of the 12th Stapp Car Crash Conf., pp. 173-184. Society of Automotive Engineers, Warrendale, PA.

BACON, D. (1989). The effect of restraint design and seat position on the crash trajectory of the Hybrid III dummy. In: SH Backaitis, HJ Mertz (Eds), Hybrid III: The First Human-like Crash Test Dummy (PT-44), pp. 641-647. Society of Automotive Engineers, Warrendale, PA.

BISS, D. J. (1988). Safety performance evaluation of slack effects in three-point safety belts using the Hybrid III dummy in frontal and frontal oblique sled tests. Proc. 16th Annual Workshop on

Human Subjects for Biomechanical Research, pp.69-114. National Highway Traffic Safety Administration, Department of Transportation, Washington, DC.

CAMPBELL, B. J. (1987). Safety belt injury reduction related to crash severity and front seated position. J Trauma, 27, 733-9.

CHANDLER, R. F. and CHRISTIAN, R. A. (1970). Crash testing of humans in automobile seats (700361). Society of Automotive Engineers, Warrendale, PA.

CULVER, C., NEATHERY, R., and MERTZ, H. (1972). Mechanical necks with human-like responses (720959). Proc. of the 16th Stapp Car Crash Conf., pp. 61-75. Society of Automotive Engineers, Warrendale, PA.

EVANS, L. (1996). Safety-belt effectiveness: the influence of crash severity and selective recruitment. Accid Anal Prev, 28, 423-33.

FARMER, C. M. (2003). Reliability of police-reported information for determining crash and injury severity. Traffic Injury Prevention, 4(1), 38-44.

FREEMAN, C. M. and BACON, D. G. C. (1988). The 3-dimensional trajectories of dummy car occupants restrained by seat belts in crash simulations (881727). Proc. of the 32th Stapp Car Crash Conf., pp. 213-222. Society of Automotive Engineers, Warrendale, PA.

HERBERT, D. C., STOTT, J. D., and CORBEN, C. W. (1975). Head space requirements for seat belt wearers (751164). Proc. of the 21st Stapp Car Crash Conf., pp. 675-704. Society of Automotive Engineers, Warrendale, PA.

HONTSCHIK, H., MÜLLER, E., and RÜTER, G. (1977). Necessities and possibilities of improving the protective effect of three-point seat belts (770933). Proc. of the 21st Stapp Car Crash Conf., pp. 795-831. Society of Automotive Engineers, Warrendale, PA.

HORSCH, J. D. (1980). Occupant dynamics as a function of impact angle and belt restraint (801310). Proc. of the 24th Stapp Car Crash Conf., pp. 419-438. Society of Automotive Engineers, Warrendale, PA.

LAUGHLIN, D. A. (1998). Digital filtering for improved automotive vehicle and crash testing with MHD angular rate sensors. Albuquerque, NM: ATA Sensors Inc.

MERTZ, H. J. and PATRICK, L. M. (1971). Strength and response of the human neck (710855). Proc. of the 15th Stapp Car Crash Conf., pp. 207-255. Society of Automotive Engineers, Warrendale, PA.

KALLIERIS, D., MELLANDER, H., SCHMIDT, G., BARZ, J., and MATTERN, R. (1982). Comparison between frontal impact tests with cadavers and dummies in a simulated true car restrained environment (821170). Proc. of the 26th Stapp Car Crash Conf., pp. 353-367. Society of Automotive Engineers, Warrendale, PA.

SCHMITT, K-U, MUSER, M., and NIEDERER, P. (2001). A new neck injury criterion candidate for rear-end collisions taking into account shear forces and bending moments (Paper No. 124). In: Proc. of the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Amsterdam, The Netherlands, June 4 – 7.

VIANO, D. C., CULVER, C. C., and PRISK, B. C. (1980). Influence of initial length of lap-shoulder belt on occupant dynamics – A comparison of sled testing and MVMA-2D modeling (801309). Proc. of the 24th Stapp Car Crash Conf., pp. 377-415. Society of Automotive Engineers, Warrendale, PA.

VIANO, D. C. and CULVER, C. C. (1981). Test dummy interaction with a shoulder or lap belt (811017). Proc. of the 25th Stapp Car Crash Conf., pp. 583-609. Society of Automotive Engineers, Warrendale, PA.

DISCUSSION

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PRESENTER: *Dr. Gunter Siegmund, MacInnis Engineering Associates*

QUESTION: *Guy Nusholtz, Daimler/Chrysler*
> First question is: Why do you think there are no muscles or simulation of muscles in the Hybrid III? And second, which follows on this: Why do you think the Hybrid III wouldn't be valid at this velocity, since it was actually developed at a fairly low velocity?

ANSWER: The answer to your first question is: It doesn't have muscles. It has fairly uniform passive properties whereas muscle-based systems have very non-linear properties and muscles turn on and off. So, I don't think the Hybrid III will ever mimic a system that has muscles. It can approximate either the no muscle condition or the full muscle activation condition or somewhere in between, but it can't transition from one to the other.

> The answer to your second question is: I don't know that it's not invalid. I just don't know that it's valid under the conditions that we tested it. Has it been validated at the speed change we're working at? I haven't seen that data.

Q: Thank you. It may be more valid at the lower velocities than it is at the high velocities, and it seems that you're trying to indicate that the validity was better at the higher velocities than it would be at the lower because that's where it's development was done--Even though there were some cadaver tests, it was done primarily on human volunteers; or, a human volunteer.

A: If you think it's more valid than I do, I think that's a good thing.

Q: J*eff Crandall, University of Virginia*

> Just a comment on the musculature. It depends, I think, on what body region you're talking about. If you're talking about neck, chest, there are some accommodations. But if you're talking about effects from restraining yourself and muscle tensing--[Right], I'm not really clear what you guys were discussing there.

A: I think we were on about neck muscles, mostly, and head excursion.

Q: Alright. So, neck muscles because all those other factors would be significant in looking at what the influence of slack or belt position would be.

A: Sure.

Q: So you've got a mismatch of regions that have muscle tensing incorporated and those that don't--

A: Right. And, we also don't have any arms on steering wheels, or various things like that. Thank you.