
Vehicle and Occupant Response in Heavy Truck to Car Low-Speed Rear Impacts

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ABSTRACT

Despite efforts by industry to reduce the problem of injury in rear impacts, there continues to be a large number of such claims. This is true even in low speed impacts which result in little or no damage to the vehicles involved. Recent studies of such incidents have been described in the literature. These studies have concentrated primarily on simple bumper to bumper impacts where the front bumper of the striking vehicle contacts the rear bumper of the struck vehicle.

Perhaps a more common type of rear impact is one in which the bumper of the striking vehicle rides over or under the rear bumper of the struck vehicle. The heavy truck to car rear impact is an example of an overriding impact. This paper describes several staged impacts of this type in which vehicle and occupant responses were measured using fully instrumented Hybrid III dummies or human volunteers. These impacts often result in significantly greater damage than bumper to bumper impacts at identical speeds, while imparting lower accelerations and forces to the occupants of the struck vehicle.

INTRODUCTION

During the past 30 years, several researchers have examined the problem of neck injury in automotive accidents. In 1971, Mertz and Patrick reported the results of a study in which human volunteers and cadavers were subjected to various accelerations on an impact simulator. Based on these results the authors concluded that in extension, the average extent of head motion relative to the torso for a 50th percentile male was found to be 77 degrees. In addition, they established recommended injury criteria for the neck in extension which included an extension moment about the occipital condyles of 57 N-m and a lower threshold dynamic neck strength in tension and compression of about 1110 N.

In 1991, James et. al described findings from a survey of crash data from 1981 and 1986. It showed that while rear impacts made up approximately 11% of all accidents, they accounted for over 23% of the injured occupants. While most of these injuries were relatively minor, even minor cervical injuries can result in significant pain and

lost wages. A further finding of the study was that over 25% of the rear impacts resulted in ΔV 's of less than 4.5 m/sec and over 50% resulted in ΔV 's of less than 6.75 m/sec.

The response of the Hybrid III dummy in rear impact scenarios has been examined in a number of studies. In 1993, Svensson, et. al reported the results of a series of sled tests at 1.4 and 3.5 m/sec with a variety of seat configurations. In addition, the dummy was equipped with an experimental neck believed to be more biofidelic in these test scenarios. The measured head to torso extension angles ranged from about 5 to 65 degrees depending on the speed and seat configuration in each test. In addition, a series of tests was performed to compare the experimental neck response to that of the standard Hybrid III neck. These tests, which were run at 3.4 and 4.2 m/sec showed that while the standard neck exhibited an extension angle between about 22 and 32 degrees, the corresponding results for the experimental neck were between about 45 and 55 degrees.

Another study reported in 1993 by Scott, et. al described the results of three rear impacts between a variety of light trucks and passenger vehicles in which the struck vehicle in each case contained a human volunteer as the restrained driver and the restrained front passenger was a 50th percentile male Hybrid III dummy. The impact speeds ranged from about 1.1 to 2.2 m/sec in each of the tests. The general findings of the tests were that while the overall distribution of rotations along the various body segments of the test subjects varied somewhat, the timing of the peak head rotation for both the human and the Hybrid III was similar. At the lowest ΔV the magnitude of the head rotation for both subjects was similar, however at the higher ΔV 's the human volunteer head rotated more than the dummy head. The head CG X axis accelerations of the volunteer and the dummy were similar in magnitude, however the volunteer head accelerations were generally somewhat greater, with the largest differences occurring at the highest speed.

In 1994, Matsushita, et al. did a series of 19 sled tests with human volunteers at accelerations up to 7.6 g's and ΔV 's between 0.7 and 1.4 m/sec. The reported maximum head accelerations in these tests ranged from 1.4 to 6.3 g's. The test subject's neck motion was recorded

cineradiographically during the tests, and it was reported that in none of the cases was the voluntary range of motion exceeded. Five of the test subjects reported minor muscle soreness beginning one day after the tests and resolving within 2 to 4 days.

Finally, in 1995, McConnell, et. al reported the results of a series of 14 vehicle to vehicle rear impact tests with a ΔV of 1.6 to 3.0 m/sec. Each of these tests involved human volunteers whose head motion was measured with tri-axial accelerometers on a biteplate and up to three axes of angular acceleration sensors. In addition the motion was recorded using high speed film. The results of these tests were used to analyze the variation of the accelerations that act throughout the head as a result of its rotational motion. It was noted that while none of the test subjects came close to experiencing extension near the limit of the cervical range of motion, most exhibited at least some signs of "whiplash" type symptoms ranging from an awareness of discomfort to headache or muscle soreness. The onset and symptoms varied from minutes to hours after the tests and lasted a few minutes to at most 3 to 4 days.

METHODS

VEHICLES-Three separate vehicle configurations were utilized to perform the testing in this study. For the first test series (series 9728), which involved four tests, the striking vehicle was a Kenworth conventional tractor in the bobtail configuration and the struck vehicle was a 1981 Ford Mustang.

The front bumper of the Kenworth mounts directly to the frame of the vehicle, and the rear bumper of the mustang consists of a bar, mounted to energy absorbers. There is a plastic covering over the entire assembly. The absorbers on the test vehicle were significantly rusted and had not obviously ever been stroked.

In the second test series (series 6738), which included three tests, the striking vehicle was a 1982 Plymouth Horizon and the struck vehicle was a 1986 Chevrolet S-10 Blazer 4X2.

The front bumper of the Horizon consists of a plated aluminum extrusion which mounts onto energy absorbers that attach to the vehicle frame. The rear bumper of the Blazer is a chrome plated steel bumper attached to the vehicle frame through mounting brackets. For this test it had a class 1 Drawite trailer hitch attached below it.

During the tests in this series, the Horizon pulled a type 301 rear impact buck with a relatively rigid coupling. The buck was ballasted so that the tests would simulate a multi-vehicle collision.

If any damage was observed to the vehicles in these tests, the components that were damaged were replaced before the next test was conducted.

In addition to the tests described above, an eighth test was performed in which the striking vehicle was a 1977 Mack R686 ST conventional tractor, ballasted to simulate hauling an empty trailer, and the struck vehicle was a 1986 Toyota Camry. The front bumper of the Mack was the same in general construction as the Kenworth in the first test series, and the rear bumper of the Camry was constructed from a rubber cover over an energy absorbing structure that mounts to the frame. Information describing the vehicles and test speeds is summarized in Tables 1, and the pre-impact vehicle line-up for each series is shown in Figures 1-3.

Each of the test configurations described above simulate field accidents in which injuries were reported by the occupants of the struck vehicles.

OCCUPANTS-In each of the tests, either a human volunteer, instrumented dummy, or both were front seat occupants of the vehicle being impacted. In test series 9728, the driver seat was occupied by a female volunteer. She was 38 years old, 1.7 m tall (5',7") and weighed 57 Kg (126 lbs.).

In test series 6738, the driver of the vehicle was a 50th percentile male Hybrid III dummy, while a human volunteer sat in the front passenger seat. During the first two tests in this series, the volunteer was a 34 year old male who stood 1.88 m tall (6',2") and weighed 90.5 Kg (200 lbs.). During the final test in the series, the volunteer was a 46 year old male who stood 1.83 m (6') tall and weighed 99.5 Kg (220 lbs.).

In the final test, the driver of the struck vehicle was a 95th percentile Hybrid III male dummy. All test subjects wore standard lap/shoulder restraints.

INSTRUMENTATION-Each time a dummy was used during the testing, it was instrumented with tri-axial accelerometers in the head, chest and pelvis. In addition, the six axis lower neck load cell was used, and the chest displacement potentiometer was used to give an indication of any significant rebound from the seat following the impact.

Each of the human volunteers held a biteplate in their mouth on which was mounted a tri-axial accelerometer package. The orientation of the accelerometers was about the same as would be found in the dummy package.

Table 1--Summary of Test Vehicles and Speeds

Test Series	Test Number	Striking Vehicle / Weight [Kg]	Struck Vehicle / Weight [Kg]	Striking Speed [m/sec]
9728	9728-1	Kenworth Conventional Tractor /6335	'81 Ford Mustang / 1177	0.45
	9728-3	Kenworth Conventional Tractor /6335	'81 Ford Mustang / 1177	1.35
	9728-5a	Kenworth Conventional Tractor /6335	'81 Ford Mustang / 1177	2.25
	9728-5b	Kenworth Conventional Tractor /6335	'81 Ford Mustang / 1177	2.25
6738	6738-3	Horizon w/Ballasted 301 Buck / 2941	'86 Chevrolet Blazer / 1425	1.35
	6738-5	Horizon w/Ballasted 301 Buck / 2941	'86 Chevrolet Blazer / 1425	2.25
	6738-7	Horizon w/Ballasted 301 Buck / 2941	'86 Chevrolet Blazer / 1425	3.35
---	9754	Ballasted Mack Tractor / 10860	'86 Toyota Camry / 1052	5.60



Figure 1—Vehicle line up for Test Series 9728



Figure 2—Vehicle line-up for Test Series 6738

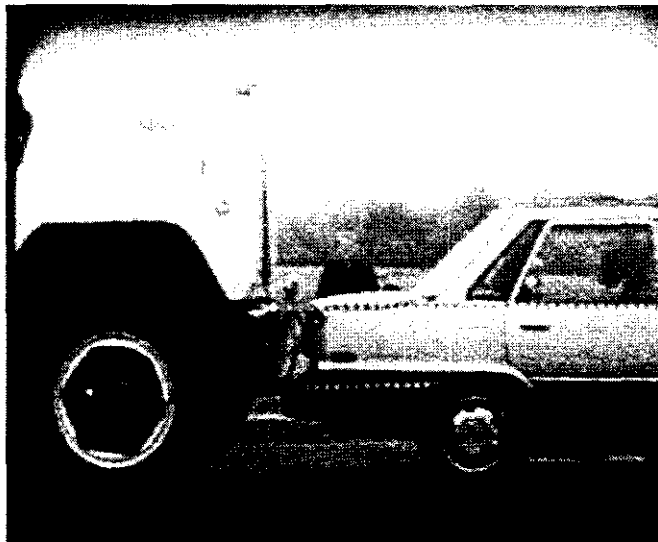


Figure 3—Vehicle line-up for Test 9754

Finally, each of the struck vehicles was instrumented with a tri-axial accelerometer package near its CG and each striking vehicle had a fifth wheel mounted to it so that the driver could monitor and control the speed of impact.

CAMERAS—For each test, high speed cameras were mounted on the front passenger door of each struck vehicle. In addition, in test series 6738 the front driver door of the struck vehicle also had a high speed camera mounted to it since both front seats were occupied by test subjects. The struck vehicles in the tests also had high speed cameras mounted on the hood recording the driver motion through the windshield. Off-board, high speed cameras viewed the zone of impact from either side, and a final high speed camera recorded an overall view of the struck vehicle from the driver side. Each of the cameras was run at 250 or 500 frames per second depending on available light. Normal speed video cameras were also used to cover the tests from several different angles.

In all of the tests, a contact switch was used to trigger a strobe which indicated first vehicle contact and allowed synchronization of the films. In addition, in the tests where

the dummy was utilized, such a switch was used to indicate time zero for the data.

RESULTS

Before the results from these tests are presented, several general issues are discussed. First, in test number 9728-3 there was a problem with the data acquisition system and no data was collected for that test. Second, test number 9728-5b was not filmed. Finally, in all the tests in series 9728, no impact event was marked in the channels, so for most of the data, while time zero is fixed for each channel in any particular test, its relationship to the time of impact is rather arbitrary. Despite this fact, the shape of the curves and the pulse duration and magnitudes can still be readily compared to the data from the other tests.

In each of the tests involving an instrumented dummy, all data was collected at 12.5 kHz and filtered per the recommendations of S.A.E. J211. In the tests involving only volunteers, data was collected at 1 kHz and filtered with a four

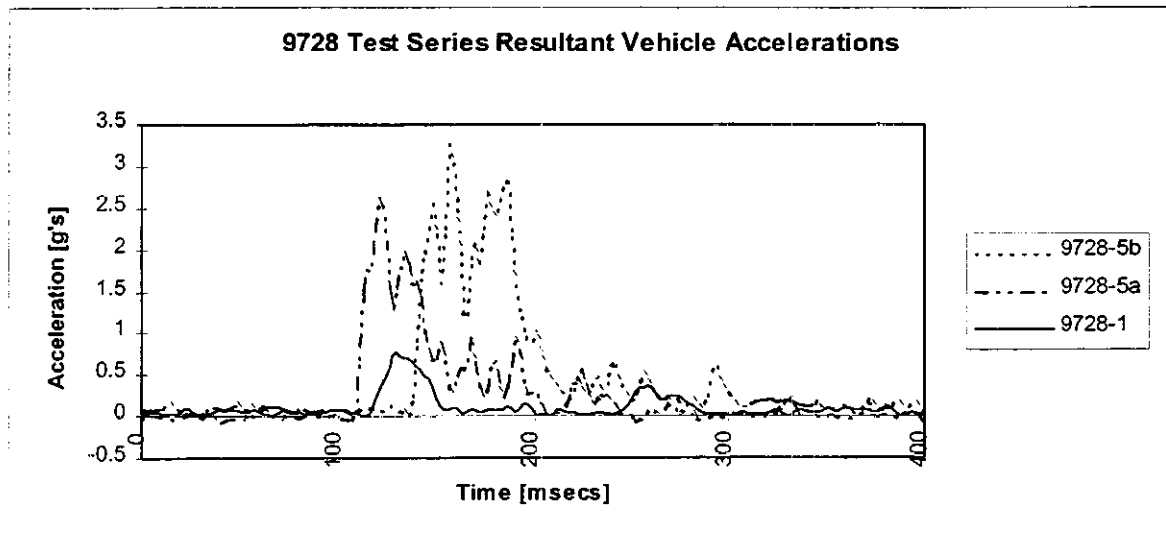


Figure 4—Resultant Vehicle Accelerations from Test Series 9728

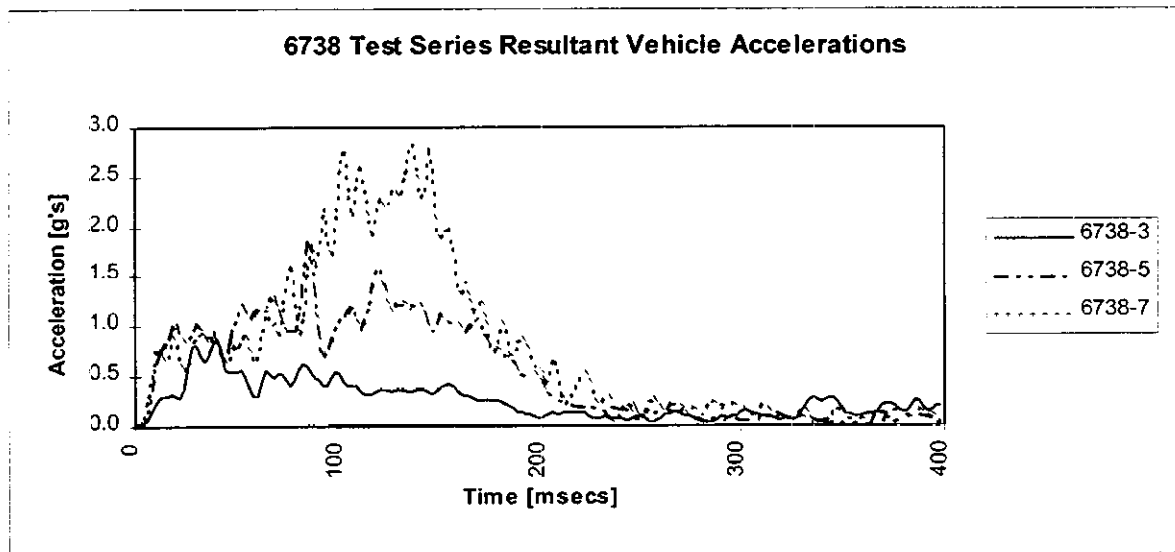


Figure 5—Resultant Vehicle Accelerations from Test Series 6738

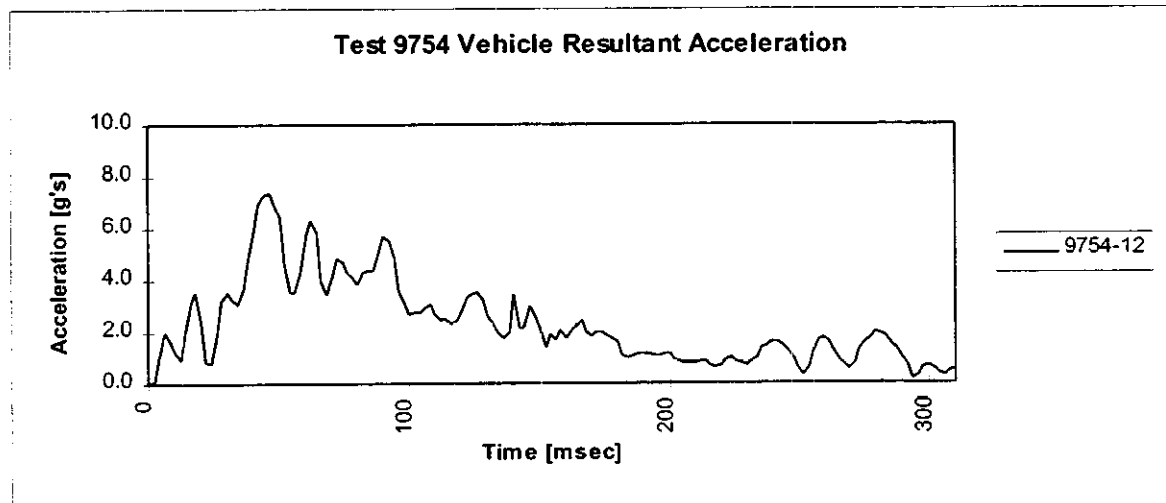


Figure 6—Resultant Vehicle Acceleration from Test 9754

pole phaseless Butterworth filter with a CFC of 60 Hz. This did not compromise the integrity of the head acceleration data.

VEHICLE ACCELERATIONS-The resultant accelerations caused by the impacts to the struck vehicles in these tests are shown in Figures 4-6. Several interesting

features can be pointed out in these figures. First, note in the curves for both test number 9728-1 and number 6738-3 that there are two distinct impact pulses. In each case, the struck vehicles were inadvertently left in park during the tests. This resulted in a second impact after the vehicle separation following the initial impact.

The most important thing to notice about these curves is the much sharper onset and shorter duration of the pulses associated with the tests in series 9728. The reason for this is that there is no capacity for energy absorption on the front surface of the Kenworth tractor. In addition, the speed of the impact is insufficient to cause any significant energy absorption by the rear of the Mustang. This is interesting to note since the Mustang rear bumper system includes energy absorbers. As noted earlier, however, it was questionable because of their age and condition how well these absorbers would function. In addition, as Figure 7 below shows, because of the override of the Mustang bumper by the truck bumper, there is very little interaction between the bumpers when the vehicles reach maximum engagement.

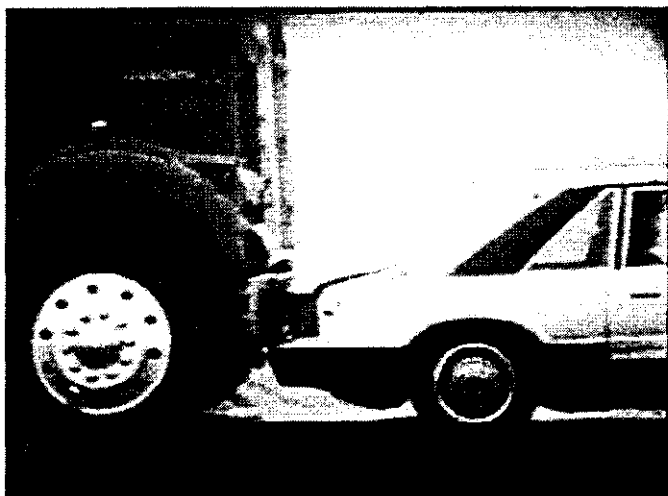


Figure 7—Maximum engagement of the Kenworth and the Mustang during Test 9728

Even though the bumper of the horizon underrode the Blazer bumper in test series 6738, they still interacted because of the trailer hitch on the Blazer. In the 1.35 and 2.25 m/sec tests, the energy absorbers of the Horizon worked just as they were designed and stroked almost completely. This is shown in Figure 8.

Figure 9 shows that at the 3.35 m/sec impact, the energy absorption capability of the Horizon bumper was overcome. When this occurred, the bumper collapsed structurally and rode under the Blazer bumper which then began to penetrate into the grill and front structure of the Horizon. There was actually more damage done to the Blazer rear bumper in the 2.25 m/sec test when the force on the trailer hitch caused the bumper to twist.

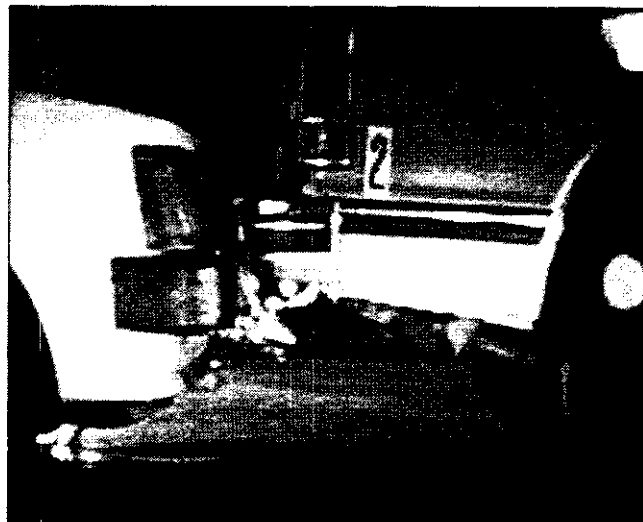


Figure 8—Maximum engagement of the Horizon and Blazer during Test 6738-5

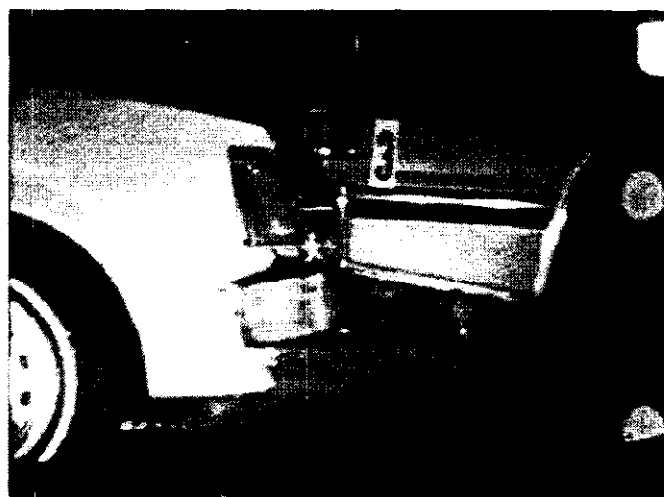


Figure 9—Maximum engagement of Horizon and Blazer during Test 6738-7

TEST SUBJECT RESPONSE -The overall response of the test subjects is illustrated in Figure 10, which shows an overlay plot of the accelerations for the dummy in test 6738-7. The phase difference in the peaks of the accelerations for the pelvis, chest and head are typical. Because of the seat geometry and the tendency for people to slouch forward, there generally is significantly more space between the upper torso and head and the seat back than between the pelvis and the seat back. As a result, when the impact occurs and the body begins to move rearward into the seat, the first interaction occurs between the pelvis and the seat back and this reaches a maximum about 100-150 milliseconds after the impact. Further, this maximum value is generally similar in magnitude to the peak vehicle acceleration. Next, about 150-200 milliseconds following the impact, the chest acceleration reaches a maximum value, which is again similar in magnitude to the vehicle acceleration pulse.

Typical Accelerations in 3.1 m/sec Rear Impact

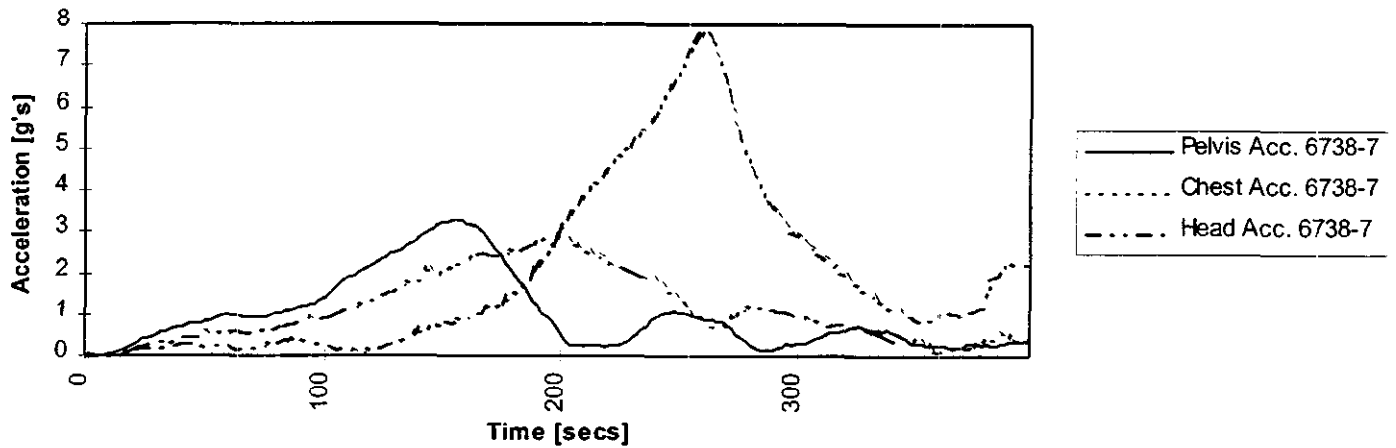


Figure 10—Dummy Resultant Accelerations in Test 6738-7

Finally, about 200 to 300 milliseconds after the impact, the head acceleration reaches its peak value. Because of the whip like motion of the spine, and the stiffness of the neck compared to the padded seat back which accelerates the chest and pelvis, the head acceleration can be from two to four times the magnitude of the vehicle acceleration. For the low speed impacts in this study the multiplication factor has been between two and three.

The head accelerations were of primary interest in this study. The design of the study allows comparison of the effects of the impact configuration, the impact speed and the test subject type on the measured head accelerations to be examined. Figures 11 through 15 show the resultant head accelerations for each test subject and each test.

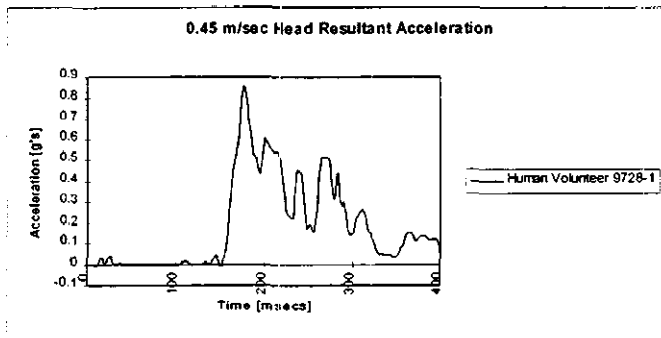


Figure 11

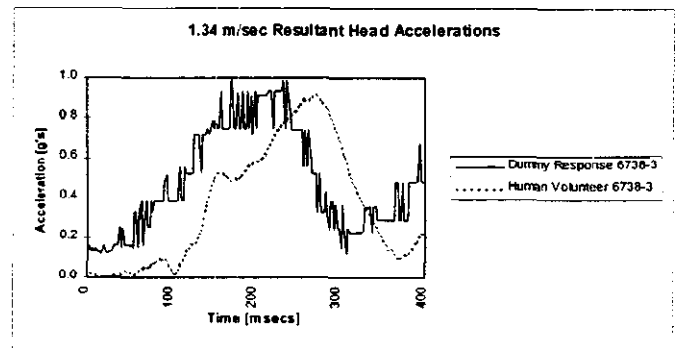


Figure 12

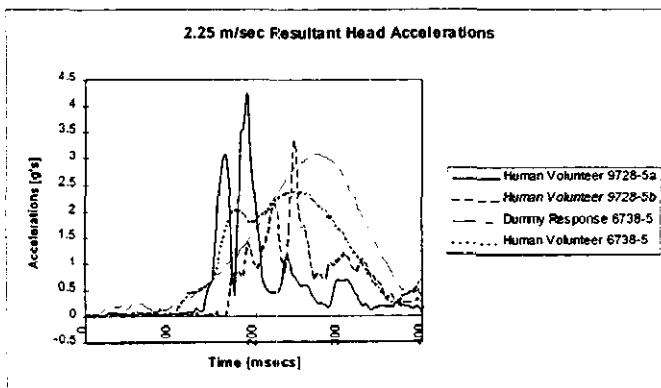


Figure 13

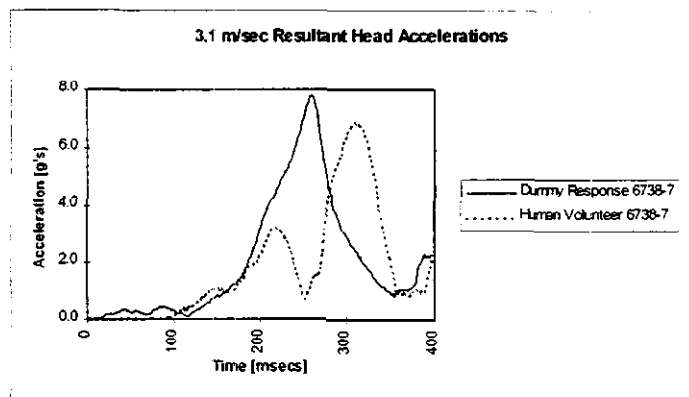


Figure 14

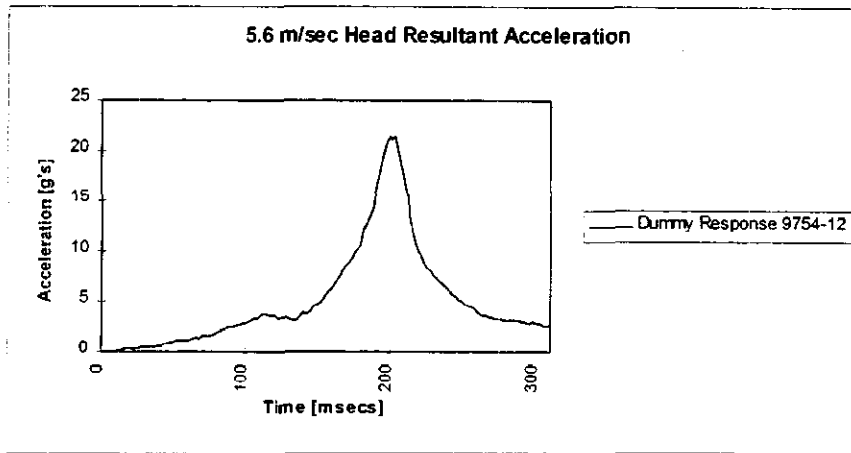


Figure15

Figure 12 represents the resultant head accelerations for a side by side dummy and human volunteer in a 1.35 m/sec impact. It shows that in this situation, the dummy and human acceleration curves are very similar in shape and magnitude, but there is a significant lag in the human response when compared to dummy response of the head.

Figure 13 shows the results from three tests at 2.25 m/sec. Two of the tests involved only human volunteers, while the third involved a side by side dummy and human volunteer. The choppy appearing curves are the results of two consecutive impacts to the rear of the Ford Mustang by the Kenworth tractor. The only difference between the two test conditions was that in the first test, the female volunteer was the test subject, and in the second the six foot male volunteer was the test subject. It is interesting to note that the male subject, who was taller, took longer to reach a maximum acceleration which was nearly one g below that experienced by the female volunteer. The most likely reason for this is the fact that there would be less interaction between the taller male and the seat back and headrest than there was for the shorter female. As a result, the male would be allowed more neck motion and possibly more seat back motion, both of which would tend to increase the available time for acceleration and thus decrease the peak acceleration.

The smoother curves in Figure 13 are the resultant head accelerations for the side by side dummy and volunteer in 2.25 m/sec test 6738-5. The reason the curves are much smoother than the other 2.25 m/sec tests is that the impact configuration in this test allows for a more gradual and smoother vehicle acceleration than the other tests. Again, the shapes of the acceleration curves for the two test subjects in this test are similar, but with a significant lag in the response of the dummy head compared to the human's. In this test, the magnitude of the acceleration experienced by the volunteer is about 20% below that of what was measured by the dummy. It seems, however, that there is no more variation between the dummy and human in the same test configuration (series 6738) than there is between the two humans in the same test configuration (series 9728).

The curves in Figure 14 again show resultant head accelerations for a side by side dummy and human volunteer, but at a 3.35 m/sec impact velocity (7.5 mph). The same

general comments apply in this case as in the lower speed tests, although as the speed is increased there is increasing deviation in the shapes of the acceleration curves from each other. A significant reason for this is the difference in accelerometer locations for the two test subjects. While the dummy accelerometers are located at the CG of the dummy head, the accelerometers which measure the human volunteer's head responses mount to a biteplate which extends out away from the head CG. Thus, as there is more and more head rotation at higher rates of angular velocity and acceleration, the accelerations measured by the transducers at the differing locations increasingly diverge.

This is illustrated in Figures 16 and 17 below, which show the X and Z components of the head acceleration in test 6738-5. Because of the angular velocity of the head, the human X axis acceleration, although tracking reasonably close to the dummy X axis acceleration, is somewhat attenuated. A larger difference is seen in the Z axis accelerations measured by the dummy and at the biteplate. The biteplate accelerometer is more sensitive to the tangential acceleration caused by the angular acceleration of the head. At these speeds, this acceleration is still relatively low, however, and doesn't cause a great deal of shift in the resultant accelerations.

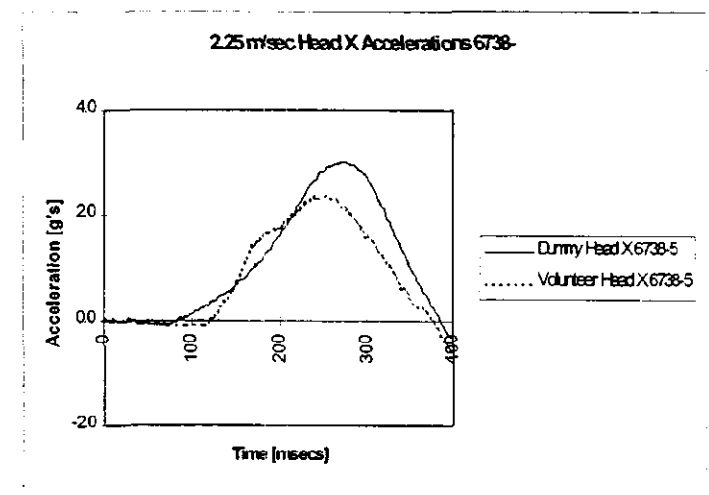


Figure 16 Head X Accelerations

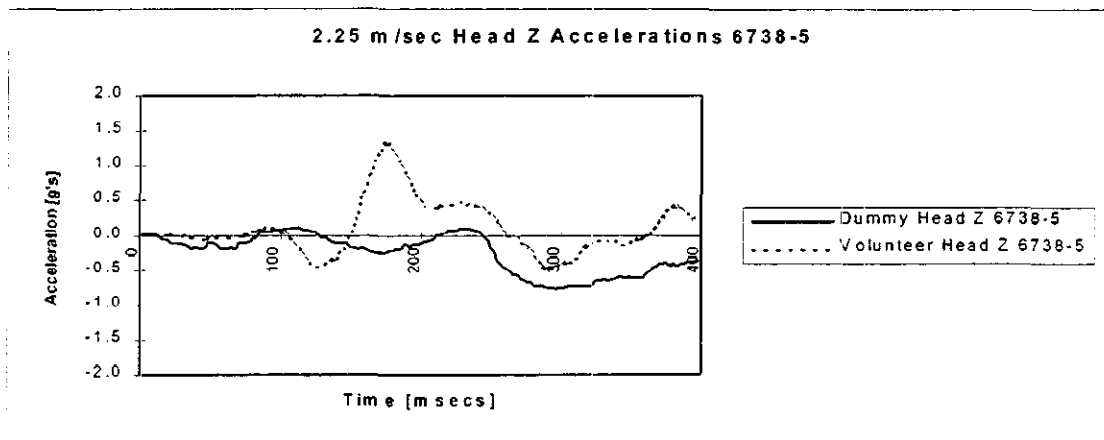


Figure 17—Head Z Accelerations

Another result of primary interest in this study is the head rotations experienced by each of the test subjects. In order to measure them, the high speed films, which had been transferred to videotape, were analyzed. The head angle of the test subjects was measured at 10 millisecond increments. In addition, an attempt was made to measure the torso angle of the test subjects from the films. Because there was very little torso motion in any of the tests except for test 9754-12, where significant seat back motion occurred, and because of the facts that none of the vehicle doors could be removed and each of the test subjects wore relatively loose clothing, the torso motion was only included in the results for test 9754-12.

An examination of the data showed that its frequency content was generally below five Hz. To remove the "noise" resulting from the measurement method employed for these tests, the data was digitally filtered with an S.A.E. J211 four pole Butterworth phaseless filter having a CFC of 12 Hz. It was noted that this did not significantly alter the shape or magnitude of the head rotation curves. The head rotation

responses measured in all of the tests are summarized in Figure 18 below.

The maximum head rotations are shown for each test in Figures 19-21 on the following page. In each figure that shows a human volunteer, the biteplate is a good indicator of the head rotation angle. In Figure 20 it is apparent that the biteplate for test number 6738-7 is not clearly visible at the maximum angle of rotation. It has been approximately marked on the figure to correct this. Careful examination of the photos reveals some other interesting features. First, in each of the photos in Figure 20, the dummy is visible in the background, and can be compared to the volunteer subject in the foreground. Also, the photos in Figure 21 clearly demonstrate the large amount of seat back motion which occurred in the 5.6 m/sec test number 9754-12, especially compared to the other tests.

The peak head rotation in test 9728-1 which involved a 0.45 m/sec impact was only about 7 degrees. The results from the 1.35 m/sec tests were more interesting, and they are given in Figure 22. The curves for the dummy and volunteer

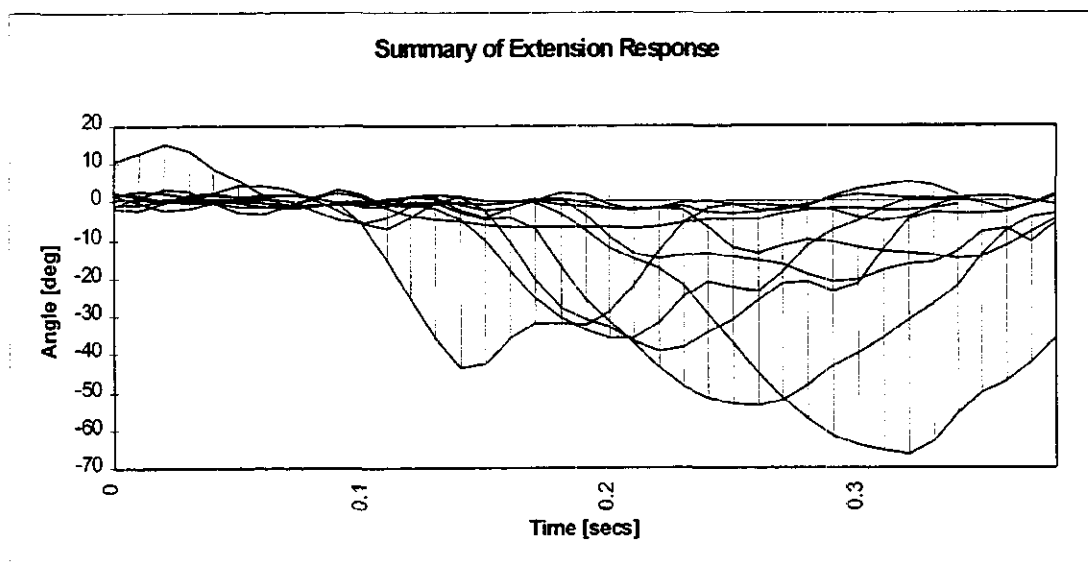


Figure 18—The Range of Head Extension Responses for all Tests in this Study



Figure 19

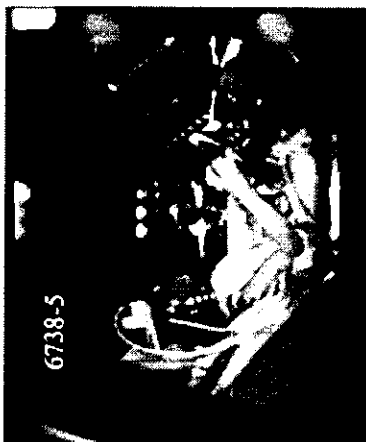
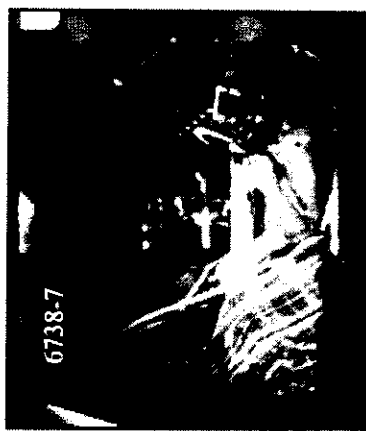


Figure 20



Figure 21

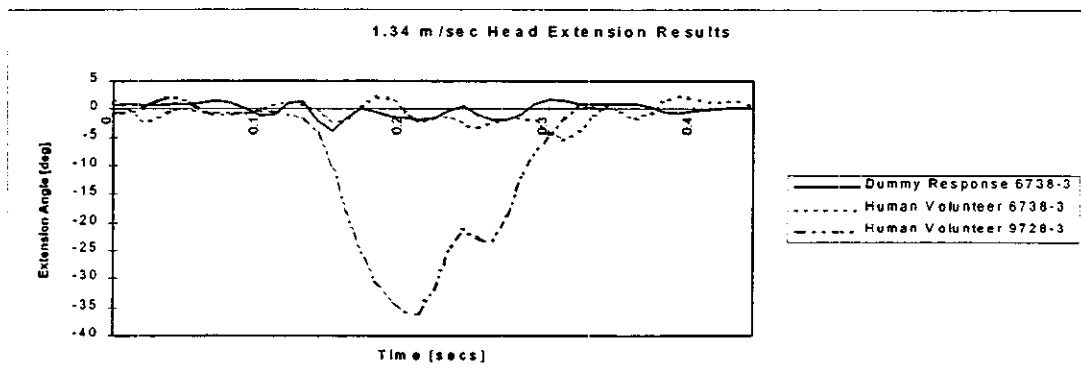


Figure 22—Head Rotation in the 1.34 m/sec Tests

in test 6738-3 each show very little rotation, although there may be some for the volunteer in the 200-300 millisecond time period. If present, it is not beyond the range of uncertainty of the measurement. The most interesting aspect of Figure 22, however, is the large amount of rotation for the human volunteer in test 9728-3 when compared to either the dummy or human volunteer in test 6738-3. Since the Mustang was struck by a heavier vehicle in test 9728-3 than the Blazer was in test 6738-3, this could account for some of the difference. However, recall from Figures 4 and 5 that although there is no data for test 9728-3, the results for 9728-1 and 9728-5 would suggest a peak acceleration for the Mustang very similar to what the Blazer received in test 6738-3. Again, the largest differences in the acceleration pulses would be the steepness of their rises, with the a steeper onset and shorter duration for the Mustang rather than the Blazer.

Other possible explanations for the differences in response include differences in the headrest positions in the two vehicles. If anything, however, these differences should mean greater head support for the shorter female volunteer in the Mustang than the taller male volunteer in the Blazer.

A final possible explanation for the differences in head rotation observed would be that the neck strength of the male volunteer in test 6738-3 was greater than the neck strength for the female volunteer in test 9728-3. Although all of the volunteers were instructed to try and remain relaxed during the tests, and reported that they did, the effects of differences in musculature could still be important.

Figure 23 is similar to Figure 22 except that it gives the head rotation results for the 2.25 m/sec tests. Note that the head rotation response from test 9728-5 is not for the same test as the head accelerations discussed above, since a different volunteer was used.

There are several interesting features to this figure. First, it is clear that again, there is much greater similarity in the results for the side by side dummy and volunteer in test 6738-5 than there is for either of those test subjects when compared to the volunteer from test 9728-5. The reasons for this fact were discussed earlier, but it is interesting to note that there is only slightly more neck rotation in test 9728-5 compared to test 9728-3, while there is a very significant increase in the head rotations observed from test 6738-3 to 6738-5. This tends to suggest that in test 9728-3 the head rotation of the volunteer may have reached the extent that the headrest would allow, and that in test 9728-5 the only reason slightly more rotation occurred was that the increased force caused a bit more seat back or headrest deformation.

It is also interesting to note that in test 6738-5, the dummy head rotated slightly more than the human volunteer. This suggests that the dummy neck is more compliant than the human volunteer's neck. This is really contrary to what one would expect if the volunteer's neck remained relaxed, but it does agree with the trend noticed for the head accelerations in this test in which the volunteer accelerations were smaller and occurred slightly earlier.

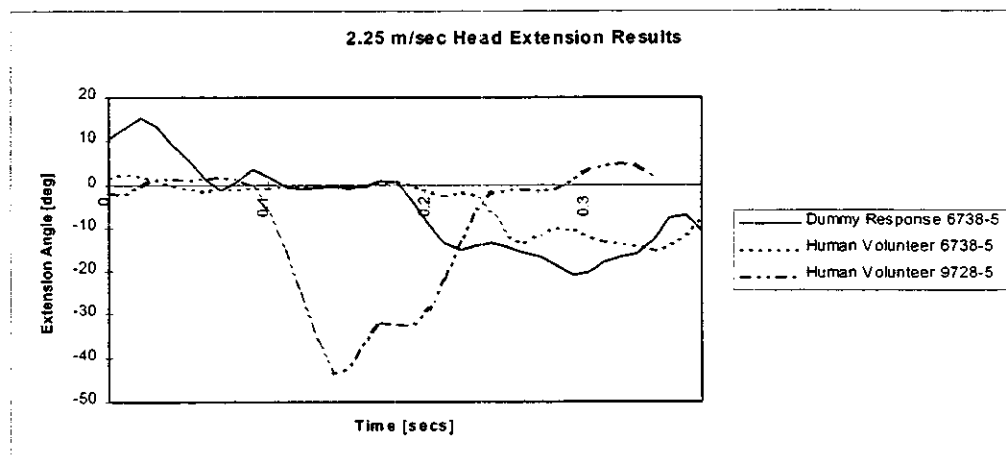


Figure 23—Head Rotation in 2.25 m/sec Tests

The head rotation results for test 6738-7 which incorporated a side by side dummy and human volunteer at an impact speed of 3.35 m/sec are shown in Figure 24. These results again show fairly similar pulse shapes, although it again appears that as the speed of impact grows the dummy neck response is stiffer than the human, with the human response lagging behind that of the dummy while exceeding it in magnitude. This may only be an artifact of the variability between different humans, however, since a different volunteer was the human subject in test 6738-7 than in tests 6738-3 and 6738-5.

For both subjects, this test showed the greatest head rotation of any of the tests. This is a bit surprising since test 9754-12, the results of which are in Figure 25, involved an impact at nearly twice the speed of test 6738-7. The simplest explanation for this is that in test 9754-12, there was significant seat back motion, which helped to minimize the whipping of the head, despite its 20 g acceleration. This seat back motion didn't occur because of seat deformation. Before that could happen, there was slipping of the seat back reclining mechanism. In either case, it seemed to mitigate the neck extension.

In fact, there was nearly as much extension in test 9728-3 at an impact speed of only 1.1 m/sec.

DISCUSSION

One interesting feature of this study was that it gave an opportunity to examine the affect of override and underide on vehicle impact response at generally low but also moderate striking speeds. It was felt that because most of the impact force during these tests would be imparted to areas of the vehicle above or below the bumper and primary structure, the damage threshold, or minimum impact speed to cause damage, would decrease. However, this did not really seem to be the case. It was also felt that, especially in the higher speed tests where more damage was expected, that the involvement of softer vehicle structures would result in reduced impact forces and accelerations.

Unfortunately, there is not much data to verify this. However NHTSA has done at least one test that compares with the 5.6 m/sec truck to Toyota Camry test. This was a test in which a 1983 Ford Thunderbird was rolled backward into a rigid barrier at 4.75 m/sec. Obviously, in such a test the force

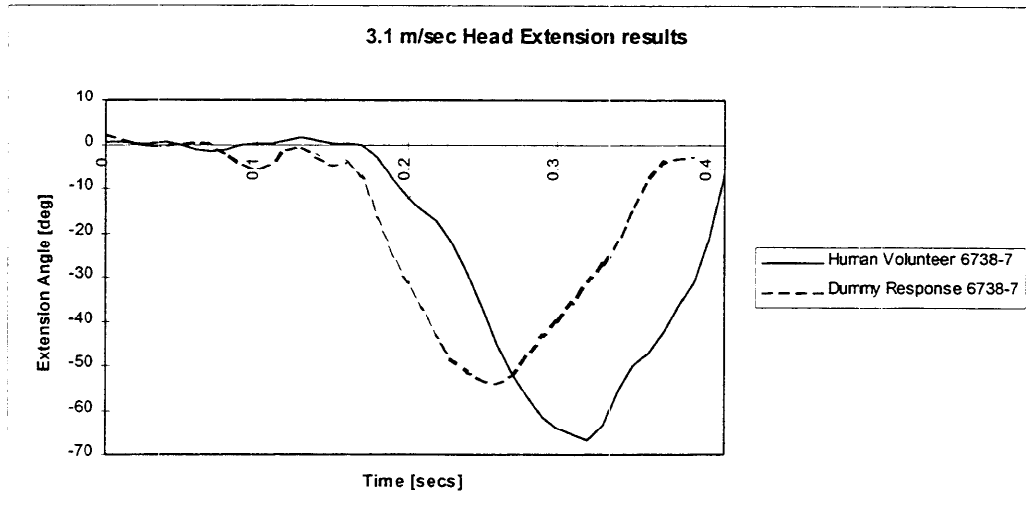


Figure 24—Head Rotation in Test 6738-7

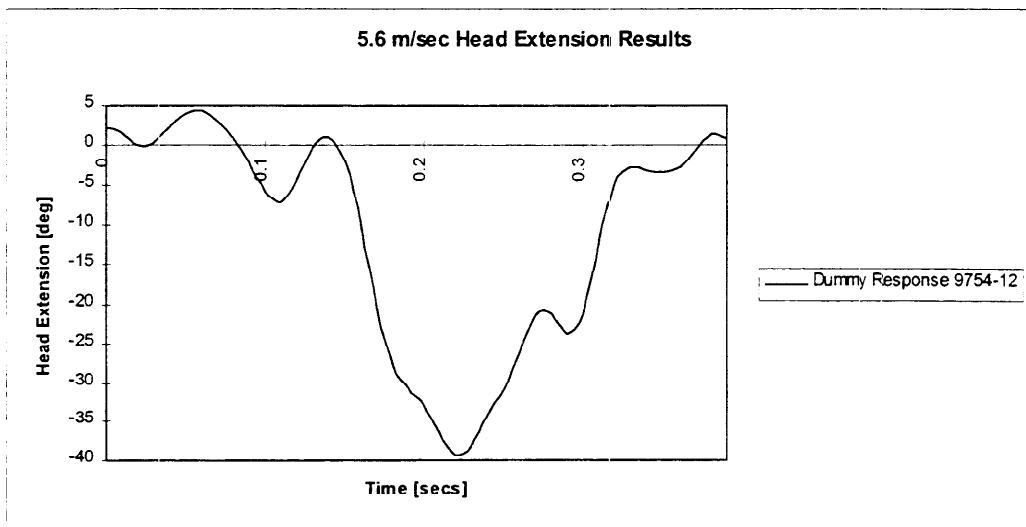


Figure 25—Head Rotation in Test 9754-12

of impact is directed to the vehicle through the bumper system. The result of this test was an average of 7.6 cm crush and a peak acceleration of 9.5 g's. To contrast, although the Camry suffered significantly greater average and maximum crush, and its speed change of 5.4 m/sec was greater than that of the Thunderbird, its maximum acceleration was only 7 g's. Thus, although the damage looked worse (see Figure 26), the forces that an occupant would experience would be smaller.

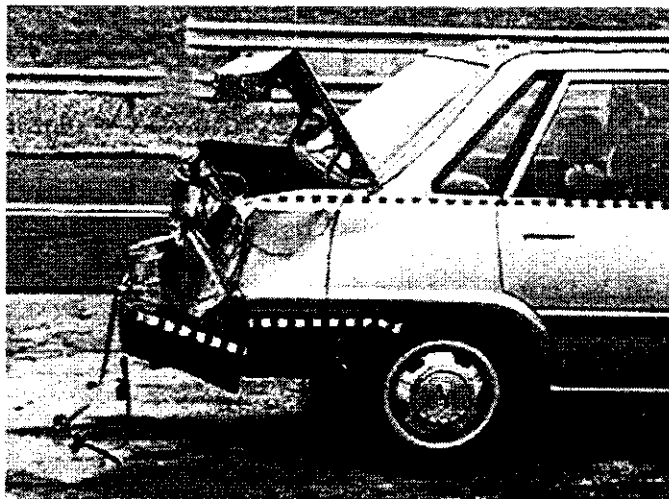


Figure 26—Test 9754-12 Post-impact Damage

If the parameters of choice to evaluate the potential for neck injury in low speed rear impacts are the maximum head acceleration and rotation, the results of these tests suggest that for ΔV 's below 2.25-2.7 m/sec. the output from using either a human volunteer or a dummy are reliable tools. If it is required that the performance of a vehicle be evaluated over the range of possible impact scenarios that could produce such a speed change, a single impact test may not be sufficient, since the occurrence of override or underride could significantly effect vehicle impact response.

If the parameters to be used to evaluate the potential for neck injury in these impacts are the forces and moments that are imparted to the neck, they can only be directly measured by a dummy with a neck load cell. However, as Figures 27-30 show, at the speeds these tests were conducted, there appears to be a consistent relationship between the head acceleration and neck force, and the head rotation and neck moment.

With this result, and the knowledge that at least for similar impact scenarios dummy and human responses were similar in these tests, a prediction of the neck loads can be made from volunteer head accelerations and rotations.

CONCLUSIONS

This study examined the results of a variety of low speed impact scenarios involving both dummies and human volunteers. The results suggest that at speeds similar to those examined in this case both dummies and human volunteers can be used in similar impact conditions to predict the potential for neck injury.

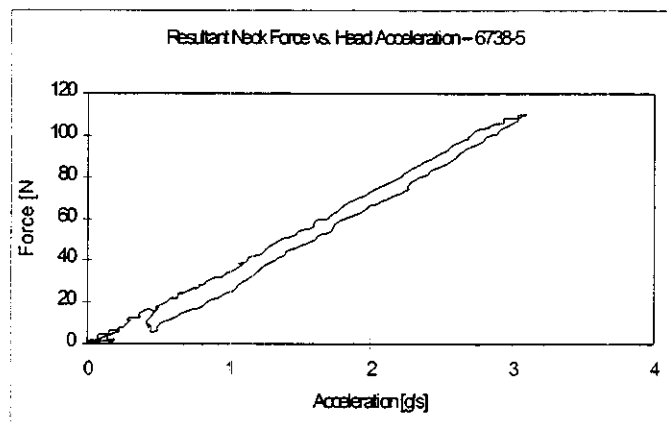


Figure 27—Force vs. Acceleration for Test 6738-5

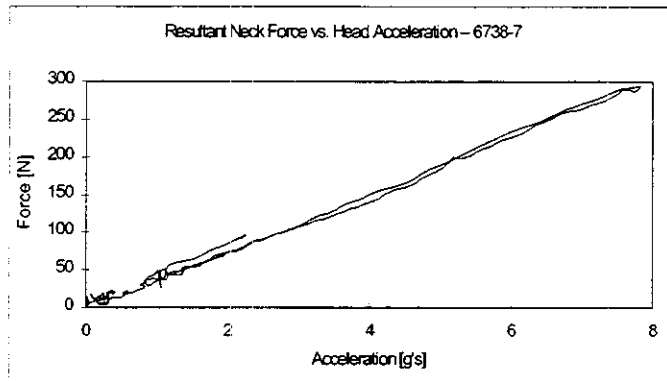


Figure 28—Force vs. Acceleration for Test 6738-7

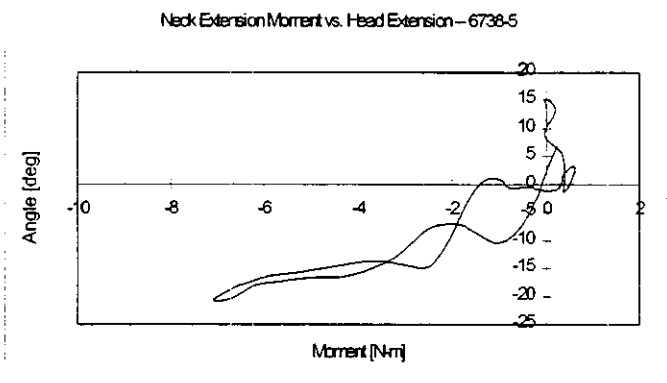
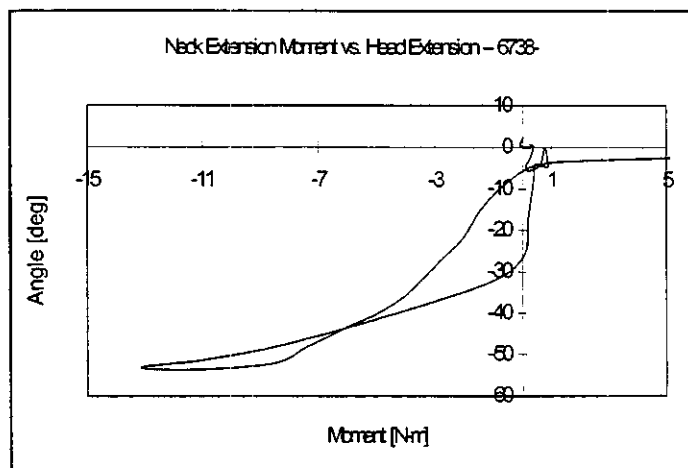


Figure 29—Moment vs. Rotation for Test 6738-5



26 Figure 30—Moment vs. Rotation for Test 6738-7

In the tests that were conducted in this study, the levels of force measured would not be predictive of injury of any kind compared to any current injury criteria. This generally agrees with the comments of the volunteers in this study. Only at the highest levels of impact was any mention made of an uncomfortable feeling or of tightness of the neck muscles, and this resolved itself within a day. It was only noted by the female subject after the 2.25 m/sec impact.

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