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WorldSID 50th Percentile Male Durability Assessment

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16. Abstract
The purpose of this report is to document the durability assessment of the WorldSID 50th Percentile Adult Male dummy when exposed to severe test conditions. In this assessment, the dummy was subjected to component qualification tests conducted at elevated energy levels. Prior to and following completion of the elevated energy tests, the dummy was exposed to baseline energy levels to help assess any possible changes in the dummy's responses due to the elevated energy tests. Additionally, the components of the dummy were closely inspected after each test to determine if any damage occurred. This assessment demonstrated that the dummy exhibits good durability.

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Table of Contents

List of Figures

1 Background

In the late 1990s the International Organization for Standardization (ISO) initiated a proposal to standardize throughout the world the side impact crash test dummies used for research, development, and regulation. The goal of the proposal was to develop a dummy with improved biofidelic response over existing side impact dummies while eliminating the need for different dummies in different areas of the world. The new dummy, representing the 50th percentile adult male, would come to be known as the Worldwide Harmonized Side Impact (WorldSID-50th) dummy.

For many years the National Highway Traffic Safety Administration has contributed to the evaluation and development of the WorldSID-50th dummy. One key component of the evaluation is an assessment of the dummy's durability when exposed to severe test conditions. Performing the qualification tests at elevated energy levels is one method for assessing the dummy's durability.

2 Objectives

To assess the durability of the WorldSID-50th dummy, the standard qualification tests - head drop tests, neck pendulum tests, and full body impact tests - were conducted at increased energy levels. The increased energy levels were achieved by performing the qualification tests at higher impact velocities or higher drop heights.

The durability tests were performed at energy increases of approximately 10 percent, 20 percent and 30 percent above the normal levels specified in the *WorldSID-50th Percentile Male Qualification Procedures Manual* (NHTSA, in process). Prior to and following completion of the elevated severity tests, tests were conducted at the baseline energy level as specified in the qualification procedures manual.

3 Test Methods

The durability baseline tests were performed according to the test procedures described in the *WorldSID-50th Percentile Male Qualification Procedures Manual* (subsequently referred to as the Qualification Procedures Manual). Following the baseline tests, the test velocity or drop height was incrementally increased to achieve the +10 percent, +20 percent, and +30 percent energy levels prior to performing a final baseline test. All impacts were imparted to the left side of the dummy (when applicable). For all of the abdomen, thorax (with- and without-arm), and shoulder impacts, the dummy was instrumented with the RibEye optical measurement system to measure displacement of the respective ribs.

Durability testing was conducted in two phases. Phase 1 of the testing occurred in 2016 and the dummy was configured with the RibEye system, body suit with half-arm sleeves, one-piece thorax pad, and the original shoulder pad design. Lessons learned during Phase 1 testing, as well as other observations, led to several design improvements which were incorporated into the dummy configuration for Phase 2 testing, which took place in 2019. The design improvements used in Phase 2 testing included the sleeveless body suit, the split thorax pad and the revised shoulder pad design. Additionally, a neck torsion qualification test was developed after Phase 1 testing was complete. Therefore, Phase 2 included elevated severity neck torsion testing.

Baseline tests conducted in Phase 1 of the evaluation were compared to the specification response corridors available in 2016. Since that time, additional repeatability and reproducibility (R&R) testing has been completed and some of the response corridors have been adjusted slightly for the Phase 2 analysis.

This report is organized according to the chronological order in which the tests were conducted; high-energy pelvis impacts were conducted first, followed by the thorax without arm impacts, etc. To better assess the dummy's durability, components were not replaced after the assessment was initiated, even if minor damage was observed.

4 Phase 1 Testing

4.1 Pelvis Impacts

4.1.1 Methodology

Pelvis qualification is accomplished with a lateral 6.7 m/s impact to the dummy's pelvis at its H-point using the Hybrid III 50th Male impact probe (23.4 kg, 152.4mm face diameter). Other test procedure details can be found in the Qualification Procedures Manual, currently in preparation.

Table 4.1 summarizes the impact velocities used for the pelvis impact durability testing.

Table 4.1. Pelvis Impact Test Conditions

Test No.	Impact Energy	Test Velocity (m/s)
Specification	Baseline	6.6-6.8
160516-12	Baseline	6.72
160518-18	+10%	7.05
160519-8	+20%	7.36
160519-11	+30%	7.65
160523-2	Baseline	6.71

4.1.2 Results

The 2016 qualification response corridors and durability test results for the pelvis impact tests are summarized in Table 4.2. Time-history plots of the criterion channels can be found in Appendix A.

Table 4.2. Pelvis Impact Durability Test Results

Test No.	Impact Energy	Pelvis Y Accel (G)	T12 Y Accel(G)	Pendulum Force (kN)	Pubic Force (kN)	Sacroiliac Y-Force (kN)
2016 Spec	Baseline	37-47	10-14	6.8-8.2	1.3-1.5	1.9-2.2
160516-12	Baseline	38.9	13.3	7.7	1.4	2.1
160518-18	+10%	42.1	13.5	8.2	1.5	2.2
160519-8	+20%	44.8	13.9	8.7	1.5	2.3
160519-11	+30%	47.0	14.2	9.1	1.6	2.4
160523-2	Baseline	40.3	13.6	7.7	1.4	2.1

4.1.3 Discussion

Responses for the baseline tests conducted before and after the elevated energy impacts were within the 2016 specification requirements. Pre- and post-test inspections revealed no apparent damage to the pelvis assembly.

4.2 Abdomen Impacts

4.2.1 Methodology

Qualification for the abdomen is accomplished with a lateral impact to the abdomen at 4.3 m/s using the Hybrid III 50th Male test probe (23.4 kg, 152.4mm face diameter) fitted with a rigid block to simulate an armrest (specifications and dimensions for the block can be found in the Qualification Procedures Manual). Other test procedure details can be found in the Qualification Procedures Manual.

Table 4.3 summarizes the impact velocities used for the abdomen impact durability testing.

Table 4.3. Abdomen Impact Test Conditions

Test No.	Impact Energy	Test Velocity (m/s)
Specification	Baseline	4.2-4.4
160513-9	Baseline	4.35
160523-4	+10%	4.50
160523-6	+20%	4.71
160523-8	+30%	4.90
160524-3	Baseline	4.30

4.2.2 Results

The qualification response corridors and durability test results for the abdomen impact tests are summarized in Table 4.4. Abdomen Impact Durability Test Results. Time-history plots of the criterion channels can be found in Appendix B.

Table 4.4. Abdomen Impact Durability Test Results

Test No.	Impact Energy	Pendulum Force (kN)	T12 Y Accel(G)	Rib Deflection Middle LED (mm)	
				Abd. Rib 1	Abd. Rib 2
2016 Spec	Baseline	2.7-3.1	15-20	33-40	30-37
160513-9	Baseline	2.9	14.7	38.9	38.0
160523-4	+10%	3.0	15.7	39.9	38.2
160523-6	+20%	3.1	15.9	42.2	41.3
160523-8	+30%	3.2	16.4	44.5	43.4
160524-3	Baseline	2.9	15.6	37.3	35.6

Red cells indicate responses that did not meet the 2016 specification corridors.

4.2.3 Discussion

The baseline test conducted prior to the elevated severity tests did not meet the specification corridors for abdomen rib 2 displacement and T12 lateral acceleration; however, it did meet the corridors in the baseline test conducted after the elevated severity impacts. It should also be noted that the revised response corridors determined in 2021 for abdomen rib 2 displacements are 32-38 mm and for T12 y-accelerations are 14.5-19.5 g. Thus, the initial baseline test would be deemed acceptable according to the new corridors. The new corridors for all of the qualification tests can be found in the report *Evaluation of the WorldSID 50th Percentile Male Side Impact Dummy – Qualification and Sled Test Repeatability and Reproducibility* (NHTSA, in press).

There was no damage observed to the abdominal or thoracic ribs throughout the entire test series. However, there was a tear in the thorax pad (W50-35024) as shown in Figure 4.1. Tears in the thorax pad have been reported by several labs and as a result the pad was subsequently redesigned into what is known as the split thorax pad. The split thorax pad design uses individual pads for each rib, eliminating the segments of the pad between the individual ribs. The split thorax pad configuration was tested later in Phase 2 of this evaluation.

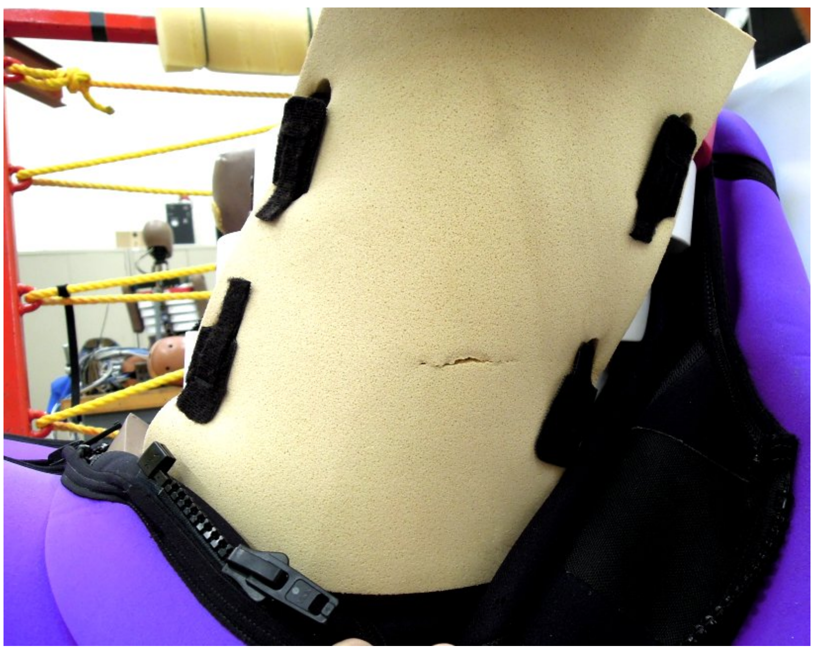

Figure 4.1. A Tear Observed in the Original One-Piece Thorax Pad

4.3 Thorax Without Arm Impacts

4.3.1 Methodology

Qualification for the thorax without arm is achieved with a lateral impact directly to the thorax at 4.3 m/s with the Hybrid III 50th Male test probe (23.4 kg, 152.4mm face diameter). The probe centerline is aligned along the centerline of the middle thorax rib. Other test procedure details can be found in the Qualification Procedures Manual.

Table 4.5 summarizes the impact velocities used for the thorax without arm impact durability testing.

Table 4.5. Thorax Without Arm Impact Test Conditions

Test No.	Impact Energy	Test Velocity (m/s)
Specification	Baseline	4.2-4.4
160513-4	Baseline	4.35
160524-6	+10%	4.50
160525-1	+20%	4.70
160525-2	+30%	4.91
160525-3	Baseline	4.29

4.3.2 Results

The qualification response corridors and durability test results for the thorax without arm impact tests are summarized in Table 4.6. Time-history plots of the criterion channels can be found in Appendix C.

Table 4.6. Thorax Without Arm Impact Durability Test Results

Test No.	Increase in Impact Energy	Pendulum Force (kN)	T4 Y Accel (G)	T12 Y Accel(G)	Rib Deflection - Middle LED (mm)		
					Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
2016 Spec	Baseline	3.4-4.0	13-19	13-21	33-43	35-43	28-36
160513-4	Baseline	3.8	14.1	14.1	38.9	40.3	35.7
160524-6	10%	3.9	14.9	14.9	41.1	40.3	36.7
160525-1	20%	4.1	15.6	16.8	42.4	43.1	39.0
160525-2	30%	4.1	15.9	16.1	48.1	46.5	41.3
160525-3	Baseline	3.7	14.1	13.7	39.5	40.2	37.0
Red cells indicate responses that did not meet the 2016 specification corridors.							

4.3.3 Discussion

In the baseline test conducted before the elevated severity impacts, all responses were within the specifications. In the baseline test conducted after the elevated severity tests, all responses were within the specifications, except for thorax rib 3 deflection. Thorax rib 3 deflection was above the upper bound of the corridor. It should be noted that the revised response corridors determined in 2021 for thorax rib 3 displacements are 32 to 40 mm and thus the final baseline test would be deemed acceptable according to the new corridors.

Post-test inspections revealed minor delamination of thorax rib 1 as shown in Figure 4.2. While the amount of delamination observed was considered to be very minor, its presence was reported to the manufacturer, Humanetics Innovative Solutions, Inc. (HIS). After conducting a thorough analysis of the delaminated ribs and the manufacturing process used to produce the ribs, HIS identified and implemented improvements to the manufacturing process intended to enhance bonding strength between the damping material and steel rib band.

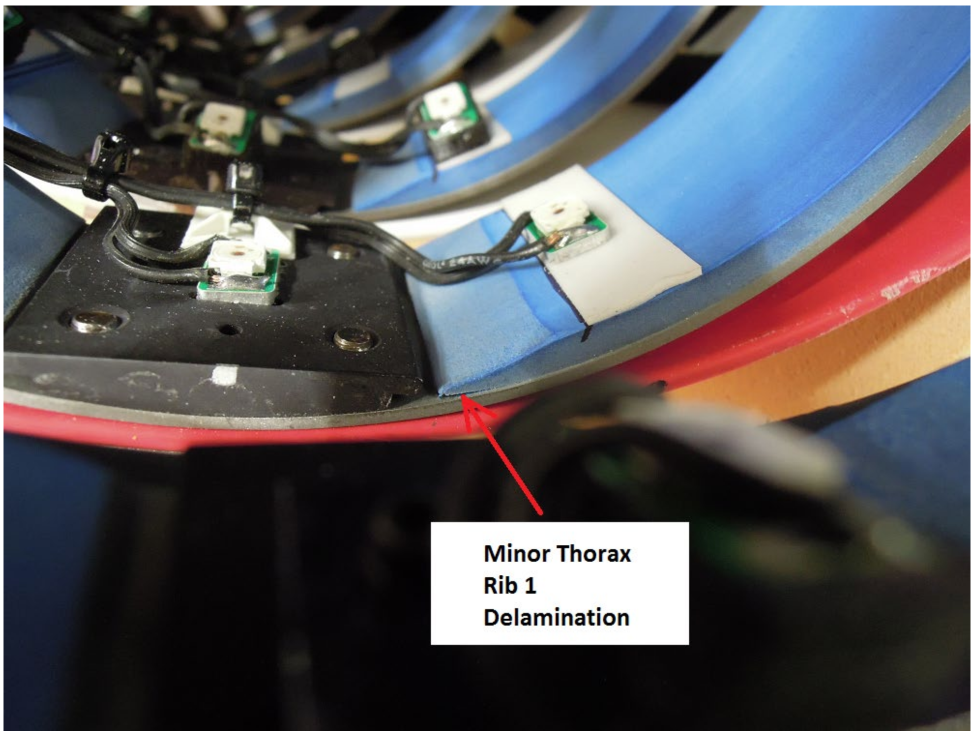

Figure 4.2. Minor Thorax Rib 1 Delamination

4.4 Thorax With Arm Impacts

4.4.1 Methodology

Qualification for the thorax with arm is achieved with a lateral impact at 6.7 m/s with the Hybrid III 50th Male test probe (23.4 kg, 152.4mm face diameter). The probe centerline is aligned along the centerline of the middle thorax rib. Other test procedure details can be found in the Qualification Procedures Manual.

Table 4.7 summarizes the impact velocities used for the thorax with arm impact durability testing.

Table 4.7. Thorax With Arm Impact Test Conditions

Test No.	Impact Energy	Test Velocity (m/s)
Specification	Baseline	6.6-6.8
160513-6	Baseline	6.67
160526-5	+10%	7.06
160526-6	+20%	7.36
160531-1	+30%	7.66
160531-3	Baseline	6.72

4.4.2 Results

The qualification response corridors and durability test results for the thorax with arm impact tests are summarized in Table 4.8. Time-history plots of the criterion channels can be found in Appendix D.

Table 4.8. Thorax With Arm Impact Durability Test Results

Test No.	Increase in Impact Energy	Pendulum Force (kN)	T4 Y Accel (G)	T12 Y Accel(G)	Rib Deflection - Middle LED (mm)		
					Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
2016 Spec	Baseline	4.9-5.8	28-37	20-26	35-47	39-49	33-41
160513-6	Baseline	5.5	30.4	22.0	41.0	48.8	41.8
160526-5	10%	5.9	32.7	22.5	44.0	48.4	41.7
160526-6	20%	5.9	33.3	23.0	47.7	50.6	44.2
160531-1	30%	6.2	35.3	24.6	47.4	50.2	44.8
160531-3	Baseline	5.7	31.7	21.6	38.9	41.6	38.6
Red cells indicate responses that did not meet 2016 specification corridors.							

4.4.3 Discussion

Inspections conducted after the +10 percent energy test revealed minor shoulder rib delamination as illustrated in Figure 4.3. As with the thorax rib delamination previously observed, the amount of delamination was barely discernable; it is only visible when the rib is flexed slightly. The delamination did not appear to worsen over the course of the testing.

Responses for all of the criteria were within the specifications for the baseline test conducted prior to the elevated severity impacts, except for rib 3 deflection. In the baseline test conducted after the elevated severity tests, all criteria were met.

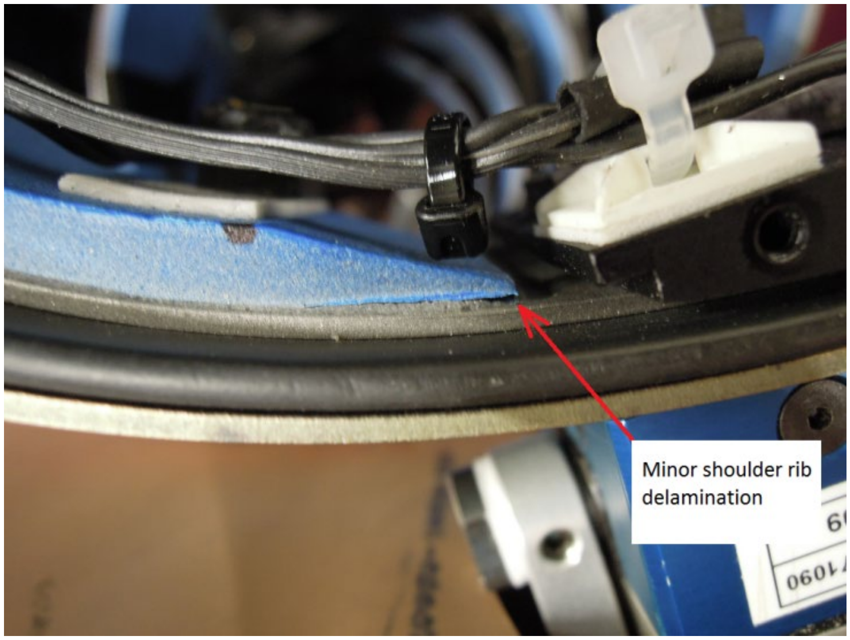

Figure 4.3. Shoulder Rib Delamination

4.5 Shoulder Impacts

4.5.1 Methodology

The shoulder qualification test consists of a lateral impact at 4.3 m/s to the shoulder with the Hybrid III 50th Male test probe (23.4 kg, 152.4mm face diameter). The probe centerline is aligned to impact directly along the centerline of the shoulder pivot joint. Other test procedure details can be found in the Qualification Procedures Manual.

Table 4.9 summarizes the impact velocities used for the shoulder impact durability testing.

Table 4.9. Shoulder Impact Test Condition

Test No.	Impact Energy	Test Velocity (m/s)
Specification	Baseline	4.2-4.4
160512-2	Baseline	4.34
160601-2	+10%	4.50
160601-7	+20%	4.70
160601-12	+30%	4.90
160601-13	Baseline	4.30

4.5.2 Results

The qualification response corridors and durability test results of the shoulder impact tests are summarized in Table 4.10. Time-history plots of the criterion channels can be found in Appendix E.

Table 4.10. Shoulder Impact Durability Test Results

Test No.	Impact Energy	Pendulum Force (kN)	Shoulder FY Load (N)	Shoulder Rib Length Change (mm)
Specification	Baseline	2.6-3.3	1500-1900	37-46
160512-2	Baseline	2.8	1687.9	40.5
160601-2	+10%	2.8	1781.8	43.5
160601-7	+20%	3.0	1808.8	45.8
160601-12	+30%	3.2	1847.9	48.6
160601-13	Baseline	2.6	1635.9	41.6

4.5.3 Discussion

All responses for the pre- and post-elevated energy tests were within the specification requirements. Post-test inspections revealed no additional damage.

4.6 Lateral Neck Flexion Tests

4.6.1 Methodology

Lateral neck flexion qualification is accomplished using the neck pendulum specified in 49 CFR Part 572 Subpart E. The neck is mounted to the WorldSID headform (W50-83000) and the assembly is instrumented with three rotary potentiometers, an angular rate sensor (ARS) and the upper neck load cell. The headform and neck assembly is connected to the neck pendulum and tested in the lateral flexion mode. Other test procedure details can be found in the Qualification Procedures Manual.

Table 4.11 summarizes the velocities used for the lateral neck flexion tests.

Table 4.11. Lateral Neck Flexion Test Conditions

Neck No./Test No.	Impact Energy	Velocity (m/s)
Specification	Baseline	3.3-3.5
DM8002/1	Baseline	3.41
DM8002/2	+10%	3.59
DM8002/3	+20%	3.73
DM8002/4	+30%	3.91
DM8002/5	Baseline	3.41

4.6.2 Results

The qualification response corridors and durability test results of the lateral neck pendulum tests are summarized in Table 4.12. Time-history plots of the criterion channels can be found in Appendix F.

Table 4.12. Lateral Neck Flexion Durability Test Results

Criteria	Impact Energy					
	2016 Spec	Baseline	+10%	+20%	+30%	Baseline
Max rotation (deg)	50-61	55.7	57.6	60.0	62.9	55.2
Rotation decay time to 0 degree (ms)	58-72	63.3	63.0	63.3	63.6	64.4
Max moment at OC (Nm)	55-68	64.8	67.2	68.8	70.5	63.9
Max moment decay time to 0 Nm (ms)	70-86	75.1	75.3	75.4	75.6	76.0
Max forward pot rotation (degree)[1]	32-39	35.4	36.7	38.3	40.1	35.1
Time of max forward pot rotation (ms)[1]	56-68	59.2	58.3	56.7	57.3	57.3
Max rearward pot rotation (degree)[1]	30-37	32.0	33.2	34.5	35.9	32.1
Time of max rearward pot rotation (ms)	56-68	56.5	58.8	55.4	58.6	57.7
Head X-axis angular rate (deg/s)	2162-2293	2321	2426	2526	2603	2324

Red cells indicate responses that did not meet the 2016 specification corridors.
[1] Criteria was included in 2016 specification but was later eliminated from requirements

4.6.3 Discussion

Pre- and post-elevated energy impacts each had one response that was outside of the specification requirements – X-axis angular rate. It should be noted that the 2016 specification corridors were relatively new at the time of Phase 1 testing and as such, the corridors were developed with small sample sizes of data. Both the pre- and post-elevated severity tests would conform to the new corridors, which were determined using considerably larger sample sizes. Pre- and post-test inspections revealed no obvious damage to the neck assembly.

4.7 Head Drop Tests

The head qualification procedure consists of a frontal drop from a height of 376 mm onto the dummy's forehead and a lateral drop from a height of 200 mm onto the sides of the dummy's head.

Table 4.13 summarizes the drop heights used for the head drop tests.

Table 4.13. Head Drop Test Conditions

Impact Energy	Frontal Head Drops		Lateral Head Drops	
	Test No.	Drop Height (mm)	Test No.	Drop Height (mm)
Baseline	121015-01	376	121515-01	200
+10%	121415-02	414	121515-02	220
+20%	121515-03	451	121615-03	240
+30%	121515-04	489	121615-04	260
Baseline	121515-05	376	121615-05	200

4.7.1 Results

The qualification response corridors and durability test results are summarized in Table 4.14. Time-history plots of the criterion channels can be found in Appendices G and H.

Table 4.14. Head Drop Durability Test Results

Impact Energy	Frontal Tests			Lateral Tests		
	Test No.	Peak Resultant Accel at CG (G)	Peak Lateral Accel (G)	Test No.	Peak Resultant Accel at CG (G)	Peak Fore-Aft Accel (G)
Baseline	2016 Spec	205-255	<15	2016 Spec	104-123	<15
Baseline	121015-01	241.2	4.4	121515-01	120.6	4.2
+10%	121415-02	257.2	9.3	121515-02	131.6	4.3
+20%	121515-03	274.5	8.6	121615-03	143.3	5.3
+30%	121515-04	294.6	-5.3	121615-04	153.2	2.4
Baseline	121515-05	236.9	1.6	121615-05	119.7	3.4

4.7.2 Discussion

Responses for all pre- and post-elevated energy impacts were within the specification requirements. Pre- and post-test inspections revealed no obvious damage to the head assembly.

4.8 Summary of Phase 1 Observations

Over the course of the elevated severity tests discussed above, the following durability observations were noted. Following the abdomen impact tests, the thorax pad exhibited tears in the region between thorax rib 3 and abdomen rib 1. Subsequently, a design revision which splits the thorax pad into multiple pads, one for each rib, has been developed and implemented. The split pad configuration is evaluated in Phase 2 of this report.

Minor delamination of the rib damping material was observed after the thorax without arm and the thorax with arm tests in thorax rib 1 and the shoulder rib, respectively. After inspection and analysis of the delaminated ribs, HIS implemented manufacturing process revisions to improve the bonding of damping material to the ribs. Updated ribs were included in the Phase 2 evaluation.

5 Phase 2 Testing

Lessons learned during Phase 1 testing, as well as observations from other test conditions (e.g. crash tests) led to several design improvements which were incorporated into the dummy configuration for Phase 2 testing. The design improvements used in Phase 2 testing included the sleeveless body suit, the split thorax pad and the revised shoulder pad design. Additionally, a neck torsion qualification test was developed after Phase 1 testing was complete. Therefore, Phase 2 included elevated severity neck torsion testing.

For the full-body impacts, test procedures and impact speeds used in the Phase 2 testing are identical to that described in Phase 1. For brevity's sake, the test methodology sections have not been repeated in this section of the report. However, test methodology is provided for the neck torsion test since it is a new test procedure. Additionally, in the period between Phase 1 and 2 testing, specification response corridors were updated to reflect larger sample size of more current dummies. The newer corridors are included in the results tables in this section.

5.1 WorldSID 50th Male Design Revisions

5.1.1 Sleeveless Suit

The original skinsuit included sleeves for the arms and contained a sizeable whole under the arm to facilitate arm motion (Figure 5.1). In this configuration, the sleeve fabric could bunch together during shoulder flexion and the hole provided a path for external light to enter the thoracic cavity, potentially interfering with the RibEye functionality. Therefore, a sleeveless skinsuit design was adopted (Figure 5.2). The sleeveless suit provides improved freedom of arm motion without bunching and eliminates the potential light path under the arm.

Figure 5.1. Suit With Sleeves

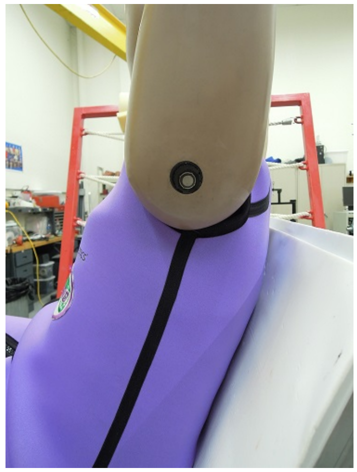

Figure 5.2. Sleeveless Suit

5.1.2 Split Thorax Pad

As discussed in Section 4.2, tears were observed in the one-piece thorax pad during the Phase 1 abdomen impacts. As a result of these observations, as well as similar observations made across the safety community, a split-pad system was implemented. The split-pad system eliminates foam padding in the areas between the ribs and also eliminates holes needed to secure the one-piece pad to the ribs. Figure 5.3 illustrates the split thorax pad system.

Figure 5.3. Split Thorax Pad System

5.1.3 Shoulder Pad Revision

In sled tests conducted to support NHTSA's WorldSID research, post-test dummy inspections revealed that the dummy's shoulder pad had become lodged into the shoulder rib cavity, effectively blocking the RibEye's shoulder-mounted sensors (Figure 5.4). This observation led to the development of a new shoulder pad configuration designed to minimize the likelihood of the pads blocking the RibEye sensors (Figure 5.5). The new shoulder pads feature internal stiffening elements designed to resist vertical forces. Additionally, the right- and left-side shoulder pads are connected via a Delrin segment that provides additional resistance to forces that could push the pad into the shoulder rib cavity.

Figure 5.4. Original Shoulder Pad Lodged Into Shoulder Rib Cavity

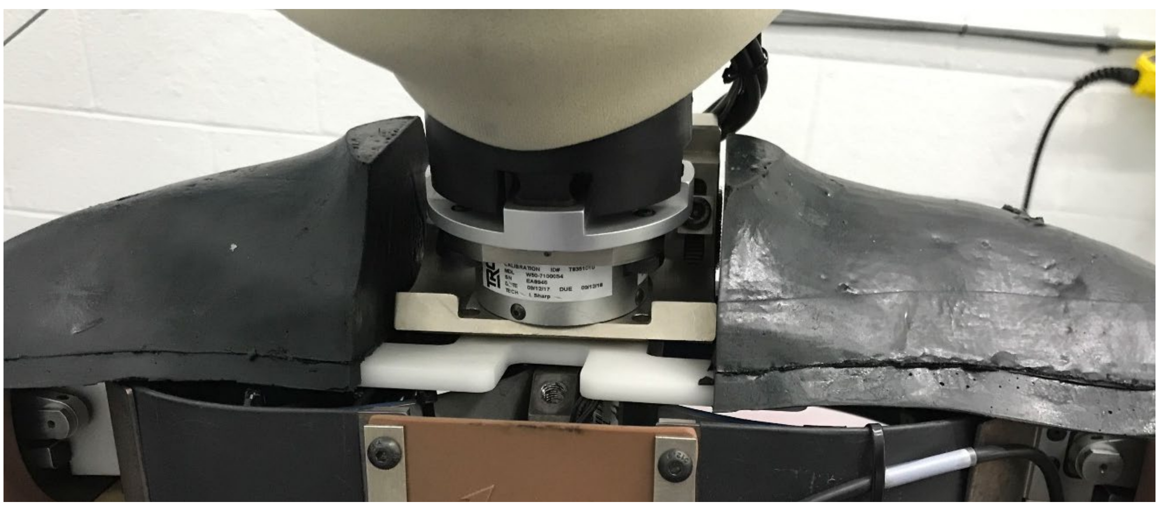

Figure 5.5. Revised Shoulder Pad Assembly

5.2 Shoulder Impact

5.2.1 Results

The qualification response corridors and durability test results of the shoulder impact tests are summarized in Table 5.1. Time-history plots of the criterion channels can be found in Appendix I.

Table 5.1. Phase 2 – Shoulder Impact Test Results

Test No.	Impact Energy	Pendulum Force (kN)	Shoulder FY Load (N)	Shoulder Rib Length Change (mm)
’21 Spec	Spec.	2.6-3.3	1.47-1.80	37-46
190606-3	Baseline	2.89	1.67	37.7
190606-6	+10%	3.07	1.67	39.2
190606-7	+20%	3.22	1.74	40.6
190606-9	+30%	3.43	1.80	44.8
190606-11	Baseline	2.95	1.63	39.3

5.2.2 Discussion

All responses for the pre- and post-elevated energy tests were all within the specification requirements. Post-test inspections revealed no additional damage.

5.3 Thorax With Arm Impacts

5.3.1 Results

The qualification response corridors and durability test results of the thorax with arm impact tests are summarized in Table 5.2. Time-history plots of the criterion channels can be found in Appendix J.

Table 5.2. Phase 2 – Thorax With Arm Impact Test Results

Test No.	Increase in Impact Energy	Pendulum Force (kN)	T4 Y Accel (G)	T12 Y Accel(G)	Rib Deflection - Middle LED (mm)		
					Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
’21 Spec	Baseline	5.3-6.2	28-37	22-28	35-47	46-56	33.5-40.5
190626-10	Baseline	5.71	35.2	24.7	42.3	49.8	35.3
190626-11	10%	5.89	36.7	27.3	46.7	52.2	36.9
190627-2	20%	6.15	39.2	28.1	47.4	53.4	37.7
190627-4	30%	6.33	39.5	28.8	49.7	56.8	41.0
190627-5	Baseline	5.53	34.7	24.7	44.4	49.9	35.1

5.3.2 Discussion

All responses for the pre- and post-elevated energy tests were all within the specification requirements. Post-test inspections revealed no additional damage.

5.4 Thorax Without Arm Impacts

5.4.1 Results

The qualification response corridors and durability test results of the thorax with arm impact tests are summarized in Table 5.3. Time-history plots of the criterion channels can be found in Appendix K.

Table 5.3. Phase 2 - Thorax Without Arm Impact Test Results

Test No.	Increase in Impact Energy	Pendulum Force (kN)	T4 Y Accel (G)	T12 Y Accel(G)	Rib Deflection - Middle LED (mm)		
					Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
'21 Spec	Baseline	3.2-3.8	14-20	14-22	33-43	35-43	32-40
190625-3	Baseline	3.53	16.4	16.8	39.5	40.9	34.2
190626-1	10%	3.63	17.7	18.1	43.1	44.4	36.6
190626-2	20%	3.75	18.4	20.2	44.5	46.9	38.8
190626-5	30%	3.88	19.5	19.9	48.0	49.5	40.7
190626-7	Baseline	3.50	17.0	16.8	41.2	42.5	34.5

5.4.2 Discussion

All responses for the pre- and post-elevated energy tests were all within the specification requirements. Post-test inspections revealed no additional damage.

5.5 Abdomen Impacts

5.5.1 Results

The qualification response corridors and durability test results of the thorax with arm impact tests are summarized in Table 5.4. Time-history plots of the criterion channels can be found in Appendix L.

Table 5.4. Phase 2 – Abdomen Impact Test Results

Test No.	Impact Energy	Pendulum Force (kN)	T12 Y Accel(G)	Rib Deflection Middle LED (mm)	
				Abd. Rib 1	Abd. Rib 2
'21 Spec	Baseline	2.7-3.1	14.5-19.5	32.5-39.5	32-38
190627-7	Baseline	2.91	16.3	35.0	36.0
190701-1	+10%	3.02	17.3	36.3	37.3
190701-2	+20%	3.15	18.1	38.6	39.7
190701-6	+30%	3.38	18.5	40.9	42.2
190701-12	Baseline	2.89	16.6	34.9	36.1

5.5.2 Discussion

All responses for the pre- and post-elevated energy tests were all within the specification requirements. Post-test inspections revealed no additional damage.

5.6 Neck Torsion Tests

5.6.1 Methodology

Neck torsion qualification is accomplished using the neck pendulum specified in 49 CFR Part 572 Subpart E. The neck is mounted to the WorldSID-50M neck torsion fixture (DL210-400) and the assembly is instrumented with a rotary potentiometer, an angular rate sensor (ARS) and the lower neck load cell. The neck torsion fixture is mounted to the neck pendulum and tested in a manner that generates neck torsion. Other test procedure details can be found in the Qualification Procedures Manual.

Table 5.5 summarizes the velocities used for the neck torsion tests.

Table 5.5. Phase 2 - Neck Torsion Test Conditions

Neck No./Test No.	Impact Energy	Velocity (m/s)
Specification	Baseline	5.1-5.3
191002-5	Baseline	5.18
191002-6	+10%	5.48
191002-7	+20%	5.71
191002-8	+30%	5.95
191002-9	Baseline	5.18

5.6.2 Results

The qualification response corridors and durability test results of the neck torsion tests are summarized in Table 5.6. Time-history plots of the criterion channels can be found in Appendix M.

Table 5.6. Phase 2 - Neck Torsion Test Results

Test No.	Impact Energy	Peak Z-Moment (Nm)	Rotation (deg)	Angular Decay Time to 0o (msec)	Peak Head Angular Rate (deg/sec)
’21 Spec	Baseline	34-42	41.5-51.0	35-43	1345-1655
191002-5	Baseline	38.5	46.2	38.9	1531.9
191002-6	+10%	40.2	48.2	38.9	1615.4
191002-7	+20%	41.7	50.0	38.6	1615.3
191002-8	+30%	43.1	52.0	38.7	1675.4
191002-9	Baseline	38.5	46.8	39.2	1545.8

5.6.3 Discussion

All responses for the pre- and post-elevated energy tests were all within the specification requirements. Post-test inspections revealed no additional damage.

5.7 Summary of Phase 2 Observations

The revisions implemented to the WorldSID-50M proved to be durable and functioned as expected. There were no post-test observations of damage to any of the revised components.

6 Summary

Overall, the WorldSID-50th male dummy exhibited good durability in the elevated severity qualification tests. Furthermore, the RibEye system performed as expected, with no loss of data from the primary sensors, nor was any physical damage sustained. For the majority of test modes, the baseline tests were within the specification corridors. In the Phase 1 baseline tests that did not meet the requirements, the results were either reasonably close to the corridors, or would have met the 2021 revised response corridors.

As a result of Phase 1 tests and observations, several design revisions were implemented. The sleeveless suit, revised shoulder pad, and split thorax pad all proved to be durable and functioned as intended. With regard to rib delamination that was observed, process improvements have been identified and implemented at the dummy manufacturer to address rib damping material delamination and Phase 2 testing with updated ribs did not generate any observed rib delamination.

7 References

As this report is being published, two associated reports are still being prepared by the Vehicle Research and Test Center, with publication in 2022. These are the tentative titles of those two reports.

WorldSID-50th Percentile Male Qualification Procedures Manual

Evaluation of the WorldSID 50th Percentile Male Side Impact Dummy – Qualification and Sled Test Repeatability and Reproducibility

Appendix A: Phase 1 - Pelvis Impacts

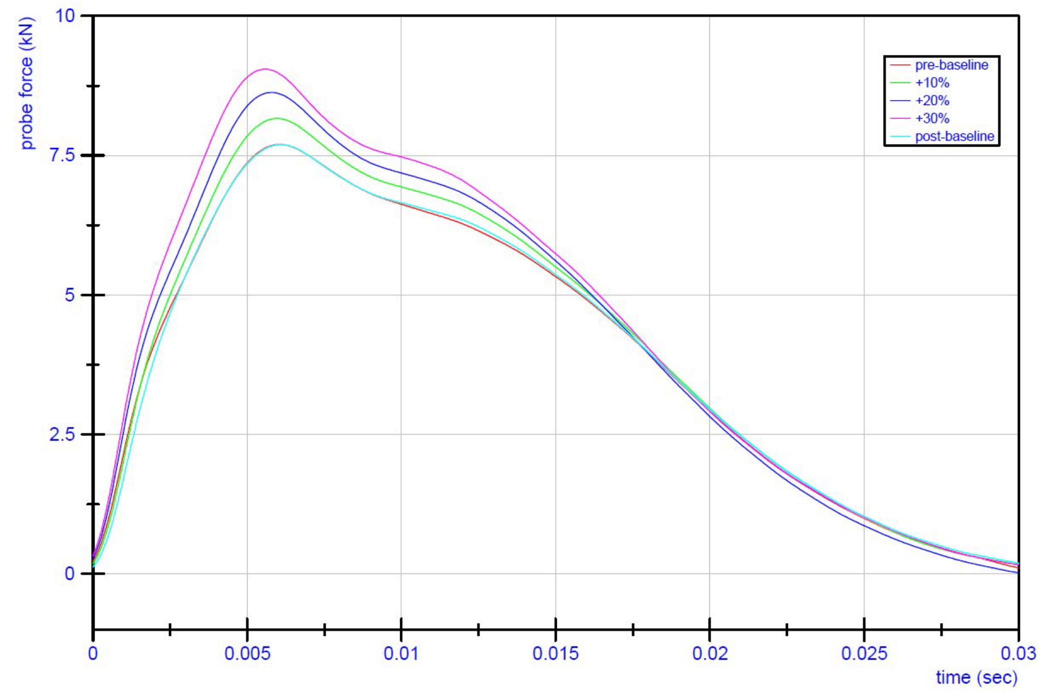

Figure A-1. Pelvis Impact - Probe Force

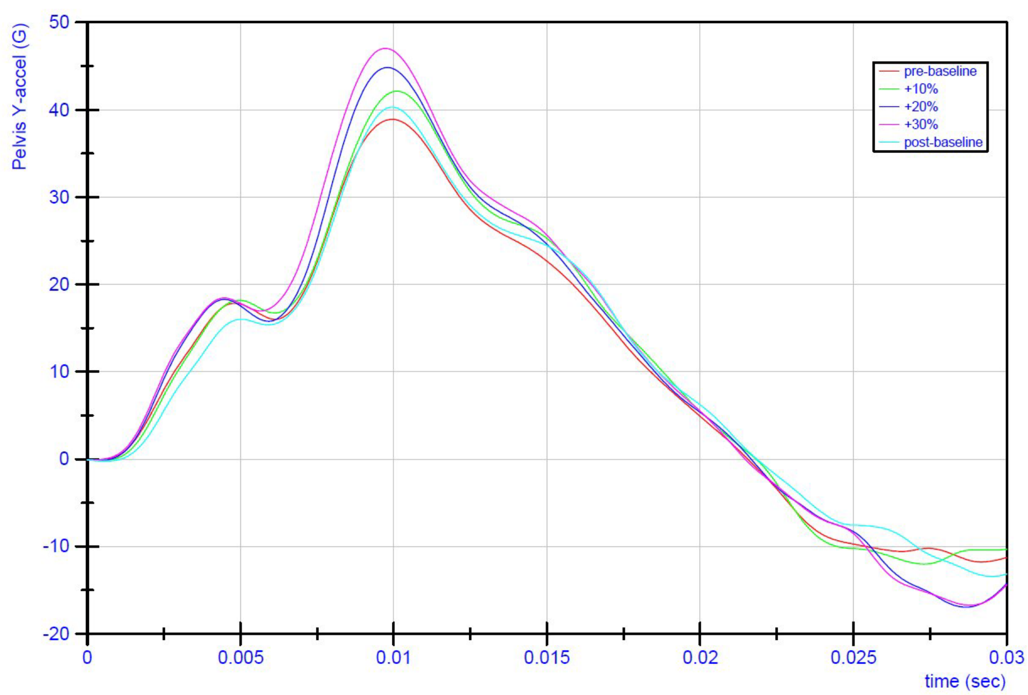

Figure A-2. Pelvis Impact - Lateral Pelvis Acceleration

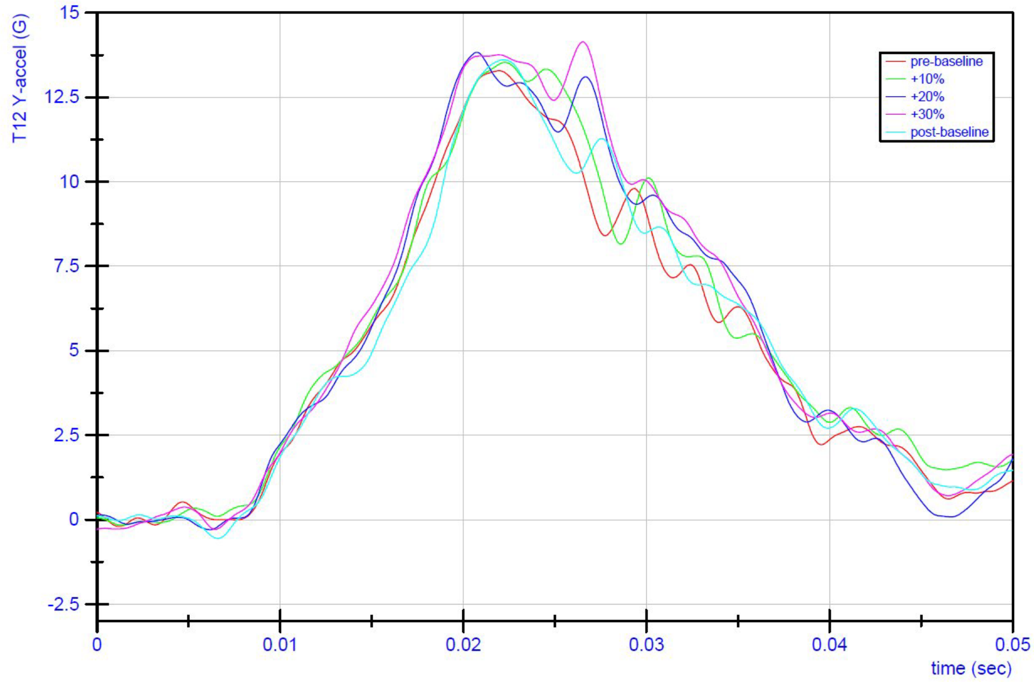

Figure A-3. Pelvis Impact - T12 Lateral Acceleration

Appendix B: Phase 1 – Abdomen Impacts

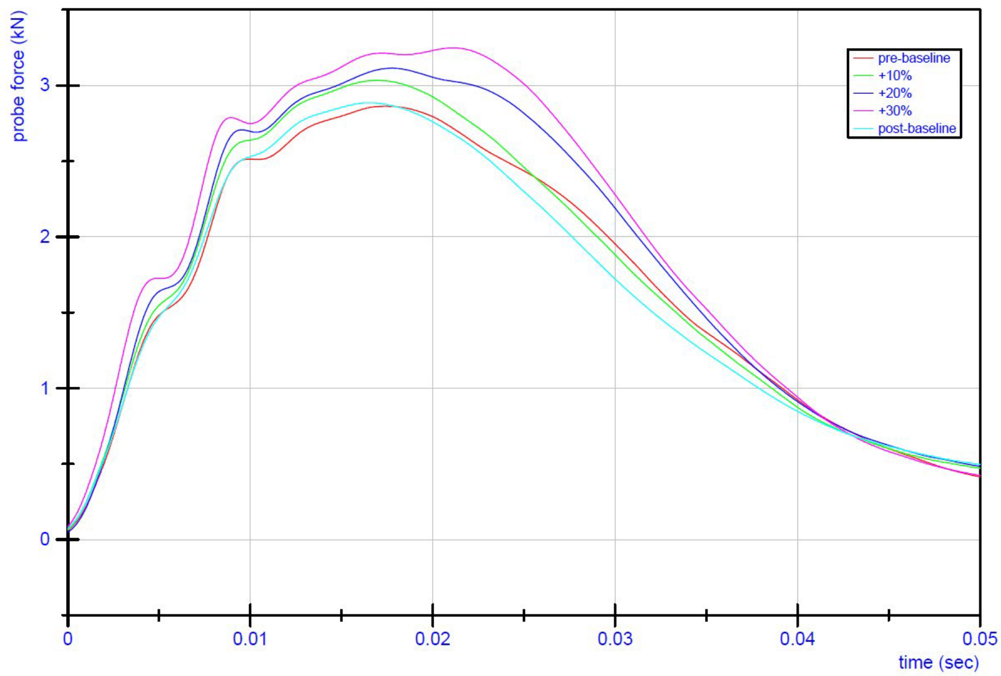

Figure B-1. Abdomen Impact - Probe Force

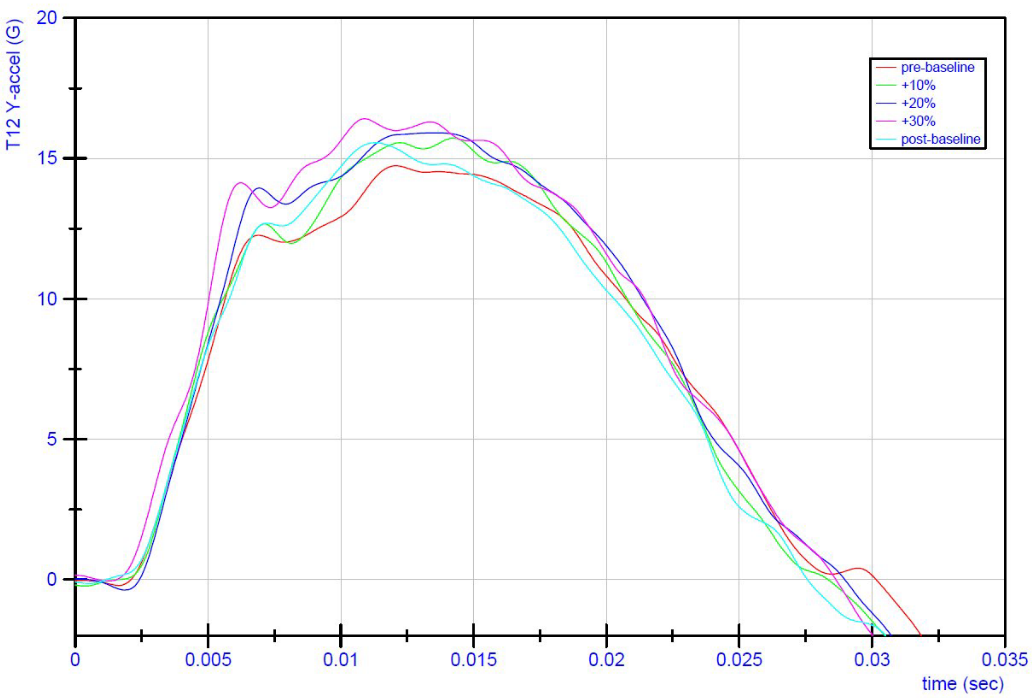

Figure B-2. Abdomen Impact - T12 Lateral Acceleration

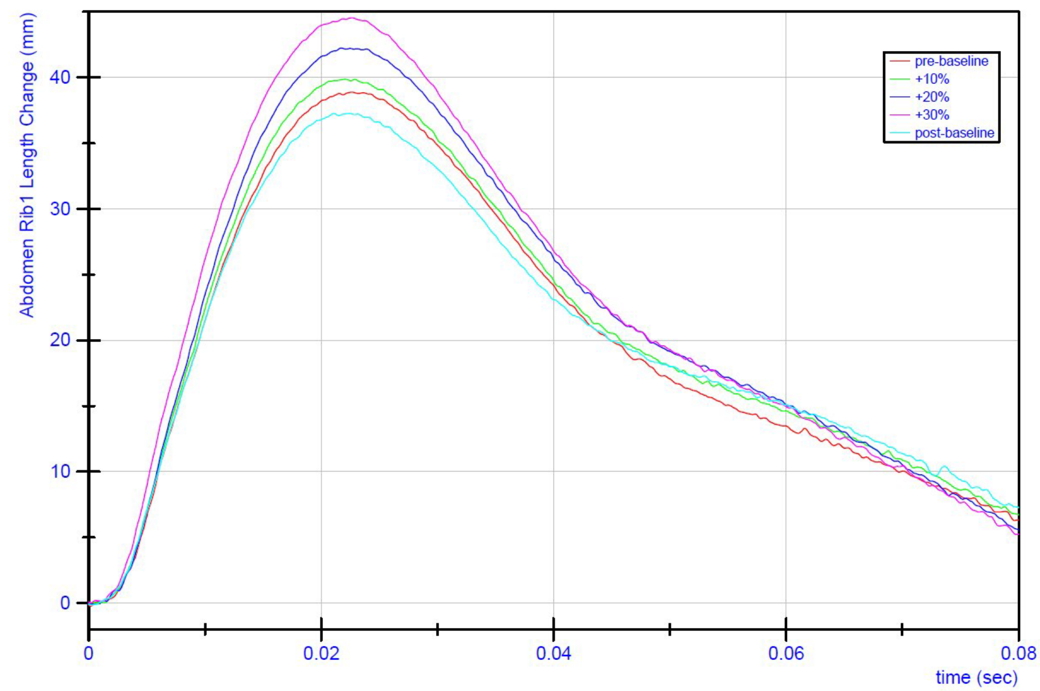

Figure B-3. Abdomen Impact - Abdomen Rib 1 Length Change

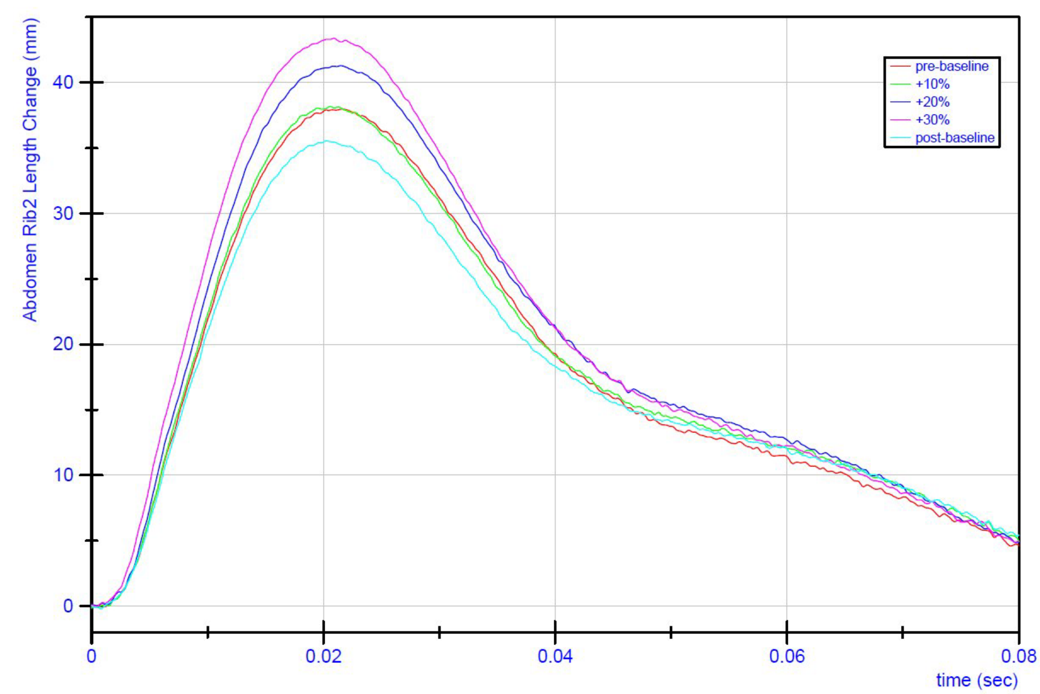

Figure B-4. Abdomen Impact - Abdomen Rib 2 Length Change

Appendix C: Phase 1 – Thorax Without Arm Impacts

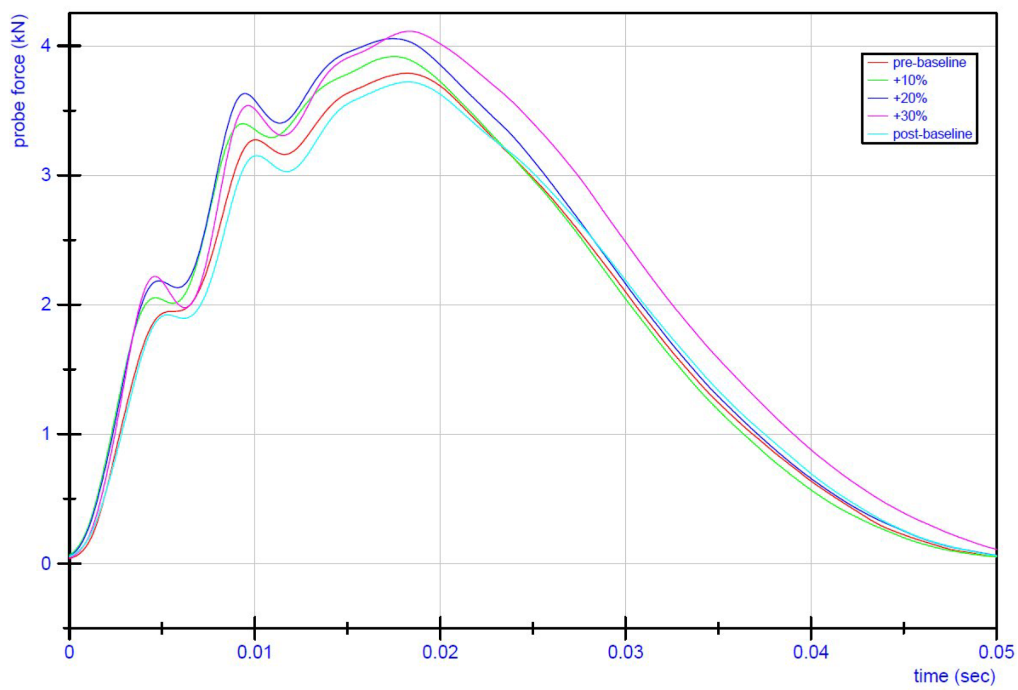

Figure C-1. Thorax Without Arm Impact – Probe Force

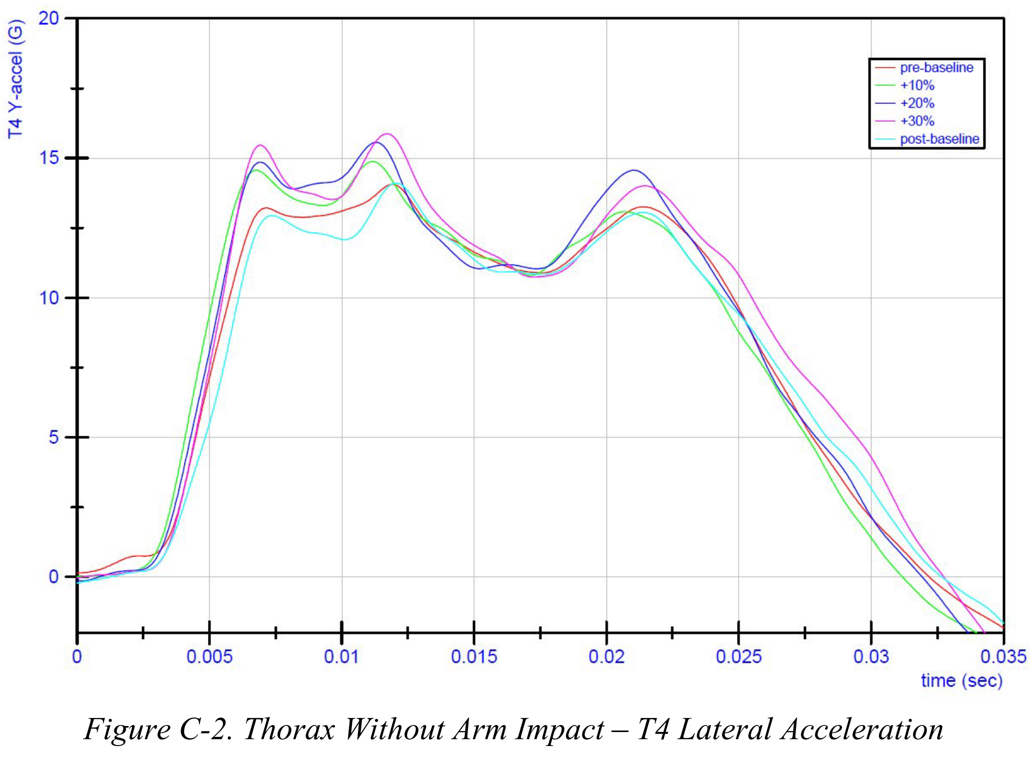

Figure C-2. Thorax Without Arm Impact – T4 Lateral Acceleration

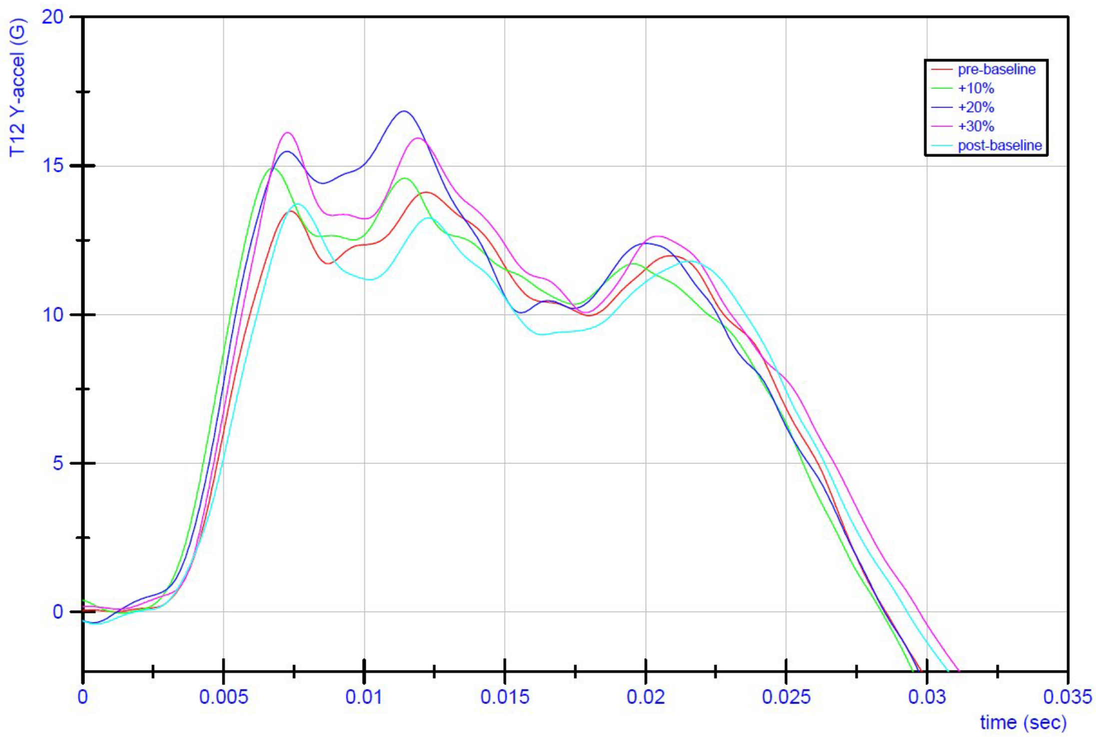

Figure C-3. Thorax Without Arm Impact – T12 Lateral Acceleration

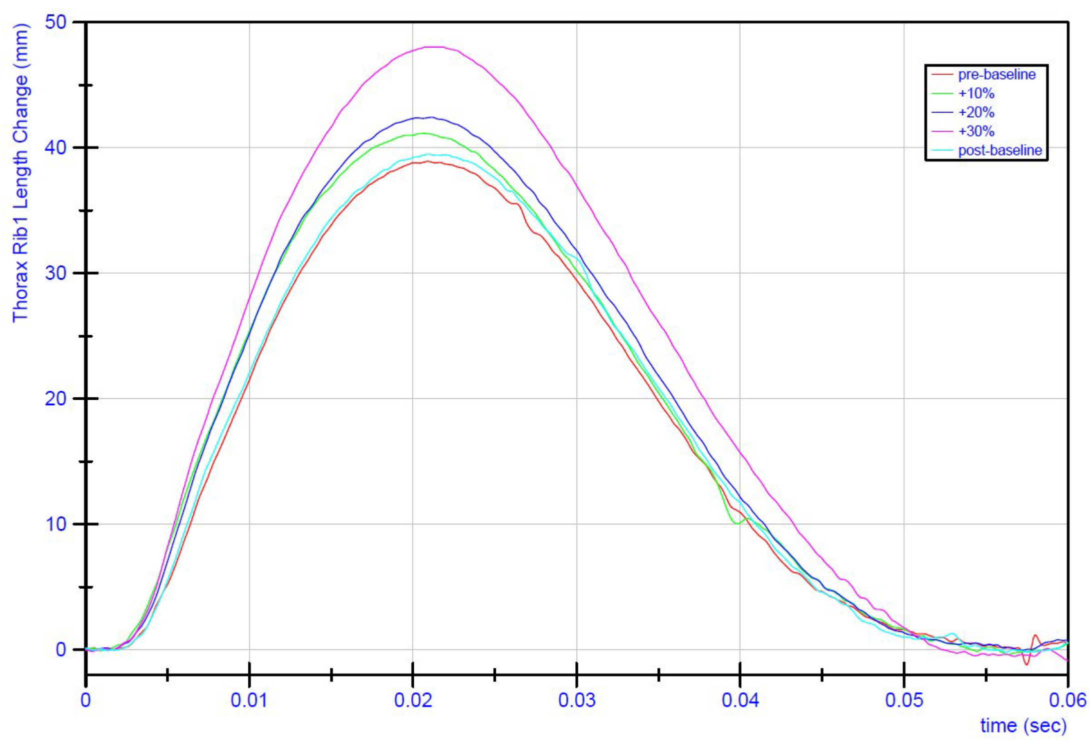

Figure C-4. Thorax With Arm Impact – Thorax Rib 1 Length Change

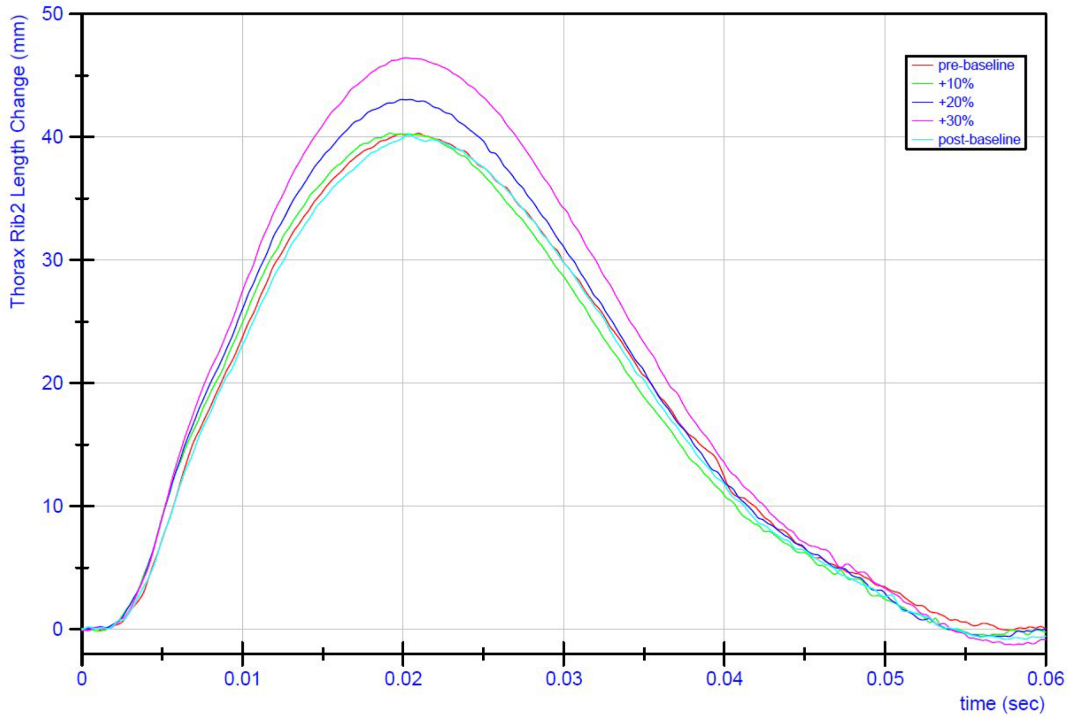

Figure C-5. Thorax With Arm Impact – Thorax Rib 2 Length Change

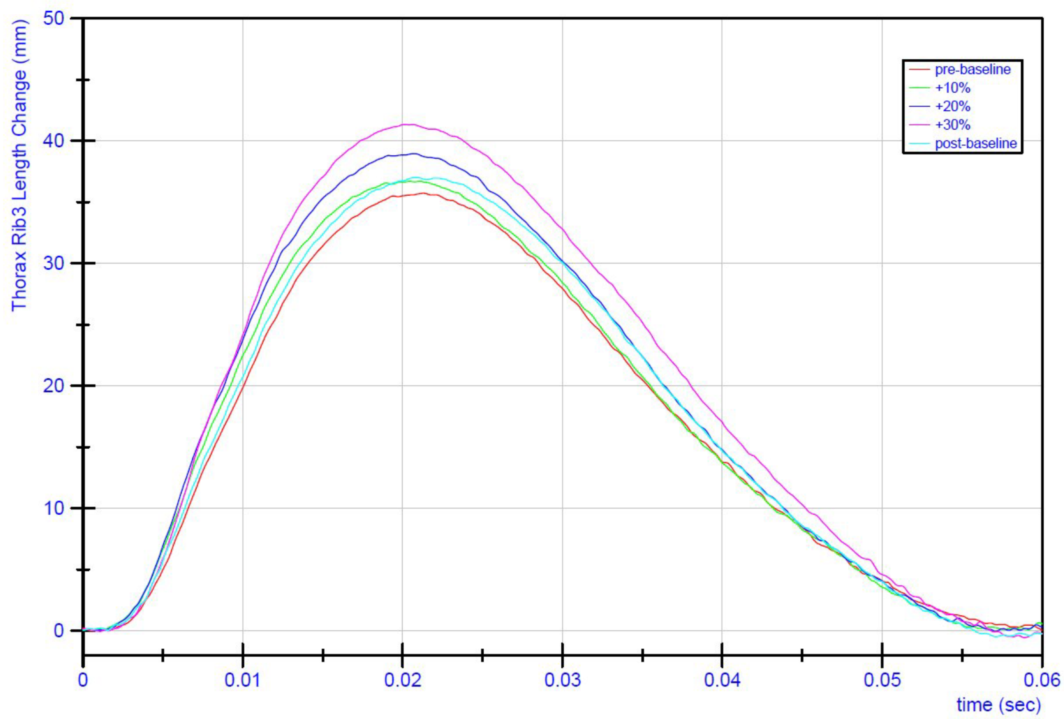

Figure C-6. Thorax With Arm Impact – Thorax Rib 3 Length Change

Appendix D: Phase 1 – Thorax With Arm Impacts

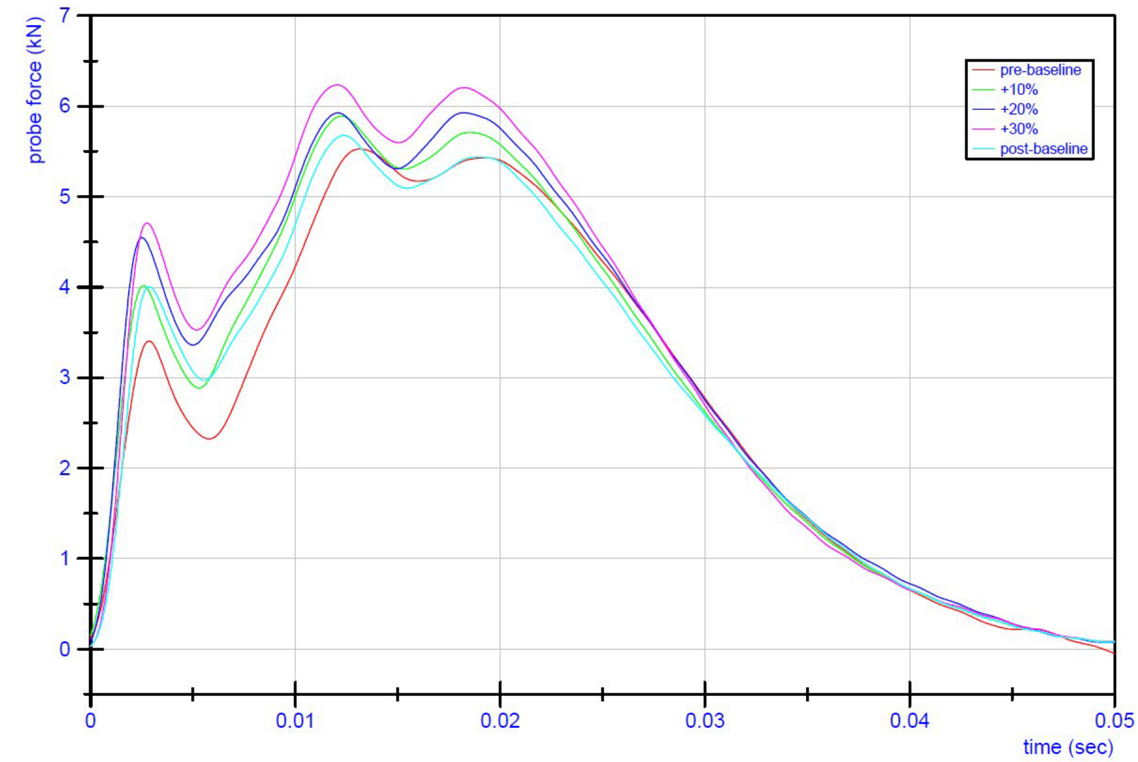

Figure D-1. Thorax With Arm Impact – Probe Force

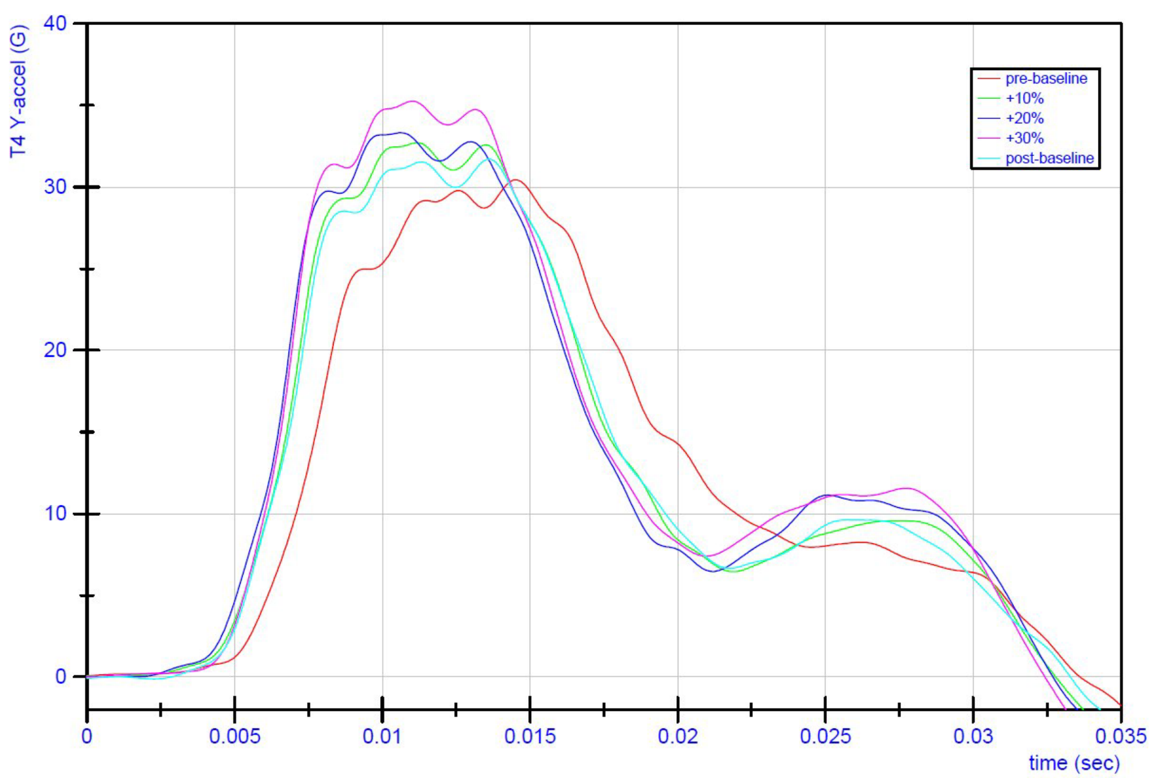

Figure D-2. Thorax With Arm Impact – T4 Lateral Acceleration

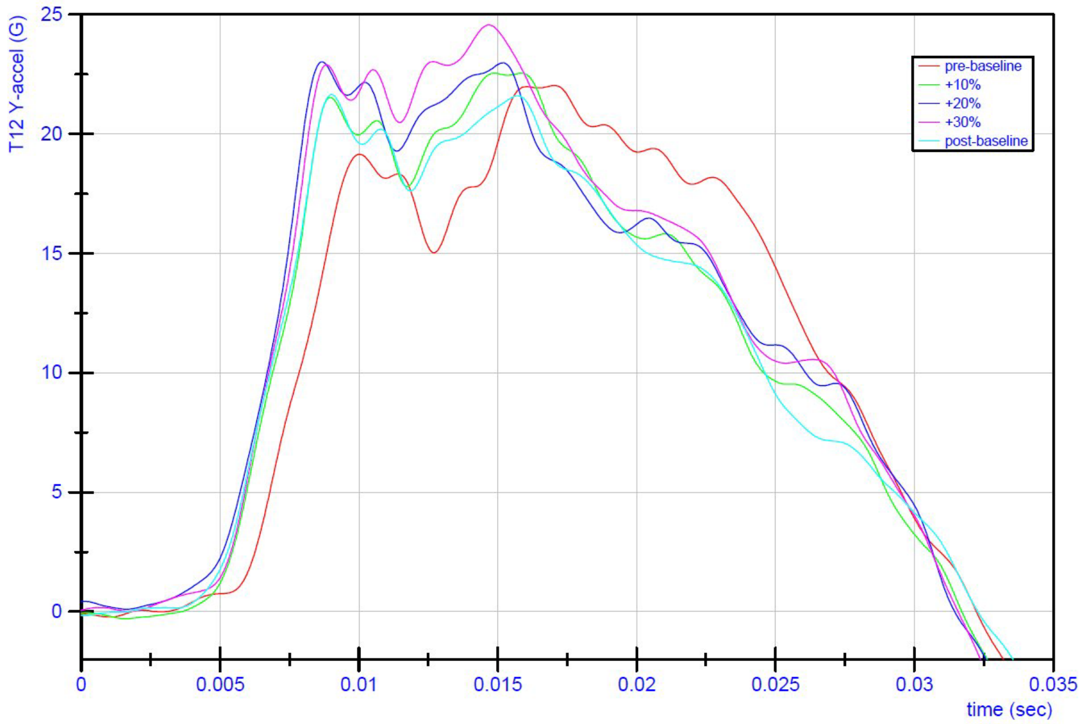

Figure D-3. Thorax With Arm Impact – T12 Lateral Acceleration

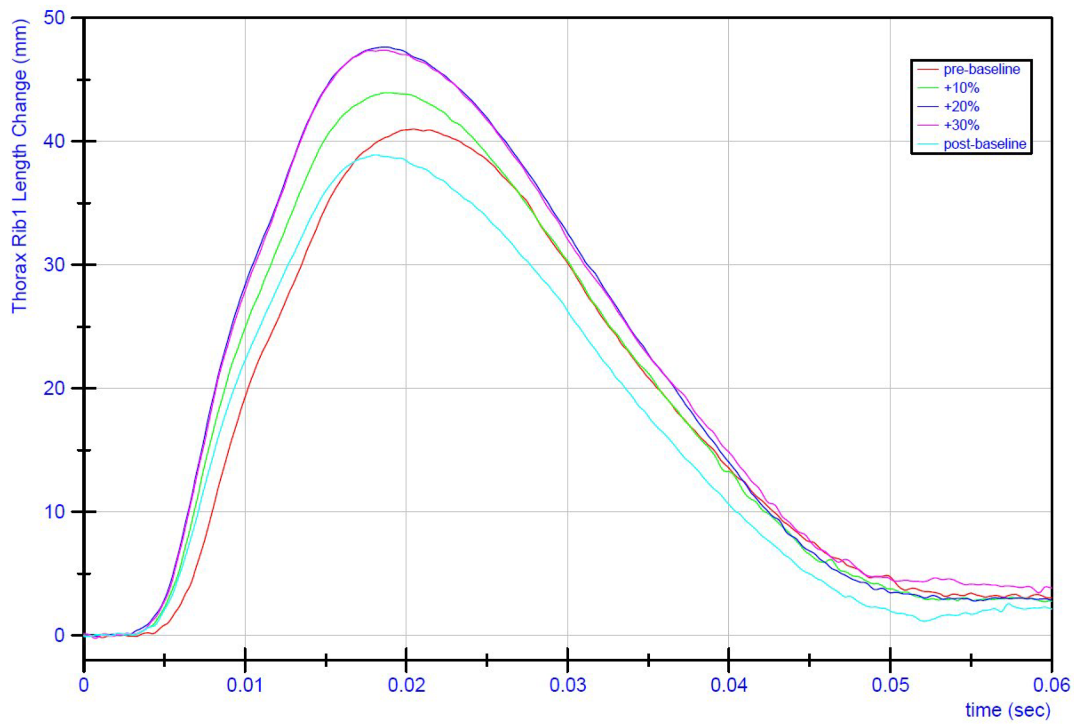

Figure D-4. Thorax With Arm Impact – Thorax Rib 1 Length Change

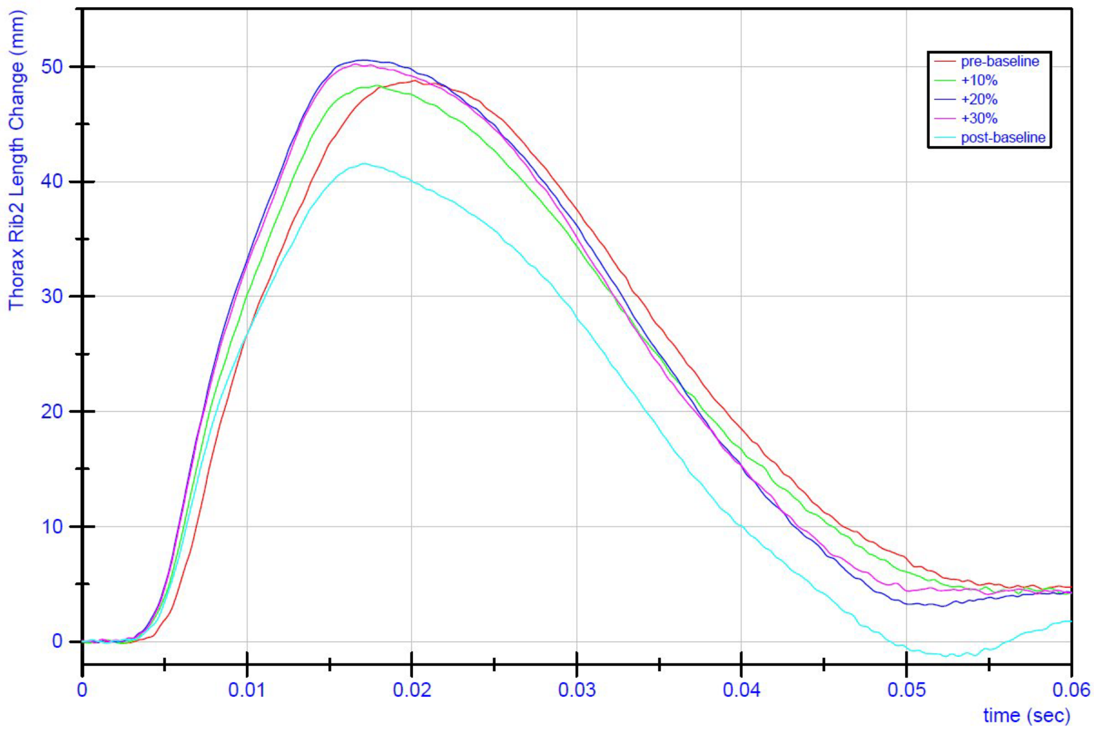

Figure D-5. Thorax With Arm Impact – Thorax Rib 2 Length Change

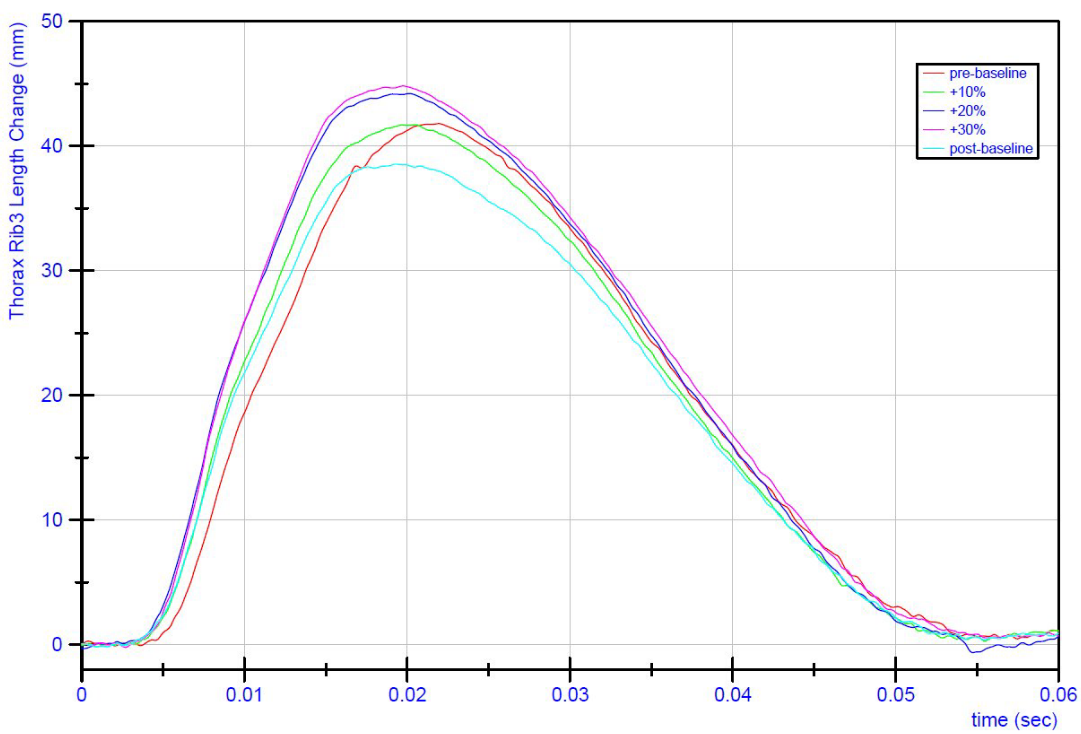

Figure D-6. Thorax With Arm Impact – Thorax Rib 3 Length Change

Appendix E: Phase 1 – Shoulder Impacts

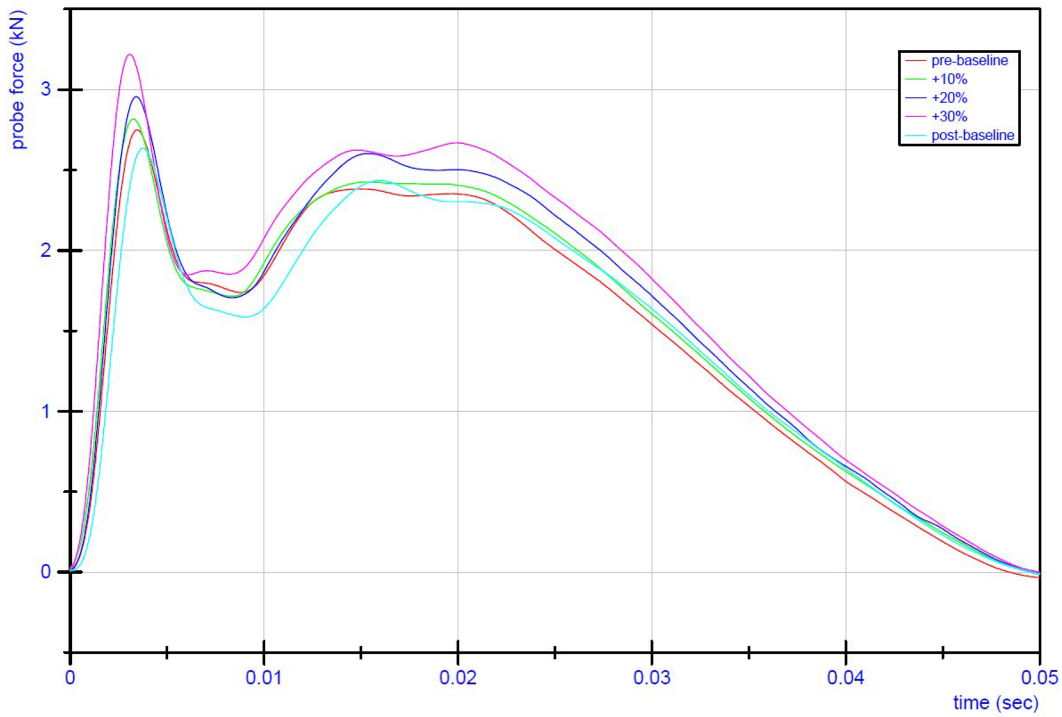

Figure E-1. Shoulder Impacts – Probe Force

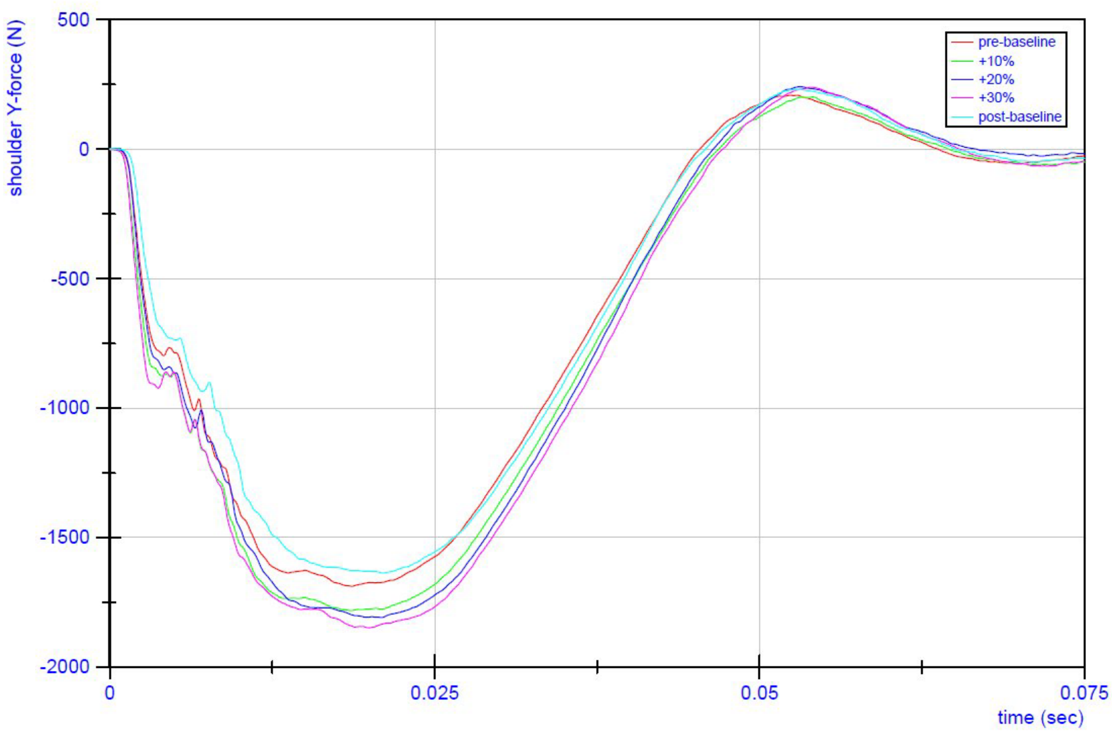

Figure E-2. Shoulder Impacts – Shoulder Lateral Force

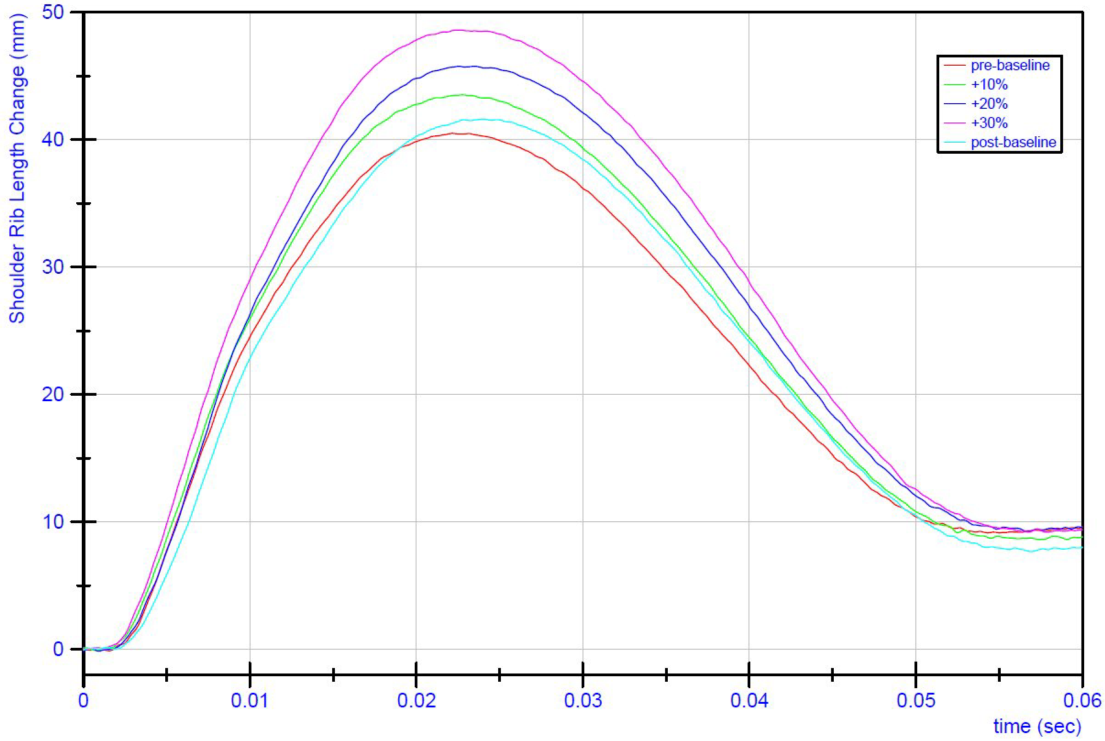

Figure E-3. Shoulder Impact – Shoulder Rib Length Change

Appendix F: Phase 1 - Lateral Neck

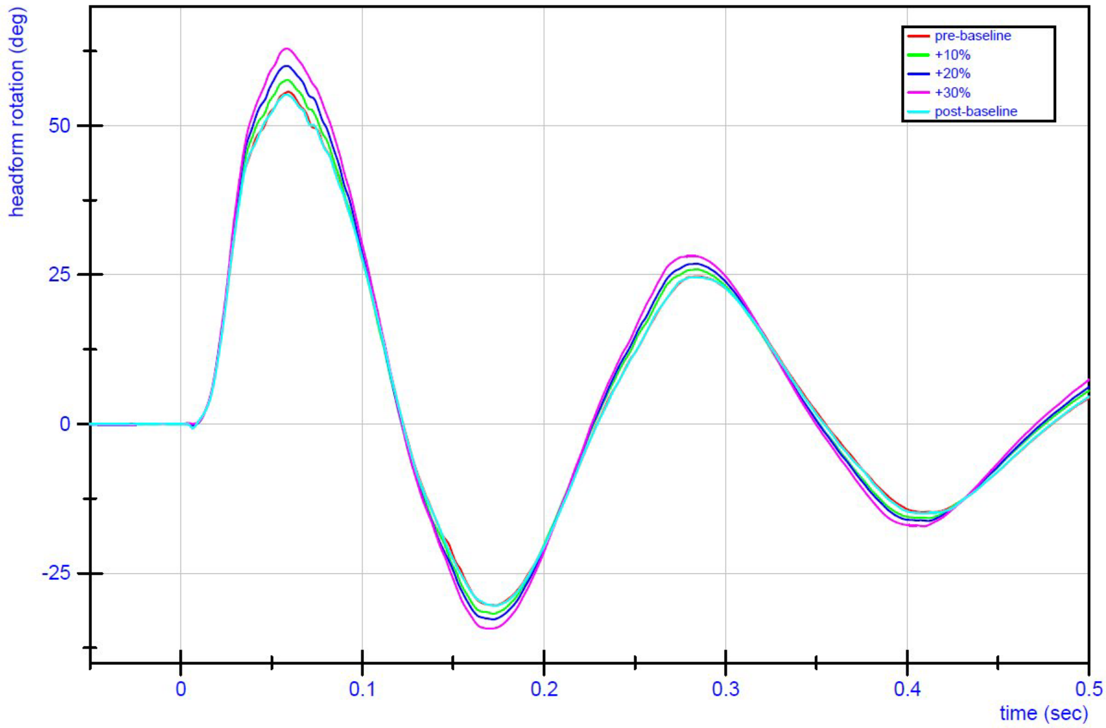

Figure F-1. Lateral Neck Test – Total Headform Rotation

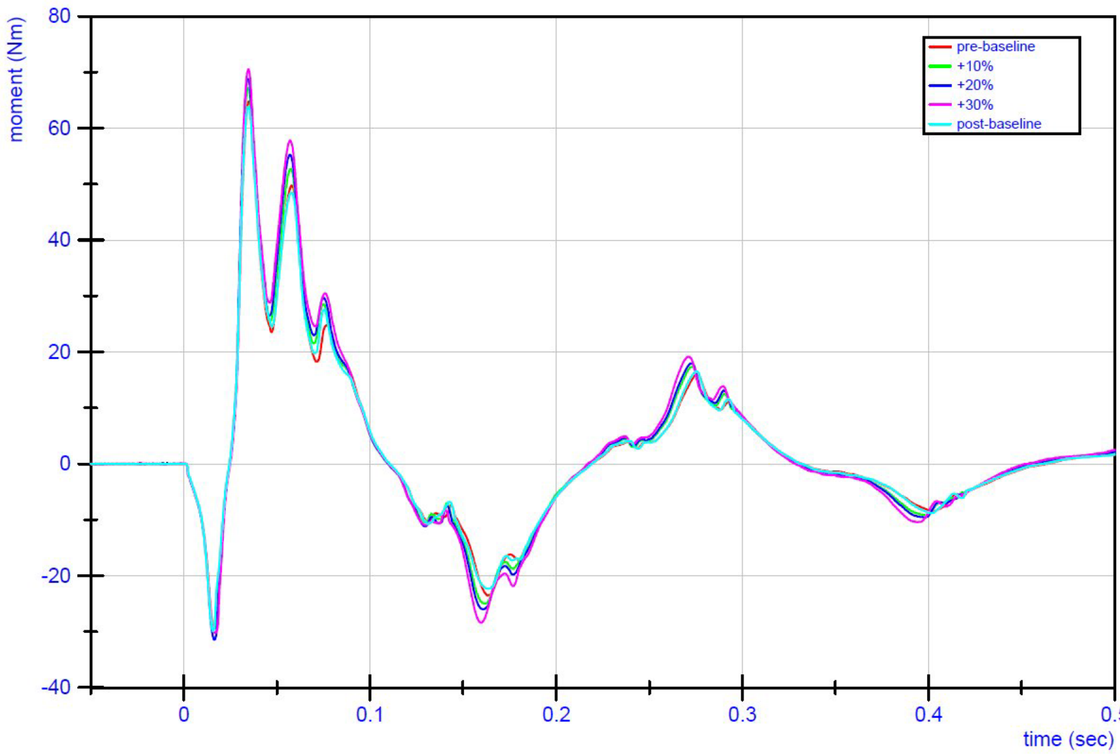

Figure F-2. Lateral Neck Test – Moment about OC

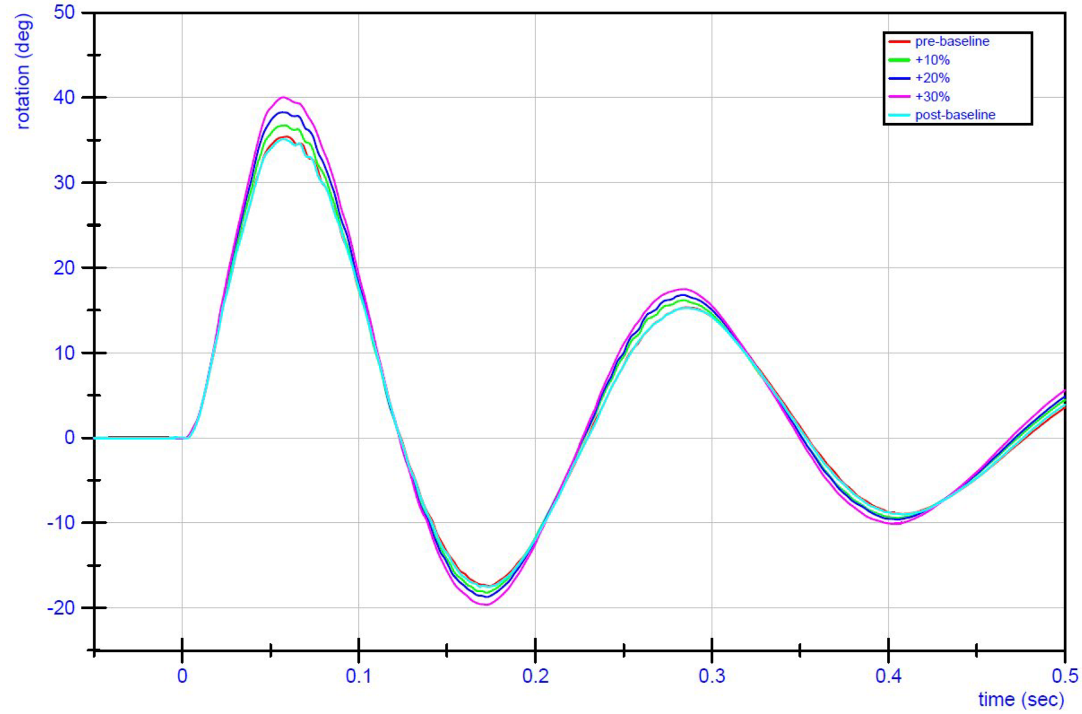

Figure F-3. Lateral Neck Test – Forward Potentiometer Rotation

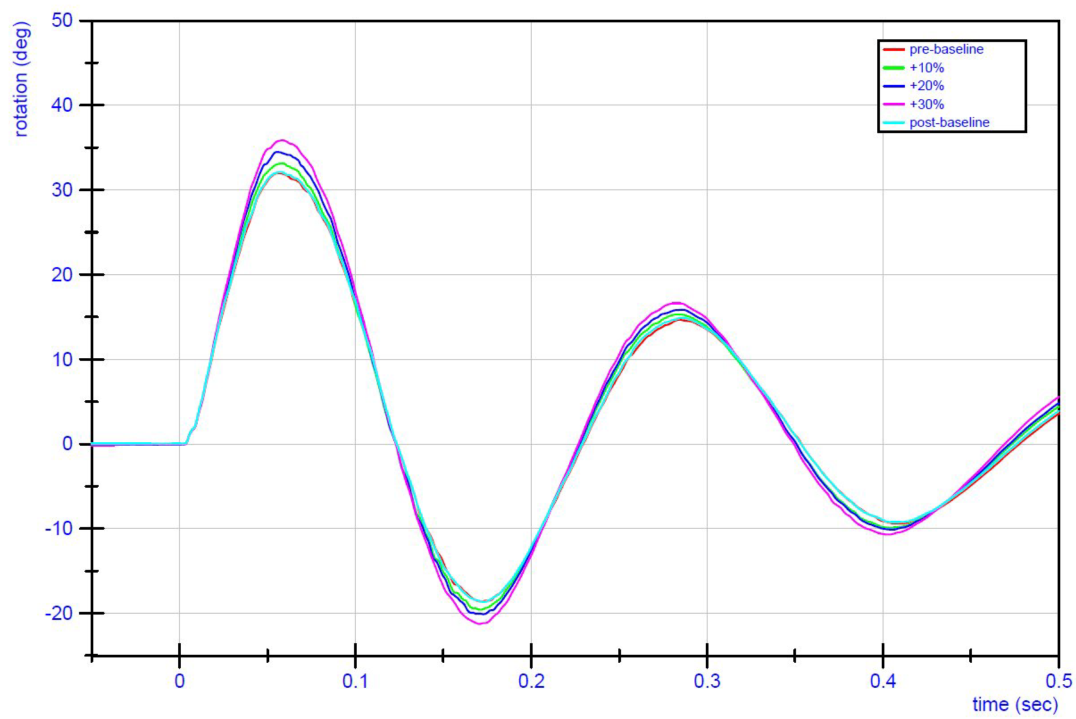

Figure F-4. Lateral Neck Test – Rearward Potentiometer Rotation

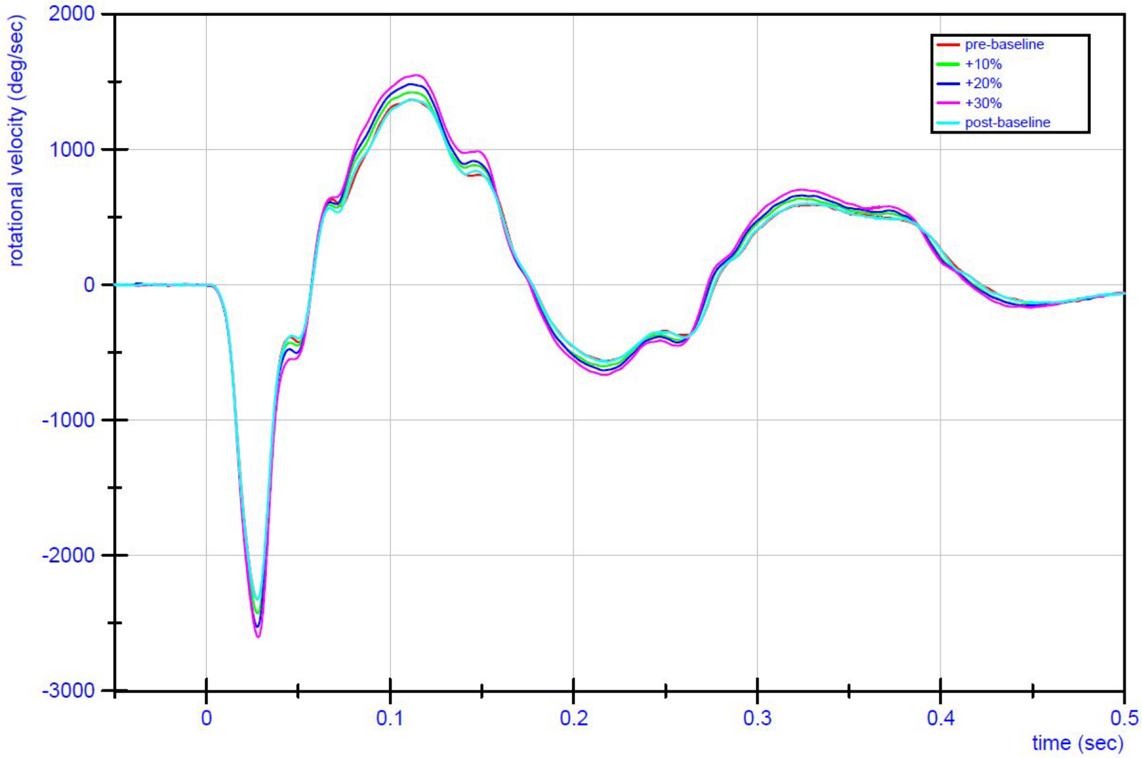

Figure F-5. Lateral Neck Test – Headform Angular Velocity

Appendix G: Phase 1 – Frontal Head Drops

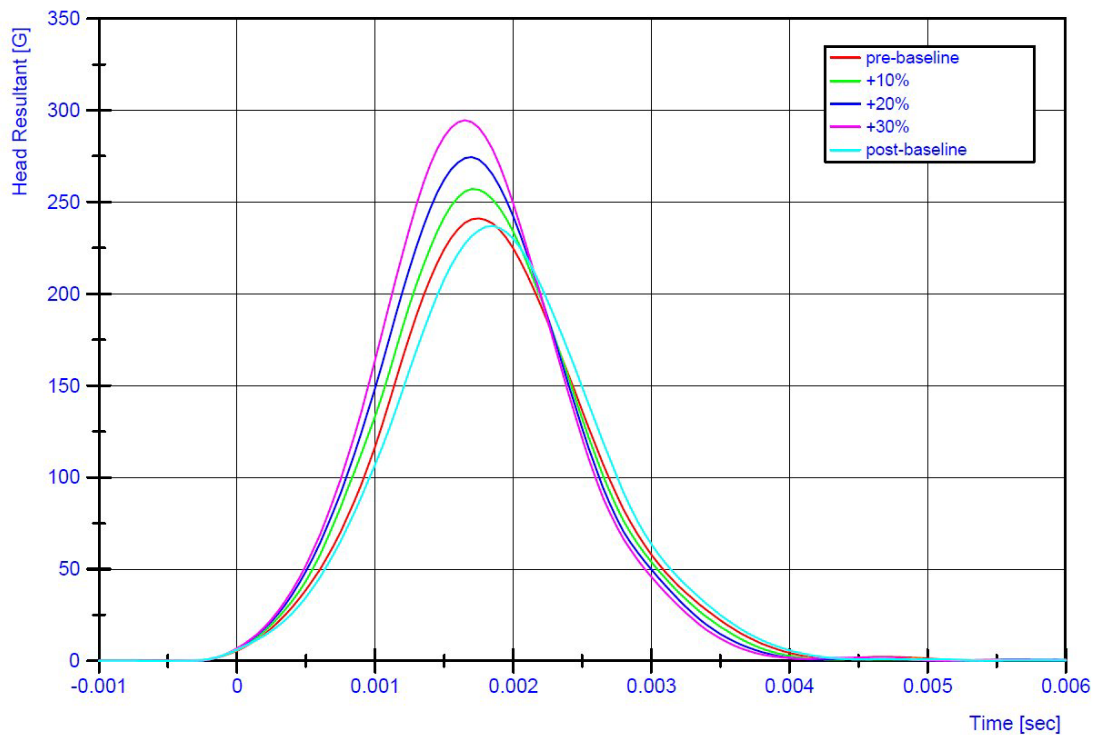

Figure G-1. Frontal Head Drop – Resultant Acceleration

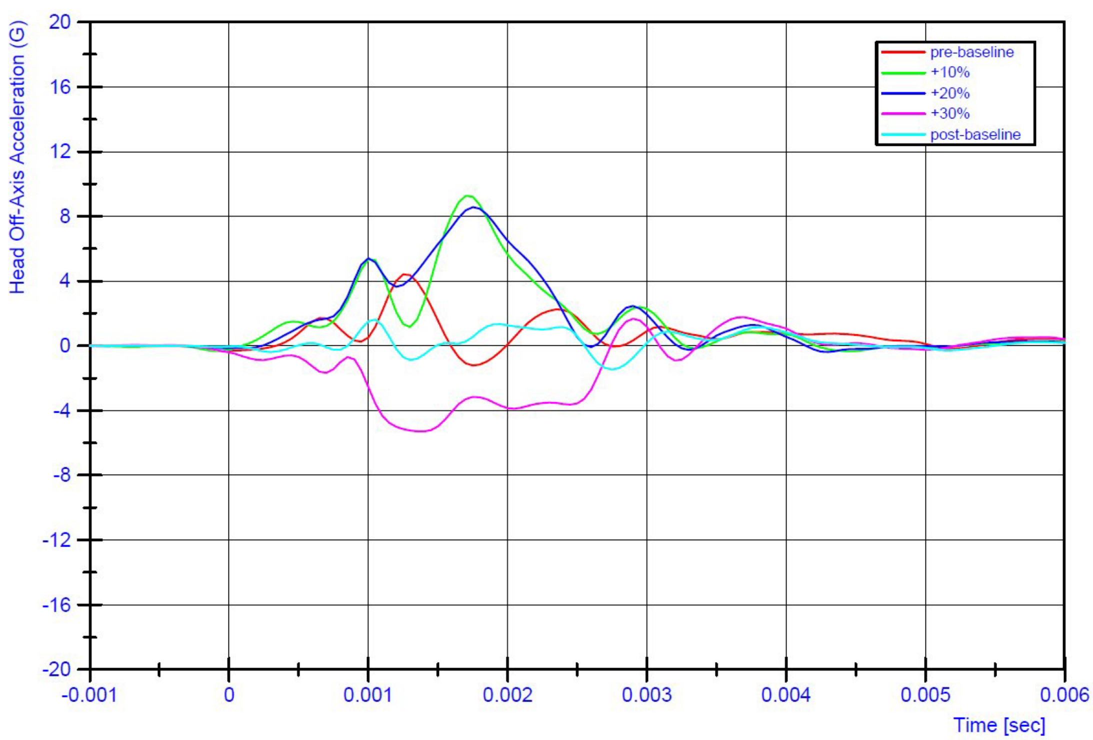

Figure G-2. Frontal Head Drop - Off-axis Acceleration

Appendix H: Phase 1 – Lateral Head Drops

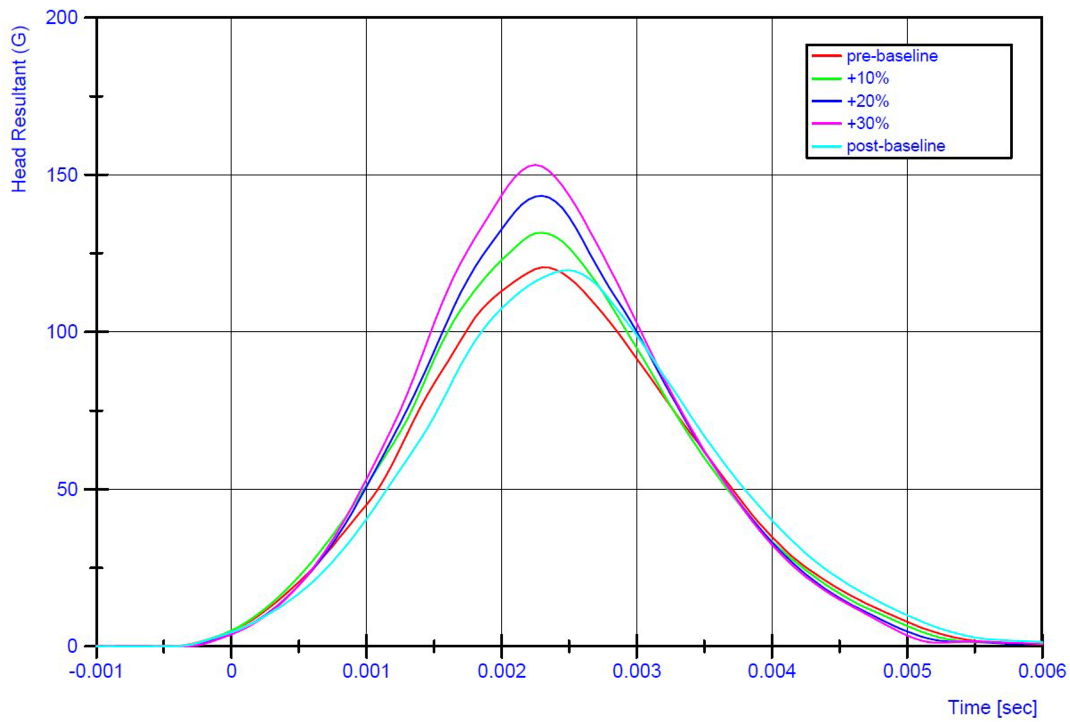

Figure H-1. Lateral Head Drop – Resultant Acceleration

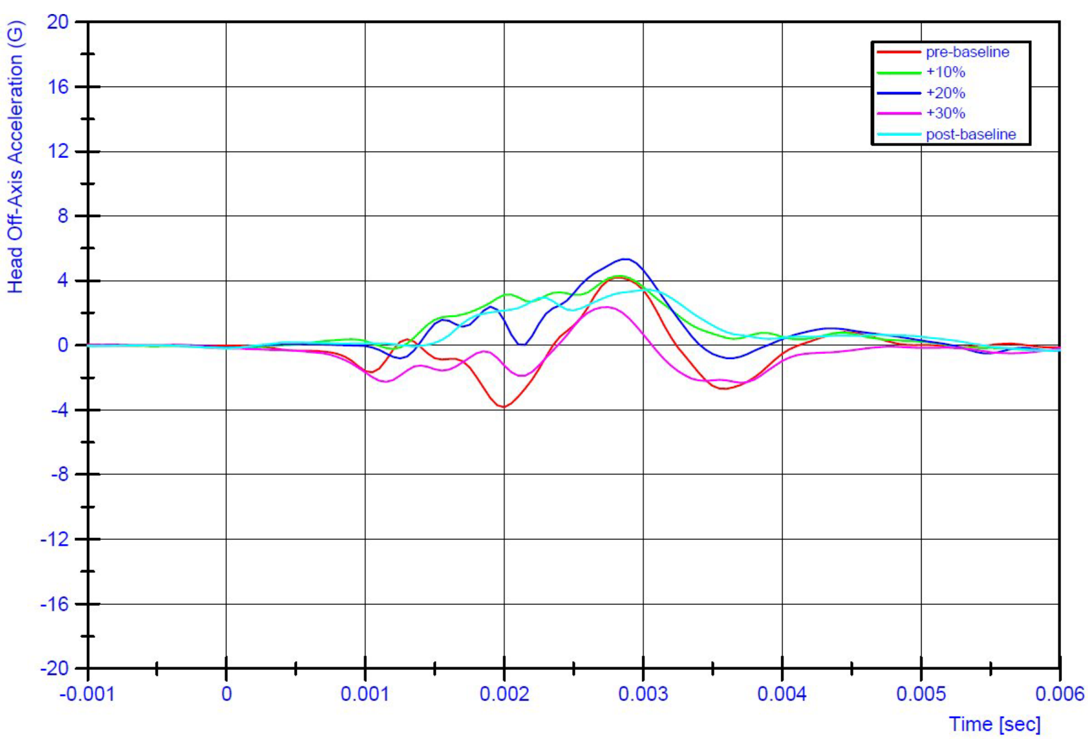

Figure H-2. Lateral Head Drop – Off-axis Acceleration

Appendix I: Phase 2 – Shoulder Impacts

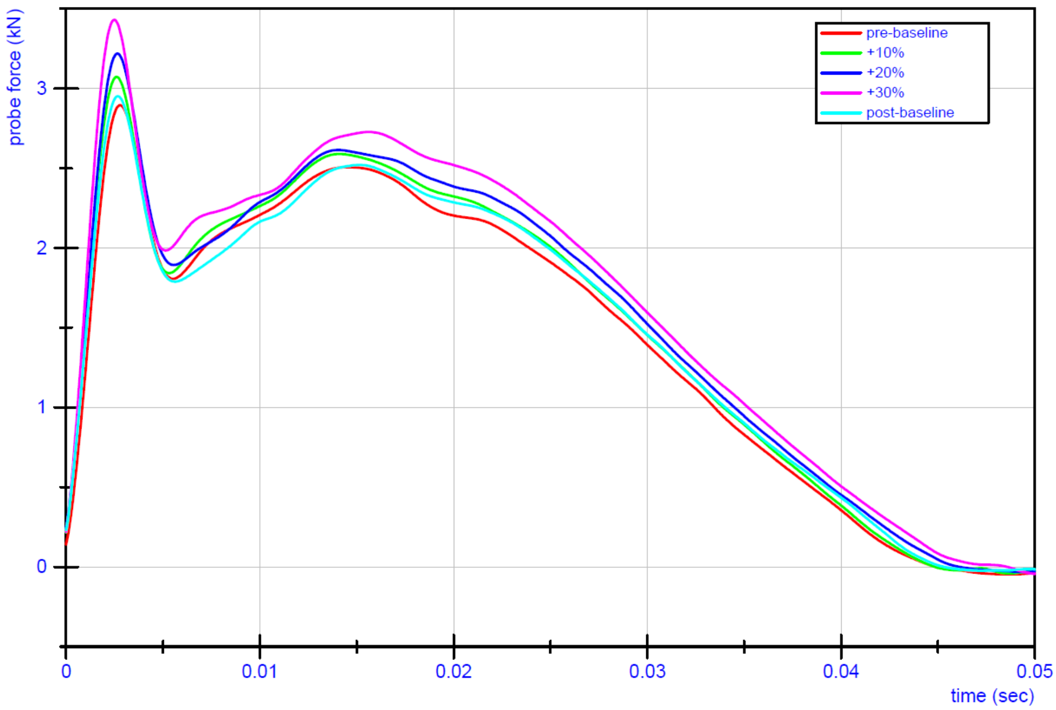

Figure I-1. Shoulder Impact – Probe Force

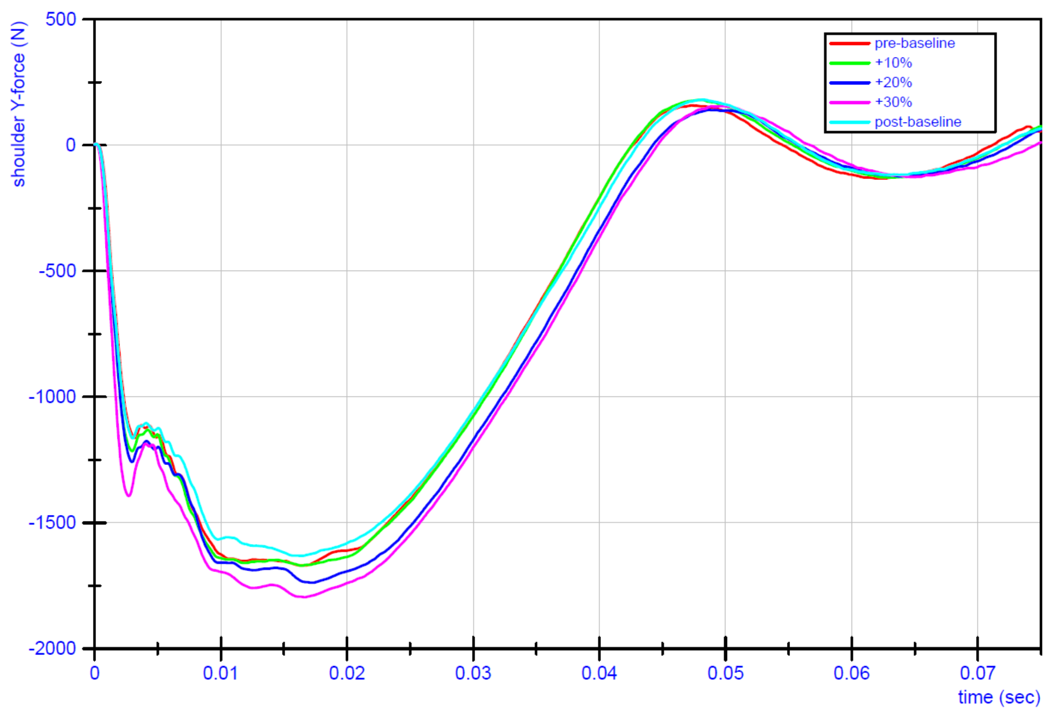

Figure I-2. Shoulder Impact – Lateral Shoulder Force

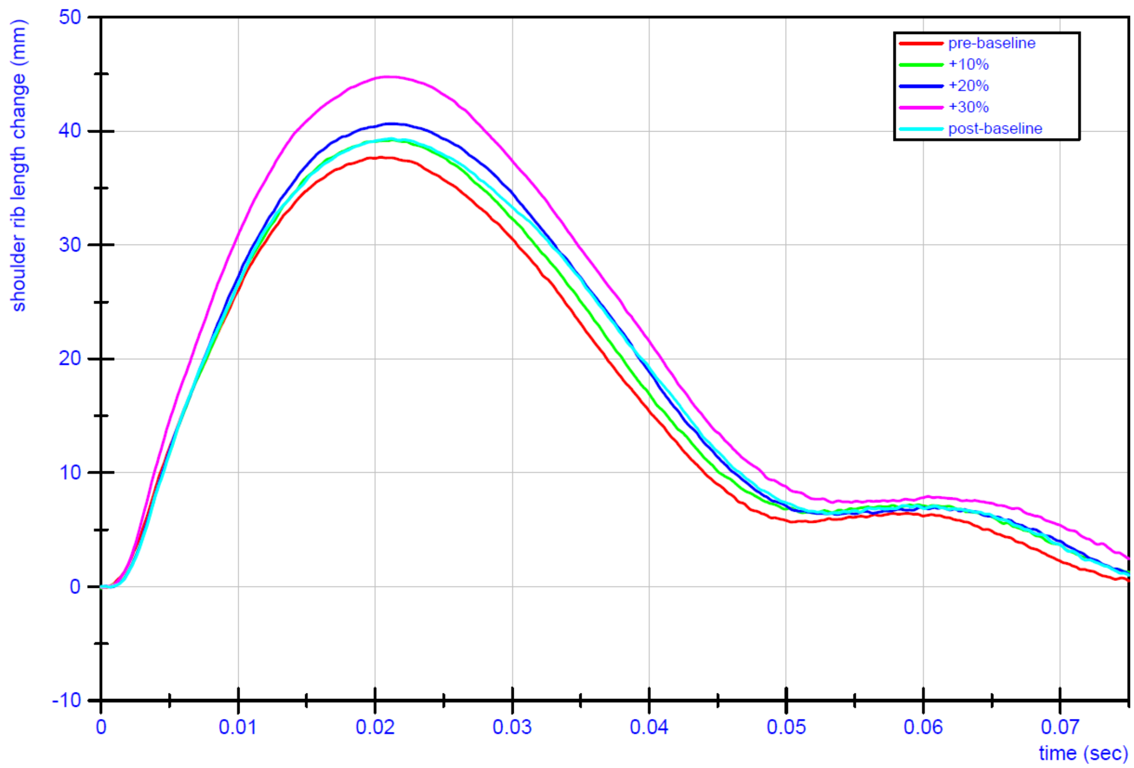

Figure I-3. Shoulder Impact – Shoulder Rib Length Change

Appendix J: Phase 2 – Thorax With Arm Impacts

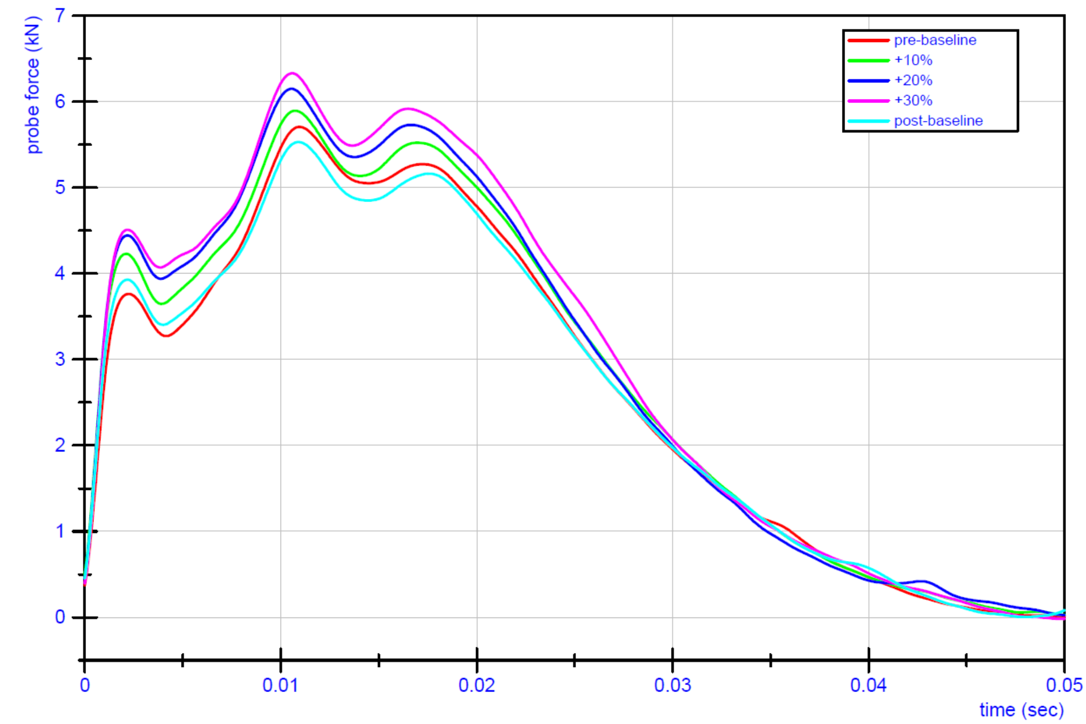

Figure J-1. Thorax With Arm Impact – Probe Force

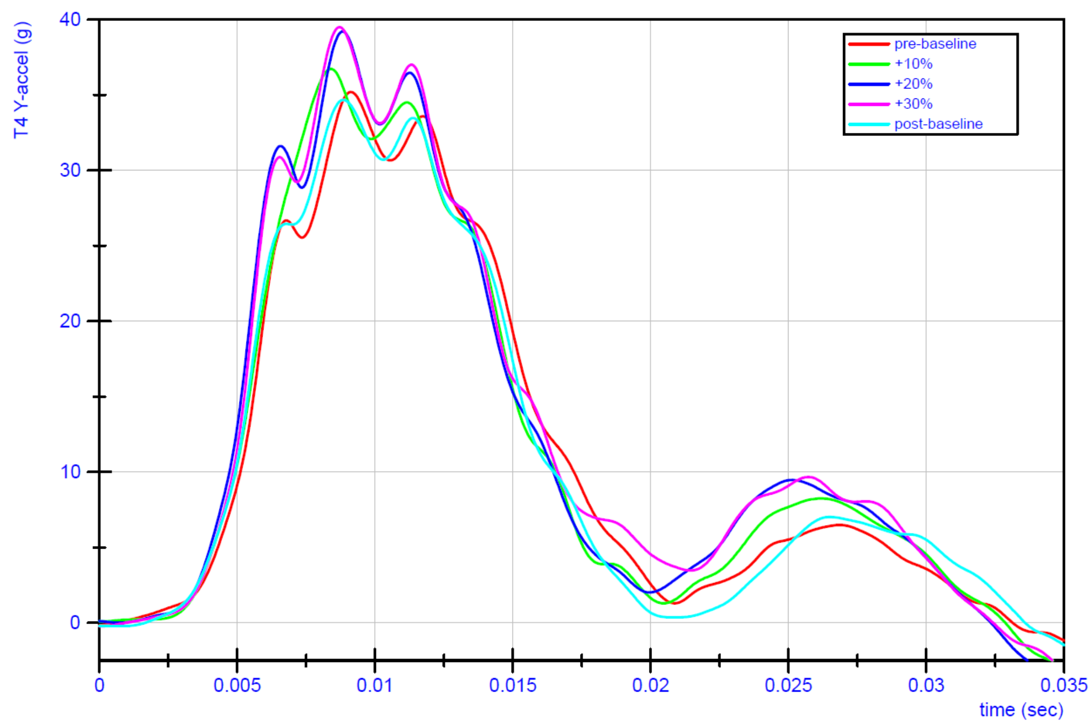

Figure J-2. Thorax With Arm Impact – T4 Lateral Acceleration

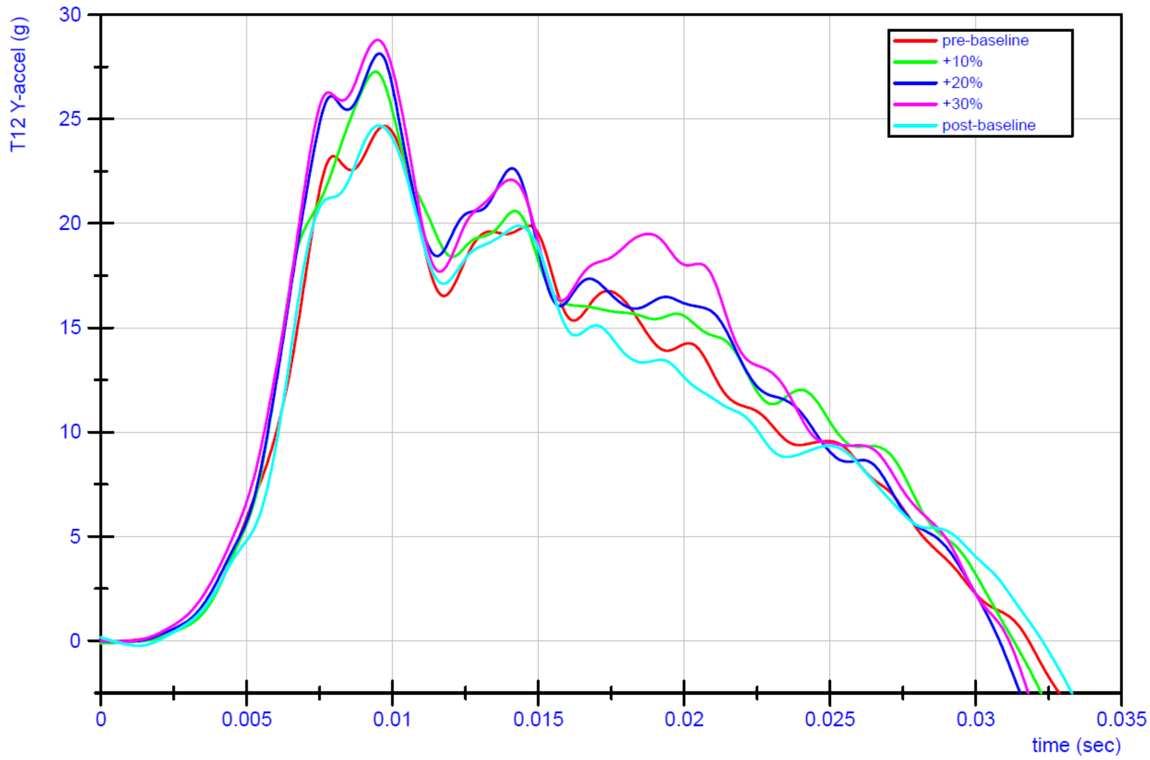

Figure J-3. Thorax With Arm Impact – T12 Lateral Acceleration

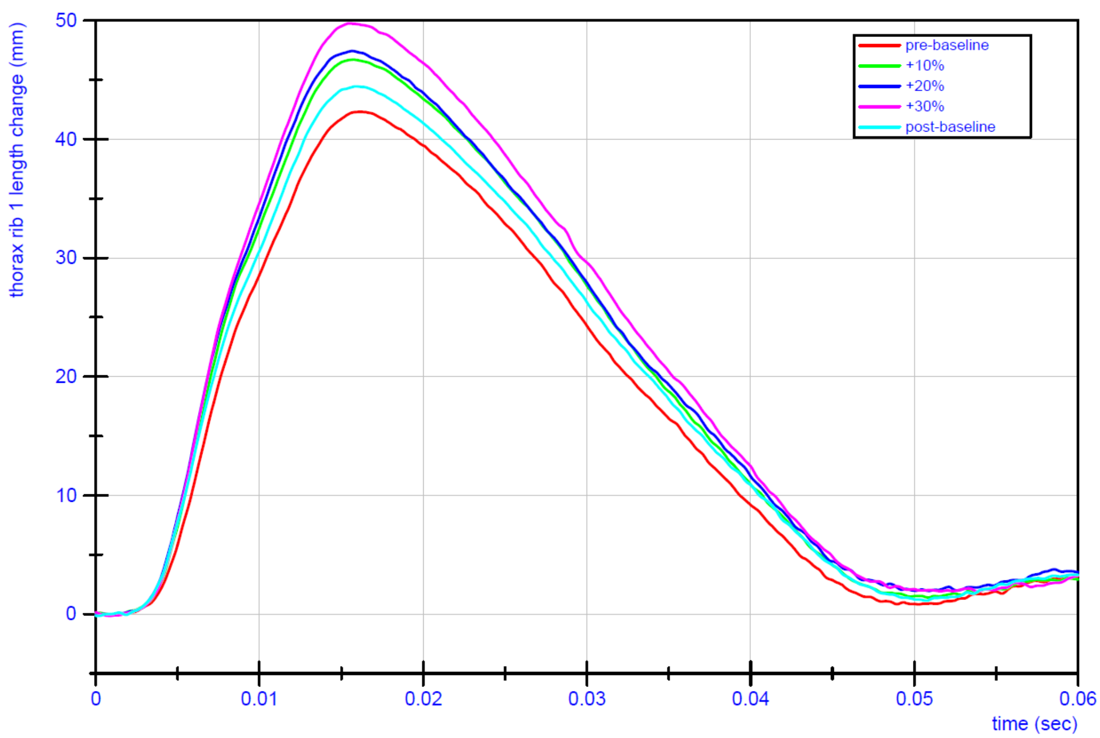

Figure J-4. Thorax With Arm Impact – Thorax Rib 1 Length Change

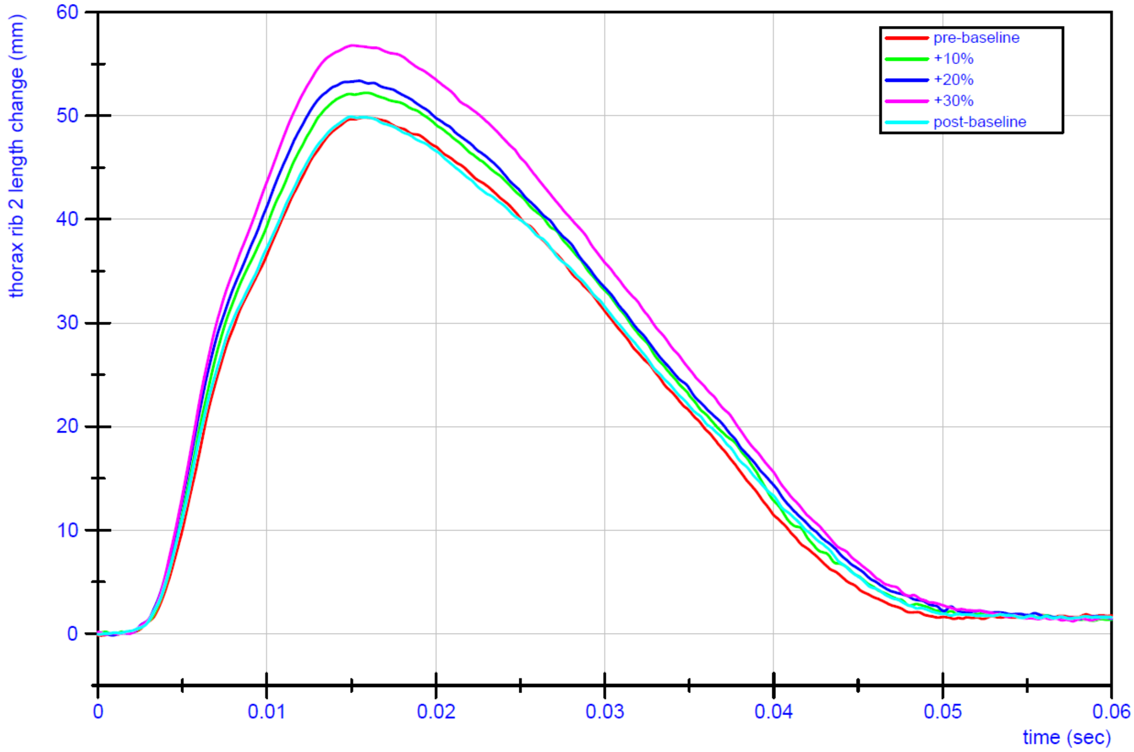

Figure J-5. Thorax With Arm Impact - Thorax Rib 2 Length Change

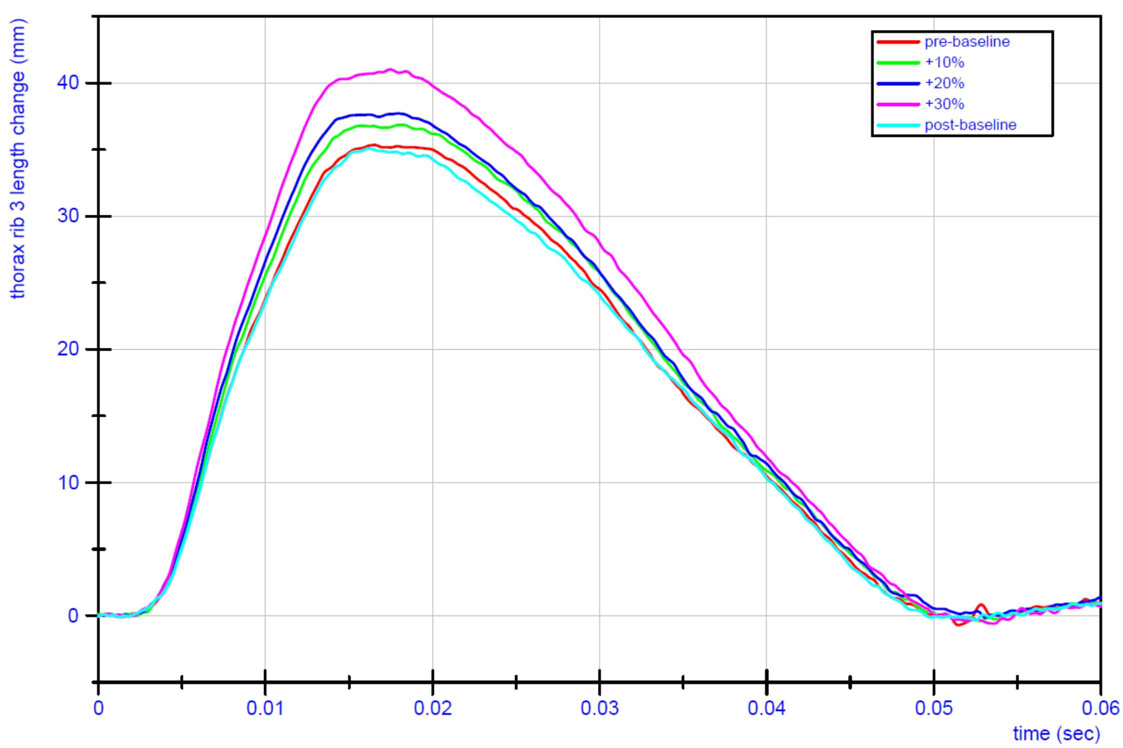

Figure J-6. Thorax With Arm Impact – Thorax Rib 3 Length Change

Appendix K: Phase 2 - Thorax Without Arm Impacts

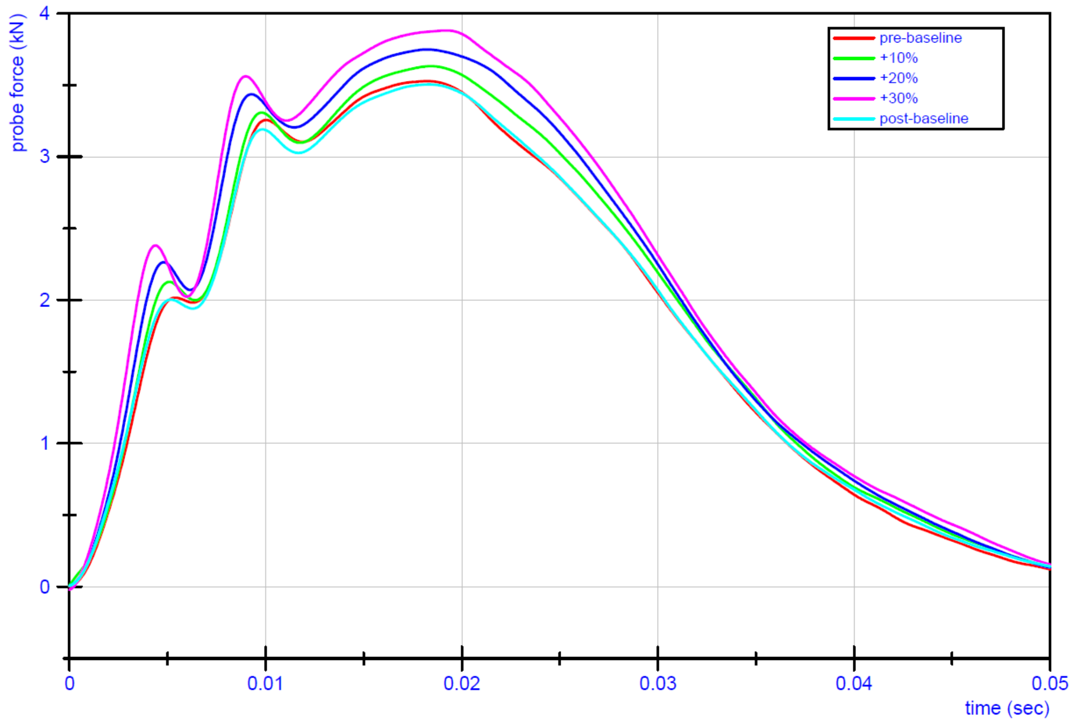

Figure K-1. Thorax Without Arm Impact – Probe Force

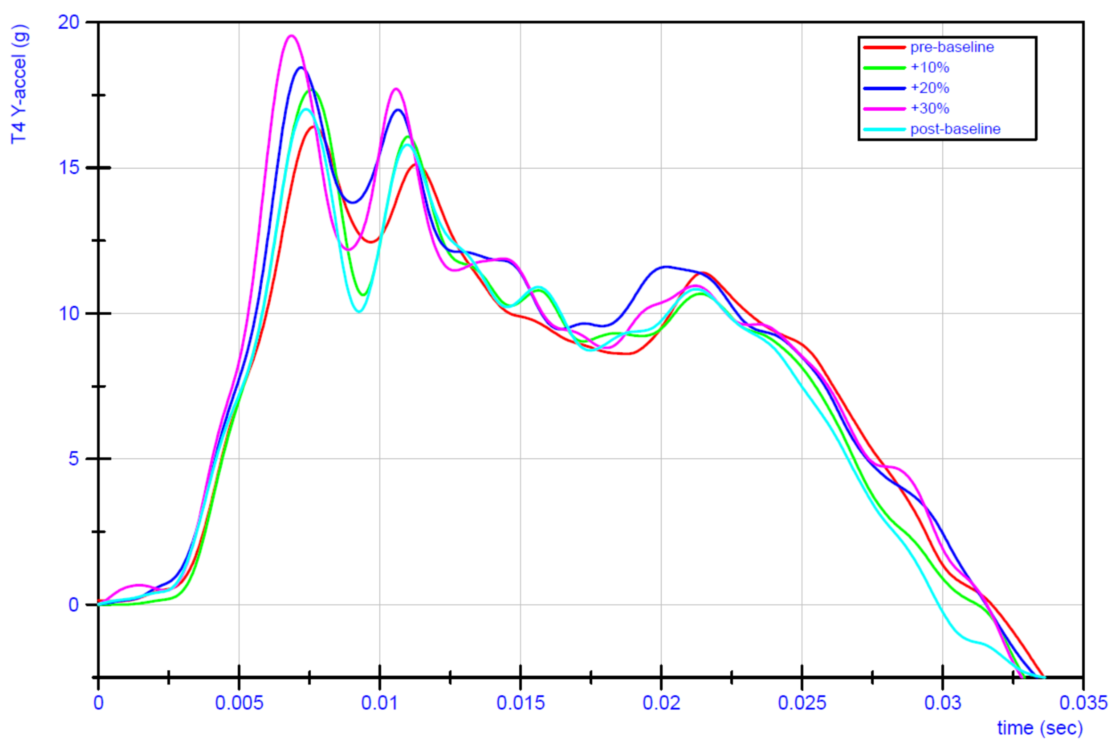

Figure K-2. Thorax Without Arm Impact – T4 Lateral Acceleration

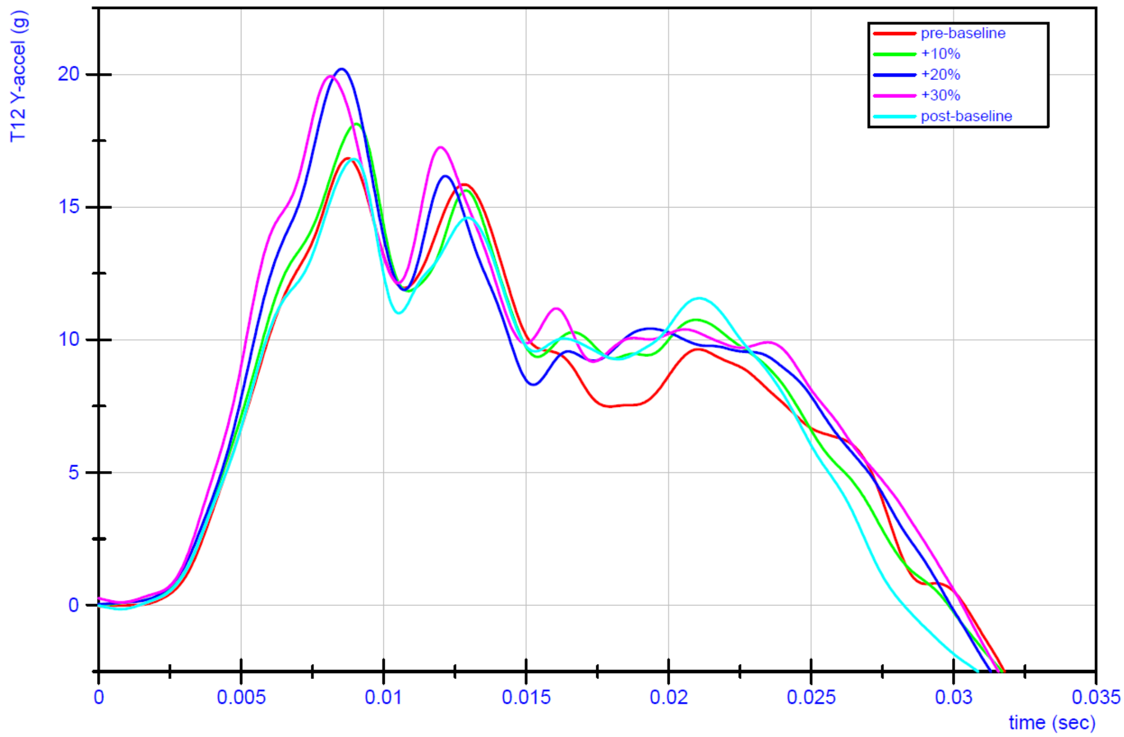

Figure K-3. Thorax Without Arm Impact – T12 Lateral Acceleration

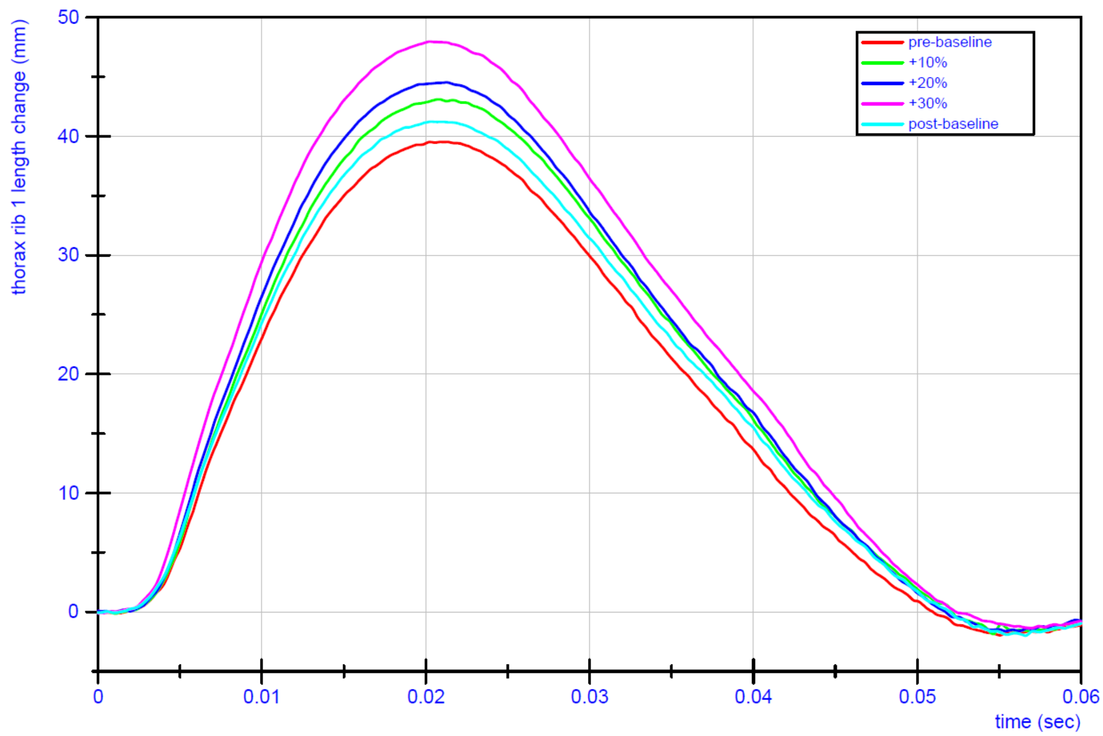

Figure K-4. Thorax Without Arm Impact – Thorax Rib 1 Length Change

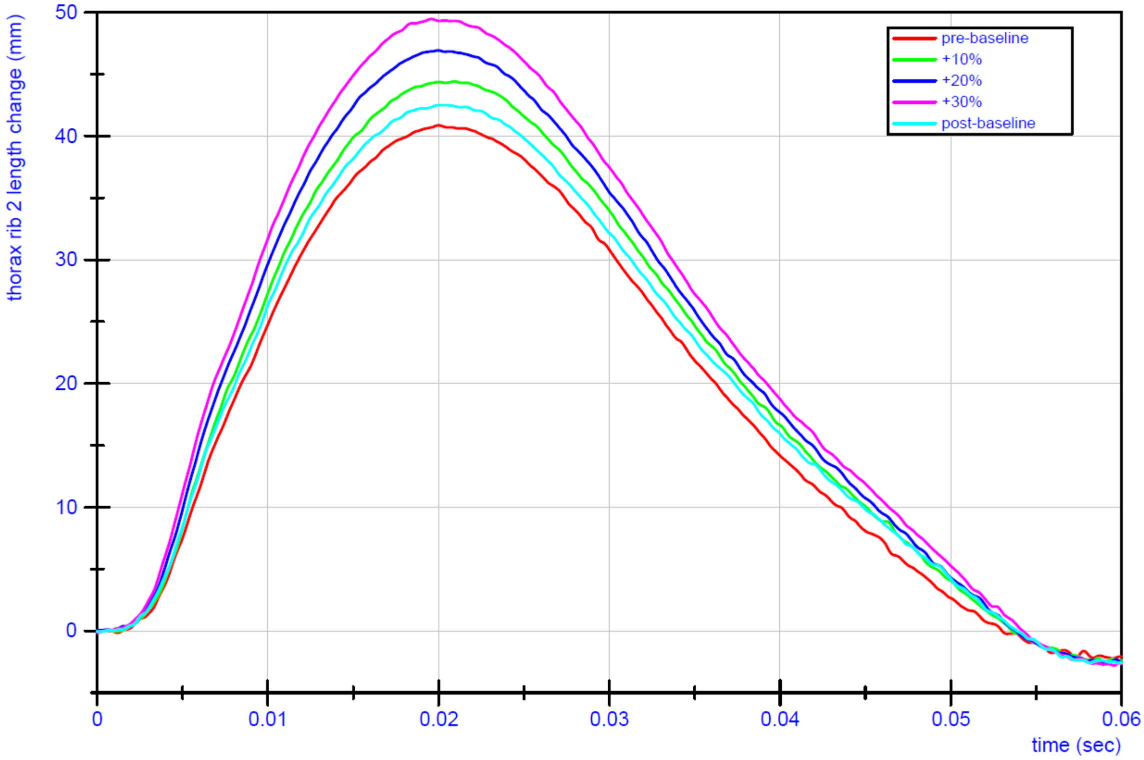

Figure K-5. Thorax Without Arm Impact – Thorax Rib 2 Length Change

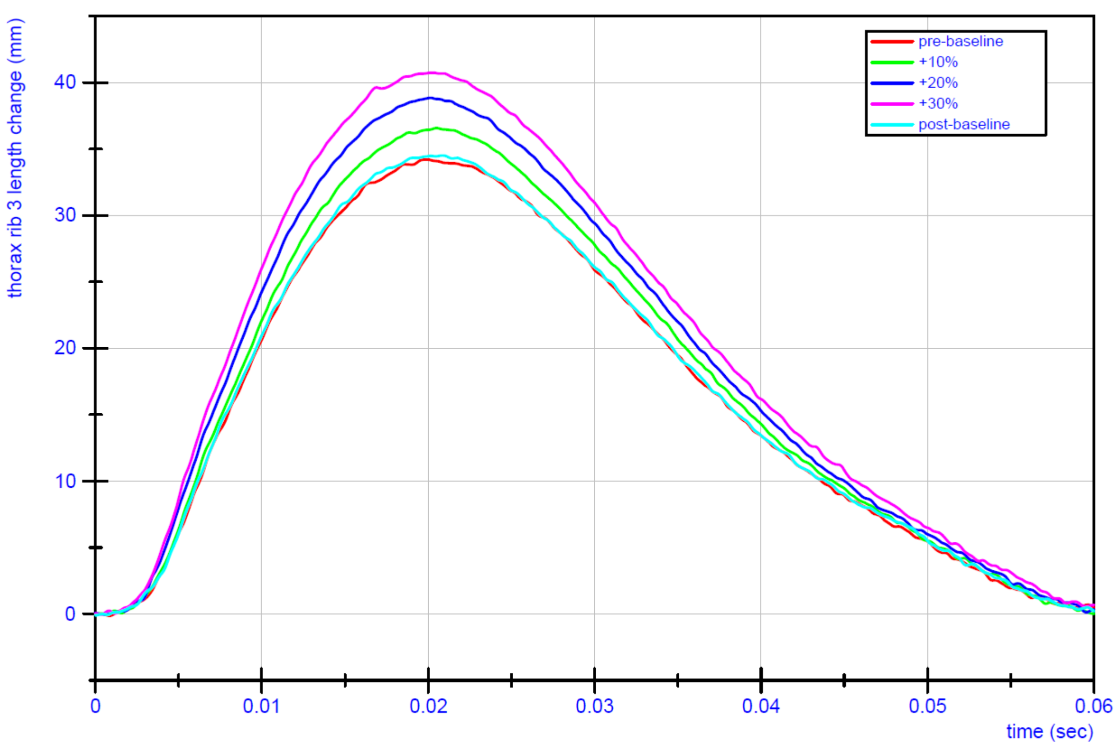

Figure K-6. Thorax Without Arm Impact – Thorax Rib 3 Length Change

Appendix L: Phase 2 – Abdomen Impacts

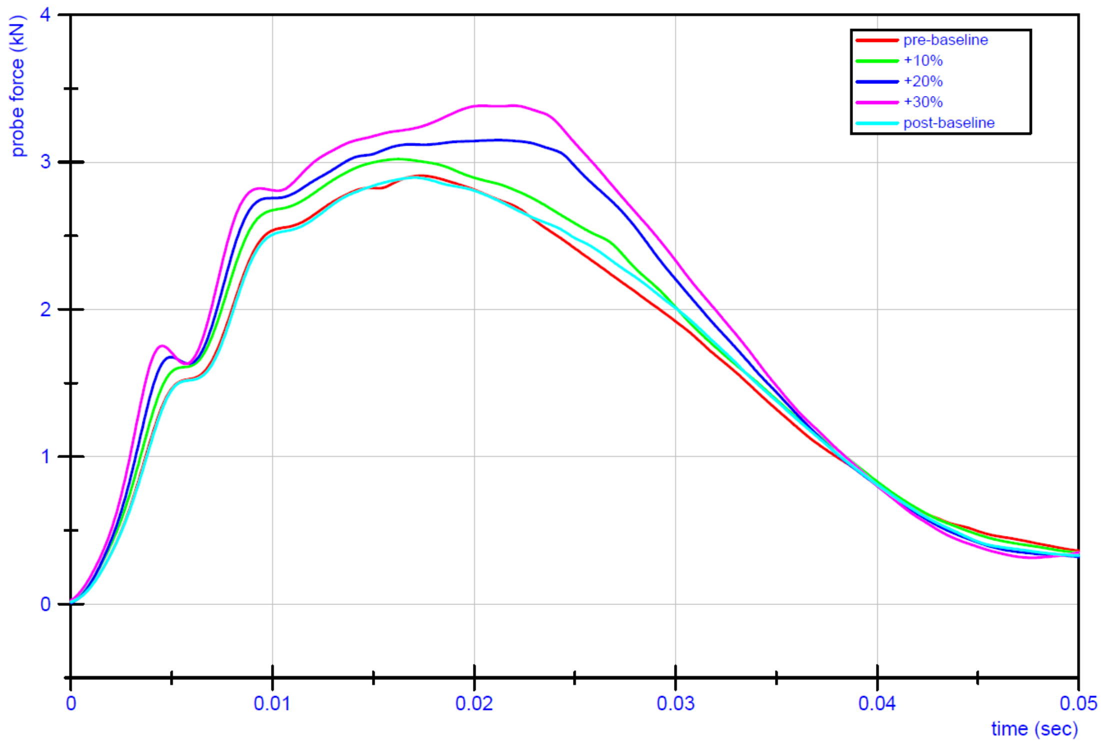

Figure L-1. Abdomen Impact – Probe Force

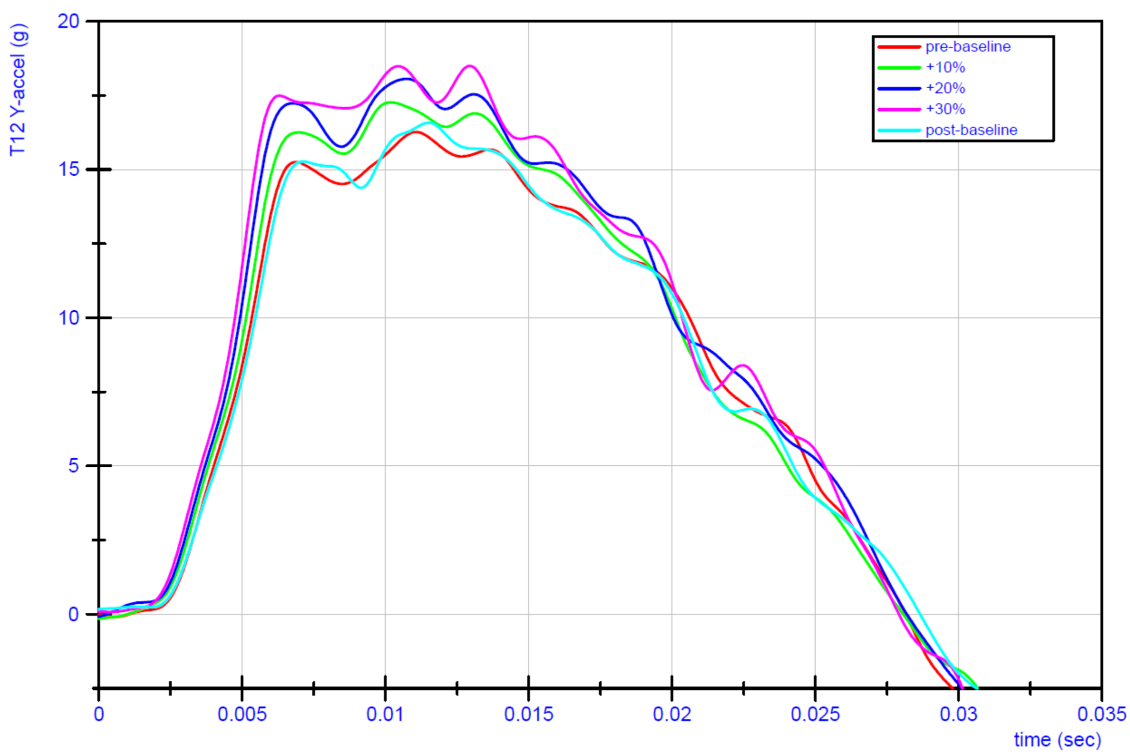

Figure L-2. Abdomen Impact – T12 Lateral Acceleration

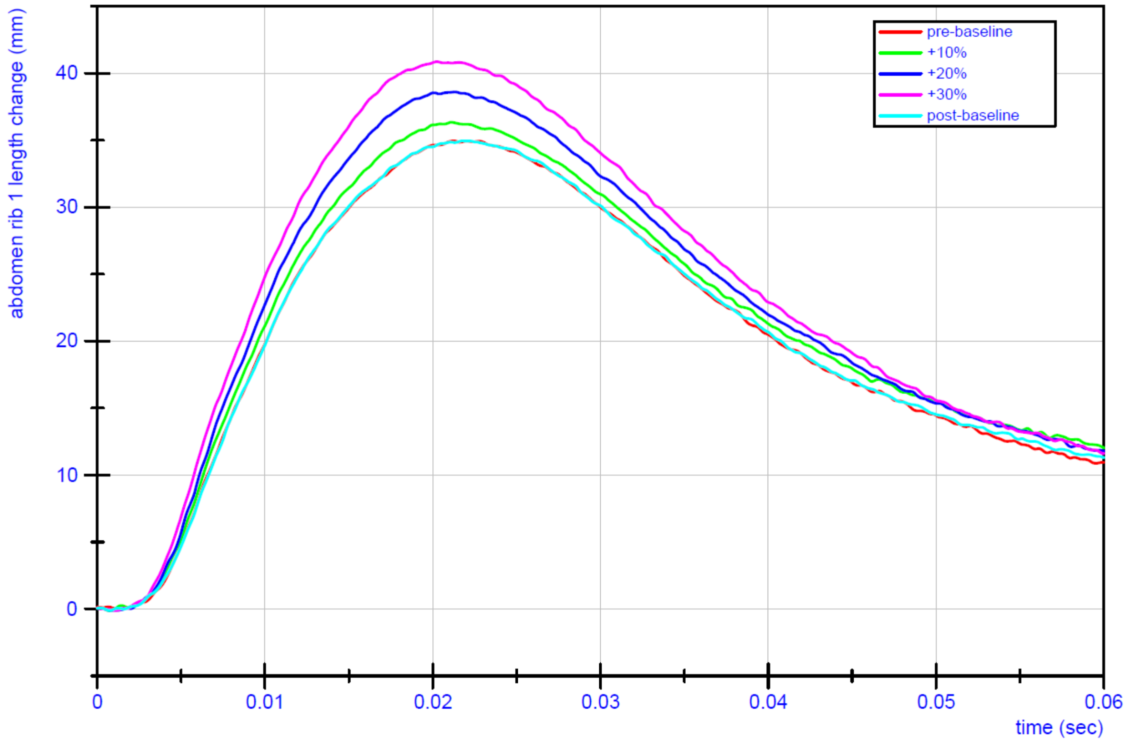

Figure L-3. Abdomen Impact – Abdomen Rib 1 Length Change

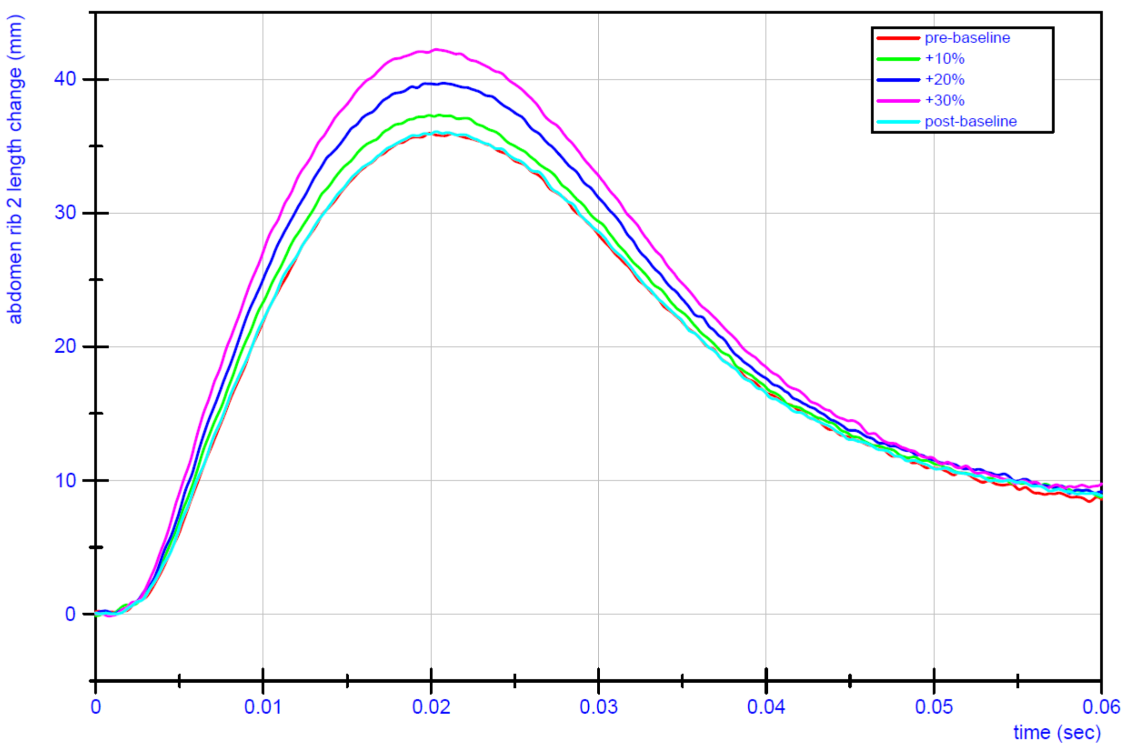

Figure L-4. Abdomen Impact - Abdomen Rib 2 Length Change

Appendix M: Phase 2 – Neck Torsion Tests

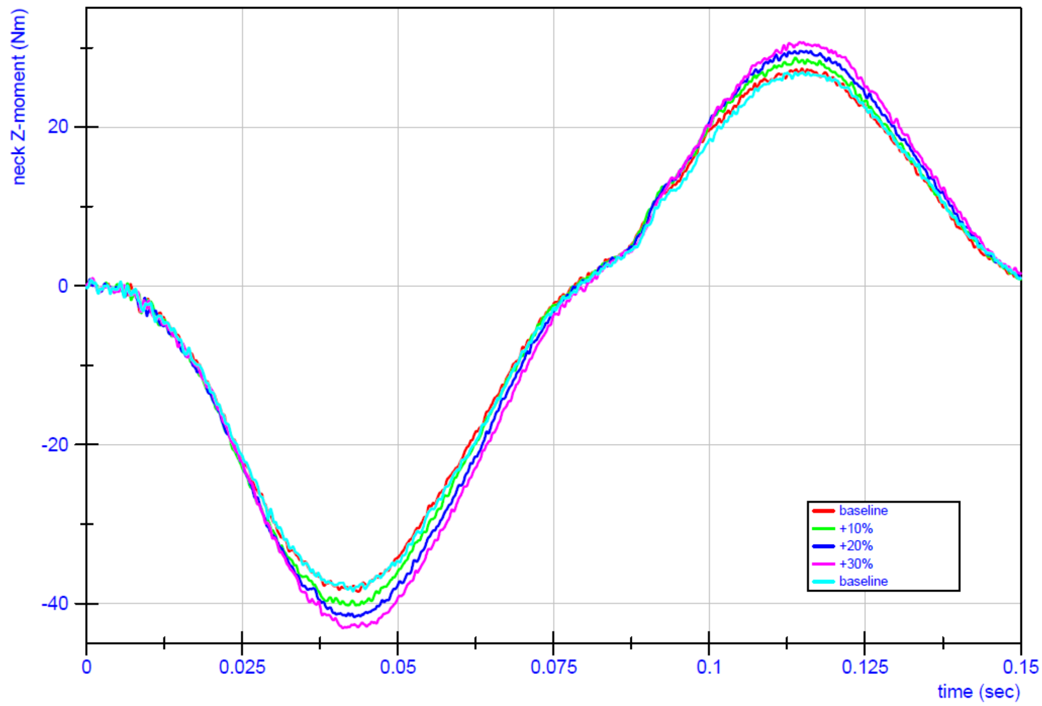

Figure M-1. Neck Torsion Test – Moment about Z-axis

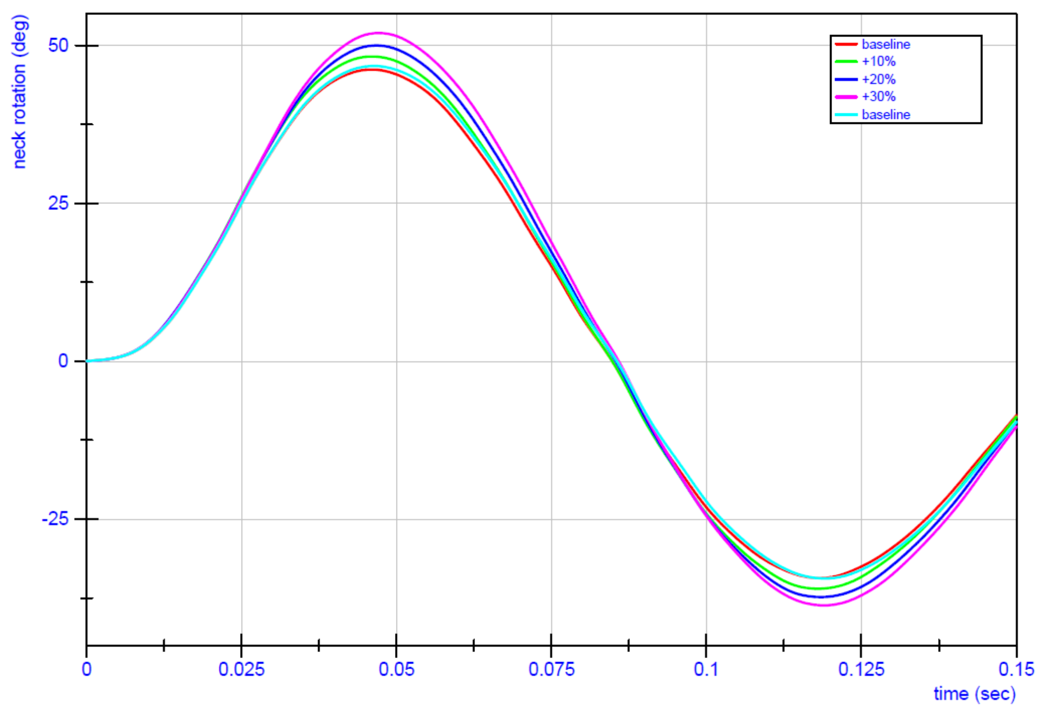

Figure M-2. Neck Torsion Test – Neck Rotation Angle

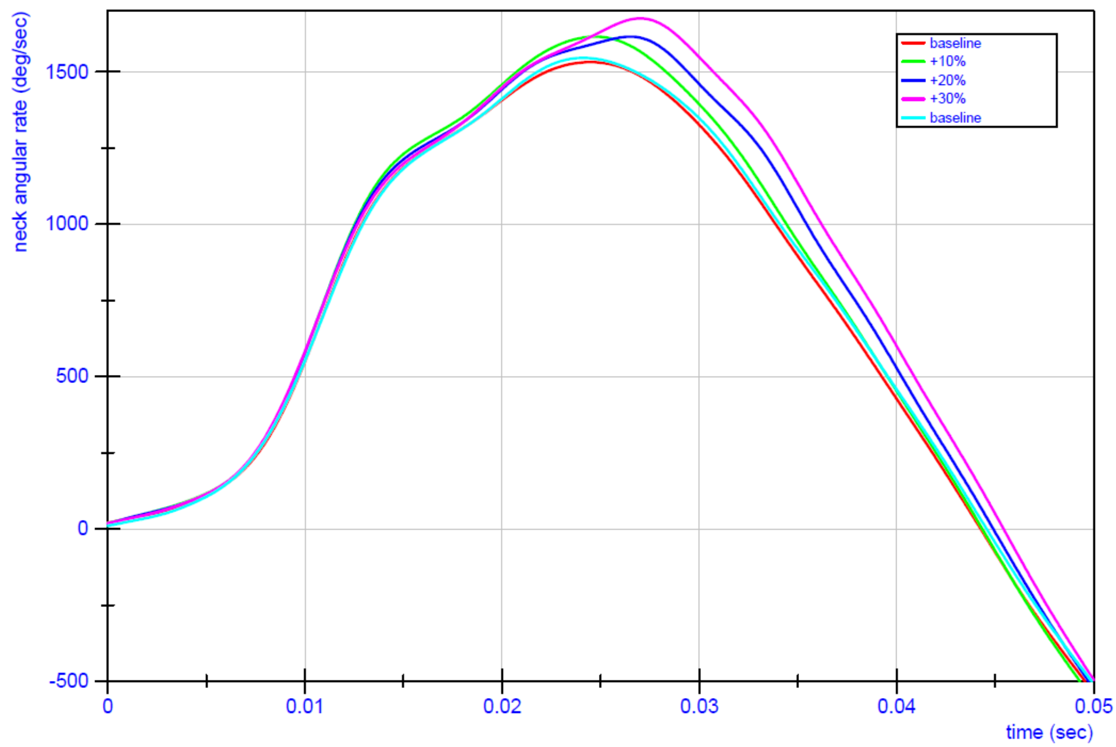

Figure M-3. Neck Torsion Test – Neck Angular Velocity

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