U.S. Department of Transportation

Federal Railroad Administration

Office of Research, Development and Technology
Washington, DC 20590

Commuter Rail Seat Testing in Open-Bay Configuration

DOT/FRA/ORD-22/16

Final Report | April 2022

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
07/31/2021

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*
October 2020-July 2021

4. TITLE AND SUBTITLE
Commuter Rail Seat Tests in Open-Bay Configuration

5a. CONTRACT NUMBER
693JJ620C000019

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Ryan Zika – Test Engineer (0000-0002-9558-6811)
Greg Shively – Test Engineer (000-0002-9875-5967)
Jeremy Wood – Project Manager (0000-0002-7825-8787)
Jennifer Young – Quality Manager (0000-0003-4302-1541)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
MGA Research
Corporation820
Suburban Park Dr.
Greer, SC 29651

8. PERFORMING ORGANIZATIONREPORT NUMBER
C20S9-017

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Washington, DC 20590

10. SPONSOR/MONITOR'S ACRONYM(S)
FRA

11. SPONSOR/MONITOR'S REPORTNUMBER(S)
DOT/FRA/ORD-22/16

12. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the FRA website.

13. SUPPLEMENTARY NOTES
COR: Jeffrey Gordon

14. ABSTRACT
Open-bay seating is a common configuration in U.S. passenger railcars. The current version of the American Public Transportation Association's safety standard on passenger seating (APTA PR-CS-S-016-99, Rev. 3) requires open-bay seats to be tested if more than 50 percent of a car's seating is configured as open-bay. The objective of this research study was to determine if existing seats developed for use in a row-to-row configuration would comply with the seat safety standard requirements in the open-bay configuration without any design modifications. Of the four seat types tested, only one satisfied all of the human injury criteria.

15. SUBJECT TERMS
Passenger seats, open-bay, facing seats, dynamic testing, structural integrity, occupant safety, crashworthiness, dynamic sled testing, anthropomorphic test device, ATD, rail passenger safety, secondary

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE		114	19b. TELEPHONE NUMBER *(Include area code)*

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

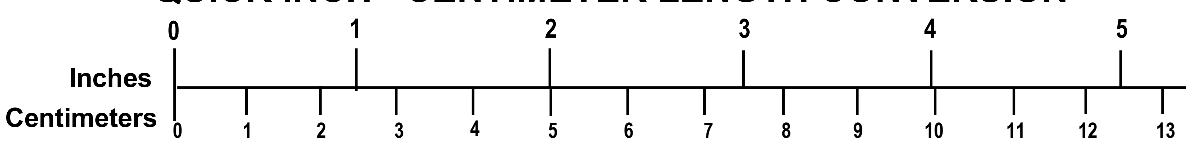
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

Acknowledgements

MGA Research Corporation would like to thank the manufacturers that donated seats for this test series.

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Executive Summary

From November 2020 through June 2021, MGA Research Corporation (MGA), located in Greer, South Carolina, performed four sled tests with standard Hybrid III 50th percentile male anthropomorphic test devices (ATDs) to evaluate seat structural integrity and corresponding ATD injury values when seated in an open-bay configuration in a simulated collision.

Open-bay seating is a common configuration in U.S. passenger railcars. Currently, the American Public Transportation Association's (APTA) industry safety standard APTA PR-CS-S-016-99, Rev. 3 (S-016), Passenger Seats in Passenger Rail Cars, requires the open-bay seating configuration to be tested if more than 50 percent of a car's passenger seating is configured as open-bay seating.

The objectives of this study were as follows:

1. Perform four sled tests with seats in the open-bay seating configuration utilizing two standard, Hybrid III 50th percentile ATDs.
2. Utilize head, neck, chest, and femur transducers to collect injury values for both ATDs.
3. Evaluate the structural performance of seats in an open-bay configuration.
4. Evaluate the ability of seats to compartmentalize occupants in an open-bay configuration.
5. Determine if seats in the open-bay configuration comply with the performance requirements in APTA S-016.

The MGA research team performed the four sled tests using seats donated by car builders and seat manufacturers according to Section 3.2.1 of S-016. The sled pulse used for the tests was calibrated to comply with the pulse specified in Section 3.2.2.1 of S-016.

For each test, technicians positioned the seats in an open-bay configuration representative of their position in a railcar. Rigid fixtures were manufactured and provided by each seat or railcar supplier to simulate the mounting that the seats would have in a railcar. Technicians positioned the two ATDs in the seats as specified in Section 3.2.1 of S-016. They used three high-speed cameras to capture the event, including one overhead and two side views. They took pre- and post-test measurements as specified in the statement of work for this study.

The team collected and analyzed the ATDs' data channels as specified in Section 3.2.1 of S-016. The test data ultimately showed only one of the seats complied with the injury value requirements. Test 1 complied with all injury criteria limits. Test 2 exceeded the head injury criterion compliance limit of 700 on the right (wall) side ATD by 294. Test 3 exceeded head injury criterion limit by 53 on the left (aisle) side. The neck injury criterion was also greater than the compliance limit of 1.0 by 20 percent on the left (aisle) ATD, and 4 percent on the right (wall) side. For test 4, the neck injury criterion for tension/extension exceeded the limit by 2 percent for the left (aisle) ATD and 23 percent for the right (wall) ATD. The right femur for the left (aisle) ATD exceeded the 10,000 N limit by 1,044 N. Other instances of non-compliance with the standard included seat separation from its attachments and non-compartmentalization of the ATDs.

1. Introduction

In March 1999, the American Public Transportation Association (APTA) released a standard for passenger safety in passenger railcars (S-016) [1]. This standard has been revised in 2003, 2010, and 2021 for passenger railcar seats. At the time of this testing (November 2020 to June 2021), APTA was in the process of adding requirements for seats used in an open-bay configuration to Revision 3 (March 2021) of the standard.

1.1 Background

Before March 2021, APTA PR-CS-S-016-99 only required dynamic testing of passenger rail seats in a row-to-row seating configuration for forward-facing and rear-facing occupants. Many railcars however, also have the option for passengers to sit in an open-bay configuration. In this configuration two rows of seats face each other, creating a greater space between an occupant and the next (facing) row of seats. In the event of a collision, occupants would travel a greater distance before impacting the seating row in front of them, resulting in a larger secondary impact velocity, compared to occupants in row-to-row seating. This could lead to (1) greater human injury, (2) a greater chance the occupant would not be compartmentalized between seating rows, and (3) a greater chance the structural integrity or attachment of the impacted seat would be compromised. The purpose of these tests was to evaluate human injury, compartmentalization, and seat structural integrity in a simulated collision with an open-bay seating configuration.

Previously, FRA sponsored quasi-static and dynamic tests of legacy Bombardier commuter rail seats in an open-bay configuration [2]. These tests were a continuation of a larger test series at Simula Technologies, Inc. which included quasi-static and dynamic row-to-row tests of three different seat types in 1998 [3]. The Bombardier commuter rail seats were dynamically tested in the open-bay configuration twice, with two Hybrid-III family ATDs seated forward facing. The first test used two 50^{th} percentile male ATDs, and the second test used a 95^{th} percentile male ATD in the wall seat and a 5^{th} percentile female ATD in the aisle seat. Both open-bay tests resulted in structural failure of the seats with the headrests breaking and seat cushions detaching. At least one ATD was not compartmentalized in each test. The seats met the head, chest, and femur human injury requirements but failed the injury requirements for the neck. The 5^{th} percentile female ATD experienced the highest neck injury criteria. Similar seat damage was also observed in a commuter train accident in Chatsworth, CA [4]. The accident report identifies open-bay seats as one of the more hazardous seating configurations, due to the large distance between seats which resulted in an increased secondary impact velocity. The vertical pitching motion of the trailing coach car caused several occupants to be launched over the top of facing seatbacks, coming to rest 20 feet or more from the initial seat position – with extensive injuries. The vertical carbody motion is not represented in sled tests, but it can make it more difficult for seats to effectively compartmentalize occupants between rows of seats in an accident.

In previous studies, while multiple seat types were tested in the row-to-row configuration, only one seat type was tested in an open-bay configuration. The researchers noted that the Bombardier commuter rail seat used in the open bay tests was relatively stiff when compared with other commuter rail seats. Note that the Bombardier commuter rail seat design predated the 1999 publication of S-016. The current study at MGA can be considered a continuation of the previous research at Simula with more modern seats designed to meet the row-to-row dynamic test performance requirements in S-016.

1.2 Objectives

- Perform four sled tests using seats in an open-bay seating configuration.
- Collect injury data for both ATDs.
- Evaluate the performance of the seats with regards to human injury, compartmentalization, and structural integrity as specified in S-016.

1.3 Overall Approach

Three anonymous manufacturers provided seats for the test series, with one manufacturer providing two seat types, for a total of four tests. Two seat types were current production seats designed to meet the current row-to-row requirements in the APTA standard. The other two were developmental seats not yet placed in rail service.

The Federal Railroad Administration's (FRA) Office of Research, Development and Technology (RD&T) sponsored the tests to improve safety on passenger rail equipment by supporting the development of S-016. All test setups were approved by a representative from the seat manufacturer and a representative from the Volpe National Transportation Systems Center (Volpe). Volpe provides technical support to the FRA's Office of RD&T on various projects, including occupant protection in passenger rail equipment.

1.4 Scope

The four tests were conducted using four different seat designs. For all tests the seats were mounted to rigid fixtures provided by each seat donor to resemble the real-world mounting conditions as closely as possible. All seats were positioned as specified by the seat donor to represent a real-world, open-bay seating configuration. All seats were attached to the fixtures using production fasteners provided by the seat donor.

Among additional test requirements, S-016 requires open-bay seats to comply with the forward-facing seat attachment test requirements in Section 3.3.4 using an uninstrumented Hybrid III 95th percentile male ATD. This test was not included in the scope of this work.

1.5 Organization of the Report

The report is organized as follows:

Section 1: Introduction

A brief overview of the test series and its objectives

Section 2: Test procedure, conditions, and pre-test measurements

An overview of the procedure for the test and all pre-test measurements

Section 3: Test results and post-test measurements

The results and post-test measurements for each seat type

Section 4: Test Summary

A brief summary of each test

Section 5: Test Discussion

2. Section 2 Test Implementation

2.1 Sled Equipment

All tests were executed using MGA's sled system – a pneumatic accelerator sled that uses compressed air to accelerate the sled carriage. The basic operation of the sled involves applying an acceleration force (through the thrust column) to the sled carriage which is initially at rest. The simulated carbody, seats, ATDs, test articles, and other data acquisition components are mounted directly to the carriage assembly. When the carriage is accelerated, the components and occupants experience a "negative acceleration" similar to the deceleration experienced in an impact (crash) event.

2.2 Calibration Pulse

Prior to the testing, MGA technicians conducted calibration tests by attaching ballast weight to the sled to simulate the weight of the ATDs and the seats. To help offset the effect of the ATD and seat kinematics during the actual test, additional ballast weight was also used to effectively increase the mass of the sled carriage. Below is the pre-test calibration pulse (Figure 1) with its corresponding velocity curve (Figure 2).

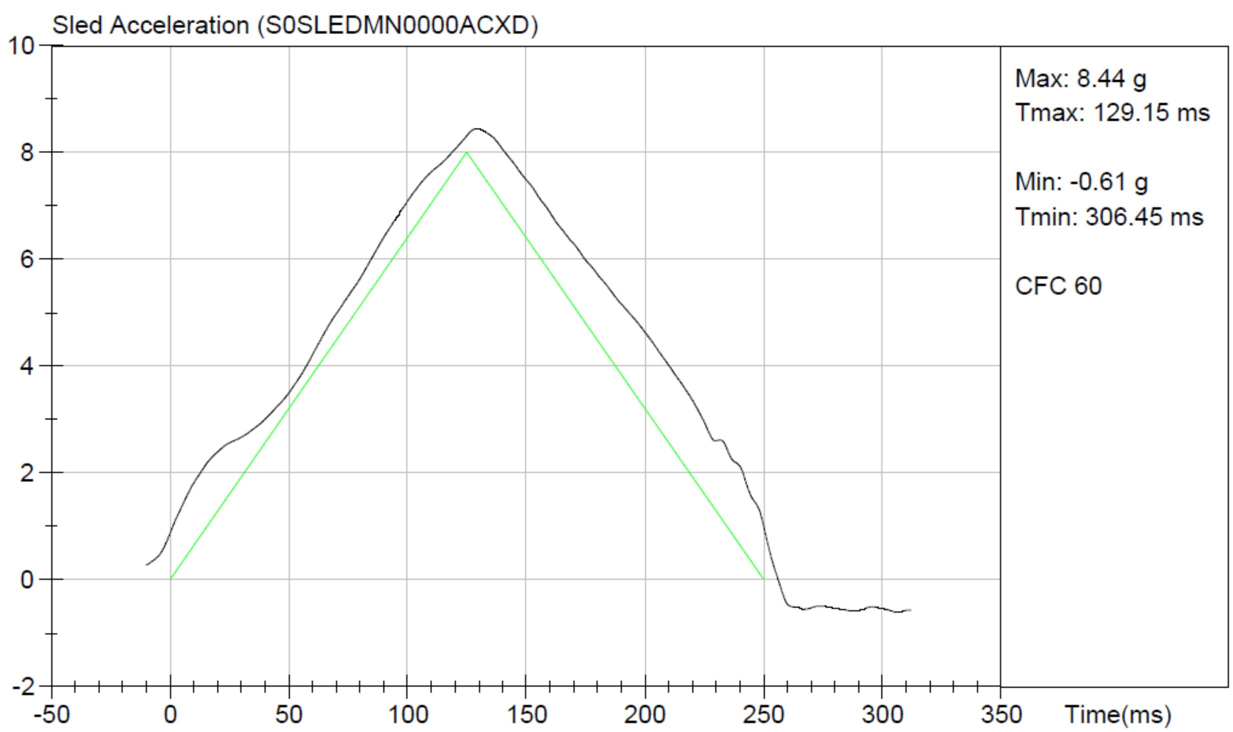


Figure 1: Pre-Test Calibration Acceleration Curve

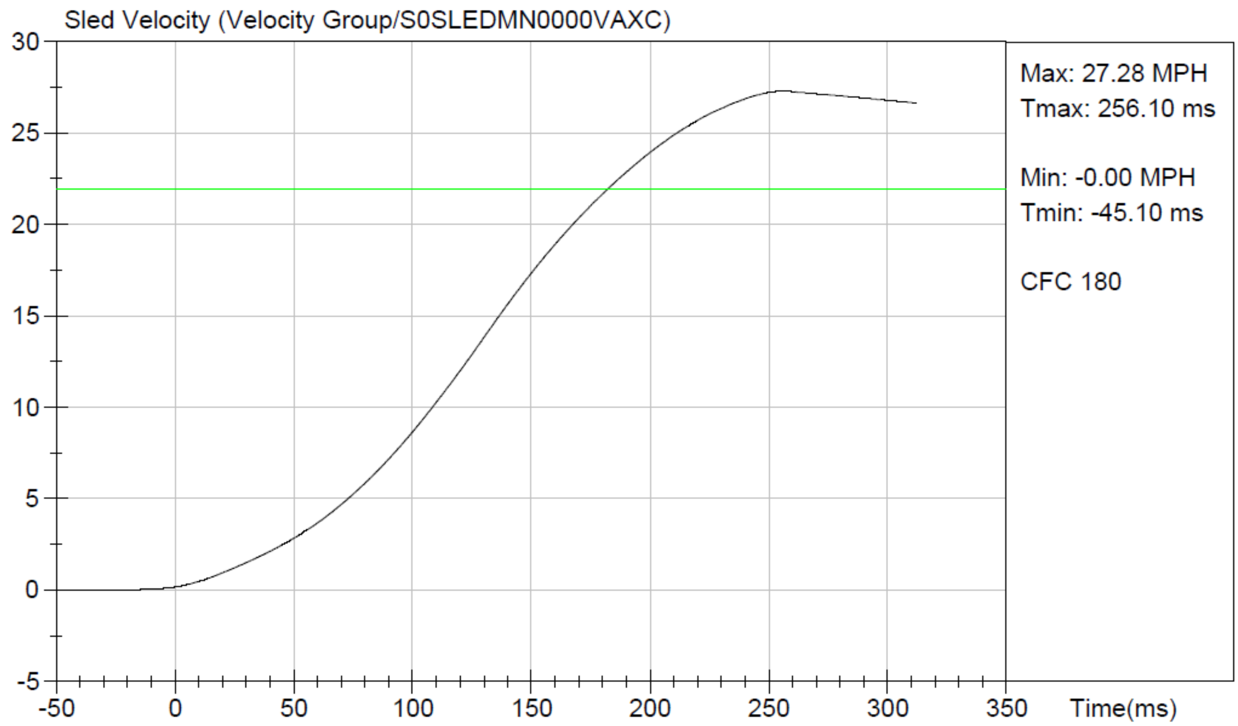


Figure 2: Pre-Test Calibration Velocity Curve

2.3 Pre-test Measurements

The simulated carbody components were rigidly attached to the test sled. Three, two-occupant seats were fastened to the simulated carbody in the nominal location for their intended rail service. This setup information, provided by each donor, was documented prior to the execution of the test using calibrated measuring devices. For documentation and verification purposes, photographs were taken of each measurement, pre- and post-test. The unoccupied rearward-facing seat in the open-bay configuration was backed by a third seat in a forward-facing position (backing seat). A simulated floor covering was included in the test setup to replicate the actual railcar floor covering. Detailed pre- and post-test photographs were taken of the seats to document the seat mounting locations and conditions to permit evaluation of any post-test damage. The pre- and post-test measurements are detailed in Figure 3 and Table 1 below. All measurements were taken at the center of each occupant position.

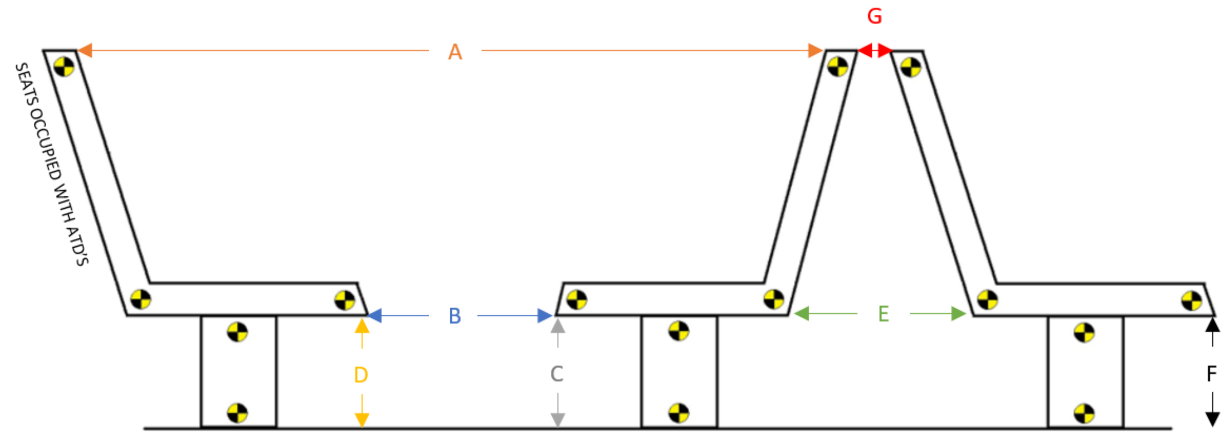


Figure 3: Schematic of Pre- and Post-Test Measurements to Be Recorded

Table 1: Pre and Post-Test Measurement Descriptions

Measurement Location	Description of Measurement
A	Longitudinal distance (in a horizontal plane) between the top of the occupied forward-facing (launch) seat and the top of the rearward-facing (impact) seat
B	Longitudinal distance (in a horizontal plane) between front edge of the occupied launch seat cushion and the front edge of the impact seat cushion
C	Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the impact seat
D	Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the launch seat
E	Longitudinal distance (in a horizontal plane) between the rear edge of the impact seat cushion and the rear edge of the unoccupied forward-facing (back) seat cushion
F	Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the backing seat
G	Longitudinal distance (in a horizontal plane) between the rear edge of the impact seatback and the rear edge of the backing seatback

2.4 ATDs

For the following tests two Hybrid III 50th percentile male ATDs were instrumented and utilized to measure human injury. Technicians instrumented the ATDs with the transducers listed in Table 2.

Table 2: ATD Transducers

Body Region	Data Channel
Head	Triaxial Head Acceleration
Chest	Triaxial Chest Acceleration
Femur	Axial Left and Right Femur Load Cell
Neck	Six Axis Load Cell

The ATDs' transducers used in Table 2 were also used to calculate the injury data below in Table 3.

Table 3: Measured ATD Injury Values

Body Region	Injury Criteria
Head	HIC15
Chest	3ms Chest Acceleration
Femur	Maximum Femur Axial Compression
Neck	Nij Maximum Neck Axial Tension and Compression

2.5 Test Procedure

The following test procedure was approved by Volpe and followed for each test:

- Fasten the test articles to the simulated carbody structures:
  - Verify the proper fasteners and torques with the customer.
  - Verify the proper floor and carbody attachments are used.
- Inspect the ATDs and note any damage prior to the test:
  - Check the ATD's clothes and skin for cuts or tears.
  - Check the tension of all ATDs' joints.
  - Every three sled runs, torque the ATDs' lumbar to 11 in/lbf ± 1 in/lbf and neck column to 12 in/lbf ± 2 in/lbf.
- Verify all ATD channels pass calibration and are functioning properly.
- Using the data acquisition system, perform a sensor check and ATD manipulations (per SAE J211).
- Verify the following requirements as stipulated by S-016 Section 5.2:
  - Back shall be placed against the seatback without clearance.
  - Knees shall be separated by 6.7 inches, center-to-center. This is also equivalent to 4 inches, inside-to-inside.

- Hands shall be placed on the thighs, palms down.
    - Feet shall be placed on the floor so that the centerlines of the lower legs are approximately parallel.
    - Lower legs shall be placed as close to vertical as possible.
    - Chalk shall be applied to the ATDs' face and knees.
    - Tether the ATD such that it will not interfere with the test or the evaluation of compartmentalization but will attempt to mitigate any additional damage when the ATDs rebound. Tether will be tied around the ATDs' waist that is shorter than instrumentation cable slack and will prevent the ATD from ultimately being ejected from the sled.
    - Verify all camera cables are well-secured to the sled carriage and booms.
    - Verify lenses are tightened onto cameras. Verify F-stop and focus adjustment set screws are tightened.
    - Verify all loose items (tools, parts, etc.) are removed from the sled carriage.
    - Take the pre-test measurements for both ATDs.
    - Create a test setup file using the data acquisition system and ensure the sled accelerometers are the correct serial numbers and are in calibration.
- The following ATD channels will be collected:
    - Triaxial head acceleration-time history
    - Triaxial chest acceleration-time history
    - Axial left and right femur force-time history
    - Upper neck extension/flexion bending moment, M_y, time history
    - Upper neck axial force, F_z, time history
    - Upper neck shear force, F_x, time history
    - Longitudinal acceleration-time history of the test sled
- Take eight pre-test photos. Check with customer or specification to see if additional views are required.
- Have the seat manufacturer and Volpe representative verify and sign off on the setup.
- Execute the test.
- Process and save test data and videos.
- Inspect the rails and carriage for any damage.
- Take post-test photos to match the pre-test photos, plus any additional views requested by the customer.
- Inspect the ATD and note any damage after the test.
- Perform a post-test calibration of the ATDs' channels to verify all channels still function appropriately post-test.

- Process the following required ATD injury criteria per SAE J211 and J1727:
  - Head injury criterion (HIC15)
  - 3ms chest g's
  - Peak axial femur load
  - Peak upper neck axial tension/compression loads
  - Peak neck injury criterion (Nij)
- Evaluate the seat based on the following criteria:
  - The ATDs shall be compartmentalized.
    - The ATD must be confined between the impact seat (potentially deformed) and the initially occupied seat until the point of maximum forward motion of the ATD, i.e., when the ATD begins to rebound and move away from the impacted seat.
  - All injury measurements computed in Section 5.1.2 must meet the criteria defined in Table 4 below.

Table 4: Injury Criteria

Description	**APTA PR-CS-S-016-99, Rev. 3 §5.2.1.3 Performance Requirements**
Head Injury Criteria (HIC15)	HIC15 ≤ 700
Neck Injury Criteria (Nij)	Nij Compression/Extension ≤ 1.0
	Nij Compression/Flexion ≤ 1.0
	Nij Tension/Extension ≤ 1.0
	Nij Tension/Flexion ≤ 1.0
Neck Axial Force (F_z) in Tension	$F_z \leq$ 4,170 N
Neck Axial Force (F_z) in Compression	$F_z \geq$ -4,000 N
Resultant Mid-thoracic Spine Acceleration (Acc)	Acc ≤ 60g over a 3ms clip
Femur Axial Force	Left Femur ≤ 10,000 N
	Right Femur ≤ 10,000 N

- Take the following post-test measurements for both occupants:
    - Longitudinal distance (in a horizontal plane) between the top of the occupied forward-facing seat and the top of the rearward-facing seat
    - Longitudinal distance (in a horizontal plane) between front edge of the occupied forward-facing seat cushion and the front edge of the rearward-facing seat cushion
    - Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the unoccupied rearward-facing seat
    - Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the occupied forward-facing seat
    - Longitudinal distance (in a horizontal plane) between the rear edge of the rearward-facing seat cushion and the rear edge of the unoccupied forward-facing seat cushion
    - Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the unoccupied forward-facing seat

3. Results

3.1 Test 1

3.1.1 Test 1: Background

The seats donated for Test 1 are developmental seats. These seats consist of a single pedestal mount and a wall mount. Both the pedestal and the wall mount were attached to a slot on the test fixture using T-stud mounting hardware. The flooring consisted of plywood covered with carpet provided by the donating party.

3.1.2 Test 1: Setup and Crash Pulse

The test setup is depicted in Figure 4 and Figure 5 below. The corresponding post-test photos are shown in Figure 6, Figure 7, and Figure 8. The test pulse is shown in Figure 9.

Figure 4: Test 1 Lateral Pre-Test Photo

Figure 5: Test 1 Isometric Pre-Test Photo

Figure 6: Test 1 Lateral Post-Test Photo

Figure 7: Test 1 Isometric Post-Test Photo

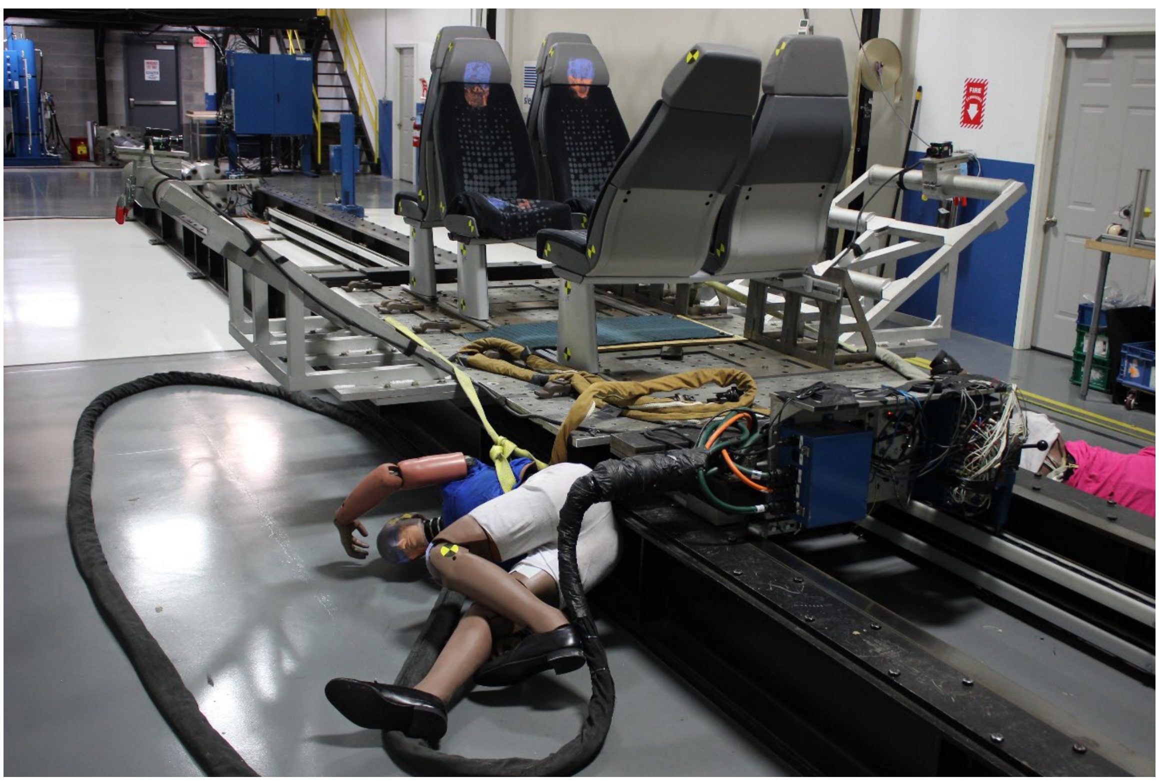


Figure 8: Test 1 Post-Test ATD Positions

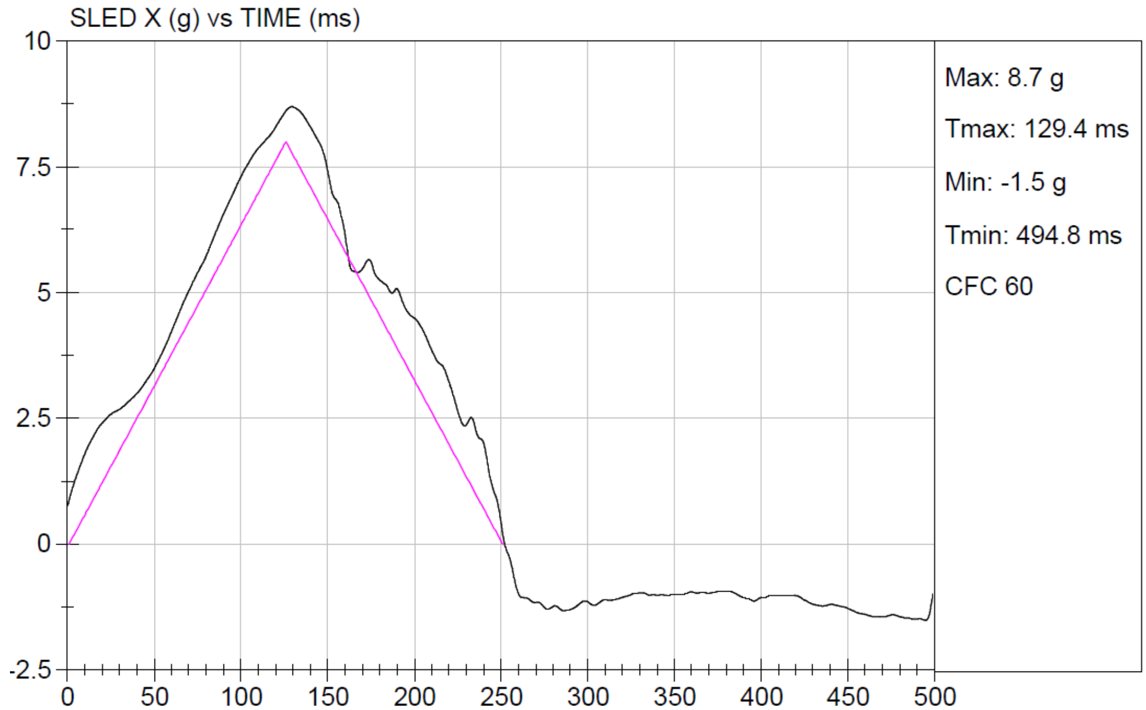


Figure 9: Test 1 Crash Pulse

3.1.3 Test 1: Post-test Observations

Figure 10: Test 1 Impact Seat Pan

Impact seat pan structure deformed during the event.

Impact seat pedestal deformed at floor mounting.

Figure 11: Test 1 Impact Seat Pedestal

Impact seat slid at the interface between the seat and wall mount bracket.

Figure 12: Test 1 Impact Seat Wall Mount Bracket

ATDs' heads impacted seatbacks of impact seats.

Figure 13: Test 1 ATD Head Impact Region

3.1.4 Test 1: Human Injury Values

Table 5 below contains the human injury evaluation for Test 1.

Table 5: Test 1 Human Injury Measurements

Description	APTA PR-CS-S-016-99, Rev. 3 §5.2.1.3 Performance Requirements	Left ATD (Aisle)	Right ATD (Wall)
Head Injury Criteria (HIC15)	HIC15 ≤ 700	682	641
Neck Injury Criteria (Nij)	Nij Compression/Extension ≤ 1.0	0.7	0.6
	Nij Compression/Flexion ≤ 1.0	0.2	0.8
	Nij Tension/Extension ≤ 1.0	0.3	0.3
	Nij Tension/Flexion ≤ 1.0	0.3	0.1
Neck Axial Force (F_z) in Tension	$F_z \leq$ 4,170 N	1679	582
Neck Axial Force (F_z) in Compression	$F_z \leq$ 4,000 N	1764	1752
Resultant Mid-thoracic Spine Acceleration (Acc)	Acc ≤ 60g over a 3ms clip	18	19
Femur Load	Left Femur ≤ 10,000 N	4746	4517
	Right Femur ≤ 10,000 N	5862	6368

3.1.5 Test 1: Pre and Post-test Measurements

Figure 14 through Figure 17 show the pre- and post-test measurements for Test 1.

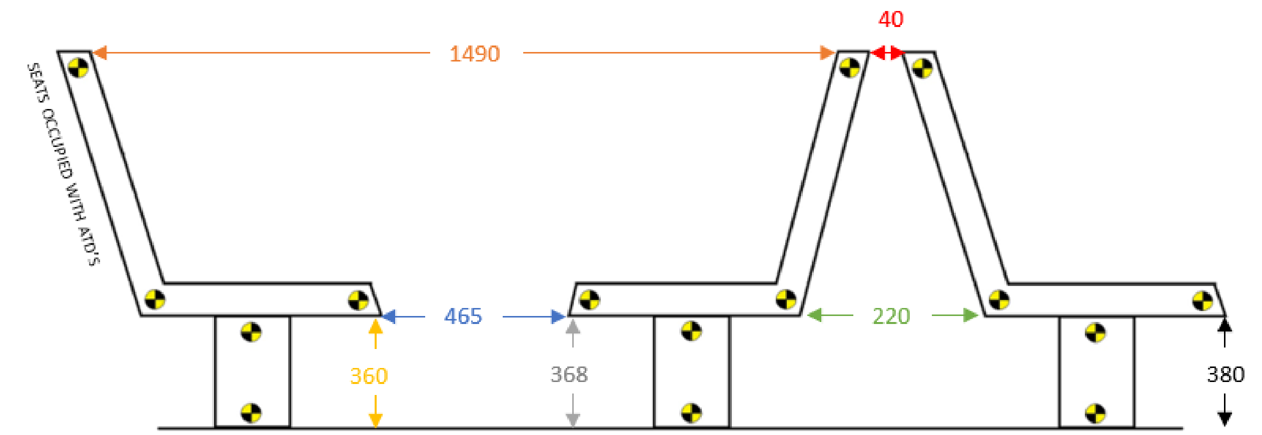


Figure 14: Test 1 Right Hand (Wall) Seat Pre-Test Measurements

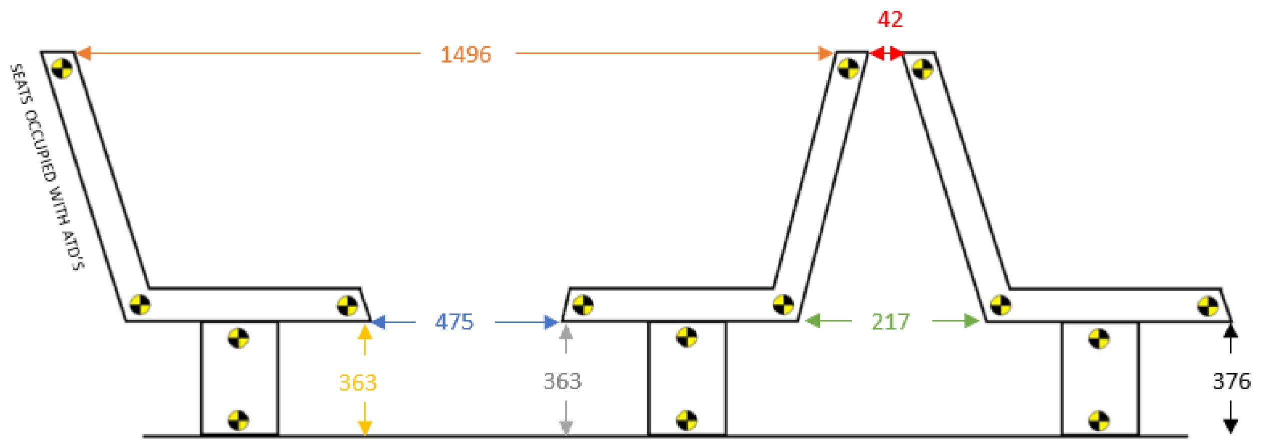


Figure 15: Test 1 Left Hand (Aisle) Seat Pre-Test Measurements

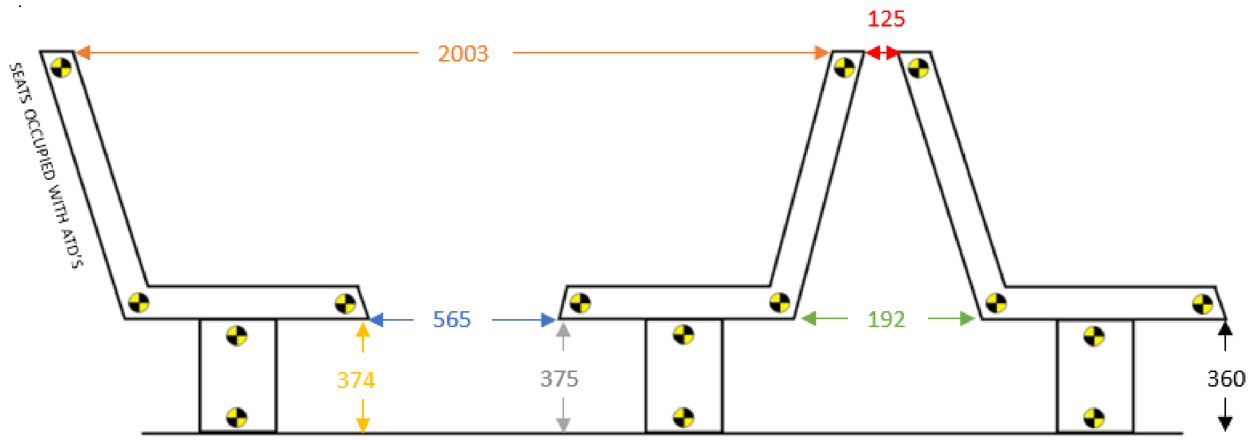


Figure 16: Test 1 Right Hand (Wall) Seat Post-Test Measurements

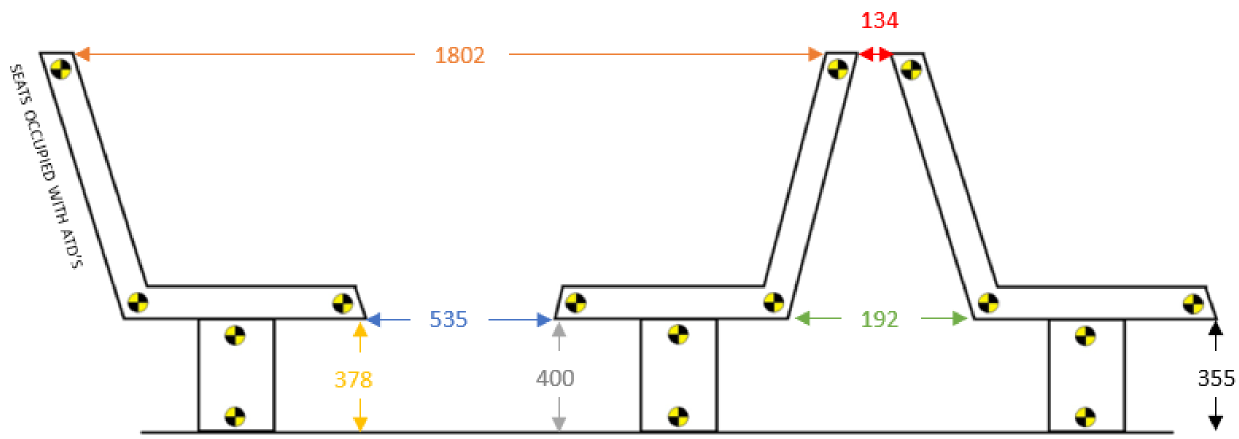


Figure 17: Test 1 Left Hand (Aisle) Seat Post Test Measurements

Table 6 below contains the pre- and post-test measurements for Test 1.

Table 6: Test 1 Pre- and Post-Test Measurements by Occupant

Measurement	Pre-test Wall [mm]	Pre-test Aisle [mm]	Post-test Wall [mm]	Post-test Aisle [mm]
Longitudinal distance (in a horizontal plane) between the top of the launch seat and the top of the impact seat	1490	1496	2003	1802
Longitudinal distance (in a horizontal plane) between front edge of the launch seat cushion and the front edge of the impact seat cushion	465	475	565	535
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the impact seat	368	363	375	400
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the launch seat	360	363	374	378
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seat cushion and the rear edge of the backing seat cushion	220	217	192	192
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the backing seat	380	376	360	355
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seatback and the rear edge of the backing seatback	40	42	125	134

3.1.6 Test 1: Post-test Evaluation

Table 7 below contains the results of the APTA post-test evaluation.

Table 7: Test 1 APTA Post-Test Evaluation

APTA Requirement	Assessment
Seats may deform but shall not tear loose from their mountings.	Seats deformed but stayed attached during the event.
Seat components shall not tear loose and become separated from the seat assembly.	No seat components tore loose during the event.
The ATDs shall be compartmentalized between rows of seats. After testing, the seats shall not be deformed to such an extent that they present an impediment to emergency egress.	The ATDs were compartmentalized as defined by APTA PR-CS-S-016-99, Rev. 3. Seat deformation would not have impeded emergency egress.
All injury measurements must meet the criteria specified in the standard.	All human injury requirements were met. Table 5 above contains the human injury evaluation for Test 1.
The anti-rotational lock mechanism in rotating seats shall not fail, and the seat shall be retained in the locked position.	N/A
Tray tables may deploy during event provided they can be moved out of the way for occupant egress.	N/A

3.2 Test 2

3.2.1 Test 2: Background

The seats donated for Test 2 are production seats. These seats are a walkover-style seat where the seat can be moved from forward-facing to rearward-facing. These seats implement an inertial anti-rotational lock to prevent them from rotating during a collision. The walkover seat structure was rigidly mounted to the sled carriage on a double pedestal.

3.2.2 Test 2: Setup and Crash Pulse

The test setup is depicted in Figure 18 and Figure 19 below. The corresponding post-test photos are shown in Figure 20, Figure 21, and Figure 22. The test pulse is shown in Figure 23.

Figure 18: Test 2 Lateral Pre-Test Photo

Figure 19: Test 2 Isometric Pre-Test Photo

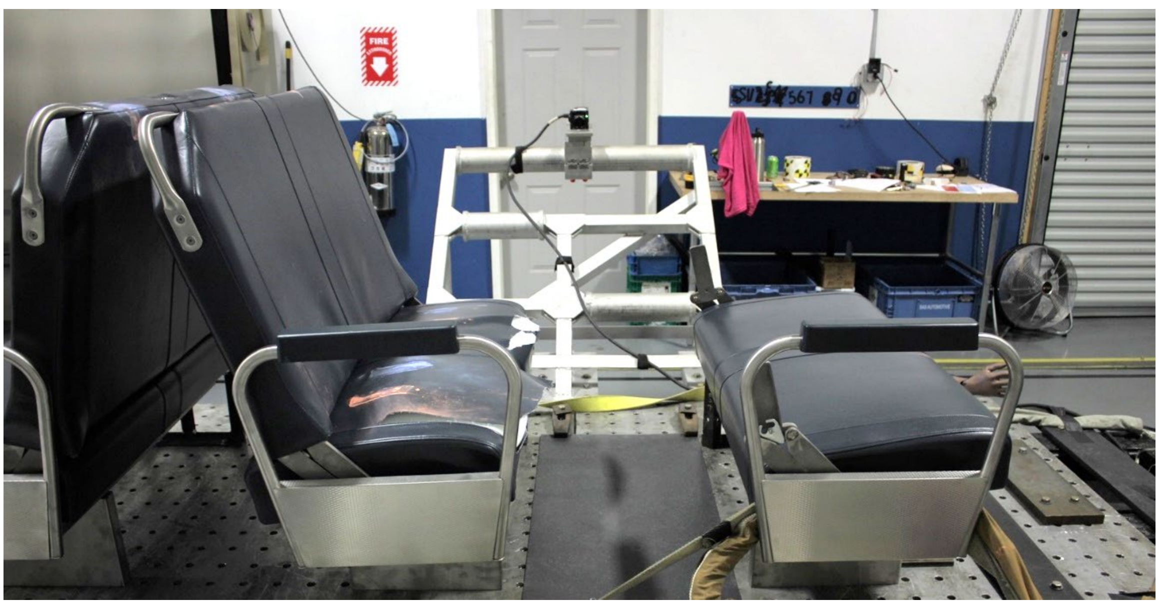


Figure 20: Test 2 Lateral Post-Test Photo

Figure 21: Test 2 Isometric Post-Test Photo

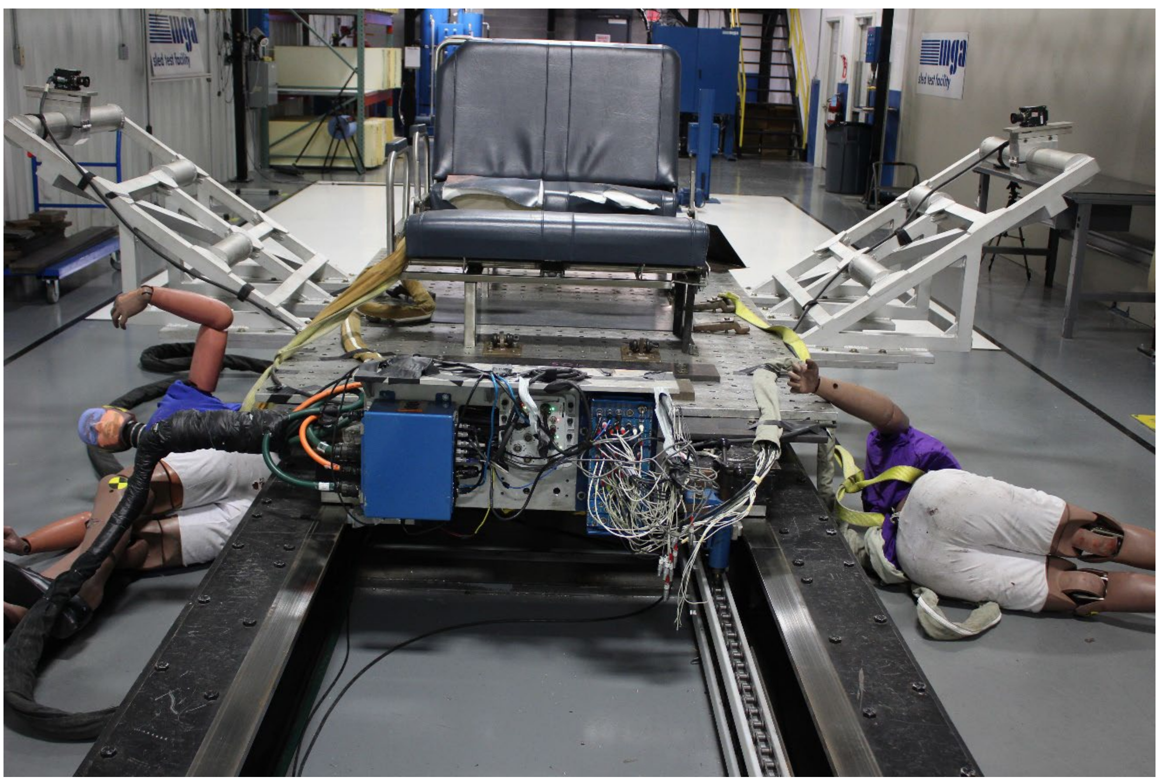


Figure 22: Test 2 Post-Test ATD Positions

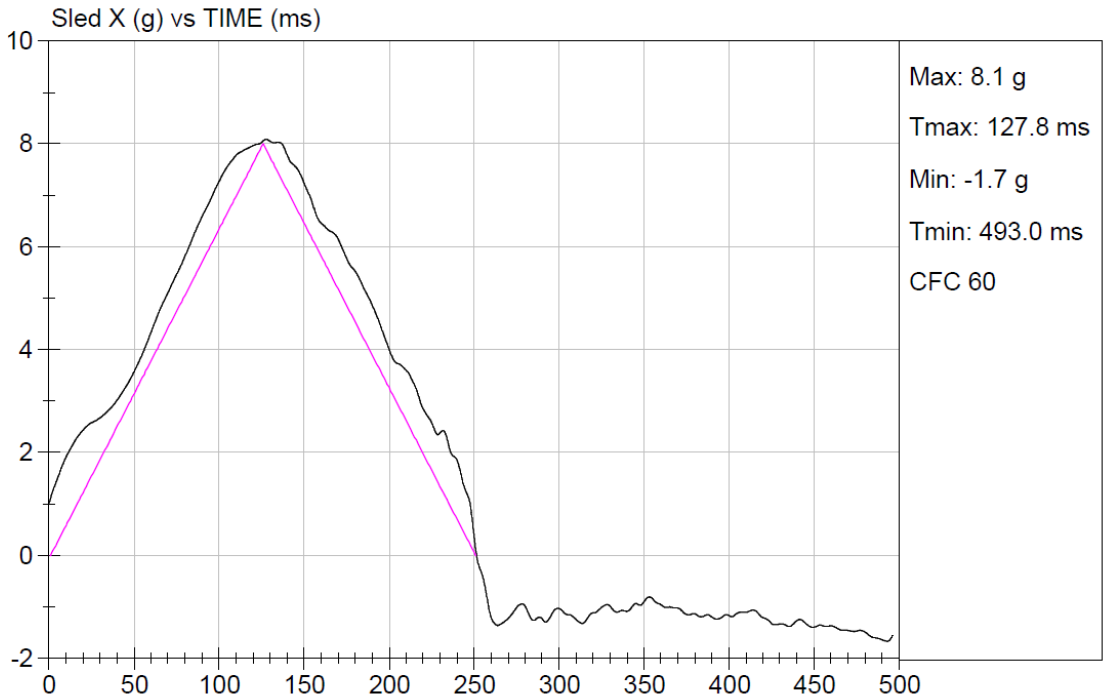


Figure 23: Test 2 Crash Test Pulse

3.2.3 Test 2: Post-test Observations

Figure 24: Test 2 Impact Seat Vinyl

ATDs' knees contacted the impact seat cushion during the event. The friction from the ATDs' knees moving across the top of the cushion caused the vinyl to tear.

Figure 25: Test 2 Launch Seat Seatback

Inertial lock on launch seat did not properly engage, allowing the seatback to rotate and detach during the event.

Figure 26: Test 2 Impact Seatback Rotational Lock

Impact seat seatback's rotational lock bent during the event.

Figure 27: Test 2 Impact Seat Pan Structure

Impact seat pan structure bent during event.

Figure 28: Test 2 ATD Head Impact Region

ATDs' heads impacted the backing seat. The ATDs' momentum carried their torsos over the impact seatback.

3.2.4 Test 2: Human Injury Values

Table 8 below contains the human injury evaluation for Test 2.

Table 8: Test 2 Human Injury Measurements

Description	APTA PR-CS-S-016-99, Rev. 3 §5.2.1.3 Performance Requirements	Left ATD (Aisle)	Right ATD (Wall)
Head Injury Criteria (HIC15)	HIC15 ≤ 700	682	994
Neck Injury Criteria (Nij)	Nij Compression/Extension ≤ 1.0	0.1	0.1
	Nij Compression/Flexion ≤ 1.0	0.5	0.8
	Nij Tension/Extension ≤ 1.0	0.2	0.2
	Nij Tension/Flexion ≤ 1.0	0.2	0.3
Neck Axial Force (F_z) in Tension	$F_z \leq 4,170$ N	681	836
Neck Axial Force (F_z) in Compression	$F_z \leq 4,000$ N	1425	2441
Resultant Mid-thoracic Spine Acceleration (Acc)	Acc ≤ 60g over a 3ms clip	19	14
Femur Load	Left Femur ≤ 10,000 N	2320	2046
	Right Femur ≤ 10,000 N	1557	2514

3.2.5 Test 2: Pre and Post-test Measurements

Figure 29 through Figure 32 show the pre- and post-test measurements for Test 2.

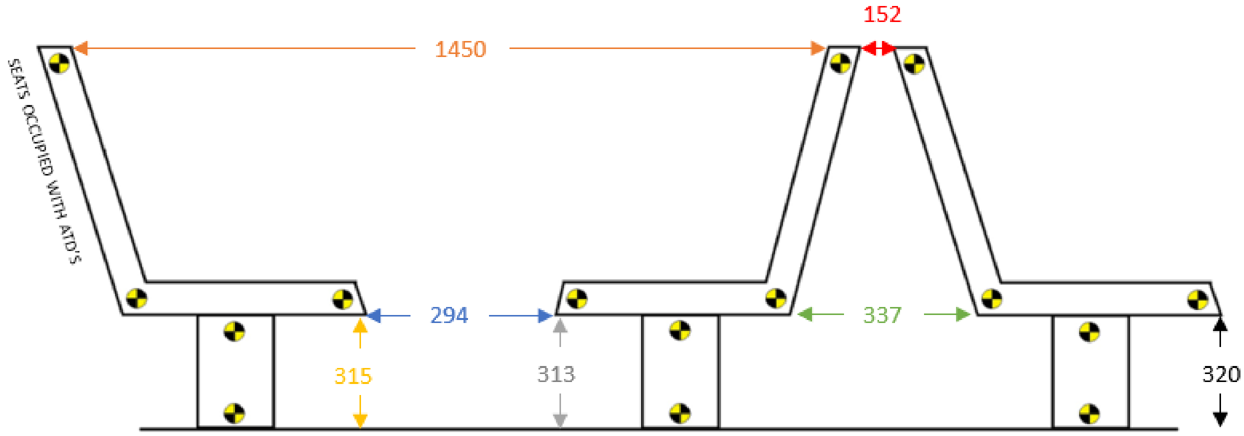


Figure 29: Test 2 Right-Hand (Wall) Seat Pre-Test Measurements

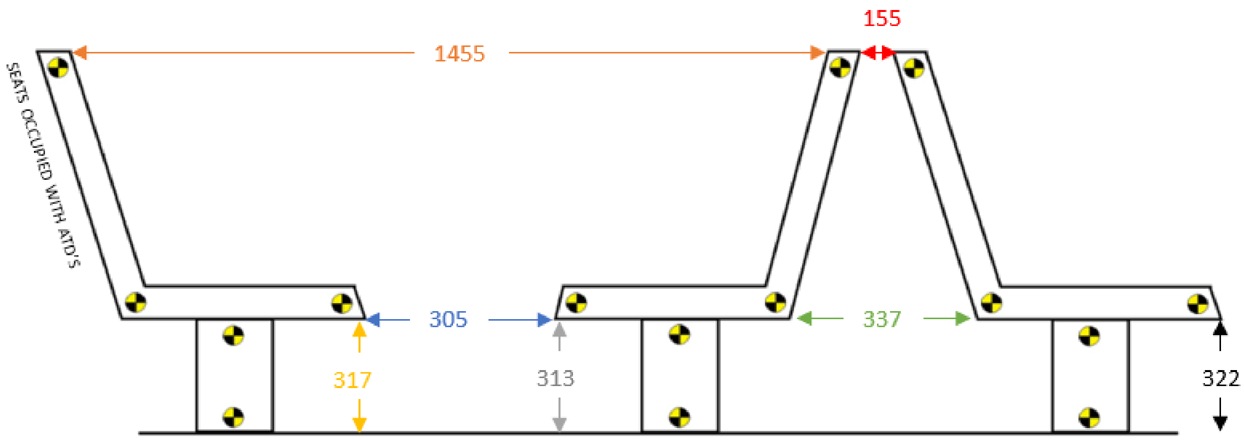


Figure 30: Test 2 Left-Hand (Aisle) Seat Pre-Test Measurements

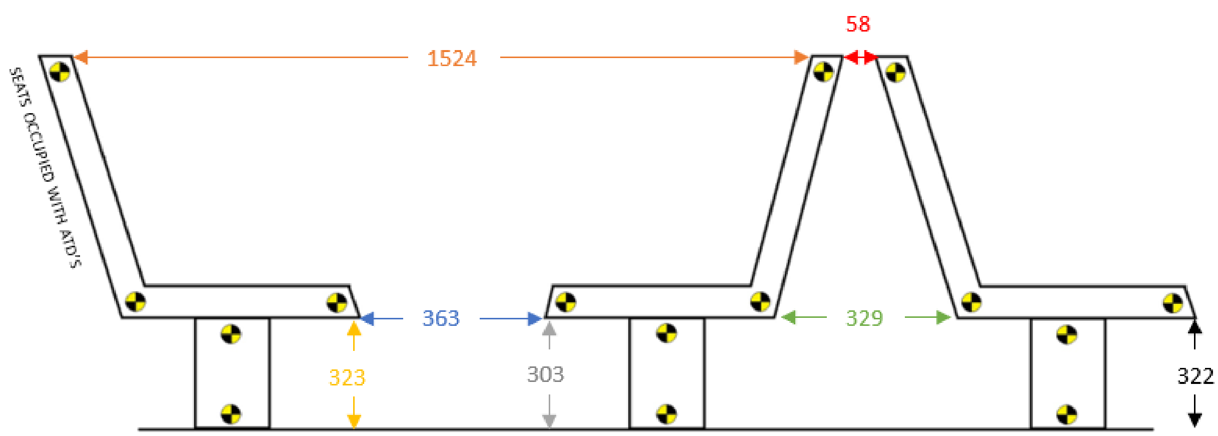


Figure 31: Test 2 Right-Hand (Wall) Seat Post-Test Measurements

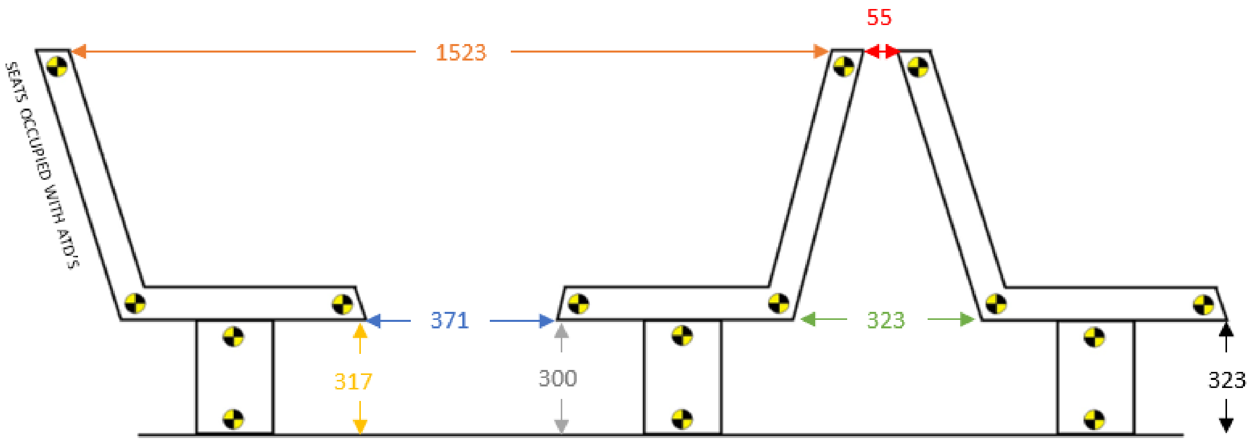


Figure 32: Test 2 Left-Hand (Aisle) Seat Post-Test Measurements

Table 9 below shows the pre- and post-test measurements for Test 2.

Table 9: Test 2 Pre- and Post-Test Measurements by Occupant

Measurement	Pre-test Wall [mm]	Pre-test Aisle [mm]	Post-test Wall [mm]	Post-test Aisle [mm]
Longitudinal distance (in a horizontal plane) between the top of the launch seat and the top of the impact seat	1450	1455	N/A	N/A
Longitudinal distance (in a horizontal plane) between front edge of the launch seat cushion and the front edge of the impact seat cushion	294	305	363	371
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the impact seat	313	313	303	300
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the launch seat	315	317	323	317
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seat cushion and the rear edge of the launch seat cushion	337	337	329	323
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the backing seat	320	322	322	323
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seatback and the rear edge of the backing seatback	152	155	N/A	N/A

3.2.6 Test 2: Post-test Evaluation

Table 10 below contains the results of the APTA post-test evaluation.

Table 10: Test 2 APTA Post-Test Evaluation

APTA Requirement	Assessment
Seats may deform but shall not tear loose from their mountings.	Launch seatback came loose during the event.
Seat components shall not tear loose and become separated from the seat assembly.	Launch seatback separated from seat assembly and became a projectile.
The ATDs shall be compartmentalized between roles of seats. After testing, the seats shall not be deformed to such an extent that they present an impediment to emergency egress.	The ATDs were not compartmentalized as their torsos passed over the impact seatback during the event. Seat deformation would not have impeded emergency egress.
All injury measurements must meet the criteria specified in the standard.	The wall ATD's HIC15 value was above the APTA limit. Table 8 above contains the human injury evaluation for Test 2.
The anti-rotational lock mechanism in rotating seats shall not fail, and the seat shall be retained in the locked position.	The anti-rotational lock on the launch seatback failed allowing the seatback to rotate during the event.
Tray tables may deploy during event provided they can be moved out of the way for occupant egress.	N/A

3.3 Test 3

3.3.1 Test 3: Background

The seats donated for Test 3 are production seats. These seats are a single pedestal seat that also mounts to the wall of the railcar. The seats utilized bolts to mount the pedestal to the sled carriage and bolts to mount the seat to the wall structure.

3.3.2 Test 3: Setup and Crash Pulse

The test setup is depicted in Figure 33 and Figure 34 below. The corresponding post-test photos are shown in Figure 35, Figure 36, and Figure 37. The test pulse is shown in Figure 38.

Figure 33: Test 3 Lateral Pre-Test Photo

Figure 34: Test 3 Isometric Pre-Test Photo

Figure 35: Test 3 Lateral Post-Test Photo

Figure 36: Test 3 Isometric Post-Test Photo

Figure 37: Test 3 Post-Test ATD Positions

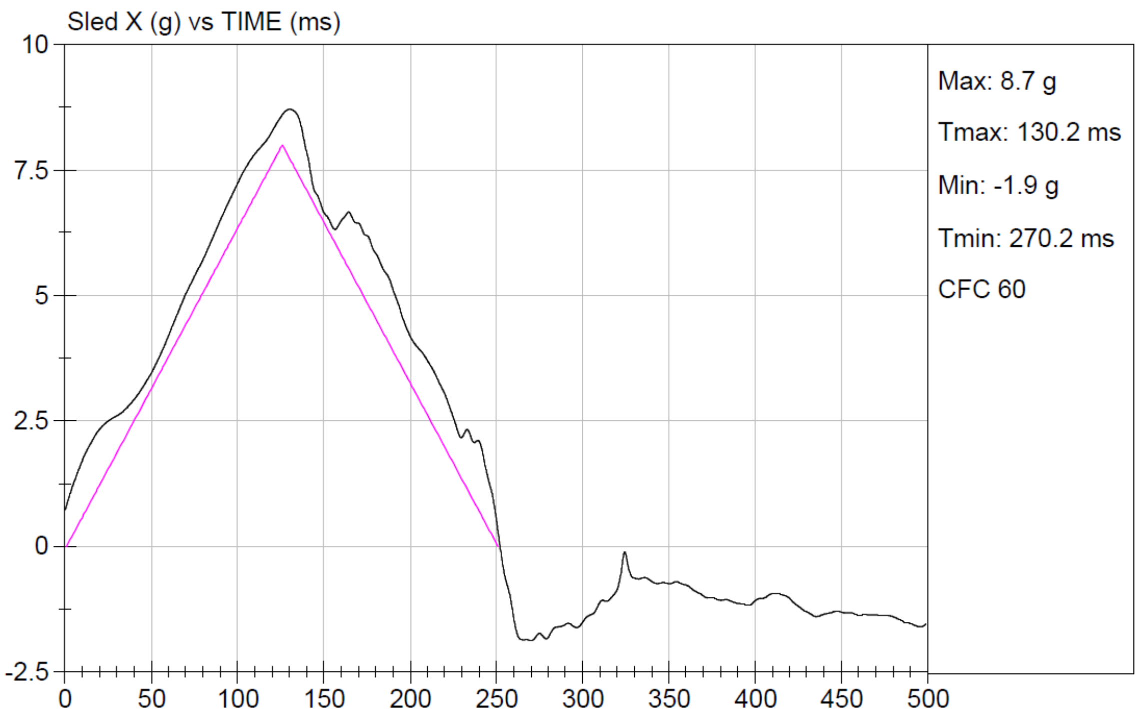
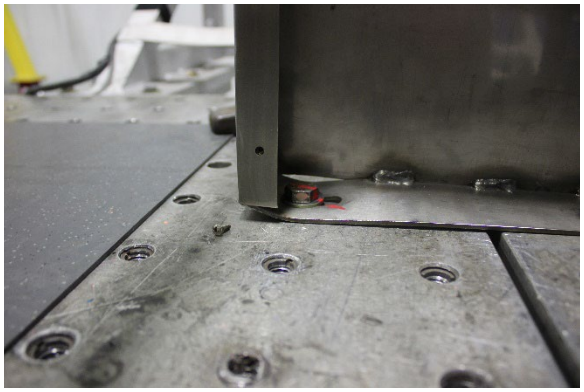


Figure 38: Test 3 Crash Test Pulse

3.3.3 Test 3: Post-test Observations

Figure 39: Test 3 Impact Seat Vinyl

ATDs' knees contacted the impact seat cushion during the event. The friction from the ATDs' knees moving across the top of the cushion caused the vinyl to tear.



Impact seat pedestal deformed at floor mounting.

Figure 40: Test 3 Impact Seat Pedestal

Impact seatback cover cracked on both sides during the event.

Figure 41: Test 3 Impact Seatback Plastic Cover

Impact seatback structure deformed during the event.

Figure 42: Test 3 Impact Seatback Structure

Figure 43: Test 3 ATD Head Impact Region

ATDs' heads contacted the impact seat's headrest, aiding in their compartmentalization.

3.3.4 Test 3: Human Injury Values

Table 11 below contains the human injury evaluation for Test 3.

Table 11: Test 3 Human Injury Measurements

Description	APTA PR-CS-S-016-99, Rev. 3 §5.2.1.3 Performance Requirements	Left ATD (Aisle)	Right ATD (Wall)
Head Injury Criteria (HIC15)	HIC15 ≤ 700	753	675
Neck Injury Criteria (Nij)	Nij Compression/Extension ≤ 1.0	0.2	0.3
	Nij Compression/Flexion ≤ 1.0	1.2	1.04
	Nij Tension/Extension ≤ 1.0	0.2	0.3
	Nij Tension/Flexion ≤ 1.0	0.1	0.1
Neck Axial Force (F_z) in Tension	$F_z \leq$ 4,170 N	641	833
Neck Axial Force (F_z) in Compression	$F_z \leq$ 4,000 N	2769	2890
Resultant Mid-thoracic Spine Acceleration (Acc)	Acc ≤ 60g over a 3ms clip	27	25
Femur Load	Left Femur ≤ 10,000 N	6045	6073
	Right Femur ≤ 10,000 N	6195	6008

3.3.5 Test 3: Pre- and Post-test Measurements

Figure 44 through Figure 47 show the pre- and post-test measurements for Test 3.

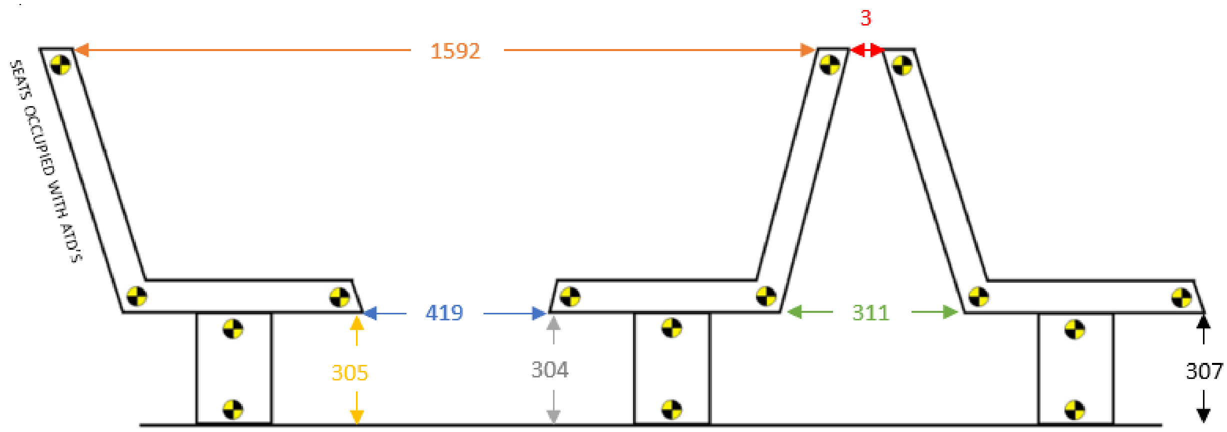


Figure 44: Test 3 Right-Hand (Wall) Seat Pre-Test Measurements

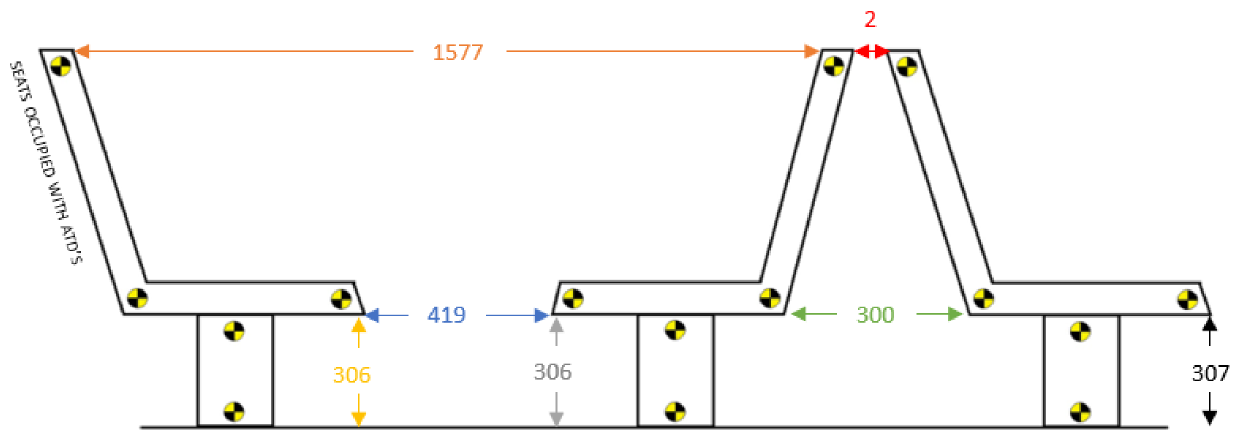


Figure 45: Test 3 Left-Hand (Aisle) Seat Pre-Test Measurements

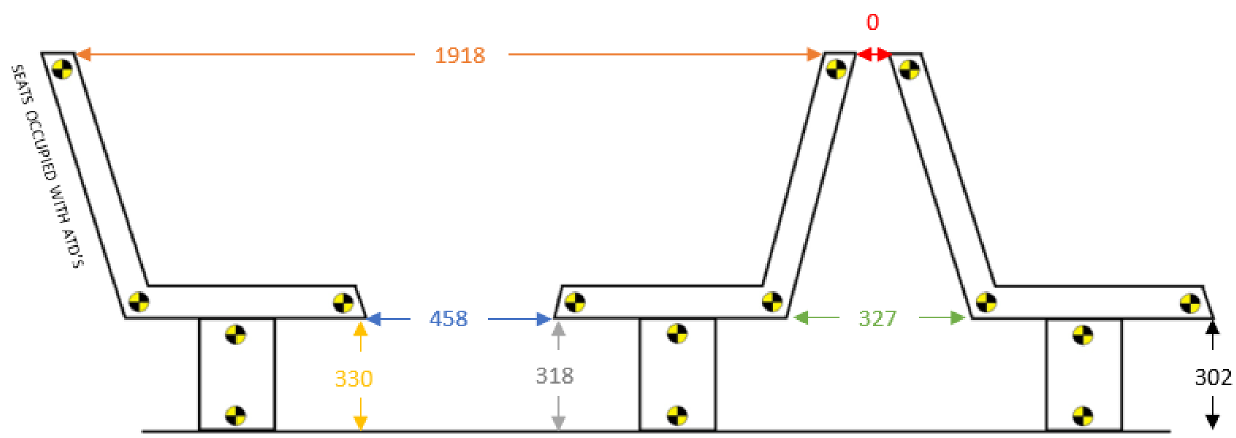


Figure 46: Test 3 Right-Hand (Wall) Post-Test Measurements

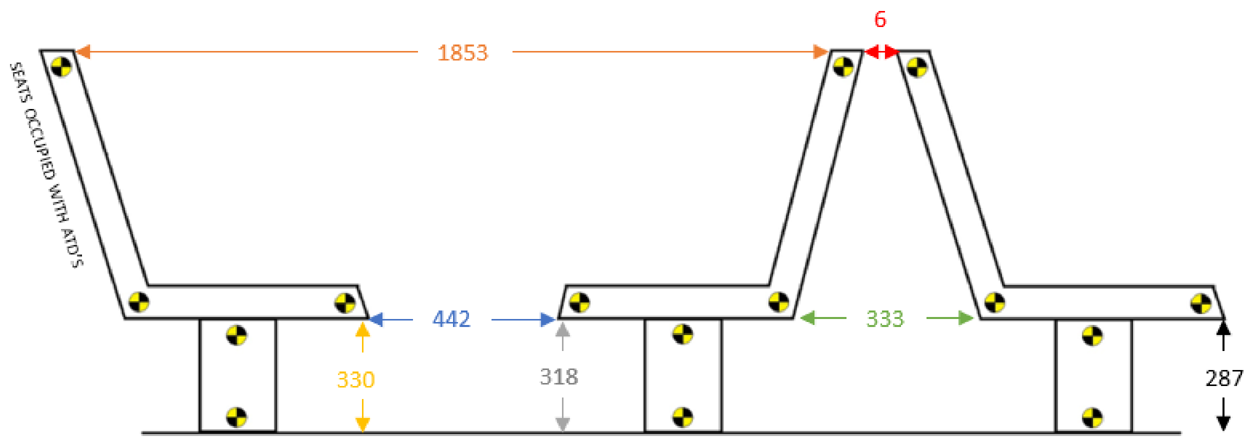


Figure 47: Test 3 Left-Hand (Aisle) Seat Post-Test Measurements

Table 12 below shows the pre- and post-test measurements for Test 3.

Table 12: Test 3 Pre- and Post-Test Measurements by Occupant

Measurement	Pre-test Wall [mm]	Pre-test Aisle [mm]	Post-test Wall [mm]	Post-test Aisle [mm]
Longitudinal distance (in a horizontal plane) between the top of the launch seat and the top of the impact seat	1592	1577	1918	1853
Longitudinal distance (in a horizontal plane) between front edge of the launch seat cushion and the front edge of the impact seat cushion	419	419	458	442
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the impact seat	304	306	318	318
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the launch seat	305	306	330	330
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seat cushion and the rear edge of the backing seat cushion	311	300	327	333
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the backing seat	307	307	302	287
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seatback and the rear edge of the backing seatback	3	2	0	6

3.3.6 Test 3: Post-Test Evaluation

Table 13 below contains the results of the APTA post-test evaluation.

Table 13: Test 3 APTA Post-Test Evaluation

APTA Requirement	Assessment
Seats may deform but shall not tear loose from their mountings.	Seats deformed but stayed attached during the event.
Seat components shall not tear loose and become separated from the seat assembly such that the components become projectiles.	No seat components tore loose during the event.
The ATDs shall be compartmentalized between roles of seats. After testing, the seats shall not be deformed to such an extent that they present an impediment to emergency egress.	The ATDs were compartmentalized as defined by APTA PR-CS-S-016-99, Rev 3. Seat deformation would not have impeded emergency egress.
All injury measurements must meet the criteria specified in the standard.	The aisle ATD's HIC15 and Nij (NCF) and the wall ATD's Nij (NCF) were above the specified criteria. See Table 11 above.
The anti-rotational lock mechanism in rotating seats shall not fail, and the seat shall be retained in the locked position.	N/A
Tray tables may deploy during event provided they can be moved out of the way for occupant egress.	N/A

3.4 Test 4

3.4.1 Test 4: Background

The seats donated for Test 4 are developmental seats. These seats consist of a single pedestal mount and a wall mount. Both the pedestal and wall mount are attached to a steel track using spring nuts. The flooring consisted of plywood covered with carpet provided by the donating party.

3.4.2 Test 2: Setup and Crash Pulse

The test setup is depicted in Figure 48 and Figure 49 below. The corresponding post-test photos are shown in Figure 50, Figure 51, and Figure 52. The test pulse is shown in Figure 53.

Figure 48: Test 4 Lateral Pre-Test Photo

Figure 49: Test 4 Isometric Pre-Test Photo

Figure 50: Test 4 Lateral Post-Test Photo

Figure 51: Test 4 Isometric Post-Test Photo

Figure 52: Test 4 Post-Test ATD Positions

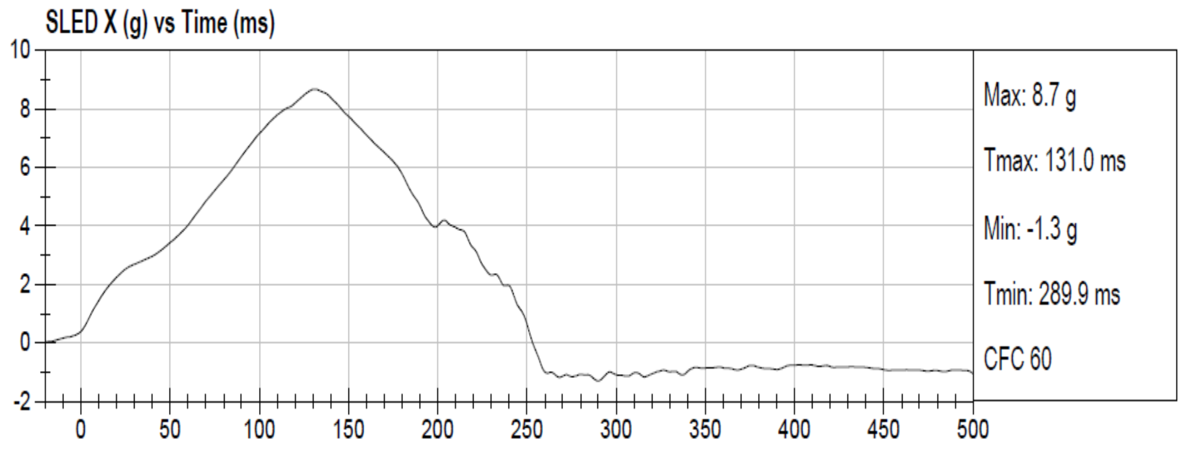


Figure 53: Test 4 Crash Test Pulse

3.4.3 Test 4: Post-test Observations

Figure 54: Test 4 Impact Seat

ATDs' faces contacted the impact seat's headrest cushions during the event. The impact seat rotated and deformed the backing seat.

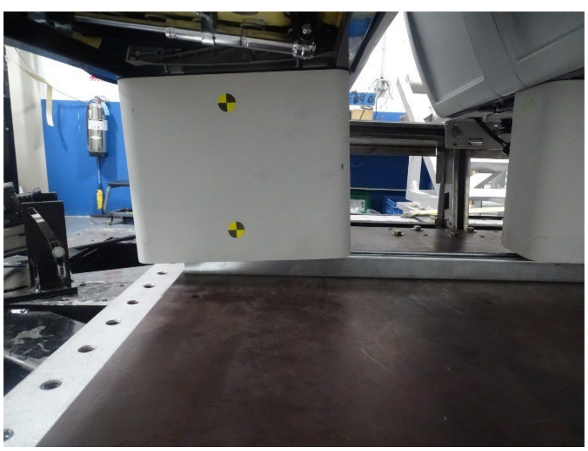
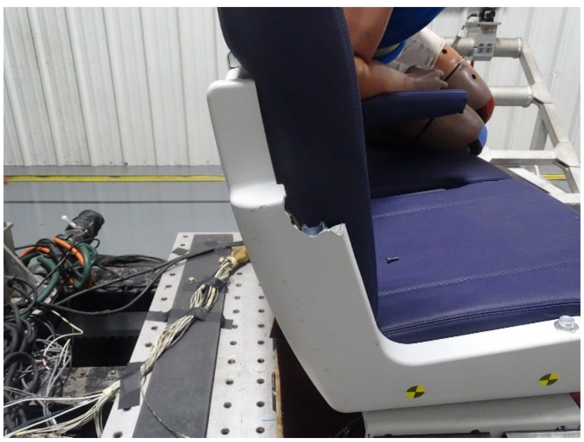


Figure 55: Test 4 Forward-Facing Unoccupied Seat

Seat pedestal of backing seat rotated and slid forward along track. This may have occurred because an incorrect floor rail was installed and carpeting was not extended to the backing seat pedestal.

Impact seat pedestal deformed at floor mounting points.

Figure 56: Test 4 Impact Seat Pedestal



Armrest separated from right side of launch seat due to impact of the ATD upon rebound.

Figure 57: Test 4 Launch Seat Armrest

The track supporting the impact and forward-facing seats deformed. The bolts and spring nuts pulled through the track. This likely occurred because an incorrect floor rail was used during setup. The rail used was made of galvanized steel rather than stainless steel.

Figure 58: Test 4 Seat Track

3.4.4 Test 4: Human Injury Values

Table 14 below contains the human injury evaluation for Test 4.

Table 14: Test 4 Human Injury Measurements

Description	APTA PR-CS-S-016-99, Rev. 3 §5.2.1.3 Performance Requirements	Left ATD (Aisle)	Right ATD (Wall)
Head Injury Criteria (HIC15)	HIC15 ≤ 700	265	599
Neck Injury Criteria (Nij)	Nij Compression/Extension ≤ 1.0	0.08	0.09
	Nij Compression/Flexion ≤ 1.0	0.25	0.28
	Nij Tension/Extension ≤ 1.0	1.02	1.23
	Nij Tension/Flexion ≤ 1.0	0.43	0.32
Neck Axial Force (F_z) in Tension	$F_z \leq 4{,}170$ N	451	570
Neck Axial Force (F_z) in Compression	$F_z \leq 4{,}000$ N	1981	2200
Resultant Mid-thoracic Spine Acceleration (Acc)	Acc ≤ 60g over a 3ms clip	23	28
Femur Load	Left Femur ≤ 10,000 N	3625	8188
	Right Femur ≤ 10,000 N	11044	6342

3.4.5 Test 4: Pre and Post-test Measurements

Figure 59 through Figure 62 show the pre- and post-test measurements for Test 4.

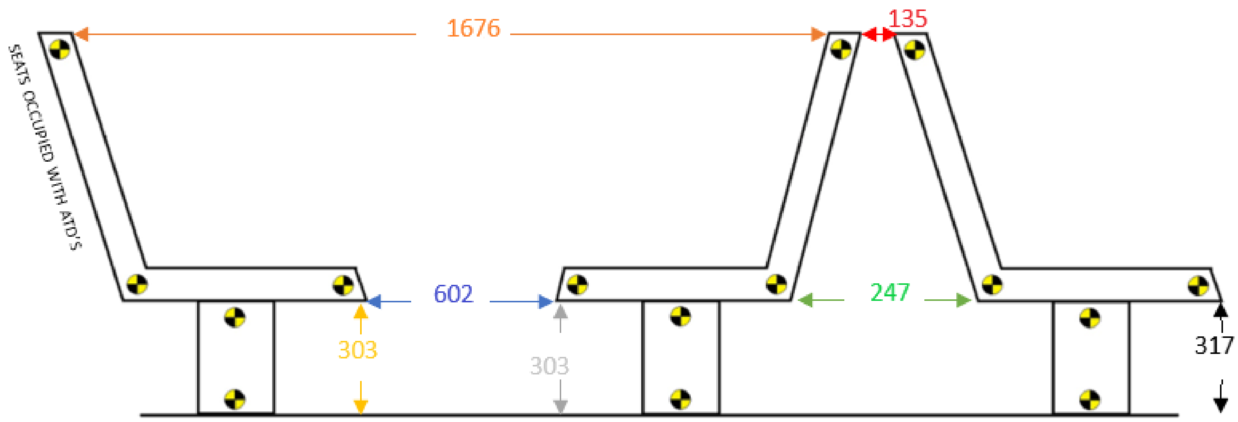


Figure 59: Test 4 Right-Hand (Wall) Seat Pre-Test Measurements

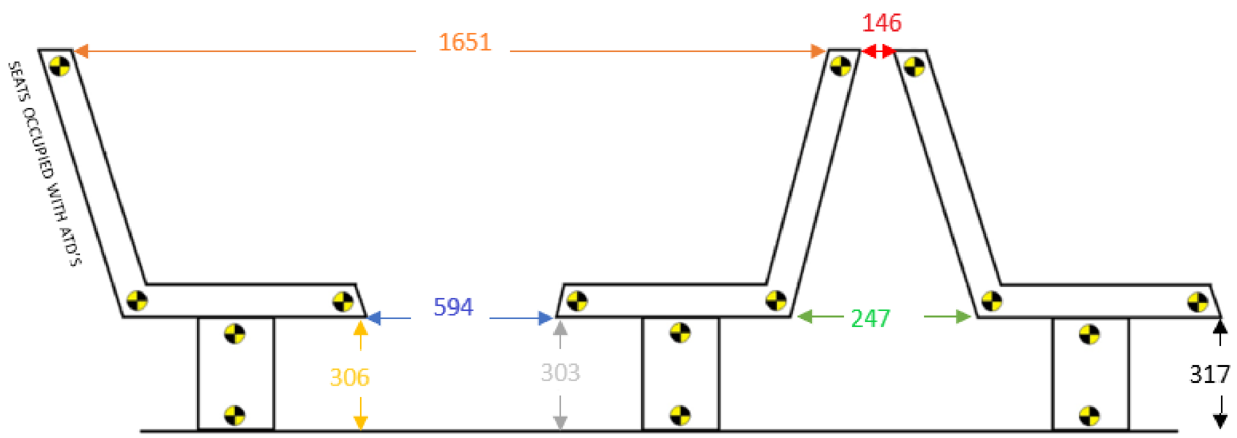


Figure 60: Test 4 Left-Hand (Aisle) Seat Pre-Test Measurements

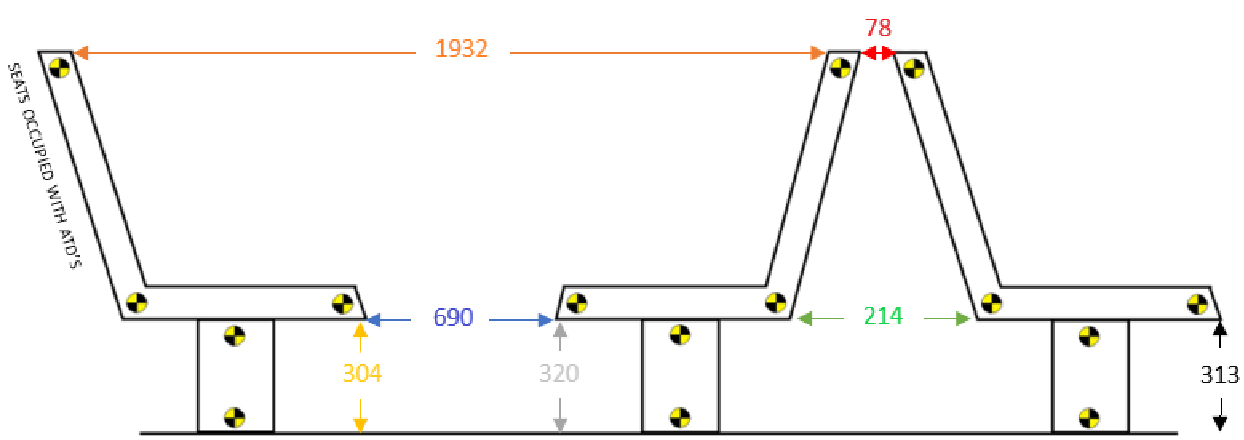


Figure 61: Test 4 Right-Hand (Wall) Seat Post-Test Measurements

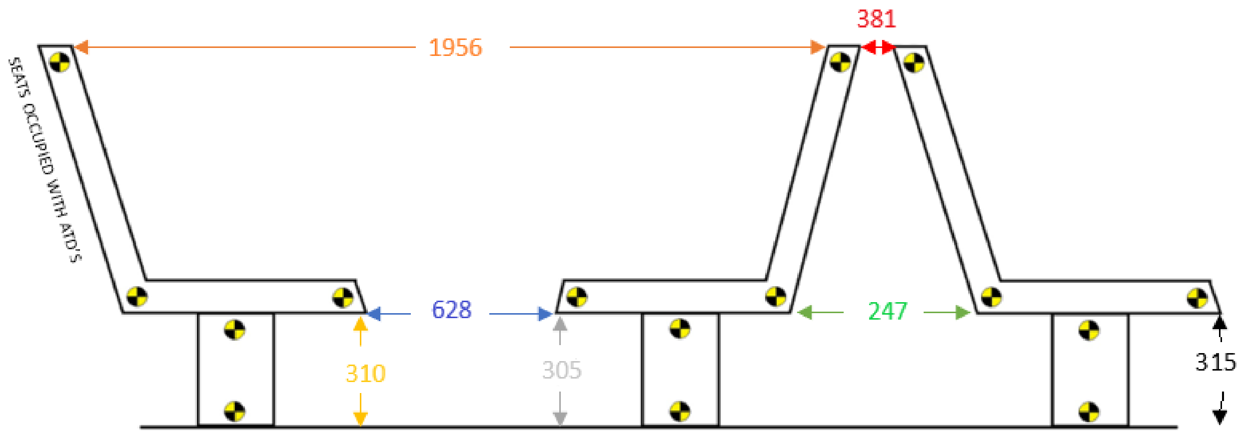


Figure 62: Test 4 Left-Hand (Aisle) Seat Post-Test Measurements

Table 15 below shows the pre- and post-test measurements for Test 4.

Table 15: Test 4 Pre- and Post-Test Measurements by Occupant

Measurement	Pre-test Wall [mm]	Pre-test Aisle [mm]	Post-test Wall [mm]	Post-test Aisle [mm]
Longitudinal distance (in a horizontal plane) between the top of the occupied launch seat and the top of the impact seat	1676	1651	1932	1956
Longitudinal distance (in a horizontal plane) between front edge of the launch seat cushion and the front edge of the impact seat cushion	602	594	690	628
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the impact seat	303	303	320	305
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the launch seat	303	306	304	310
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seat cushion and the rear edge of the backing seat cushion	247	247	214	247
Vertical distance measured from the floor to the bottom of the front edge of the seat cushion on the backing seat	317	317	313	315
Longitudinal distance (in a horizontal plane) between the rear edge of the impact seatback and the rear edge of the backing seatback	135	146	78	381

3.4.6 Test 4: Post-test Evaluation

Table 16 below contains the results of the APTA post-test evaluation.

Table 16: Test 4 APTA Post-Test Evaluation

APTA Requirement	Assessment
Seats may deform but shall not tear loose from their mountings.	Impact seat and forward-facing seat pulled out of seat track due to incorrect material used for floor track.
Seat components shall not tear loose and become separated from the seat assembly.	The armrest from the right launch seat separated when impacted by ATD during rebound.
The ATDs shall be compartmentalized between roles of seats. After testing, the seats shall not be deformed to such an extent that they present an impediment to emergency egress.	The ATDs were compartmentalized as defined by APTA PR-CS-S-016-99, Rev. 3. Seat deformation would not have impeded emergency egress.
All injury measurements must meet the criteria specified in the standard.	The measurements did not meet the human injury requirements. The Nij (Tension/Extension) on both sides and the aisle side femur load exceeded the performance requirements. Table 14 above contains the human injury evaluation for Test 4.
The anti-rotational lock mechanism in rotating seats shall not fail, and the seat shall be retained in the locked position.	N/A
Tray tables may deploy during event provided they can be moved out of the way for occupant egress.	N/A

4. Summary

Dynamic testing requirements for passenger rail seats in an open-bay configuration were added in Revision 3 (March 2021) of S-016 while this test series was being conducted. Test 1 complied with all injury criteria compliance limits. Test 2 exceeded the head injury criterion compliance limit of 700 on the right (wall) side ATD by 294. Test 3 exceeded head injury criterion limits by 53 on the left (aisle) side. The neck injury criterion was also greater than the compliance limit of 1.0 by 20 percent on the left (aisle) ATD and 4 percent on the right (wall) side. For test 4, the neck injury criterion for tension/extension exceeded the limit by 2 percent for the left (aisle) ATD and 23 percent for the right (wall) ATD. The right femur for the left (aisle) ATD exceeded the 10,000 N limit by 1,044 N. Also, the team observed that low-back seats were less likely to compartmentalize the ATDs. Both of these observations can be attributed to the greater distance the ATD was allowed to travel before impacting the next seating row, causing the ATD to have a greater impact velocity.

The individual tests are summarized below. Please note that all the seats were designed to meet the row-to-row test requirements in S-016 and were not designed to meet the open-bay seat test requirements. Open-bay seat test requirements were not included in S-016 (Rev. 2) which was the approved version at the start of this test series.

The tests described in this report evaluated seat performance in the open-bay configuration only.

4.1 Test 1

The seats for Test 1 were developmental samples that had not been implemented in railcars on the U.S. railroad system at the time of the test. These seats implement a high-back, single-pedestal, wall-mounted design. The seats were less rigid when compared to the other samples, allowing the seats to deform and absorb more of the ATDs' energy while limiting contact forces. This resulted in the seats having lower injury values than other samples. Also, these seats had a high back, creating a relatively soft area for the ATD's face to contact the headrest foam. The high-back design also aided in the ATDs' compartmentalization.

4.2 Test 2

The seats for Test 2 are production seats used in railcars on the U.S. railroad system. These seats are a walkover, double-pedestal seat and are designed to be able to transition between forward- and rearward-facing. They use an anti-rotational lock designed to prevent the seatback from moving during a crash. These seats also had a lower seatback than the other samples. The lower seatback design allowed the ATDs' momentum to carry its torso over the impacted seat, resulting in the ATD being judged as non-compartmentalized. Furthermore, the anti-rotational lock of the launch seat malfunctioned, allowing the launch seat's seatback to rotate and detach during the test. Since the ATDs' heads contacted the top of the impact seatback which contained a stiff frame member, both ATDs had high HIC15 values. The ATD seated near the wall did not comply with the APTA injury requirement for HIC15.

4.3 Test 3

The seats for Test 3 are production seats used in railcars on the U.S. railroad system. These seats are a high-back, single-pedestal, wall-mounted seat. These seats had a more rigid construction than that of the same style seat in Test 1. As a result, the ATD injury values were generally higher than those for Test 1. The aisle ATD's HIC15 and Nij (Compression/Flexion) and the wall ATD's Nij (Compression/Flexion) did not comply with the requirements. The high seatback aided the ATDs compartmentalization during the event. The seats deformed but no part of the seat detached during the event.

4.4 Test 4

The seats for Test 4 are current production seats in railcars. These seats are a high-back, single-pedestal, wall-mounted seat. These seats had more rigid construction than that of the same style seat in Test 1. The high seatback aided the ATDs' compartmentalization during the event. The impact and forward-facing seats deformed and the armrest on the wall launch seat separated due to impact of the ATD during rebound. The track supporting the impact and backing seats deformed during the event. The bolts and spring nuts pulled through the track. This occurred due to the incorrect rail being used during setup. The installed rail was made of galvanized steel rather than stainless steel. Both ATDs' Nij (Tension/Extension) exceeded the injury requirements. The test was not repeated with the appropriate track because it would not have changed the test outcome. A properly restrained seat would have likely resulted in higher neck injury measurements.

5. Discussion

In the open-bay seating configuration, the occupants are allowed a greater amount of travel before they impact the next seating row as compared with occupants in a row-to-row configuration. As a result, the occupants have a greater impact velocity in an open-bay configuration. This can lead to greater human injury values and a greater likelihood for occupants to not be compartmentalized.

Figure 63: Test 1 Impact Seat

The thick foam and thinner structural members in the headrest for Test 1 limited contact forces and resulted in compliant head injury values.

Figure 64: Test 2 Impact Seat

The lower seatback in Test 2 resulted in the ATDs' heads impacting the top of the seatback where there is a stiff frame member leading to higher HIC15 values.

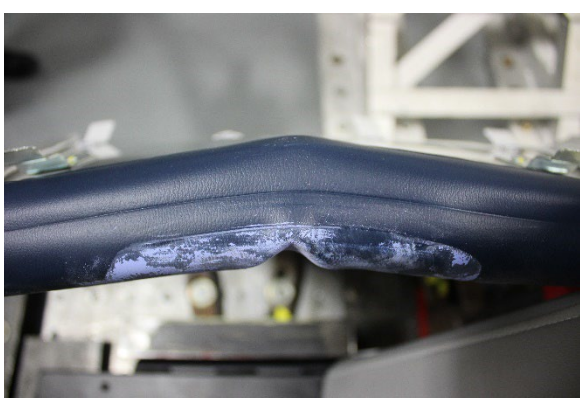


Figure 65: Test 3 Impact Seat

The thin foam and stiff seatback structure in the headrest for Test 3 resulted in high HIC15 values as the ATDs' heads impacted a relatively hard surface.

The thick foam and thinner structural members in the headrest for Test 4 allowed for lower contact forces and compliant head injury values.

Figure 66: Test 4 Impact Seat

The placement and stiffness of the seatback structural members is crucial for seat designers to consider when creating seats for open-bay configurations. Thicker foam in the head impact region may lead to greater energy absorption and in turn lower injury values. Additional impact testing to measure energy absorption in the head impact regions could benefit the APTA standard, as it would help seat designers create seats that would absorb more energy and in turn lower human injury potential.

6. Conclusion

The objective of this test series was to conduct four sled tests according to APTA PR-CS-S-016-99, Rev. 3, with the seats in an open-bay configuration with Hybrid III 50th percentile male ATDs. The test series showed that occupants in an open-bay seating configuration generally do not meet all of the requirements for human injury when an ATD impacts an unoccupied seat. Human injury would likely be even greater in a real-world accident in which occupants were seated in the opposite seat, resulting in person-to-person impact.

Furthermore, the testing showed an increased difficulty for open-bay seats to compartmentalize the occupants; they travel a greater distance, resulting in a greater impact velocity in a collision when compared to those in traditional row-to-row seating. This outcome would likely be exacerbated under the conditions of the S-016 forward-facing seat attachment test performed using the larger Hybrid III 95th percentile male ATDs. In cases where open-bay configurations are utilized for a majority of passenger seating, it is important that the open-bay configuration be dynamically tested to evaluate the overall safety afforded to passengers with special attention on various aspects of seat design, including the effects of seat pitch (spacing), seat mounting, and structural design.

7. References

[1] American Public Transportation Association. (March 2021). APTA PR-CS-S-016-99, Rev. 3 - Standard for Passenger Seats in Passenger Railcars. Washington, DC.

[2] VangIngen-Dunn, C. (December 2003). Commuter Rail Seat Testing and Analysis of Facing Seats [DOT/FRA/ORD-03/06]. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

[3] VangIngen-Dunn, C., and Manning, J. (July 2002). Commuter Rail Seat Testing and Analysis [DOT/FRA/ORD-01/06]. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

[4] Tyrell, D., Severson, K., Jacobsen, K., Carolan, M., Lapre, P., Whelan, C., Schuster, J., Sandler, M., and Marceau, P. (September 2017). Passenger/Freight Train Collision September 12, 2008, Chatsworth, CA: Main Report and Appendices [DOT/FRA/ORD-17/20]. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

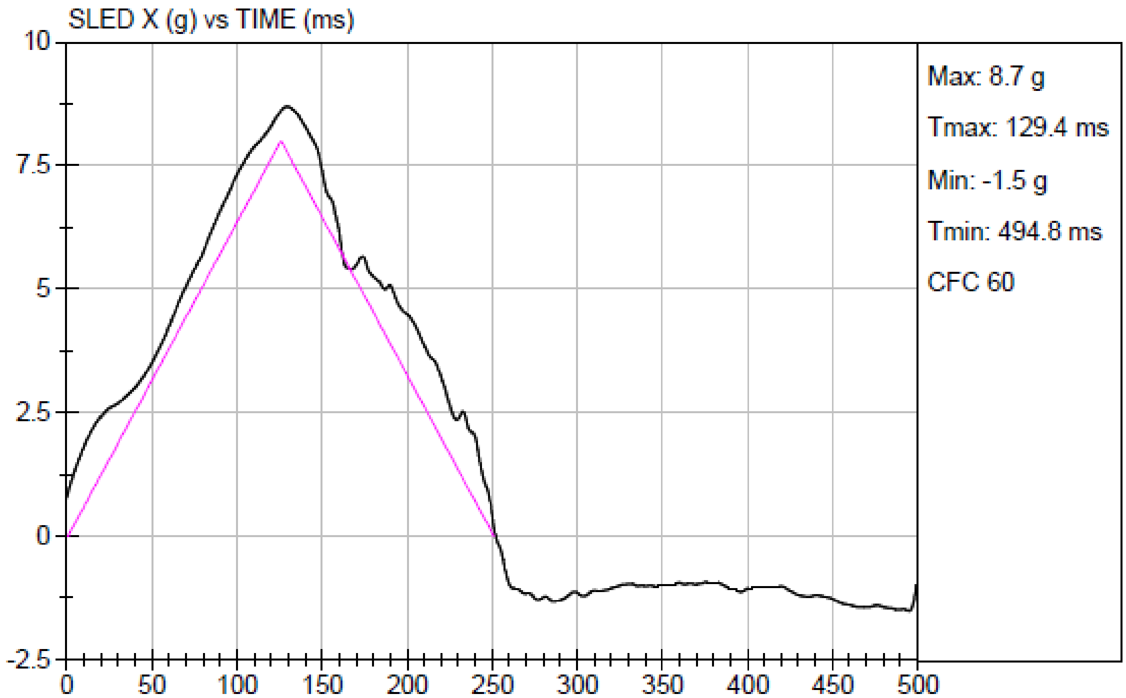
Appendix A: Test Data

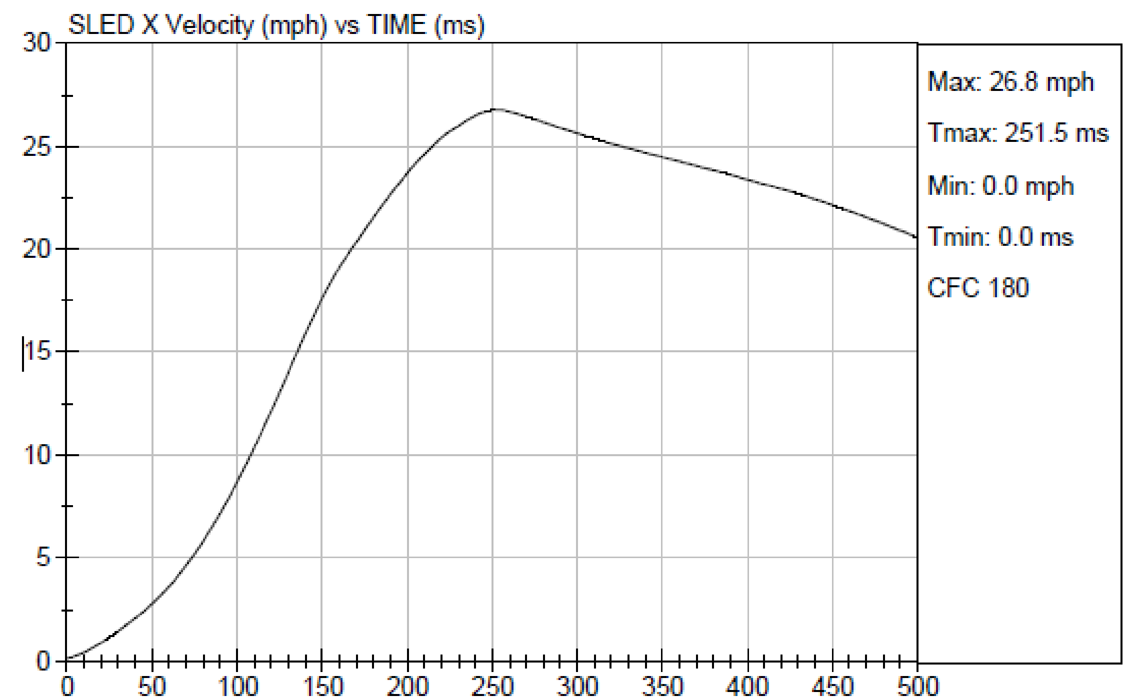
The following contains the full test data for the reported tests. Left indicates the ATD that was seated in the aisle seat, and right indicates the ATD that was seated in the wall seat.

A.1: Test 1 Data

APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

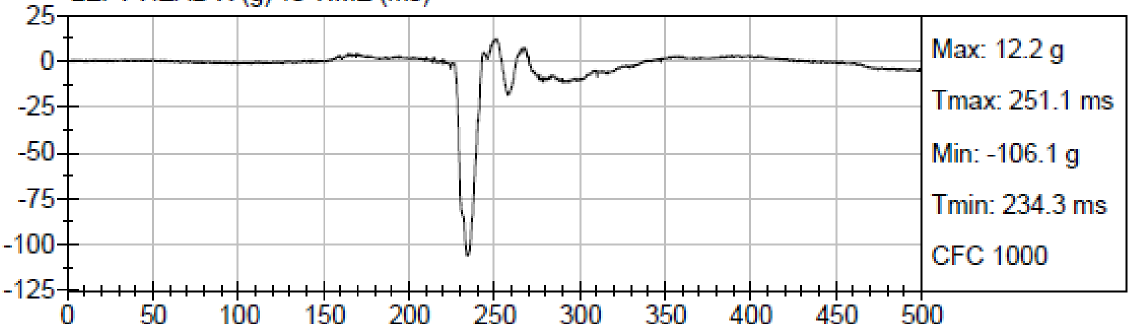




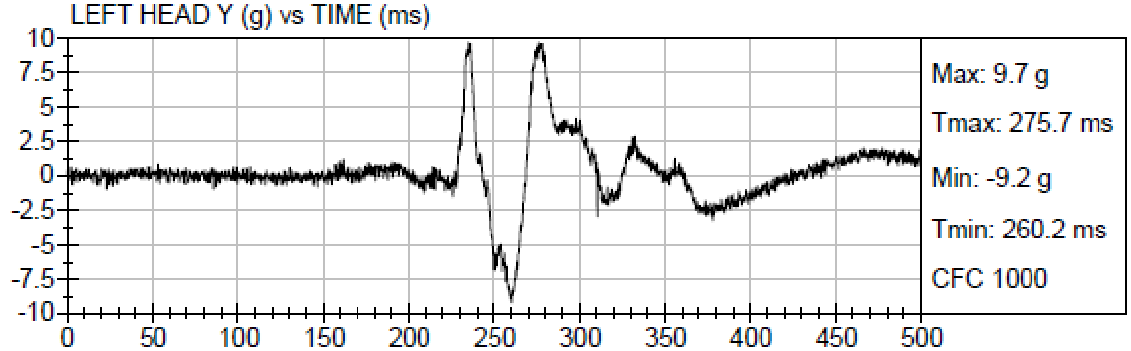
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

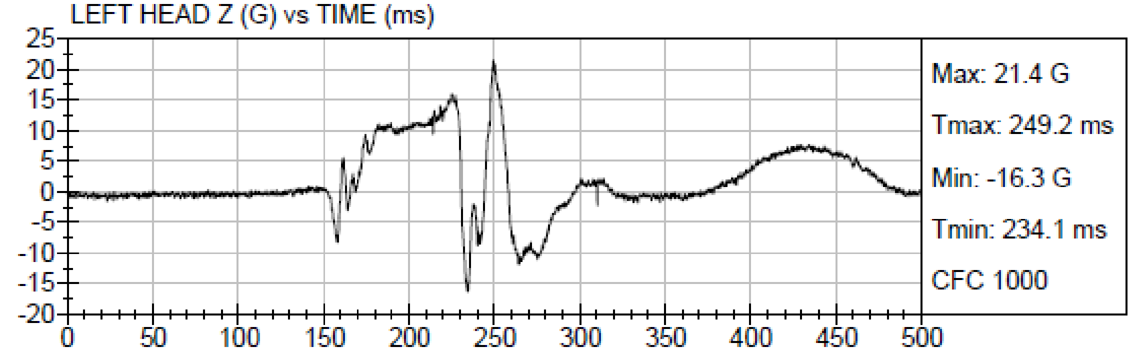
LEFT HEAD X (g) vs TIME (ms)



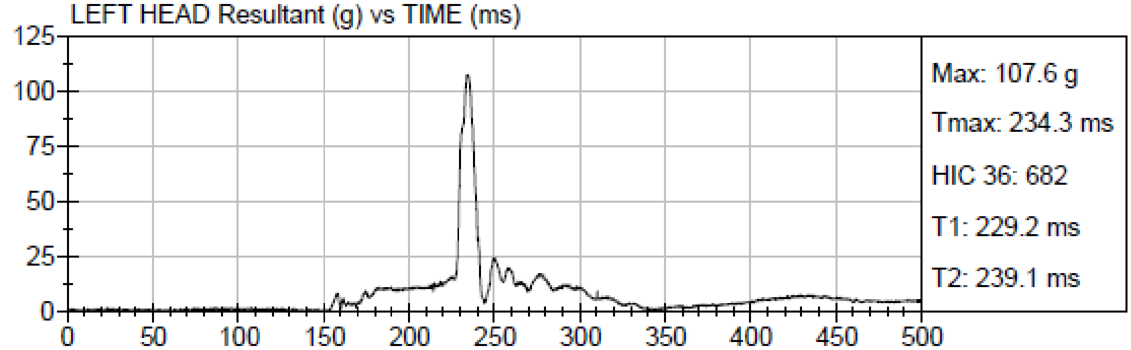
LEFT HEAD Y (g) vs TIME (ms)



LEFT HEAD Z (G) vs TIME (ms)



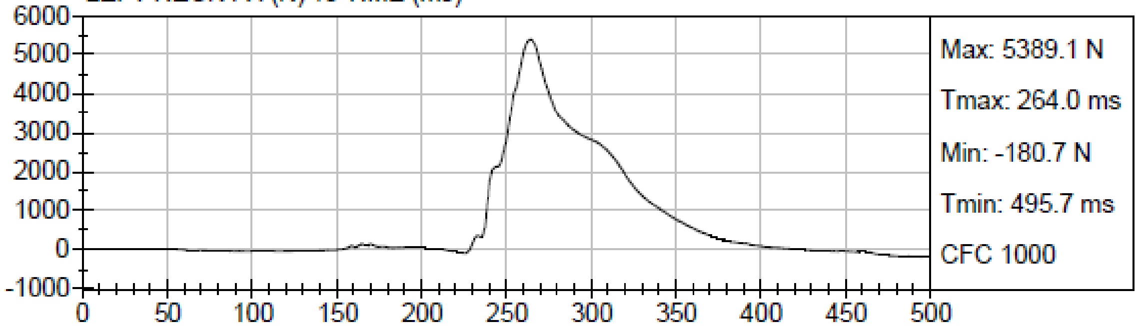
LEFT HEAD Resultant (g) vs TIME (ms)



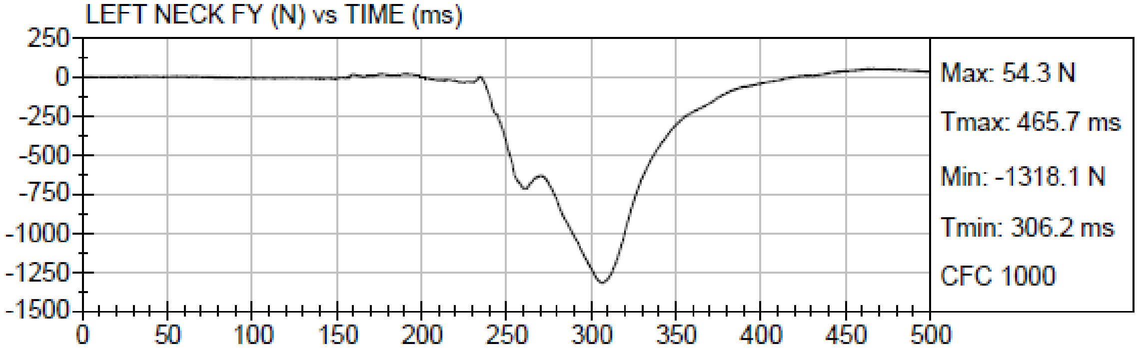
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

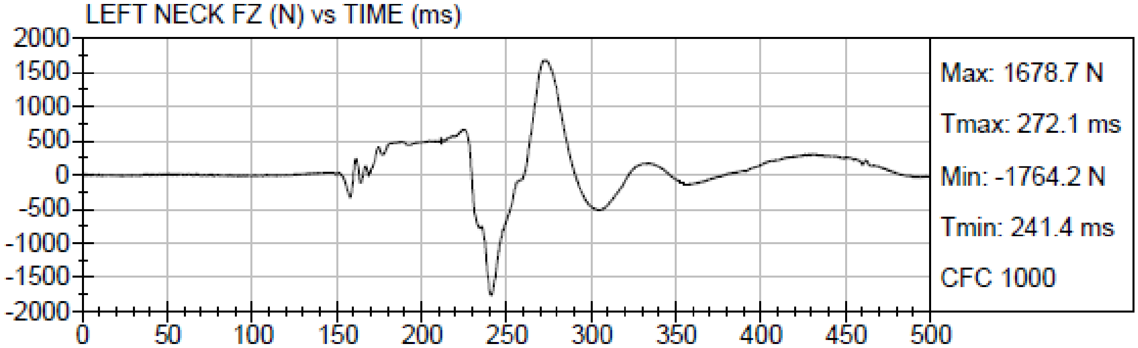
LEFT NECK FX (N) vs TIME (ms)



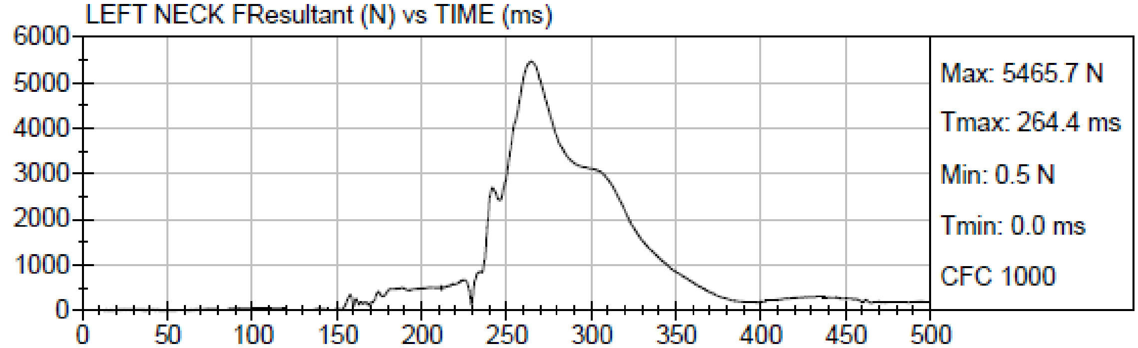
LEFT NECK FY (N) vs TIME (ms)



LEFT NECK FZ (N) vs TIME (ms)



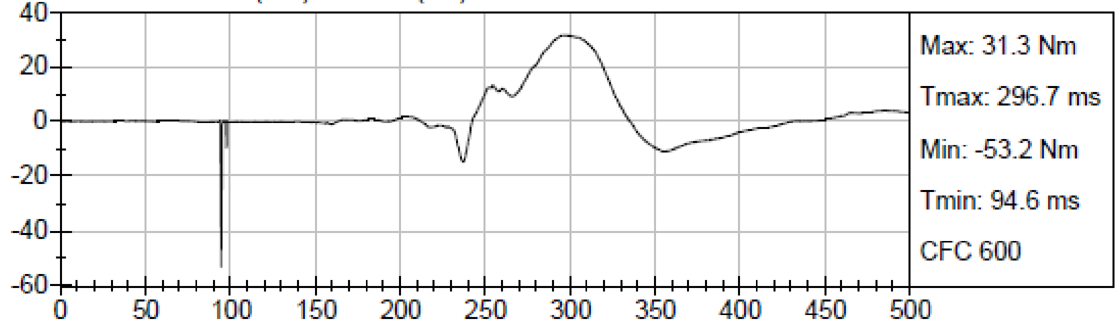
LEFT NECK FResultant (N) vs TIME (ms)



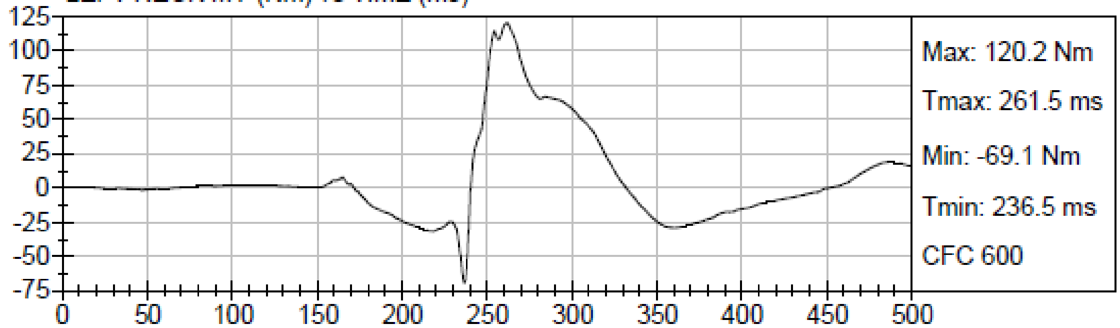
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

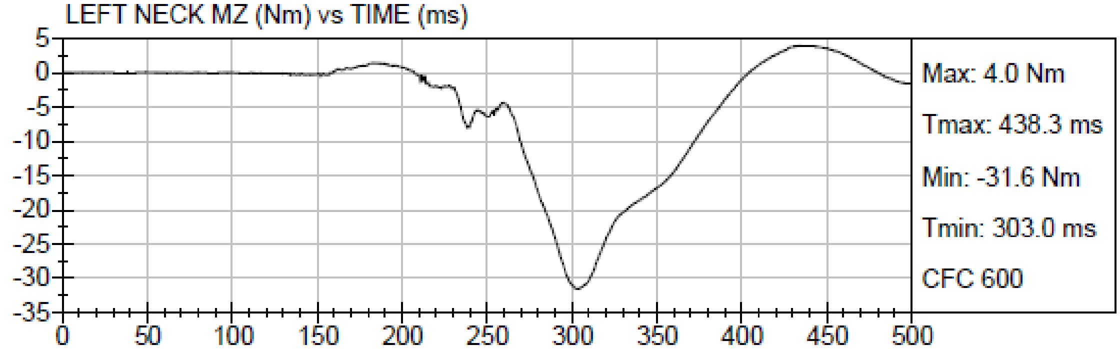
LEFT NECK MX (Nm) vs TIME (ms)



LEFT NECK MY (Nm) vs TIME (ms)



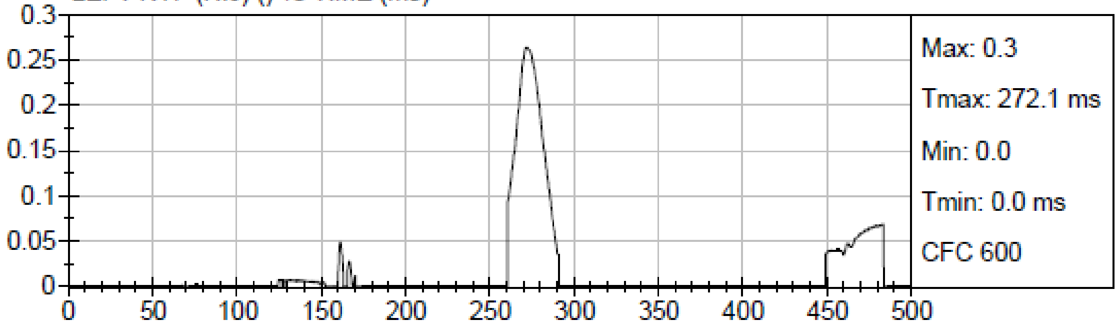
LEFT NECK MZ (Nm) vs TIME (ms)



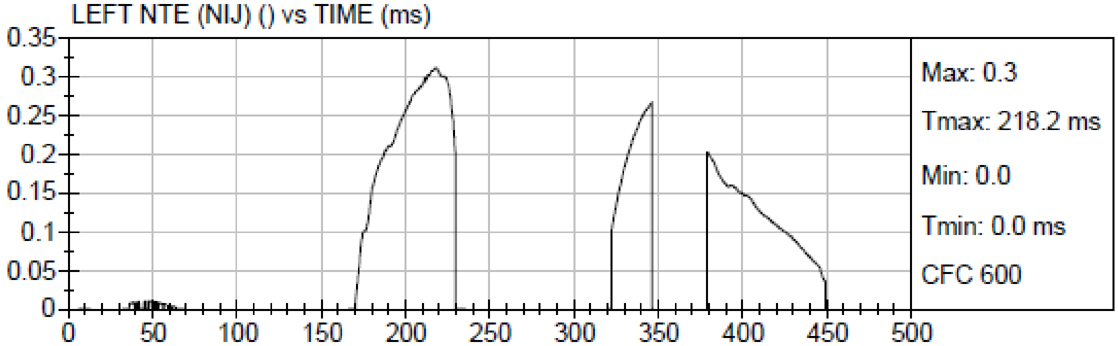
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

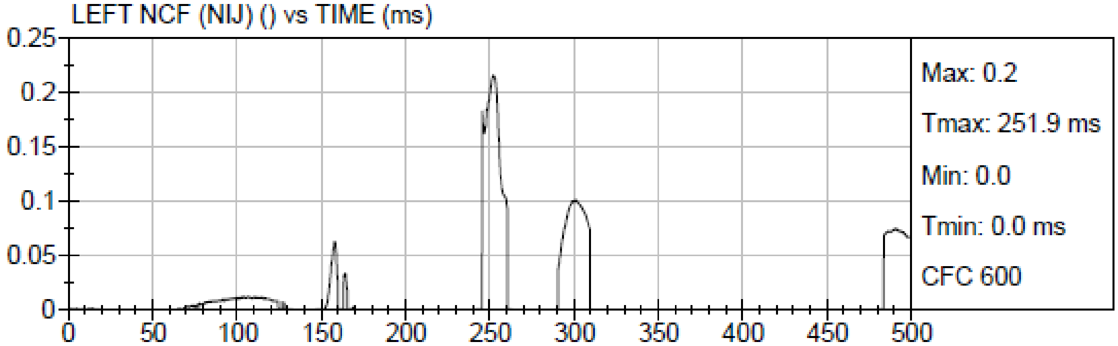
LEFT NTF (NIJ) () vs TIME (ms)



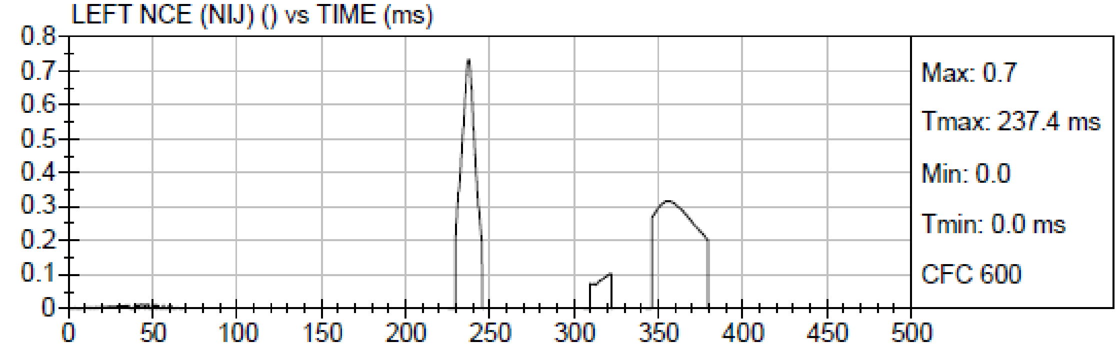
LEFT NTE (NIJ) () vs TIME (ms)



LEFT NCF (NIJ) () vs TIME (ms)



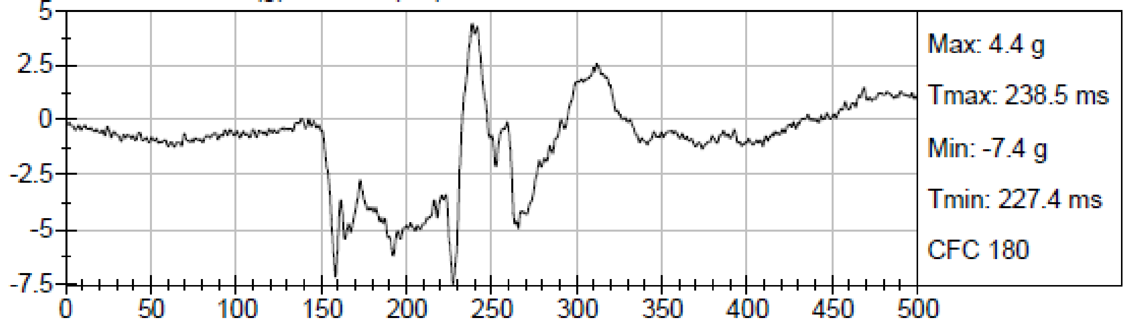
LEFT NCE (NIJ) () vs TIME (ms)



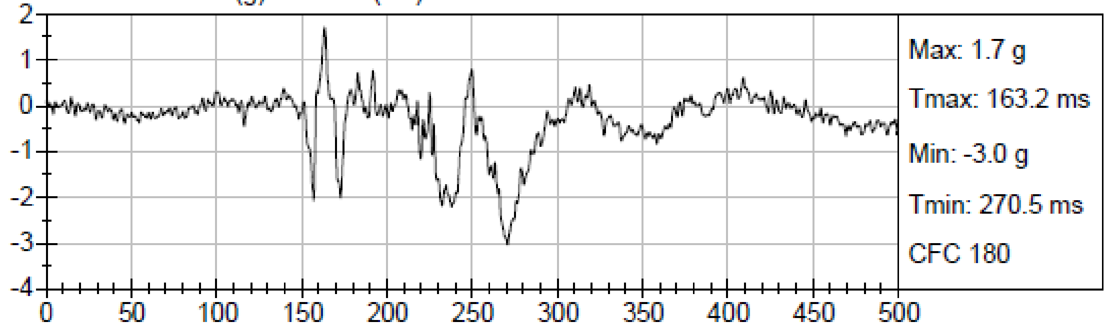
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

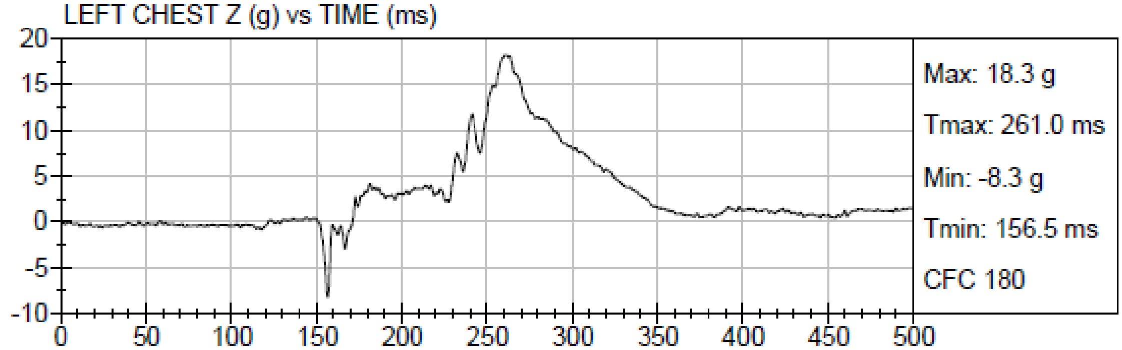
LEFT CHEST X (g) vs TIME (ms)



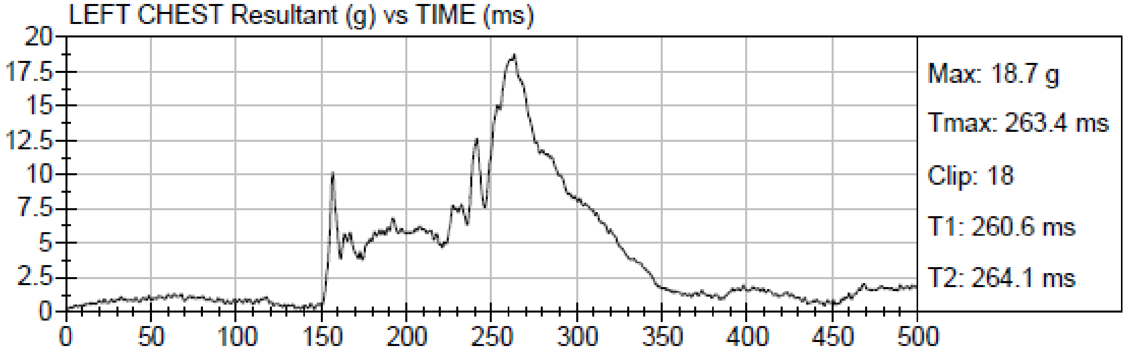
LEFT CHEST Y (g) vs TIME (ms)



LEFT CHEST Z (g) vs TIME (ms)



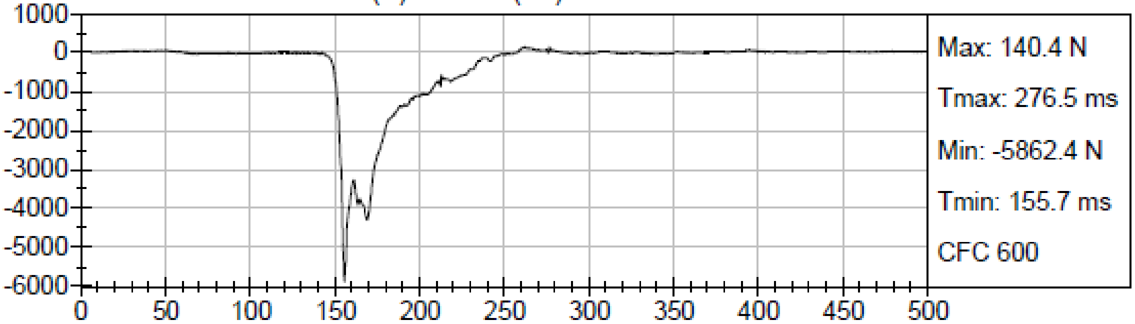
LEFT CHEST Resultant (g) vs TIME (ms)



APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

LEFT RIGHT FEMUR FZ (N) vs TIME (ms)



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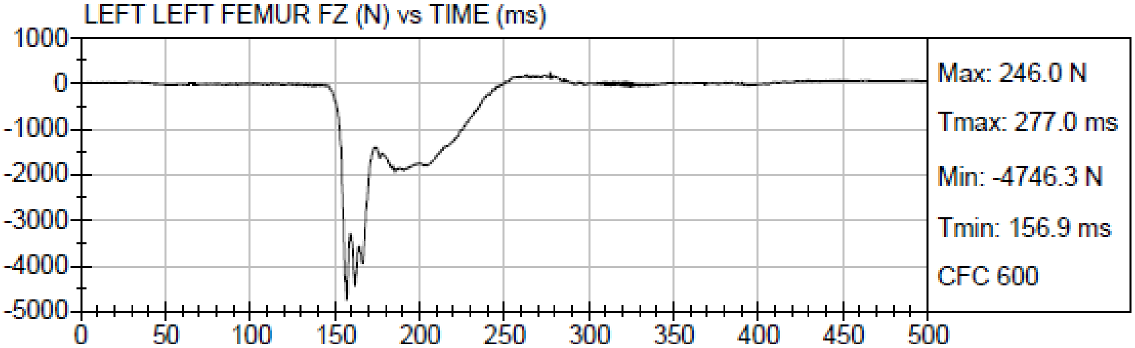
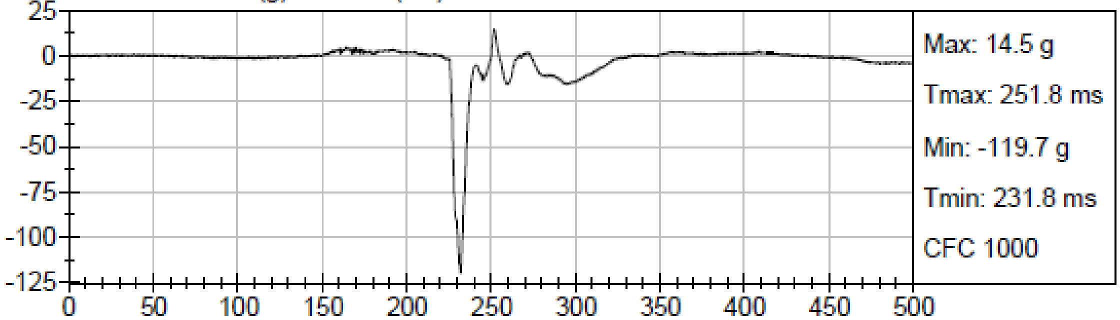


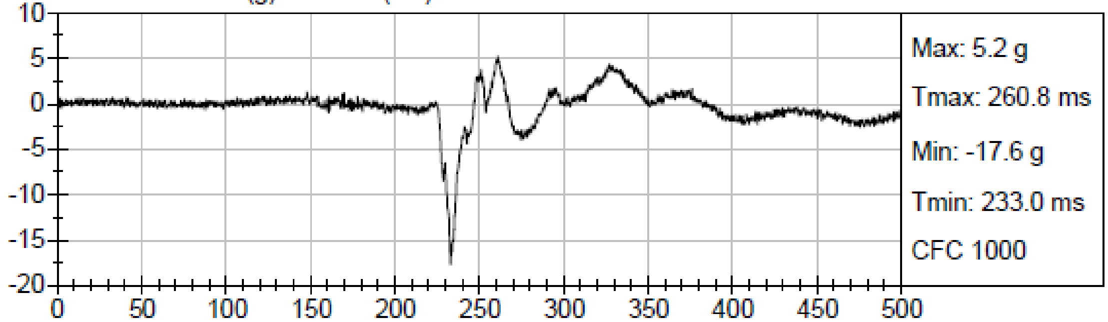
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

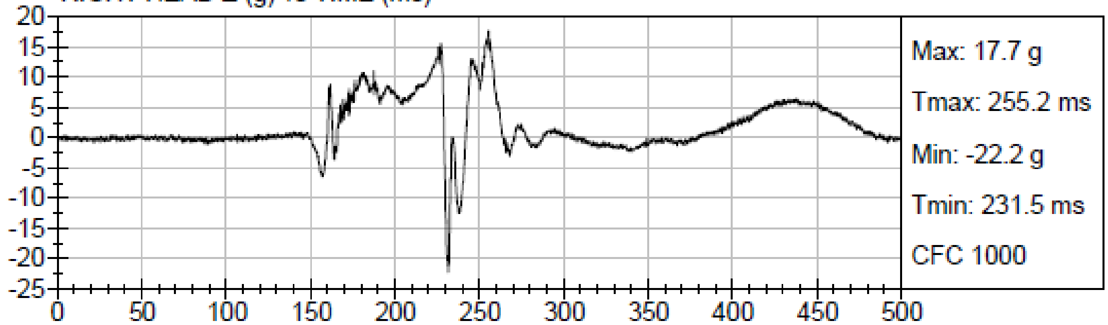
RIGHT HEAD X (g) vs TIME (ms)



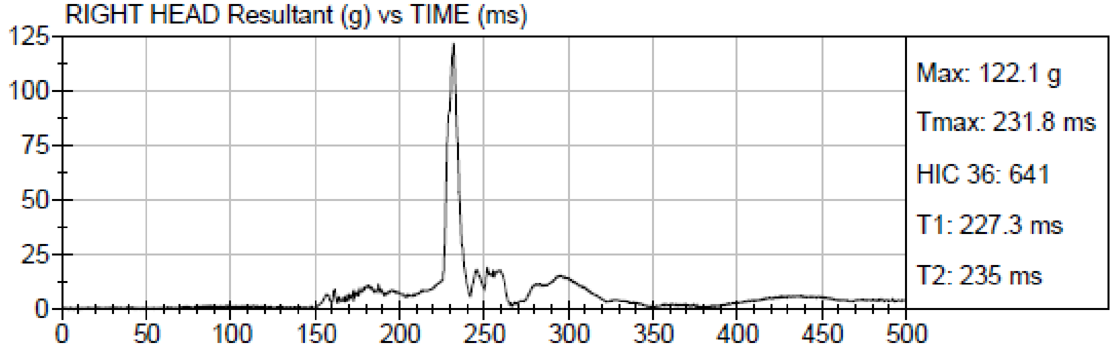
RIGHT HEAD Y (g) vs TIME (ms)



RIGHT HEAD Z (g) vs TIME (ms)



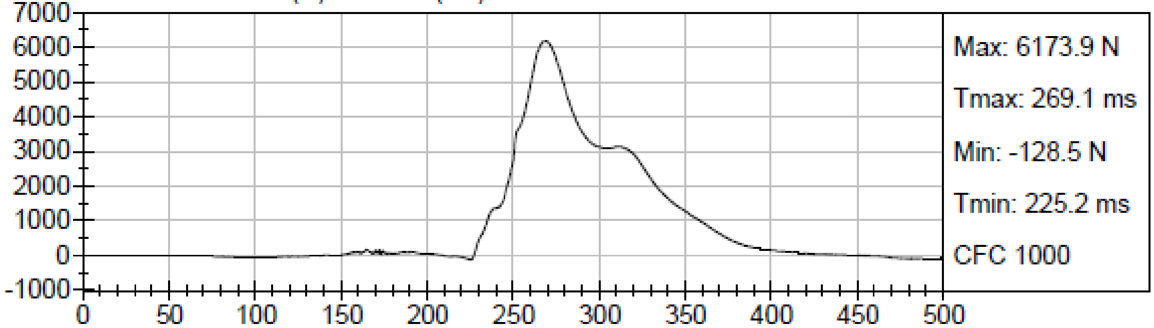
RIGHT HEAD Resultant (g) vs TIME (ms)



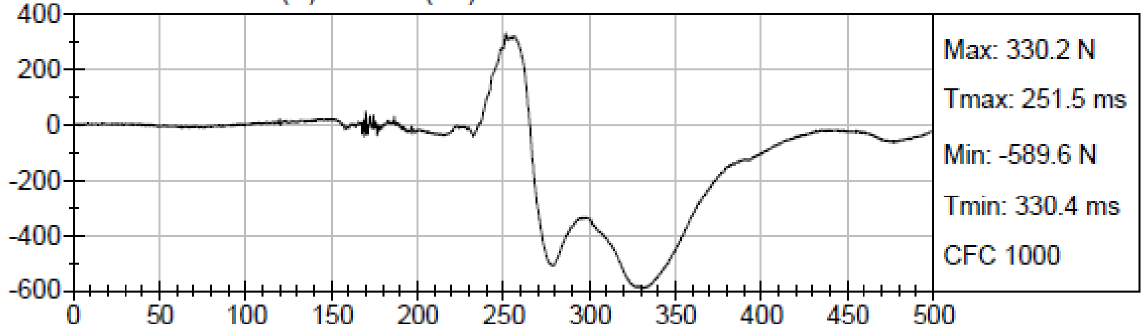
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

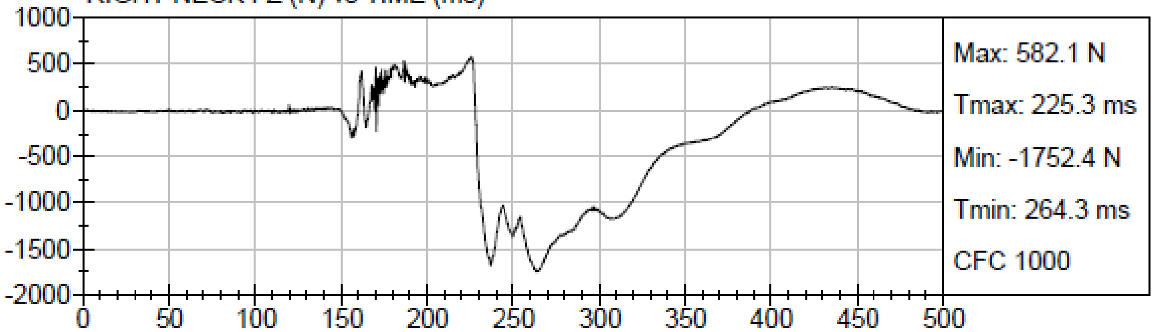
RIGHT NECK FX (N) vs TIME (ms)



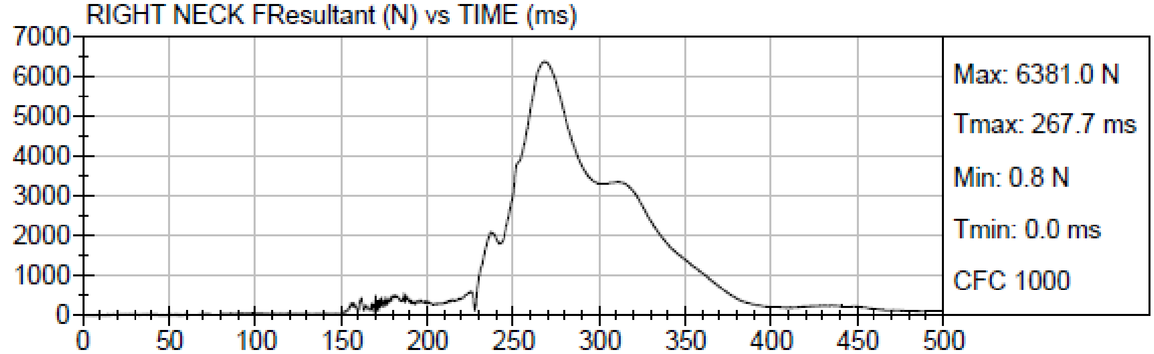
RIGHT NECK FY (N) vs TIME (ms)



RIGHT NECK FZ (N) vs TIME (ms)

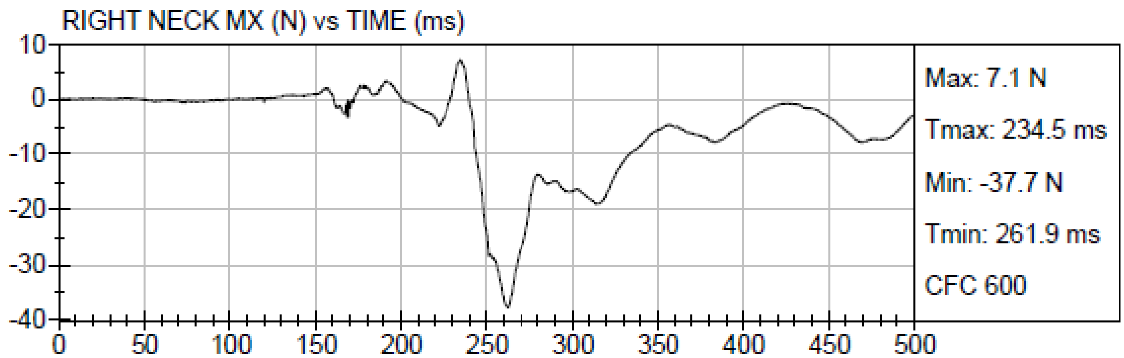


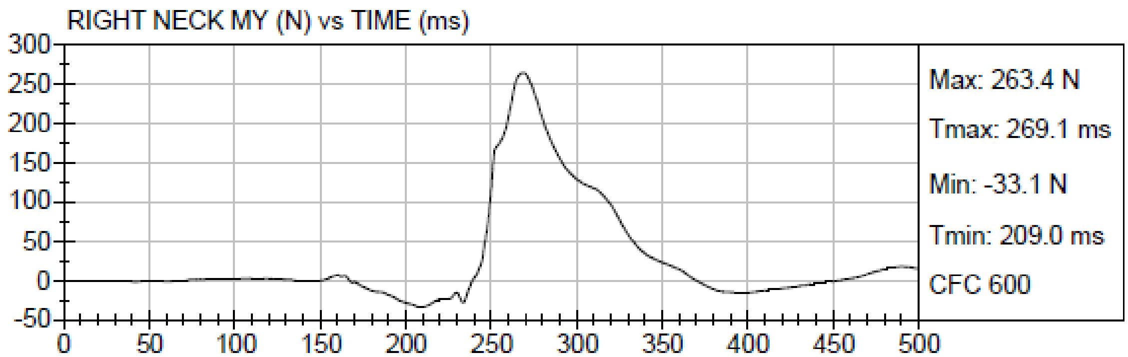
RIGHT NECK FResultant (N) vs TIME (ms)

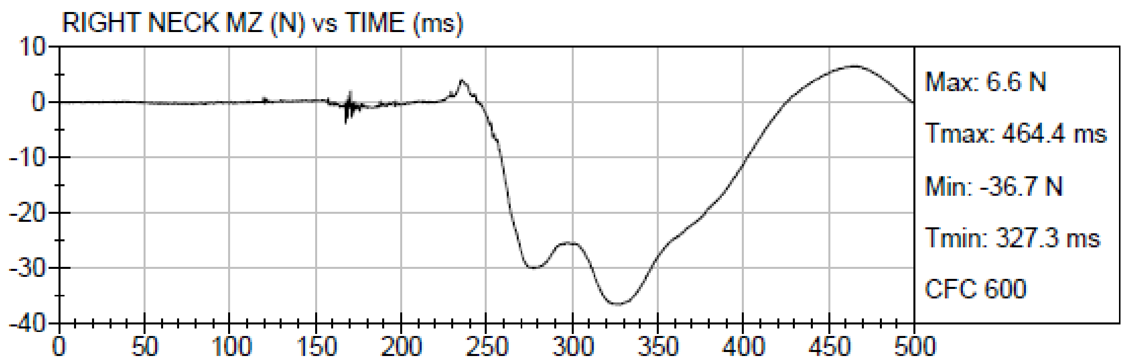


APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

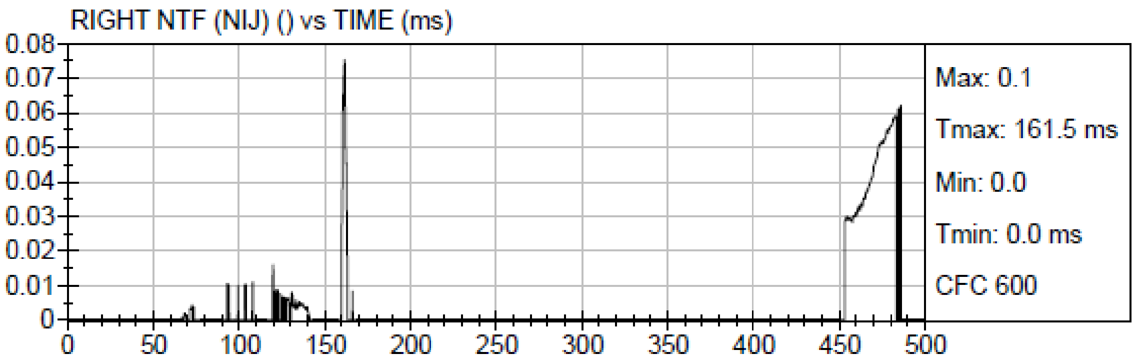


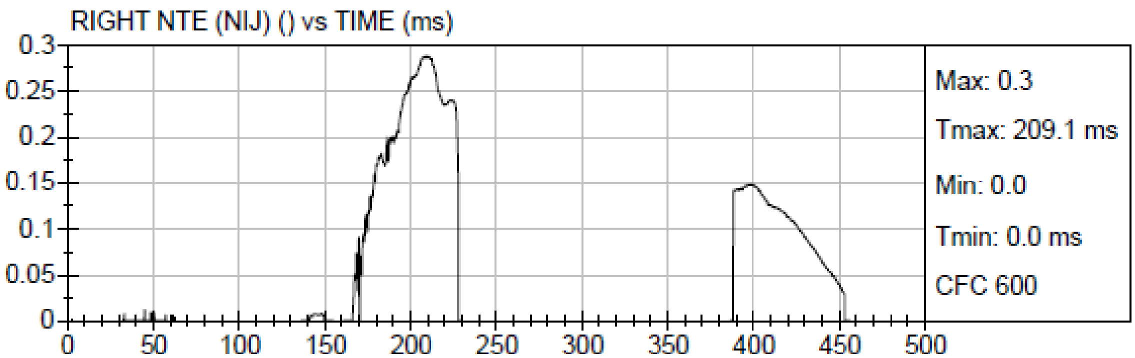


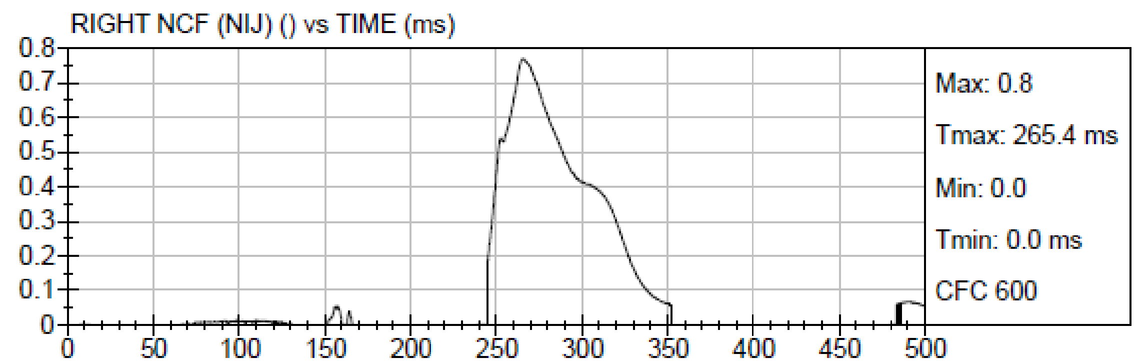


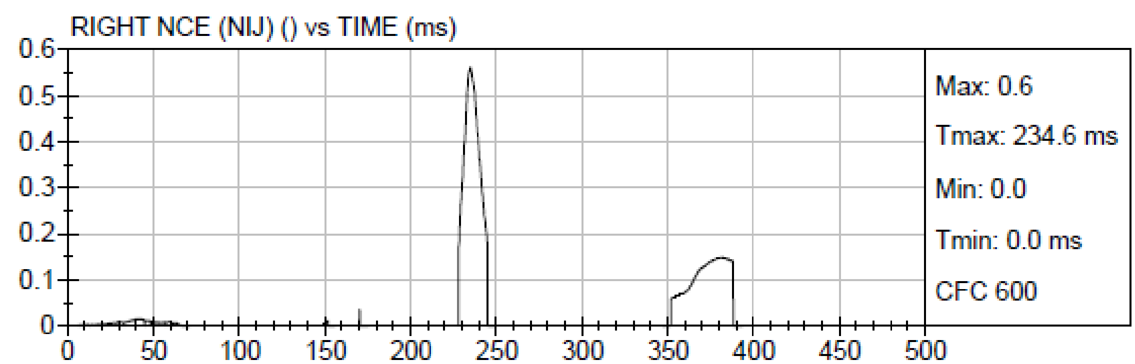
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304





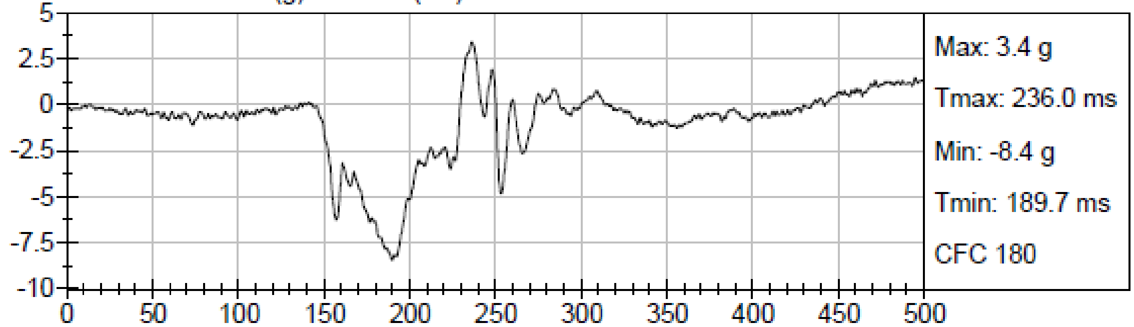




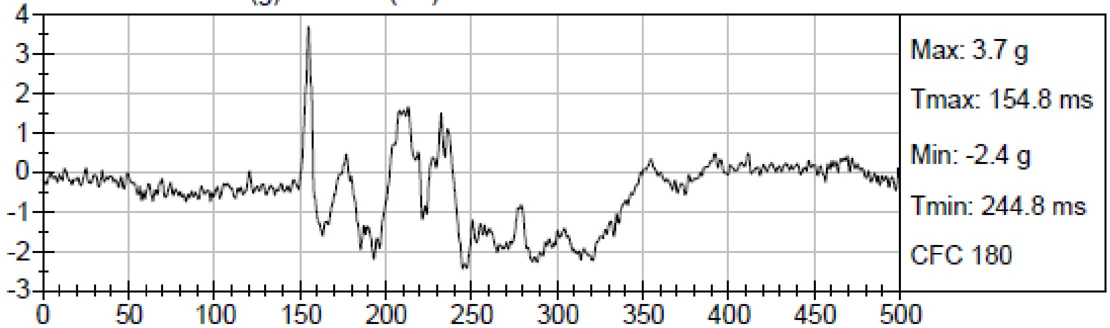
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

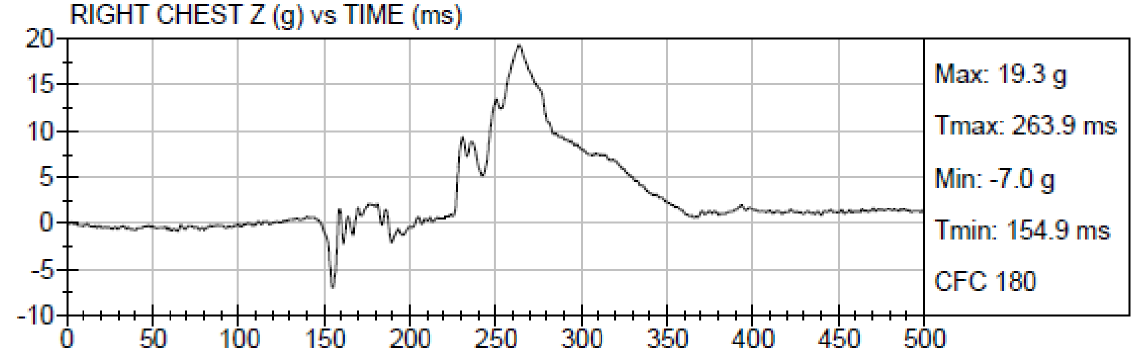
RIGHT CHEST X (g) vs TIME (ms)



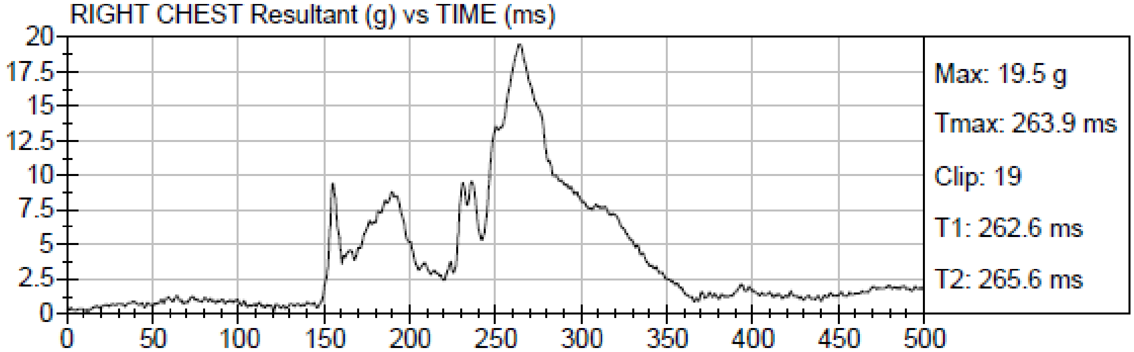
RIGHT CHEST Y (g) vs TIME (ms)



RIGHT CHEST Z (g) vs TIME (ms)

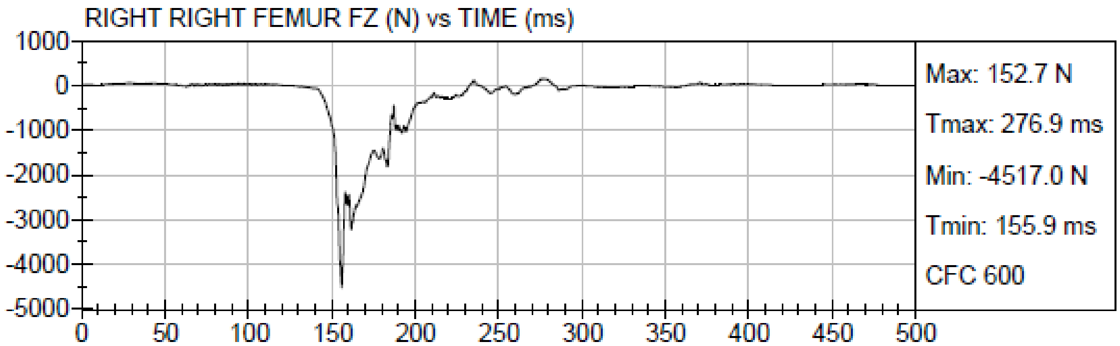


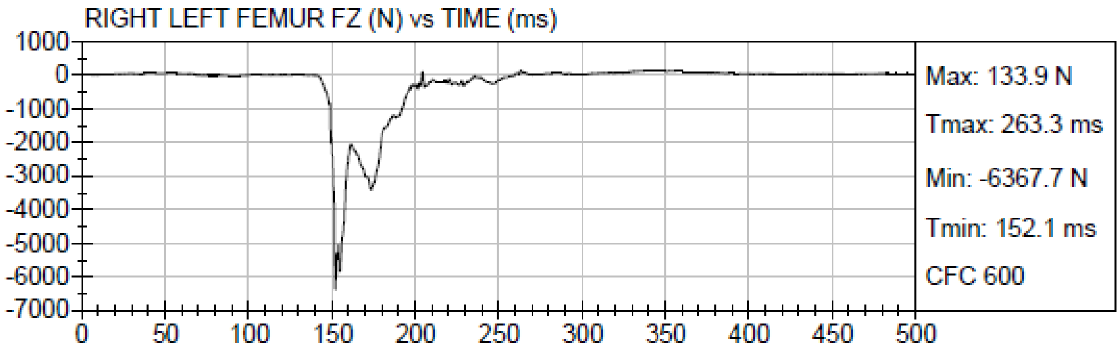
RIGHT CHEST Resultant (g) vs TIME (ms)



APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20304

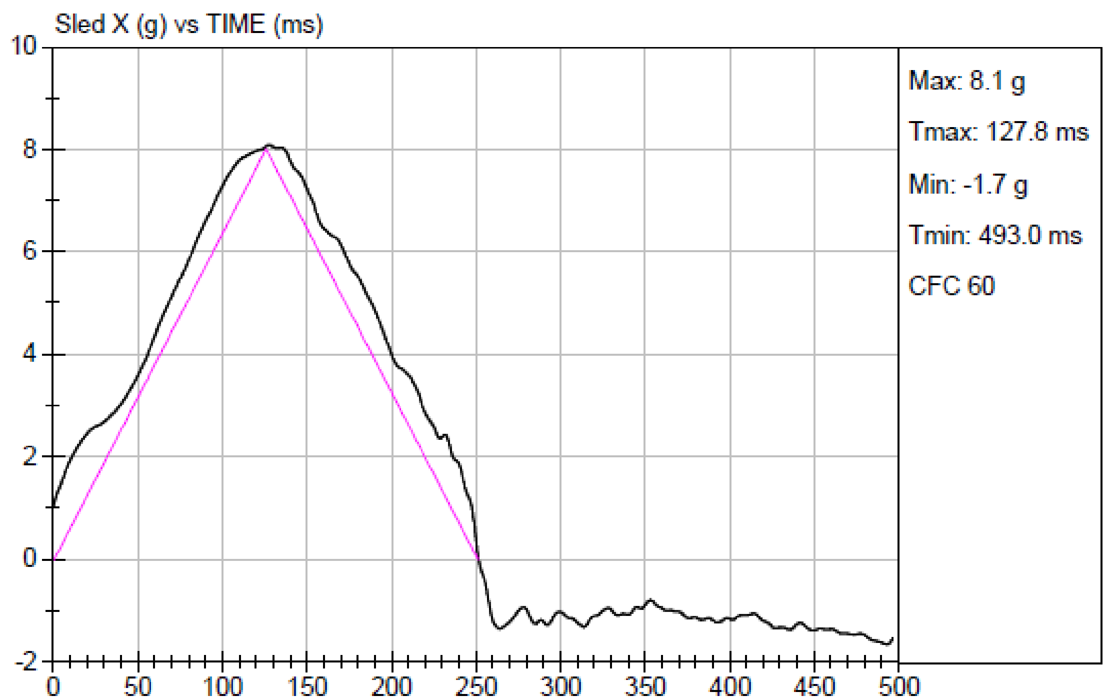


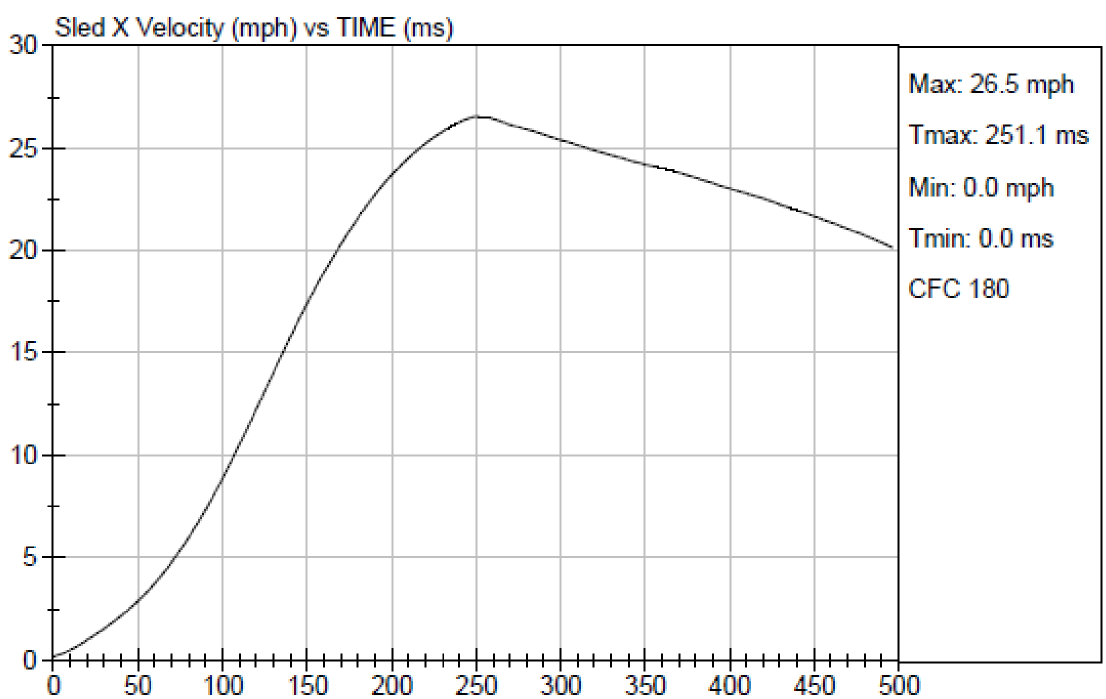


A.2: Test 2 Data

APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

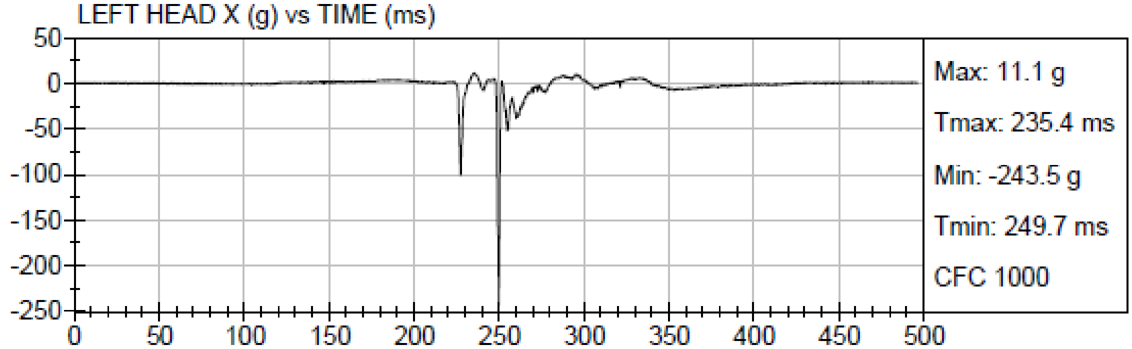




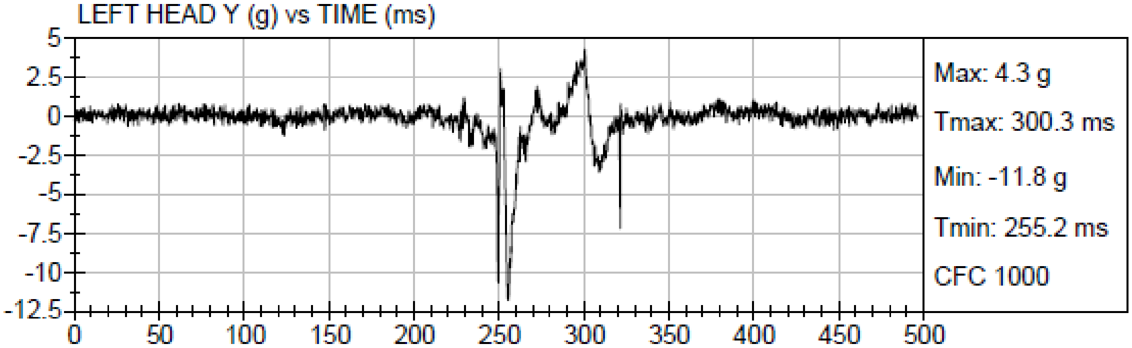
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

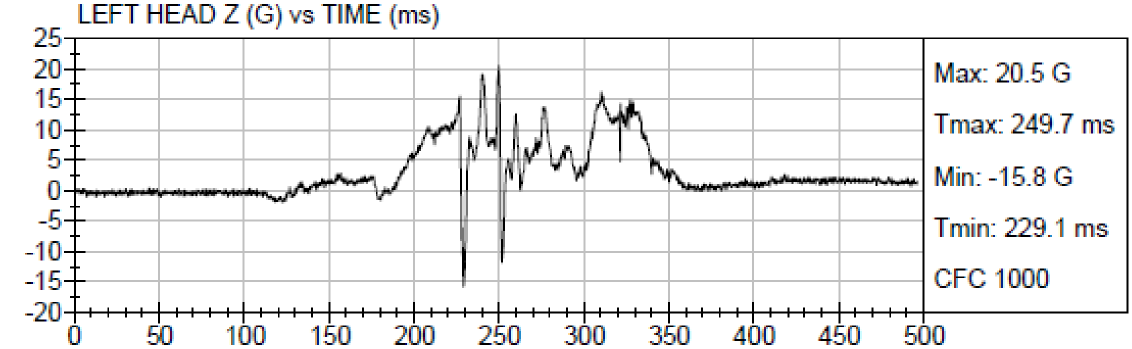
LEFT HEAD X (g) vs TIME (ms)



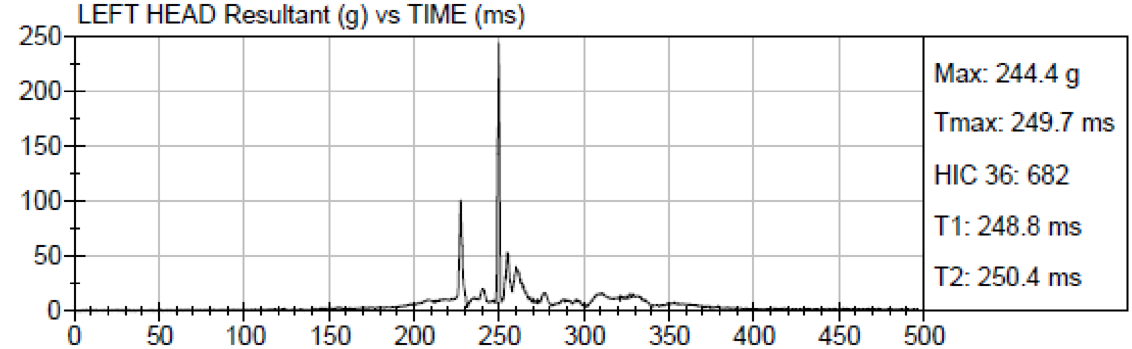
LEFT HEAD Y (g) vs TIME (ms)

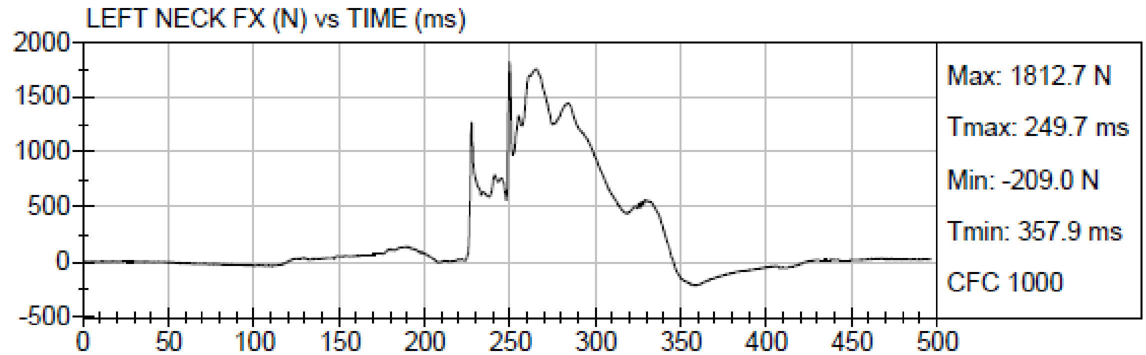


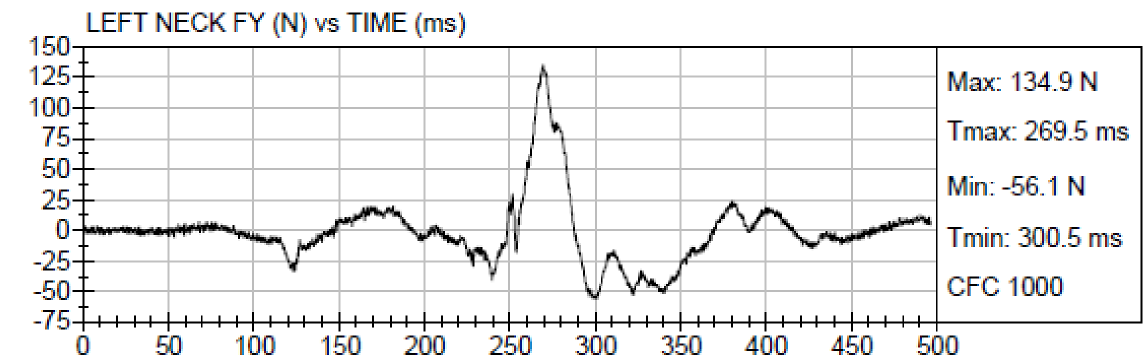
LEFT HEAD Z (G) vs TIME (ms)

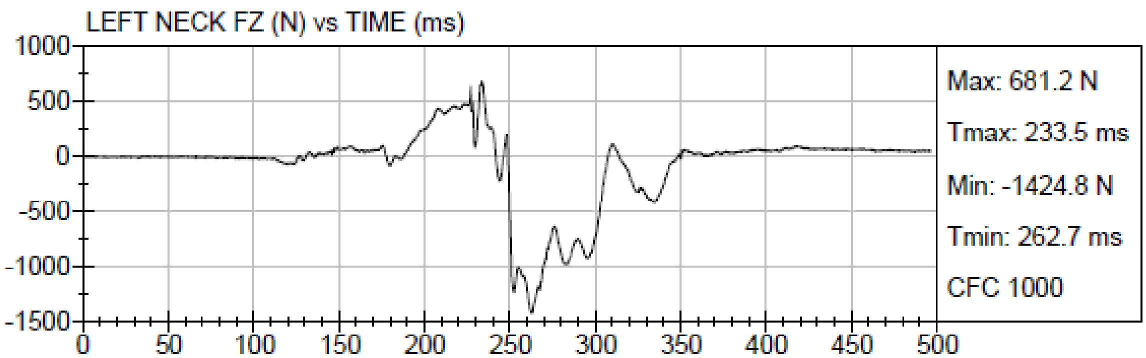


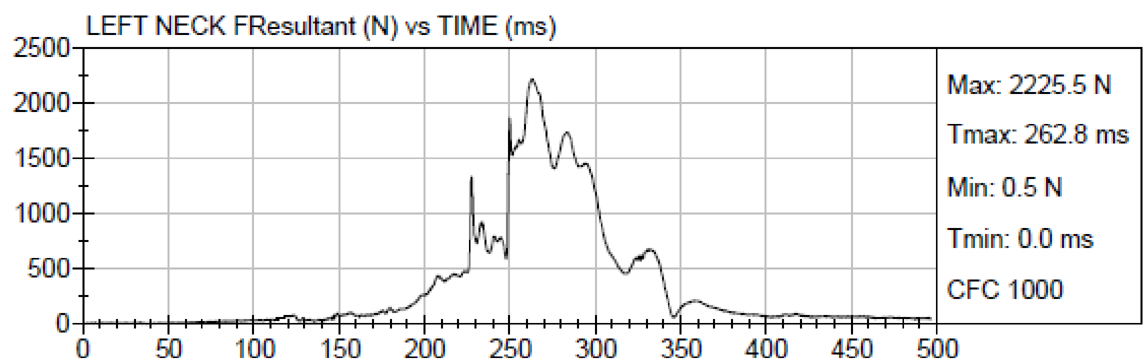
LEFT HEAD Resultant (g) vs TIME (ms)




LEFT NECK FX (N) vs TIME (ms)
Max: 1812.7 N
Tmax: 249.7 ms
Min: -209.0 N
Tmin: 357.9 ms
CFC 1000


LEFT NECK FY (N) vs TIME (ms)
Max: 134.9 N
Tmax: 269.5 ms
Min: -56.1 N
Tmin: 300.5 ms
CFC 1000

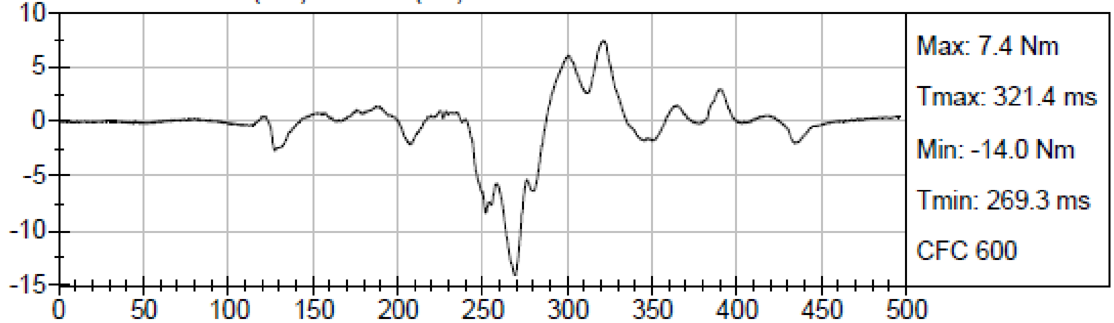

LEFT NECK FZ (N) vs TIME (ms)
Max: 681.2 N
Tmax: 233.5 ms
Min: -1424.8 N
Tmin: 262.7 ms
CFC 1000


LEFT NECK FResultant (N) vs TIME (ms)
Max: 2225.5 N
Tmax: 262.8 ms
Min: 0.5 N
Tmin: 0.0 ms
CFC 1000

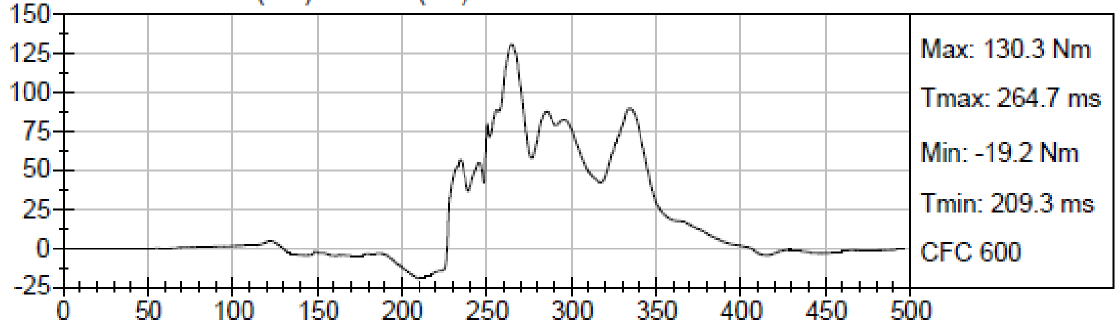
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

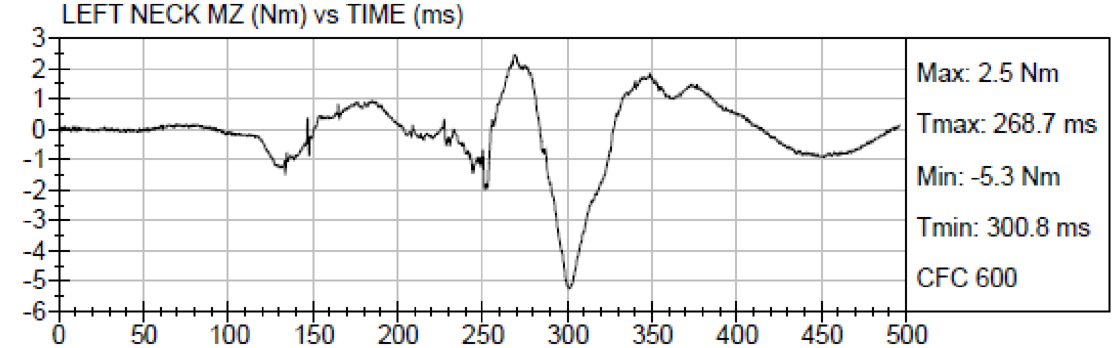
LEFT NECK MX (Nm) vs TIME (ms)



LEFT NECK MY (Nm) vs TIME (ms)



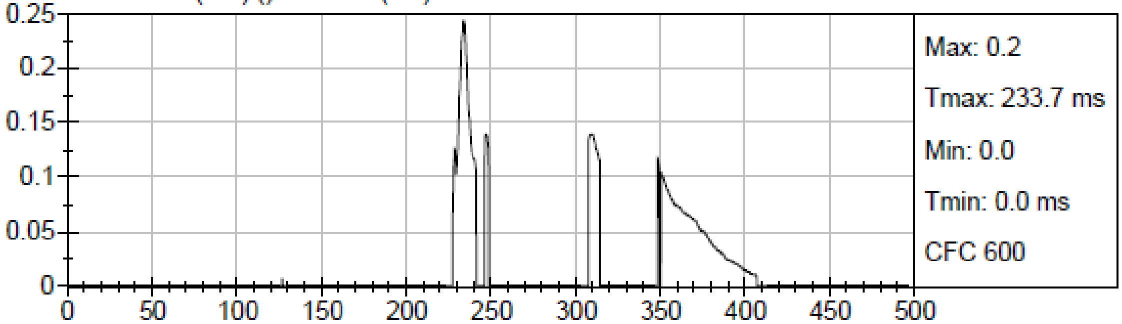
LEFT NECK MZ (Nm) vs TIME (ms)



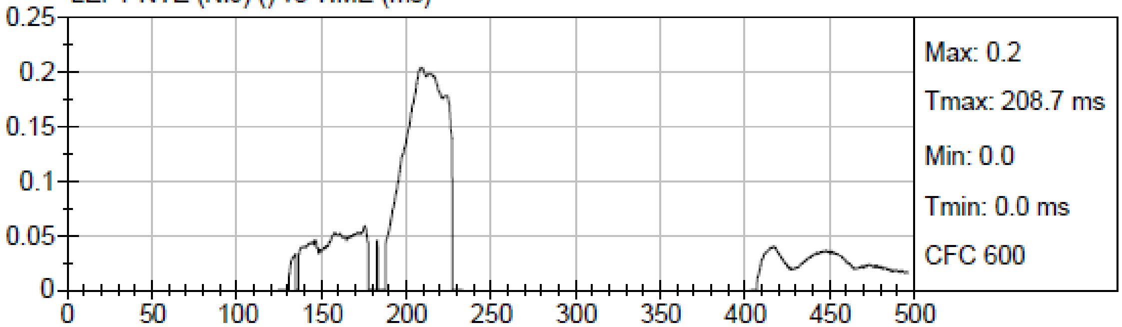
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

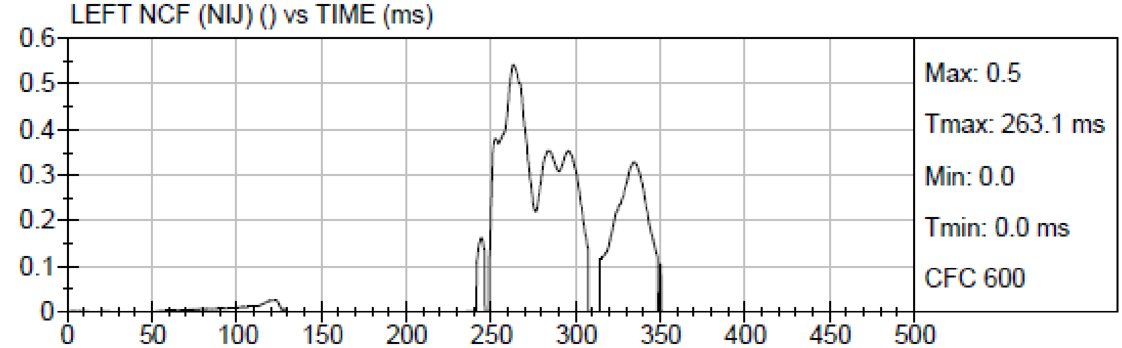
LEFT NTF (NIJ) () vs TIME (ms)



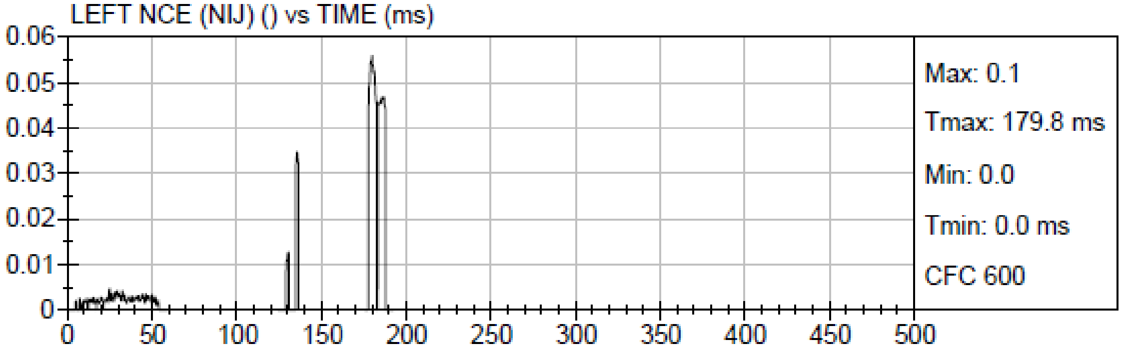
LEFT NTE (NIJ) () vs TIME (ms)



LEFT NCF (NIJ) () vs TIME (ms)



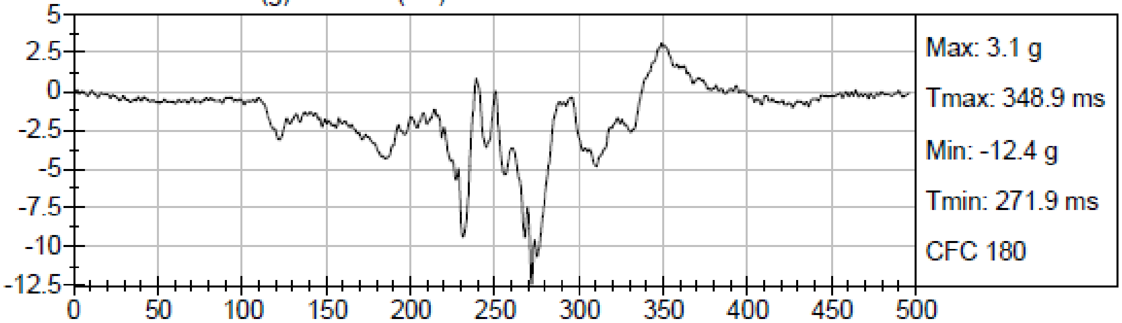
LEFT NCE (NIJ) () vs TIME (ms)



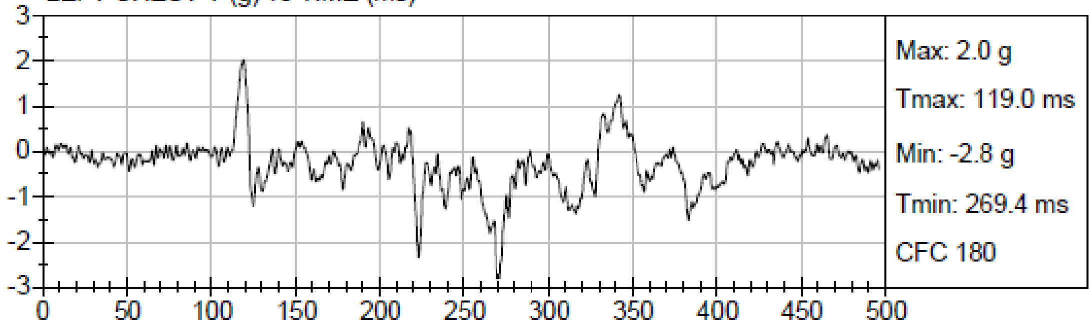
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

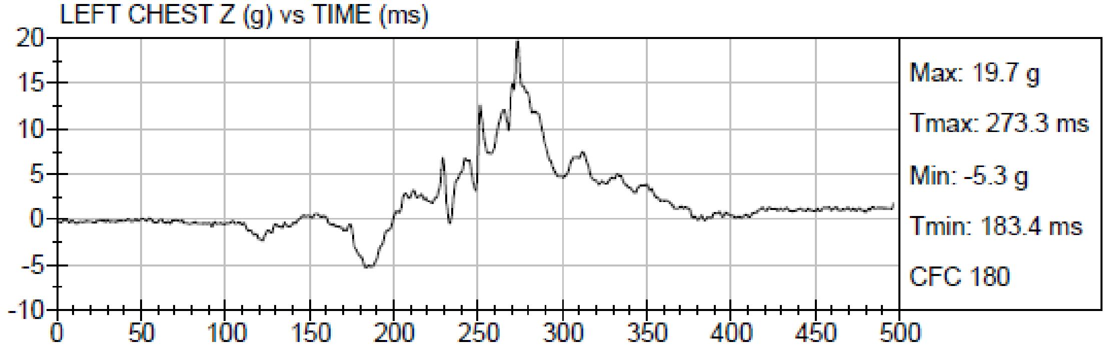
LEFT CHEST X (g) vs TIME (ms)



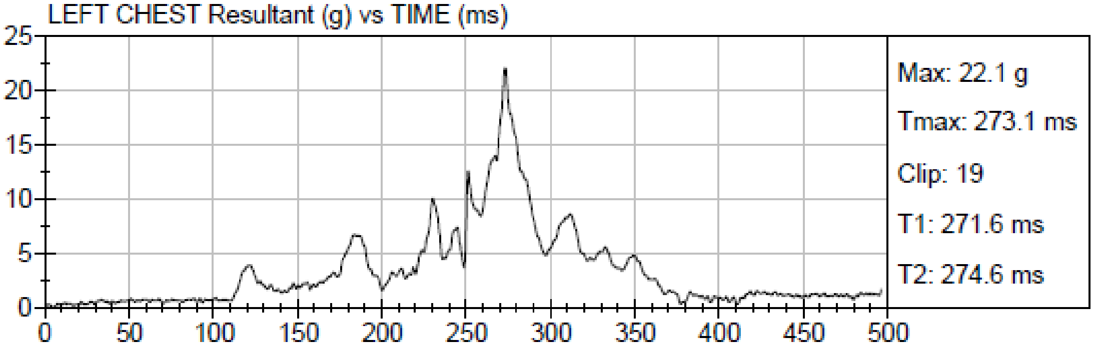
LEFT CHEST Y (g) vs TIME (ms)



LEFT CHEST Z (g) vs TIME (ms)

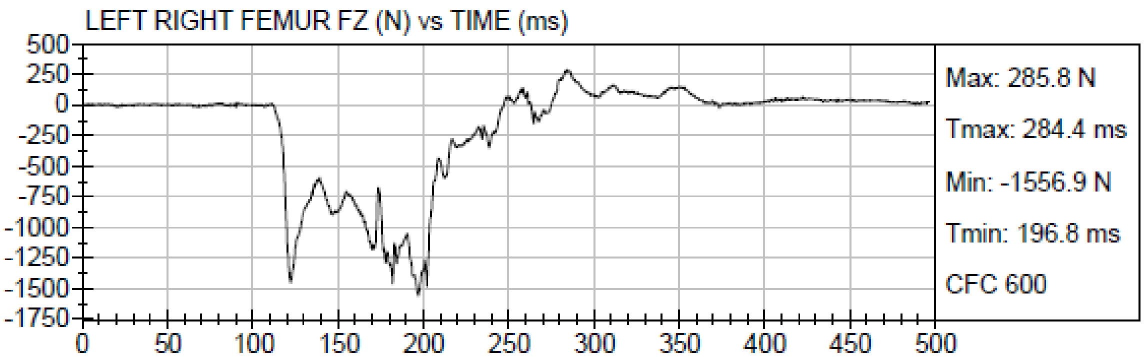


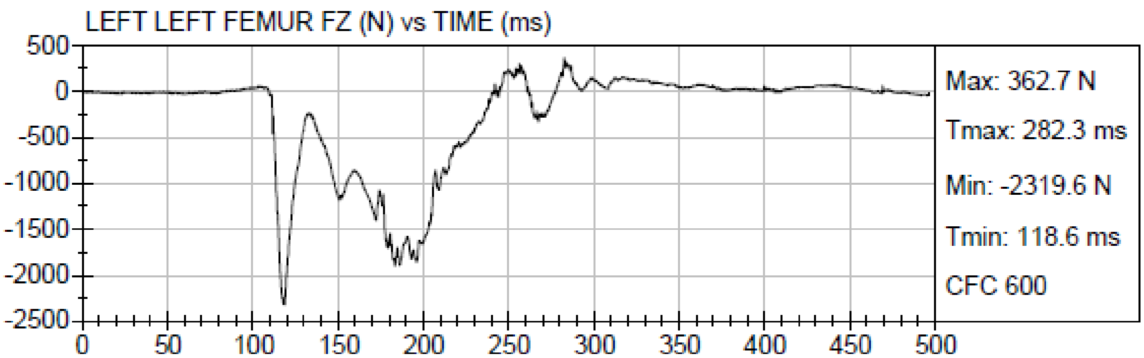
LEFT CHEST Resultant (g) vs TIME (ms)



APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

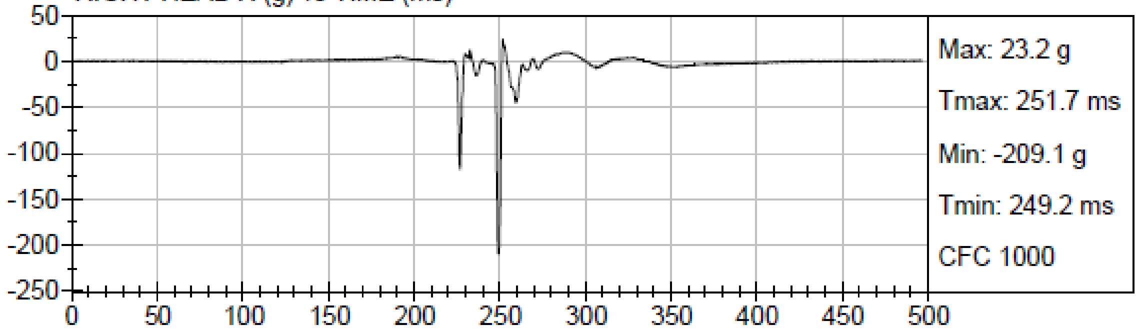




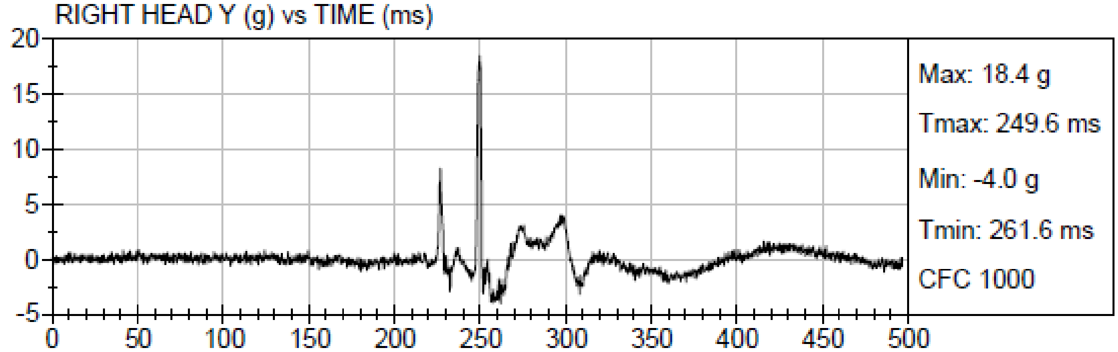
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

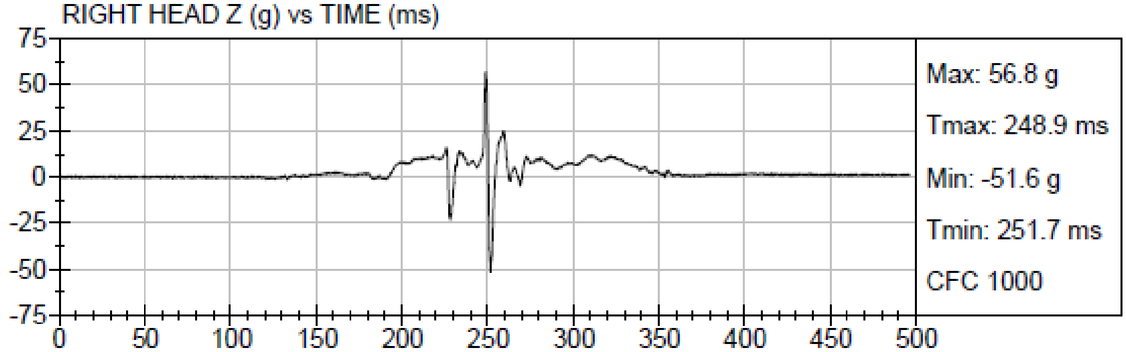
RIGHT HEAD X (g) vs TIME (ms)



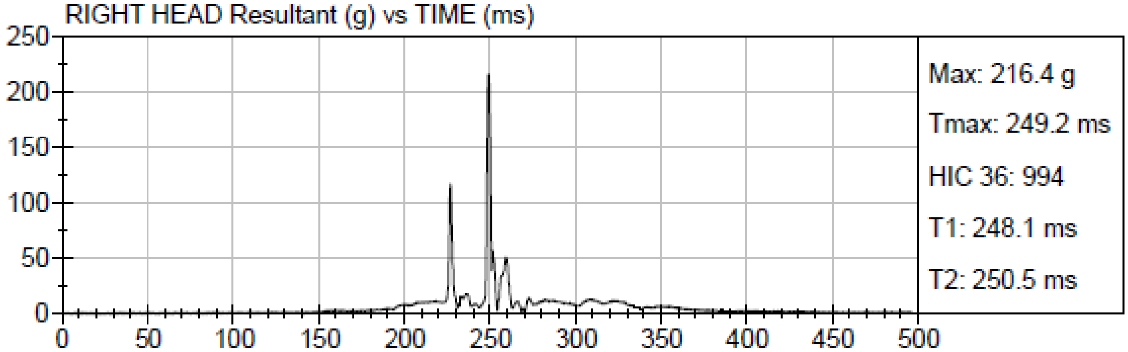
RIGHT HEAD Y (g) vs TIME (ms)



RIGHT HEAD Z (g) vs TIME (ms)



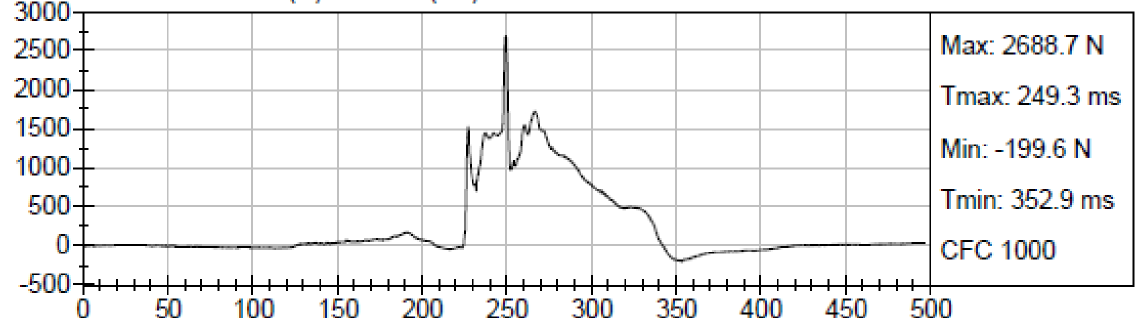
RIGHT HEAD Resultant (g) vs TIME (ms)



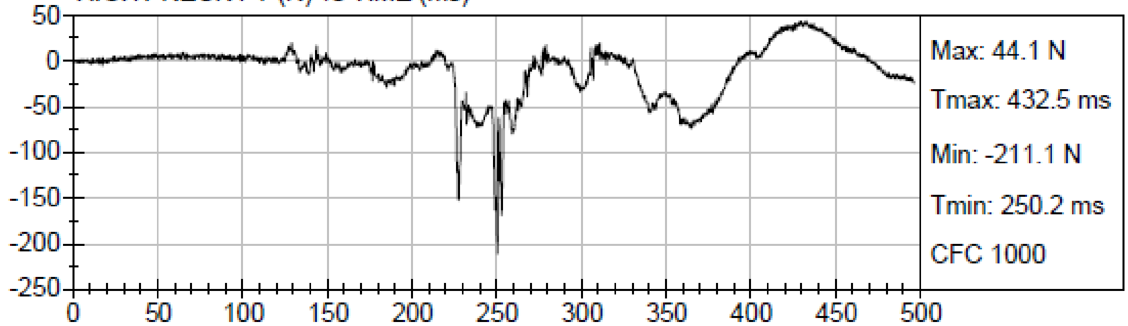
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

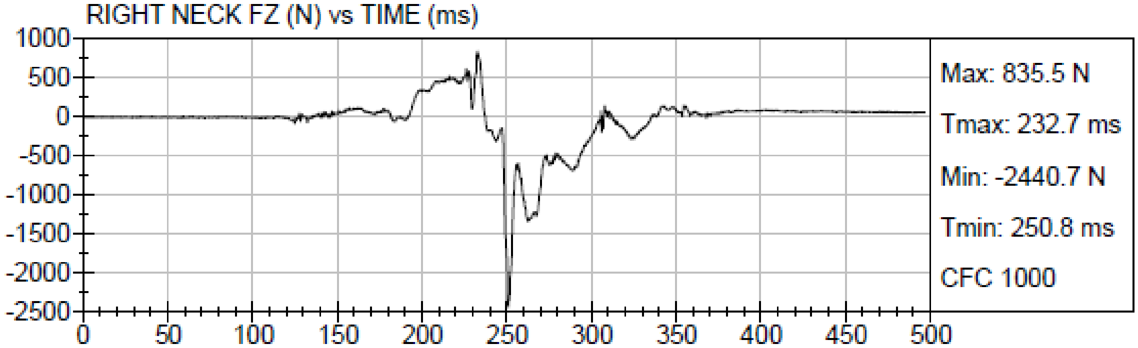
RIGHT NECK FX (N) vs TIME (ms)



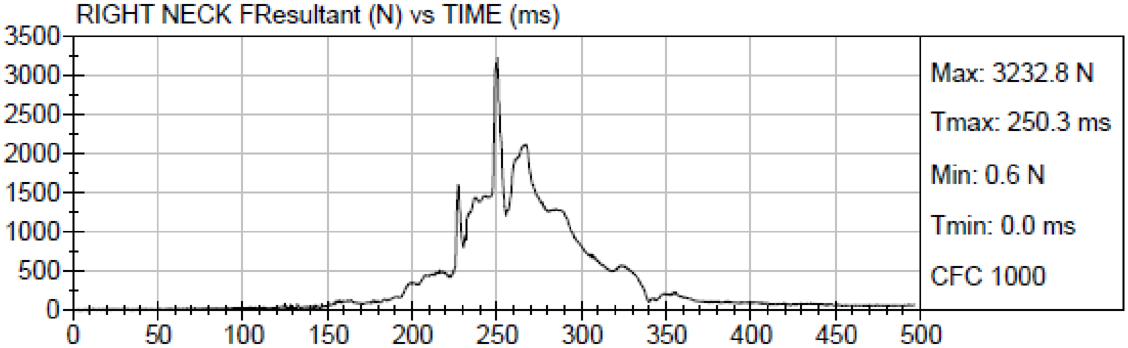
RIGHT NECK FY (N) vs TIME (ms)



RIGHT NECK FZ (N) vs TIME (ms)



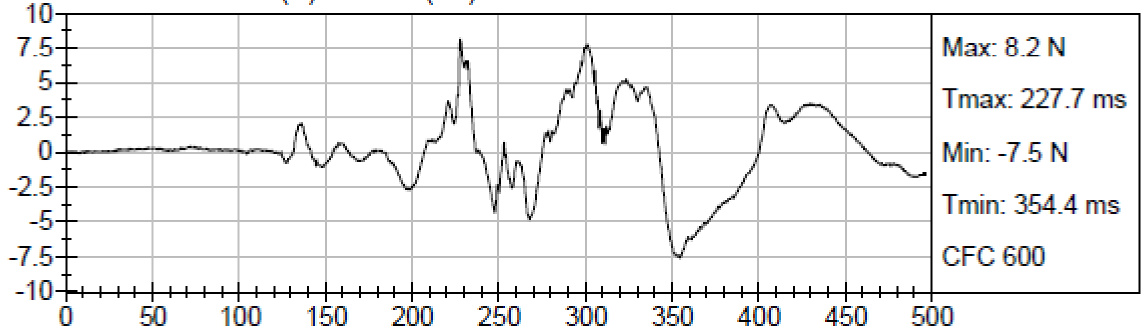
RIGHT NECK FResultant (N) vs TIME (ms)



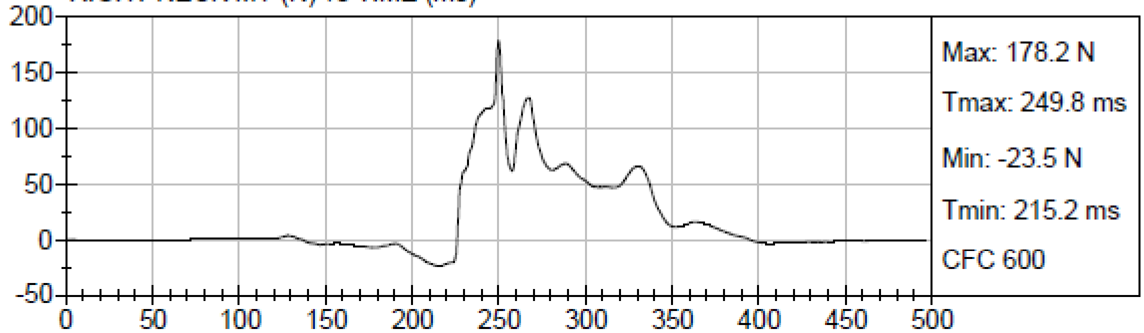
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

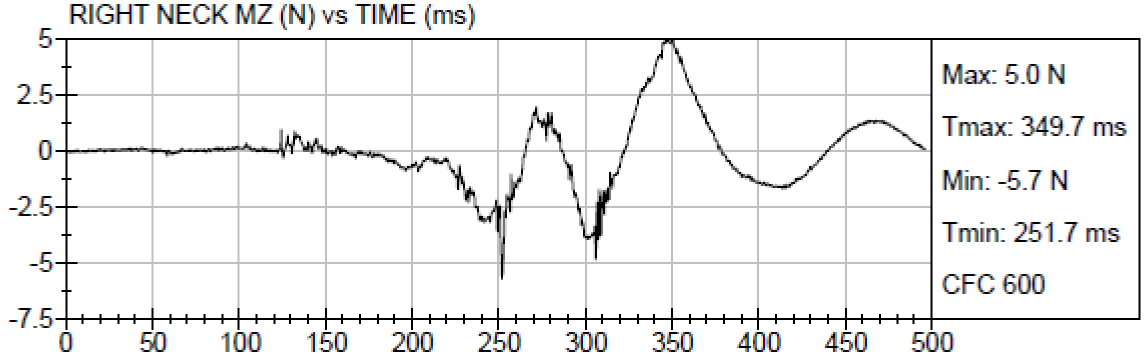
RIGHT NECK MX (N) vs TIME (ms)



RIGHT NECK MY (N) vs TIME (ms)

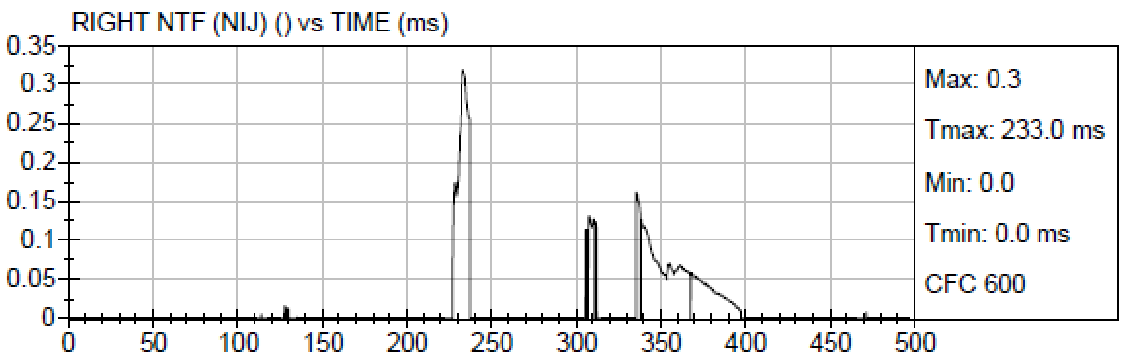


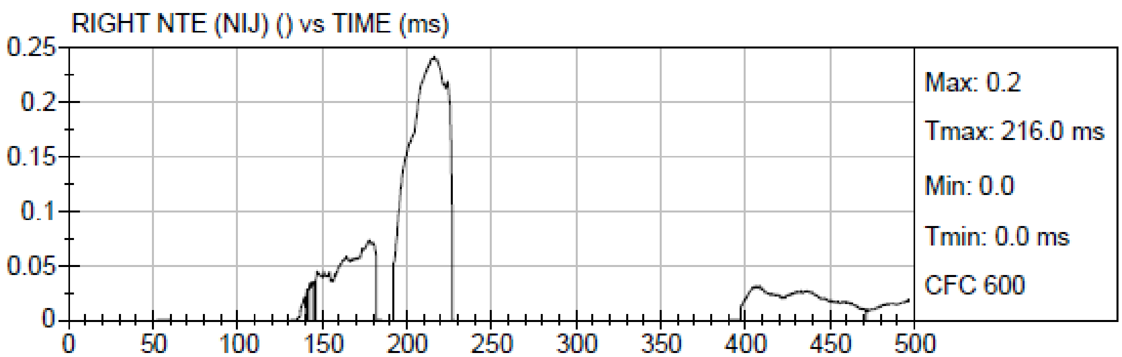
RIGHT NECK MZ (N) vs TIME (ms)

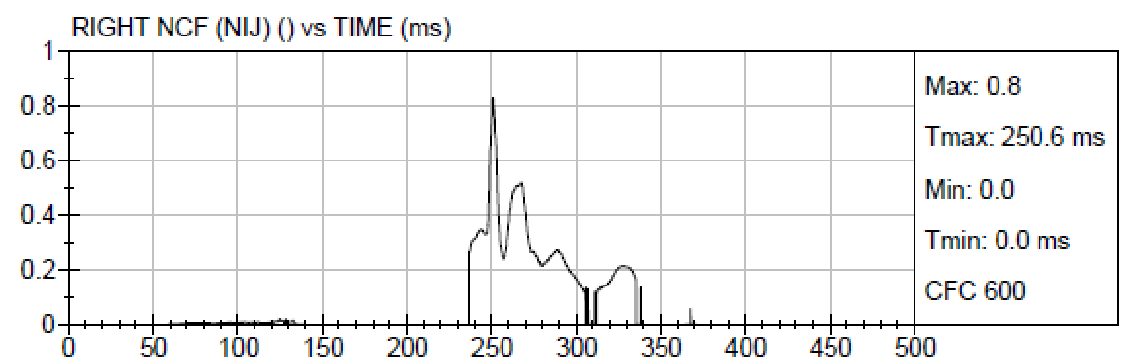


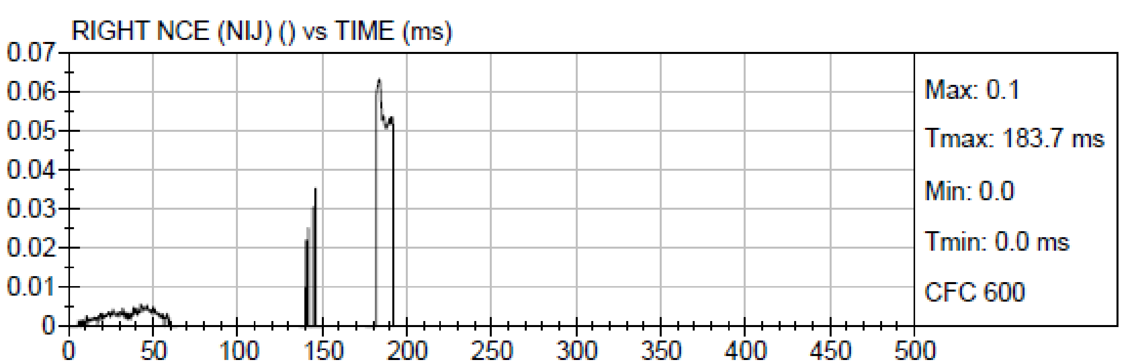
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305



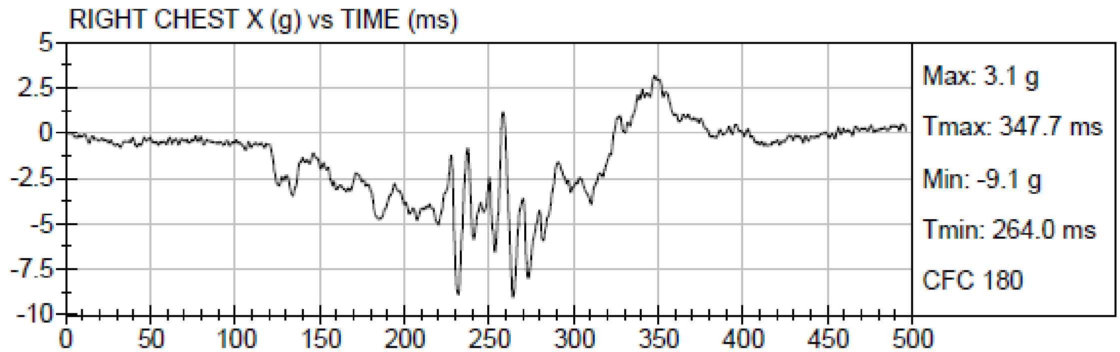


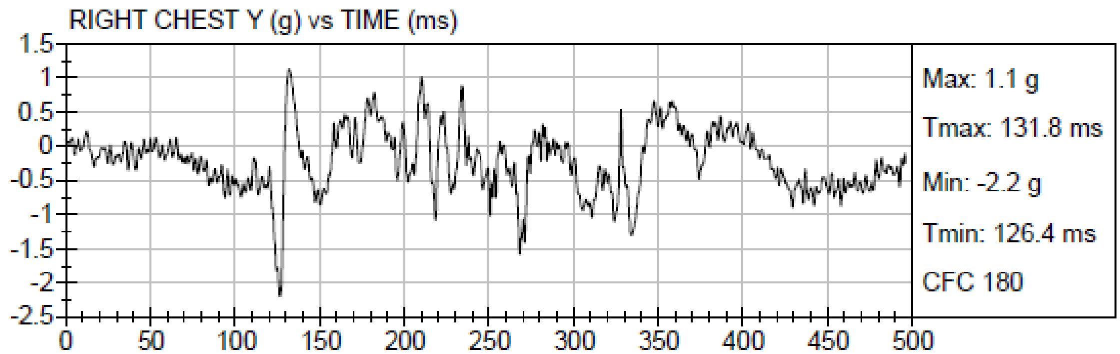


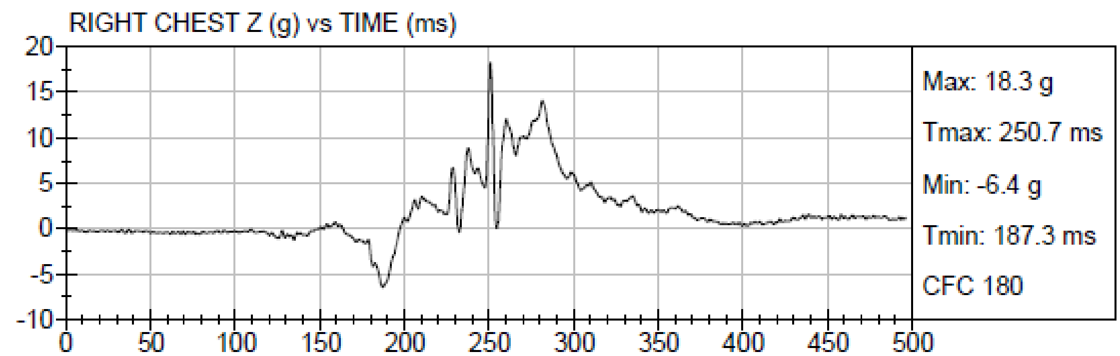


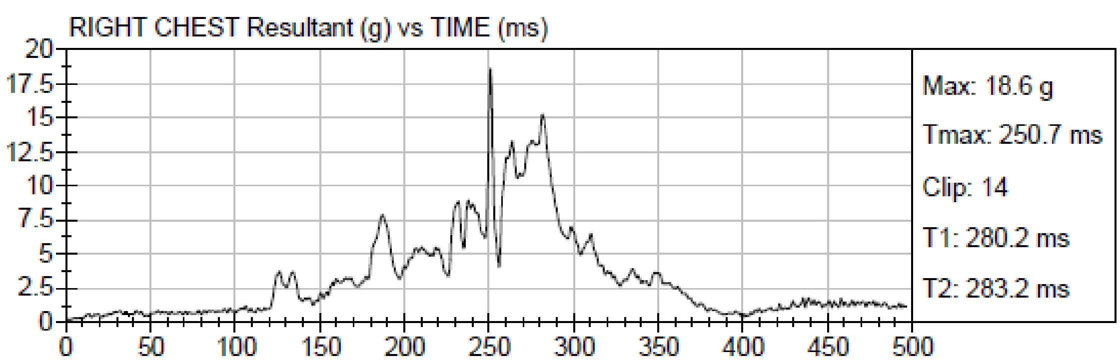
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305





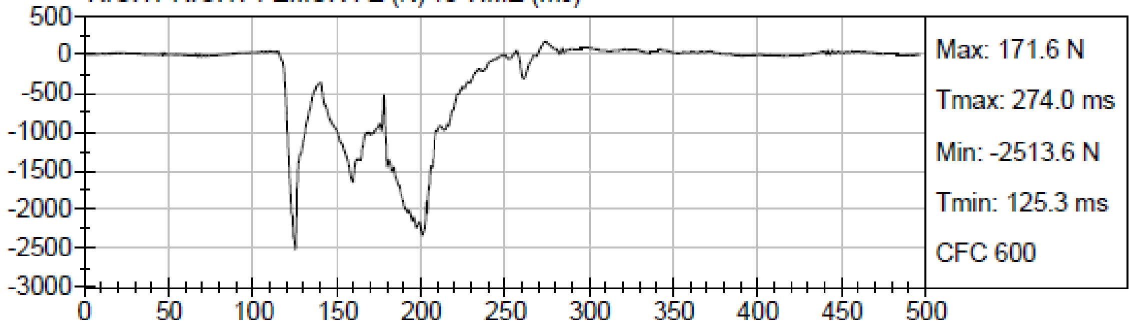




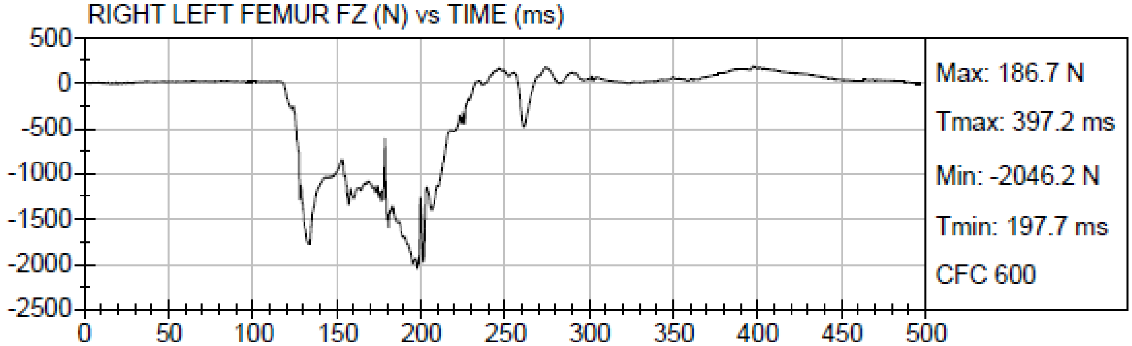
APTA RAIL TEST

TEST DATE: 10/26/2020
TEST #: S20305

RIGHT RIGHT FEMUR FZ (N) vs TIME (ms)



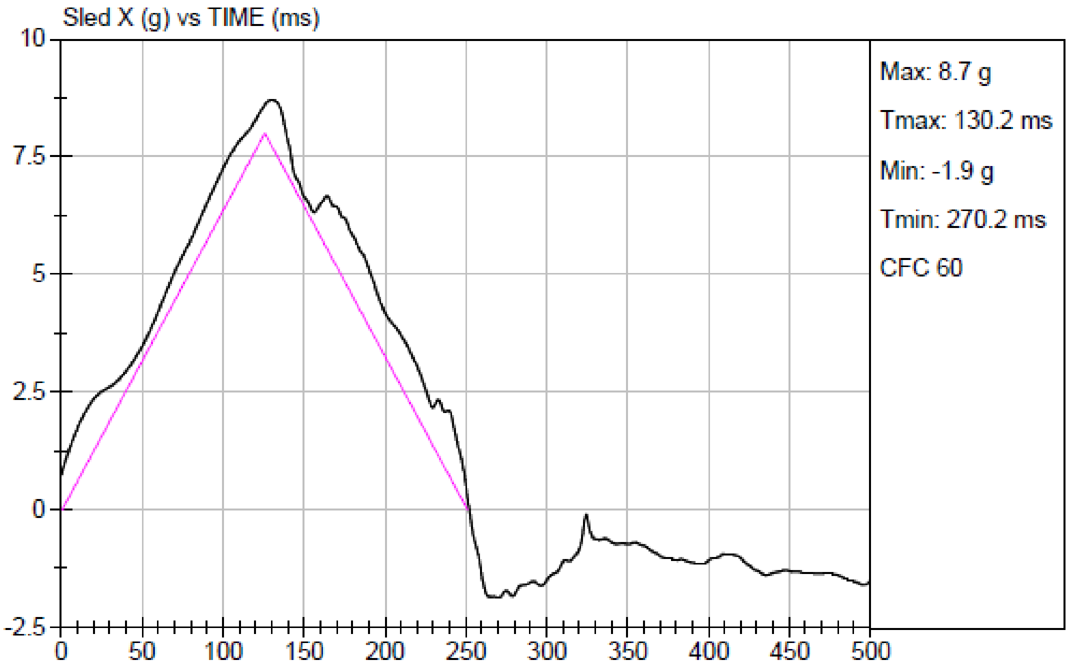
RIGHT LEFT FEMUR FZ (N) vs TIME (ms)

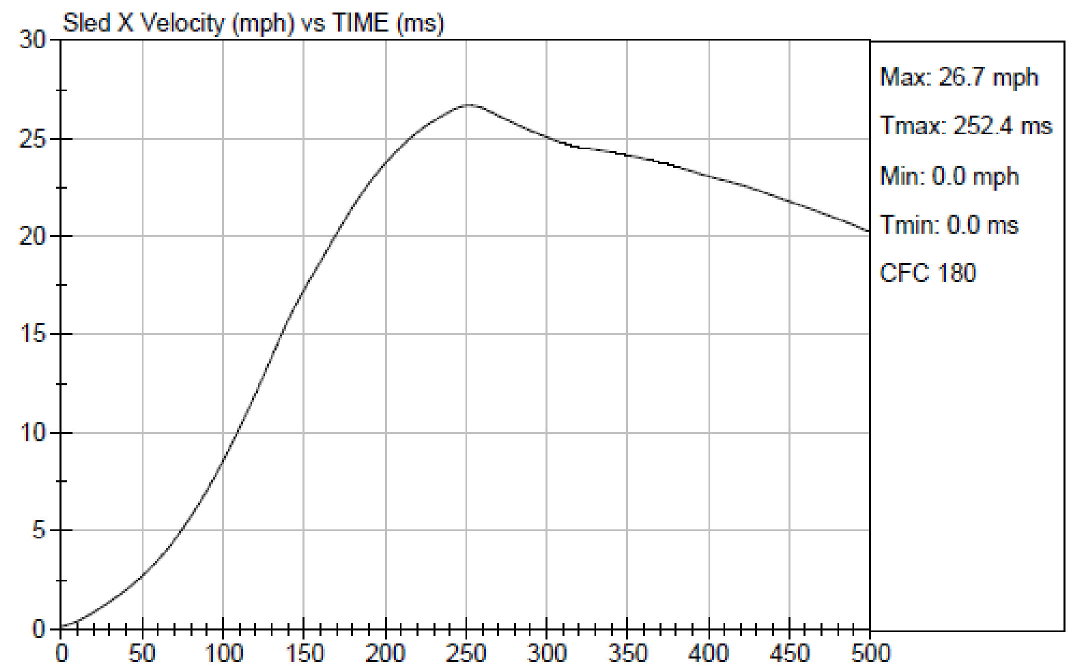


A.3: Test 3 Data

APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306

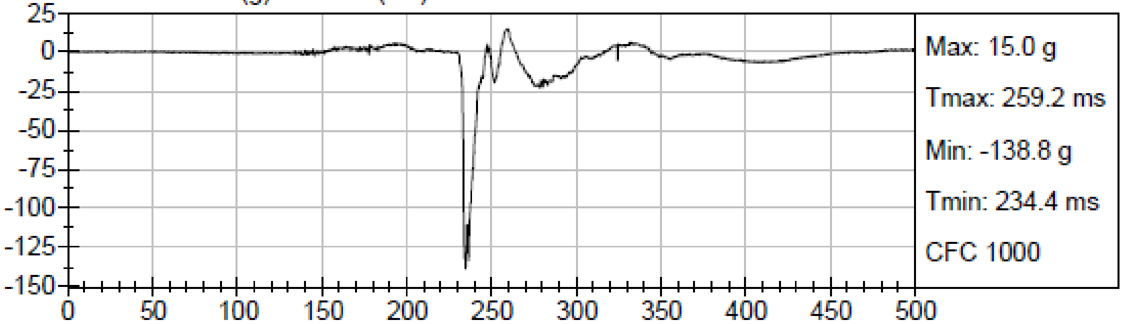




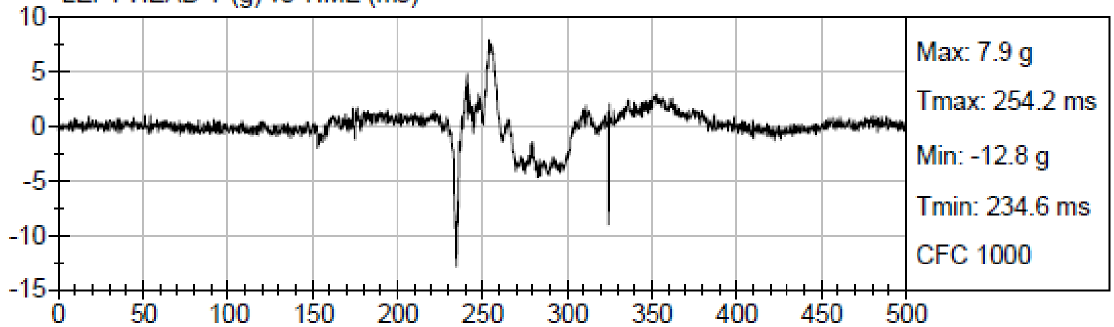
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306

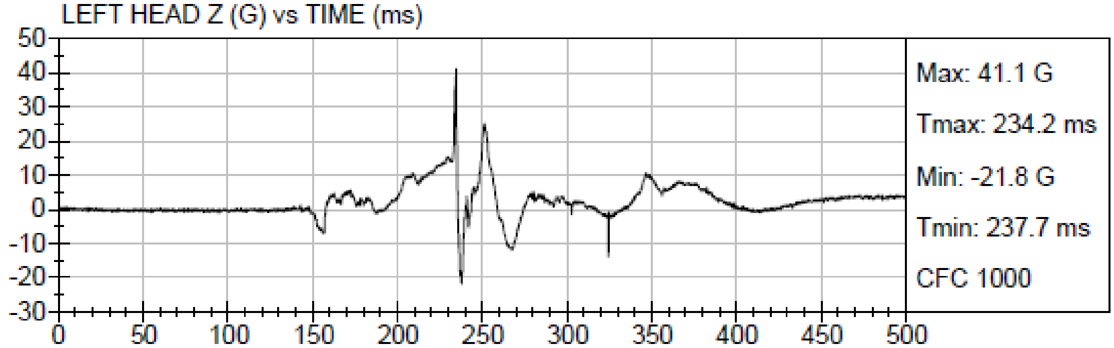
LEFT HEAD X (g) vs TIME (ms)



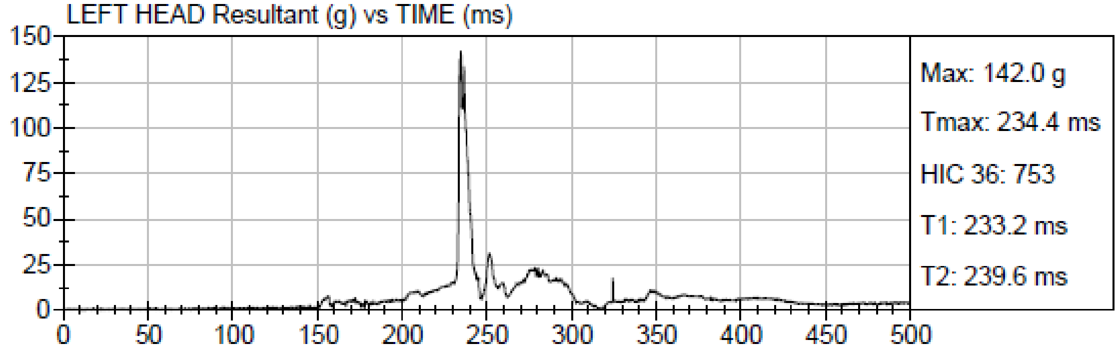
LEFT HEAD Y (g) vs TIME (ms)



LEFT HEAD Z (G) vs TIME (ms)



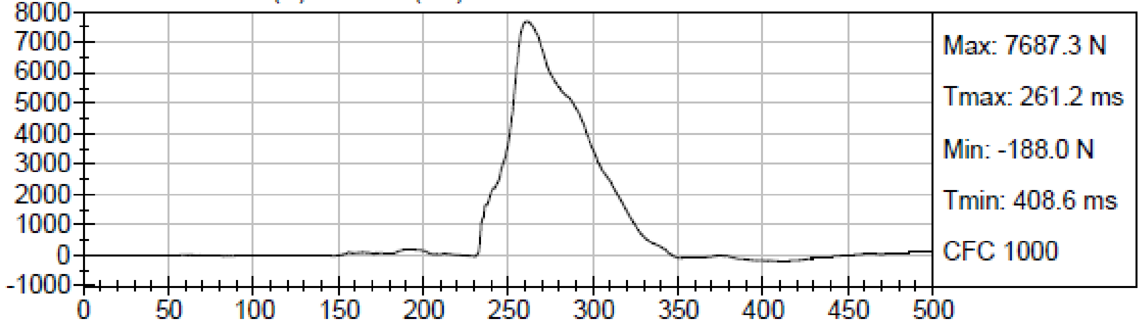
LEFT HEAD Resultant (g) vs TIME (ms)



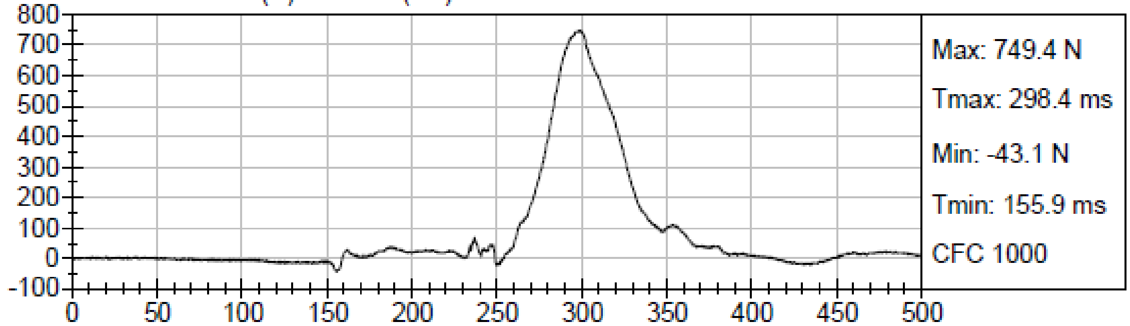
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306

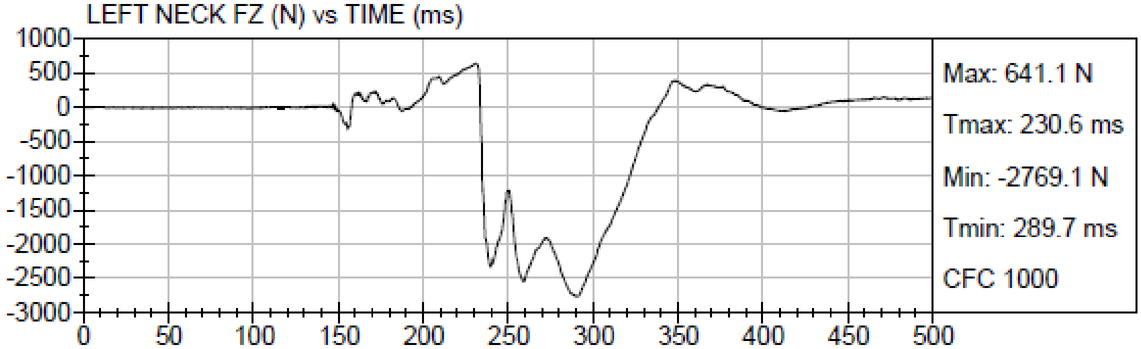
LEFT NECK FX (N) vs TIME (ms)



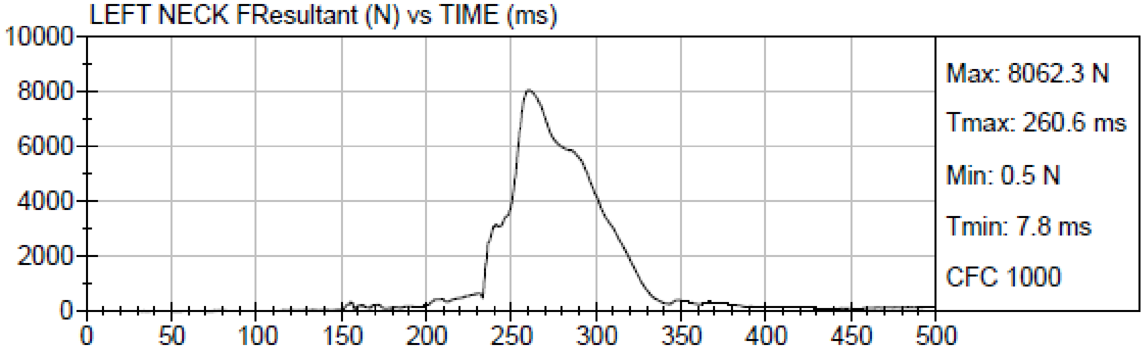
LEFT NECK FY (N) vs TIME (ms)



LEFT NECK FZ (N) vs TIME (ms)



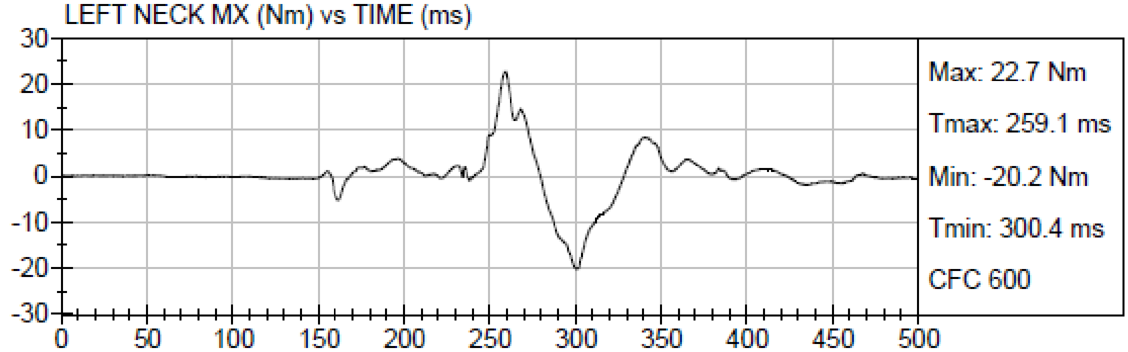
LEFT NECK FResultant (N) vs TIME (ms)



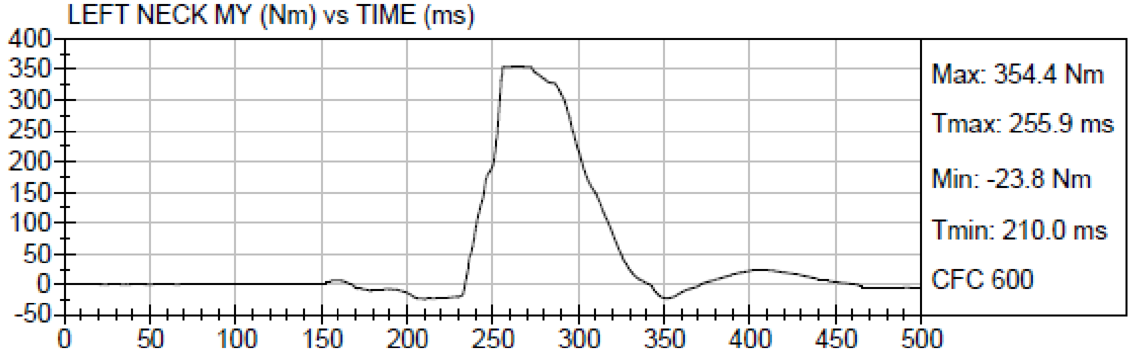
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306

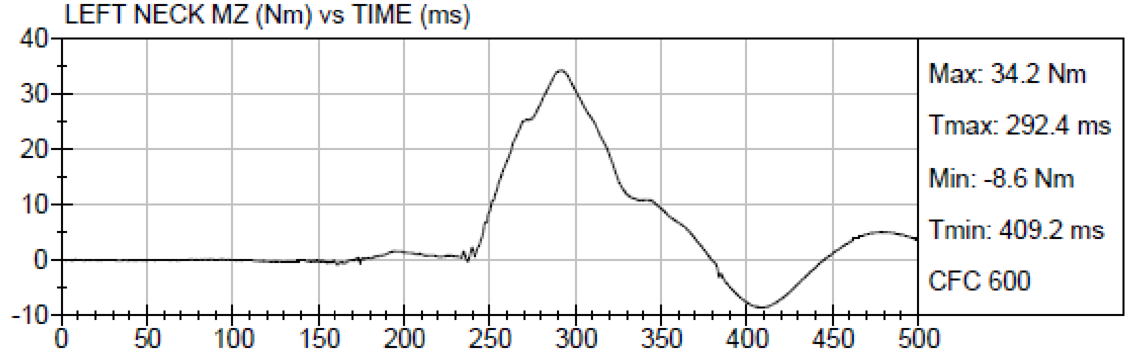
LEFT NECK MX (Nm) vs TIME (ms)



LEFT NECK MY (Nm) vs TIME (ms)

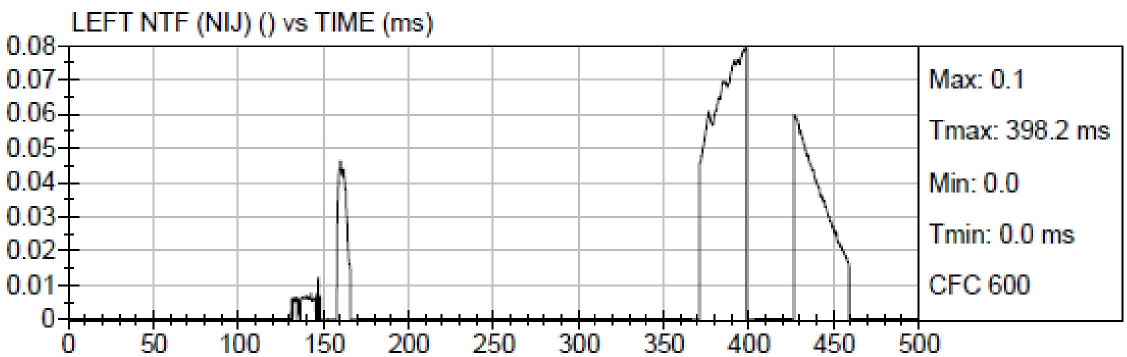


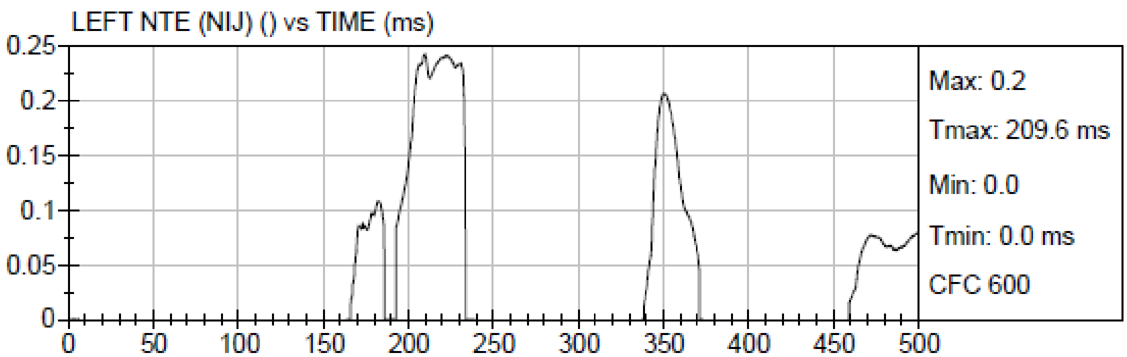
LEFT NECK MZ (Nm) vs TIME (ms)

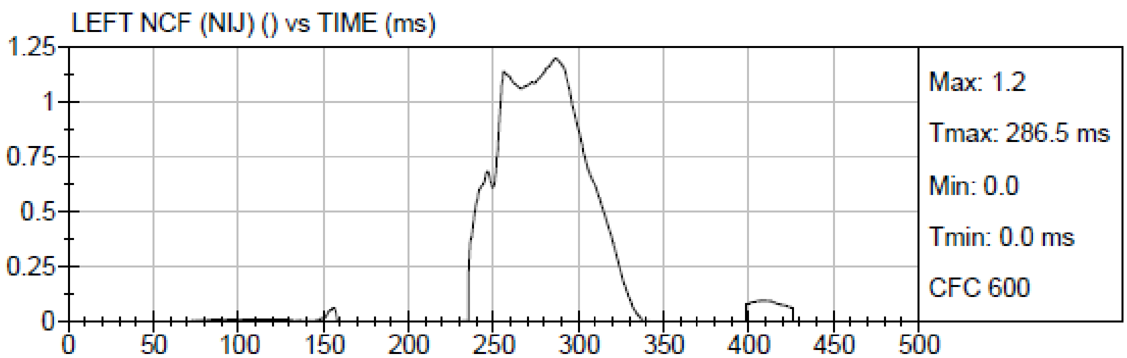


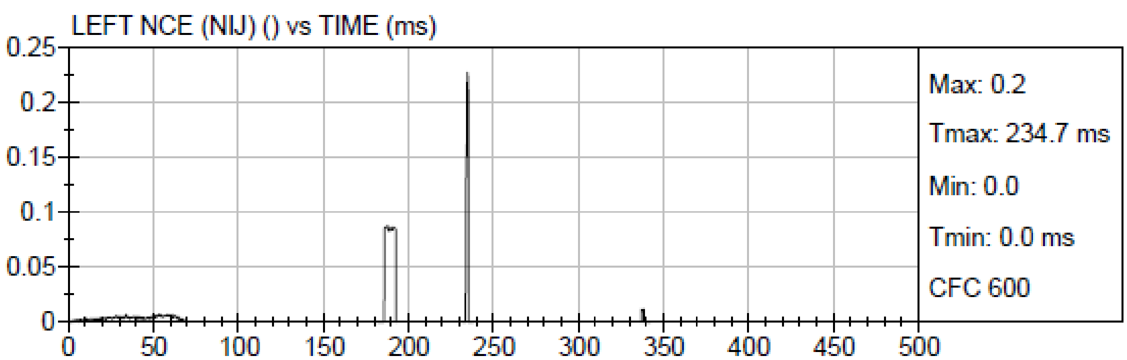
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306



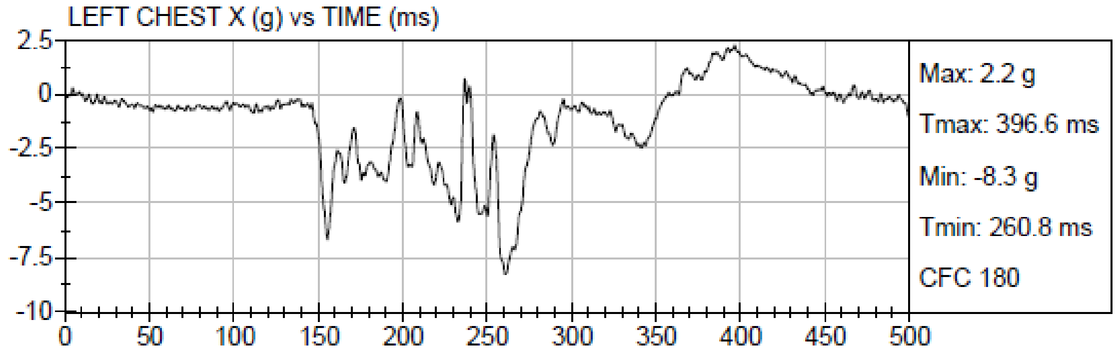


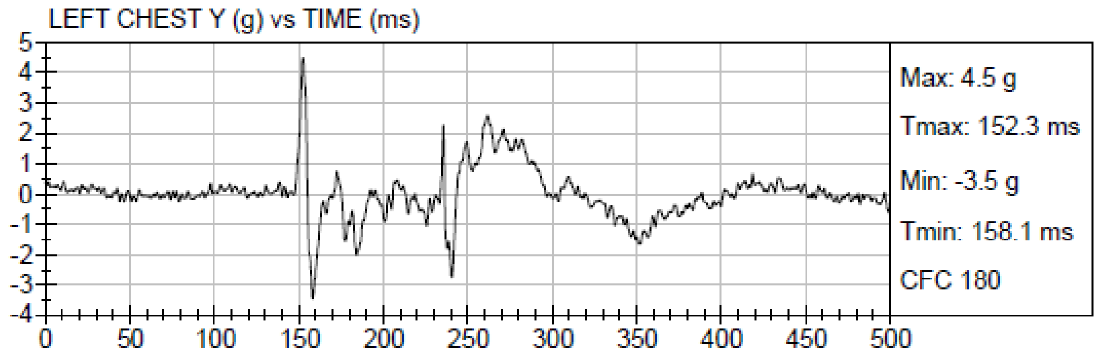


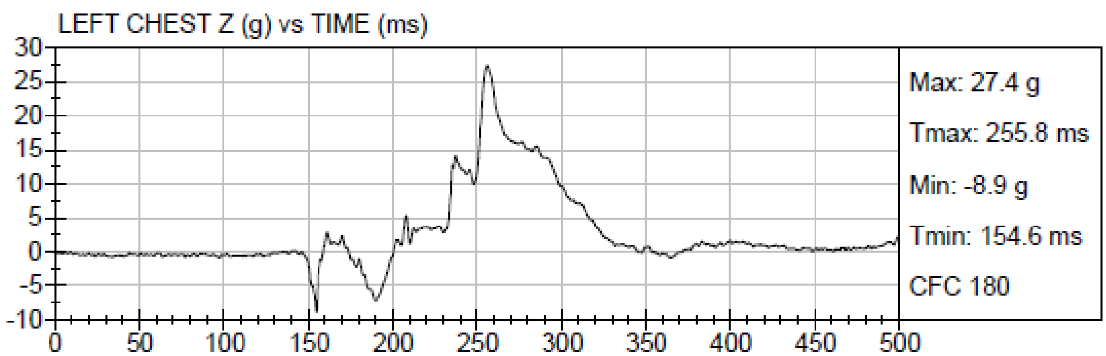


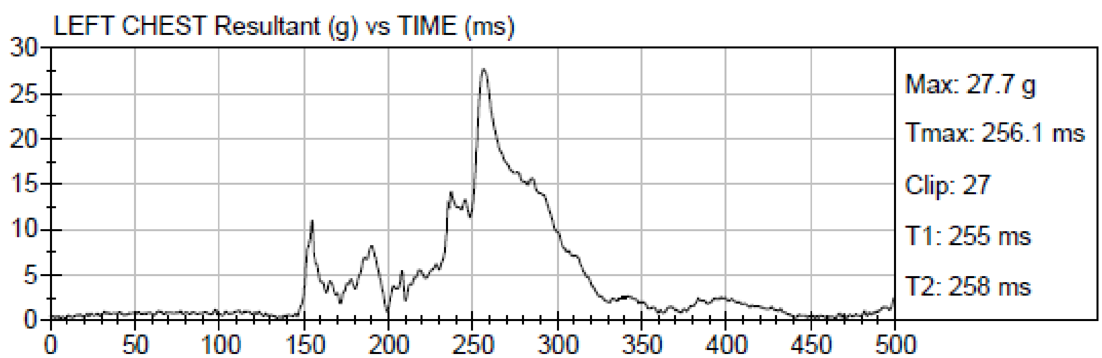
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306



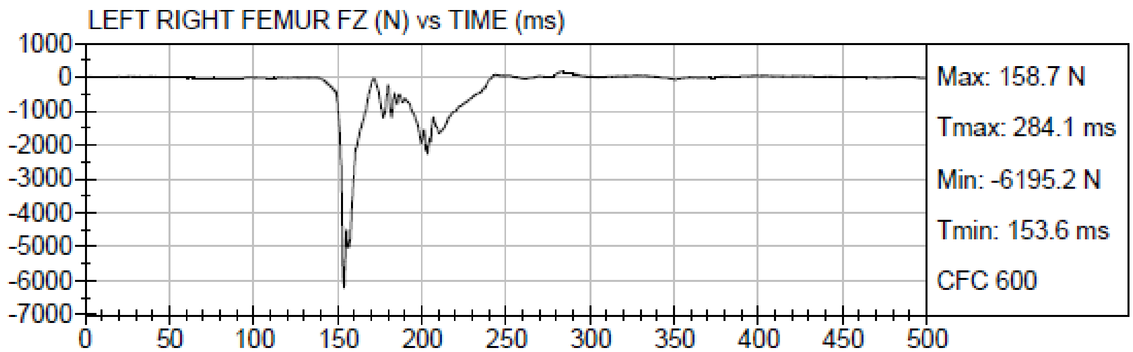


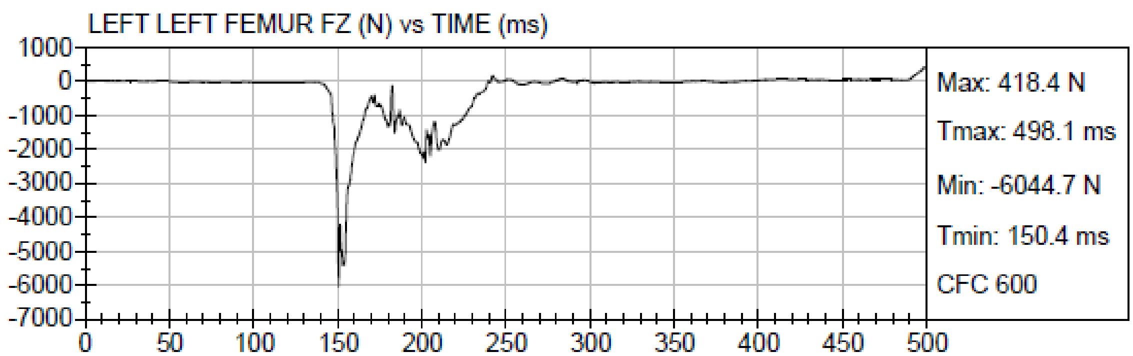




APTA RAIL TEST

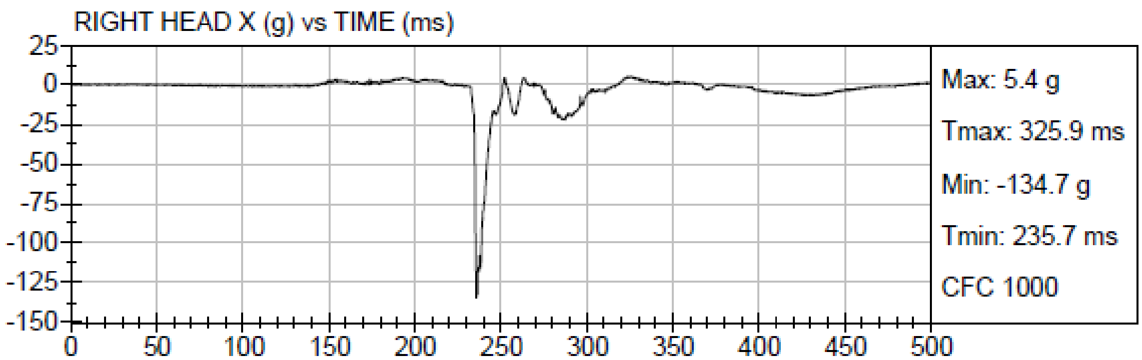
TEST DATE: 10/26/20
TEST #: S20306

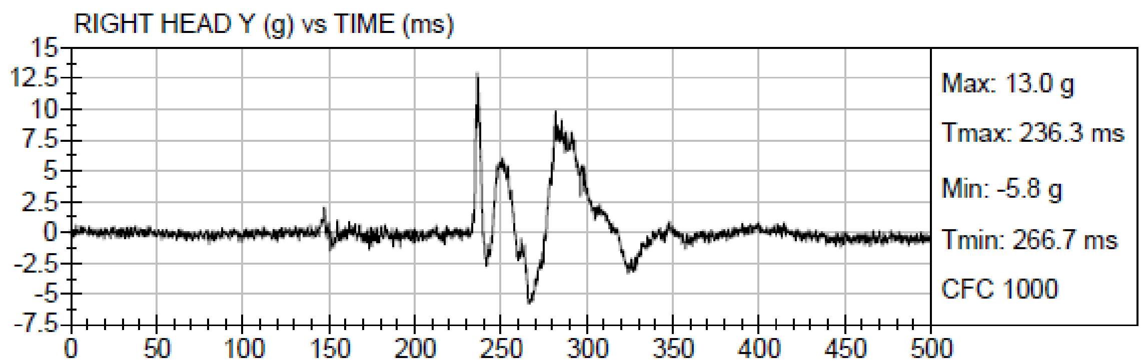


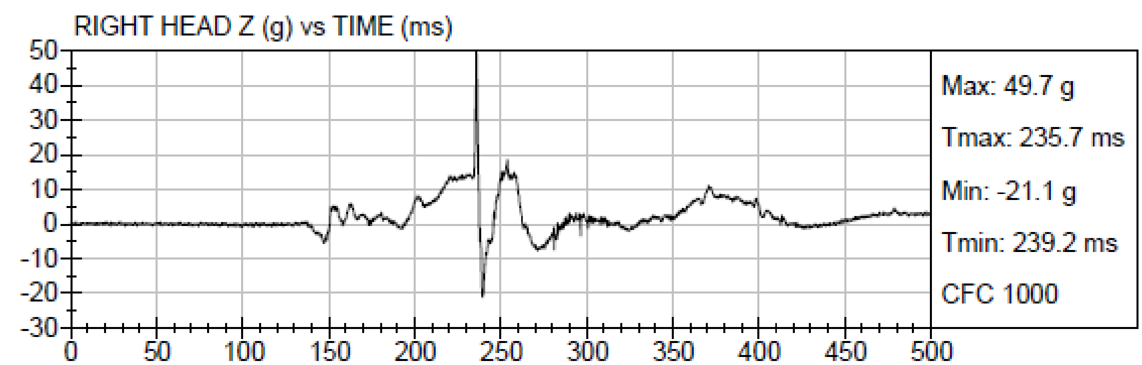


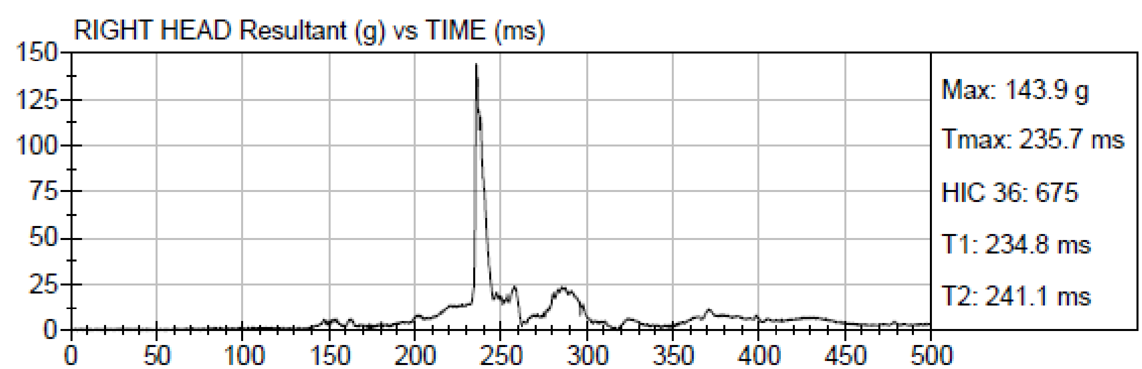
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306





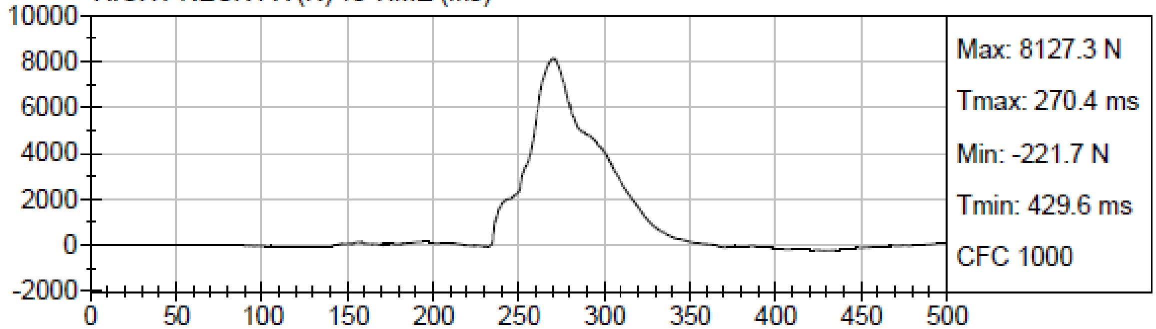




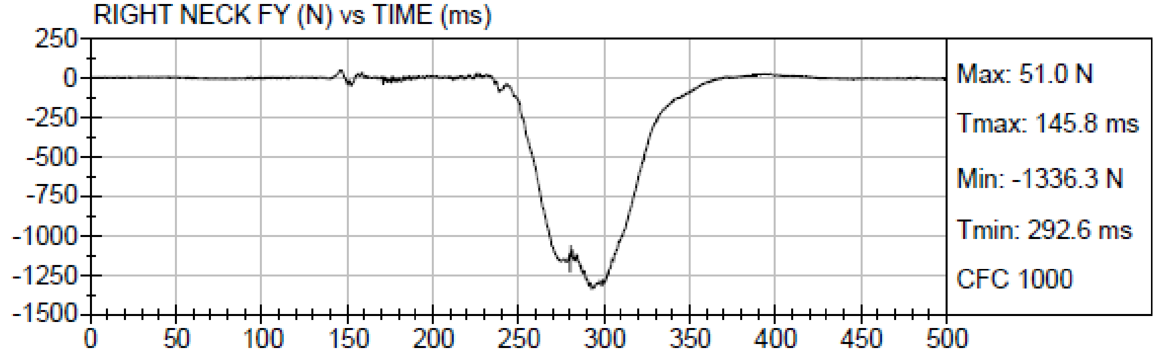
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306

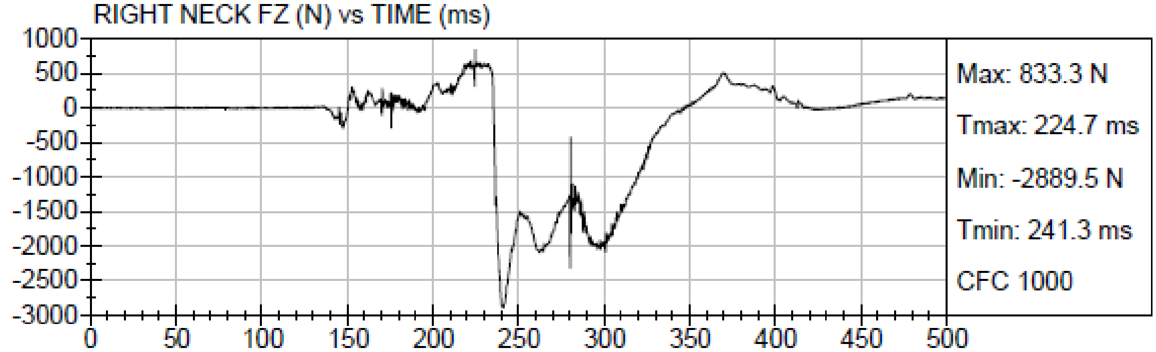
RIGHT NECK FX (N) vs TIME (ms)



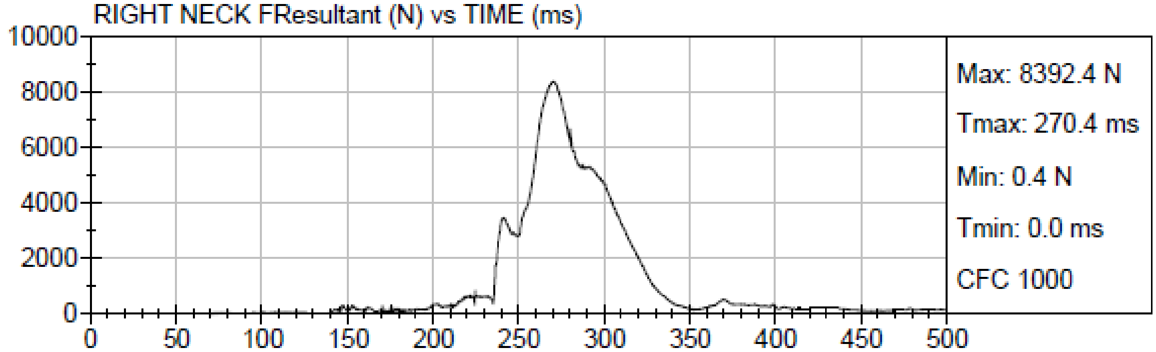
RIGHT NECK FY (N) vs TIME (ms)



RIGHT NECK FZ (N) vs TIME (ms)



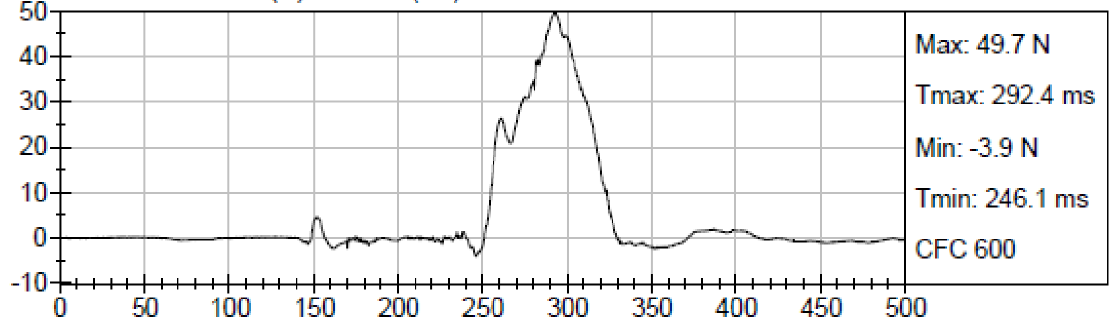
RIGHT NECK FResultant (N) vs TIME (ms)



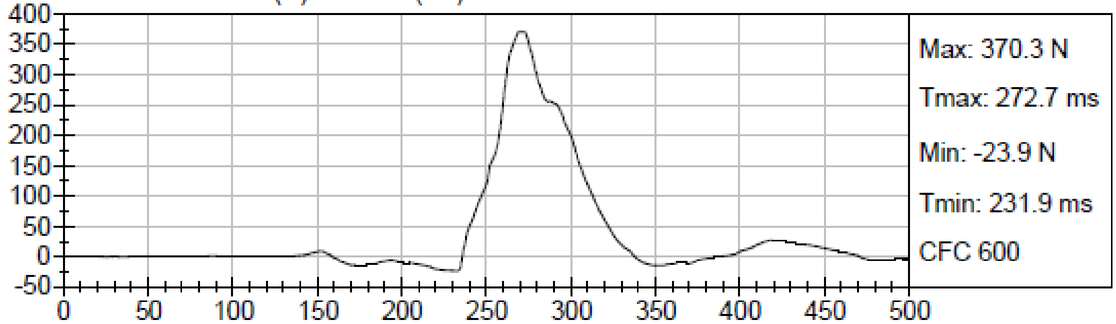
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306

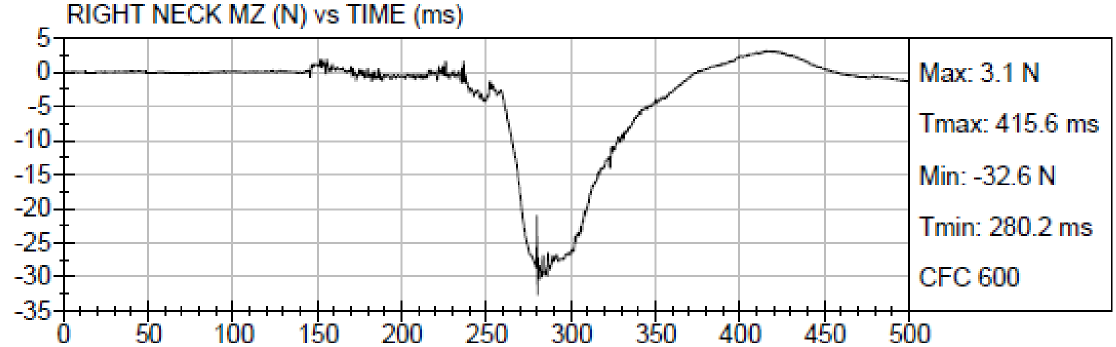
RIGHT NECK MX (N) vs TIME (ms)



RIGHT NECK MY (N) vs TIME (ms)

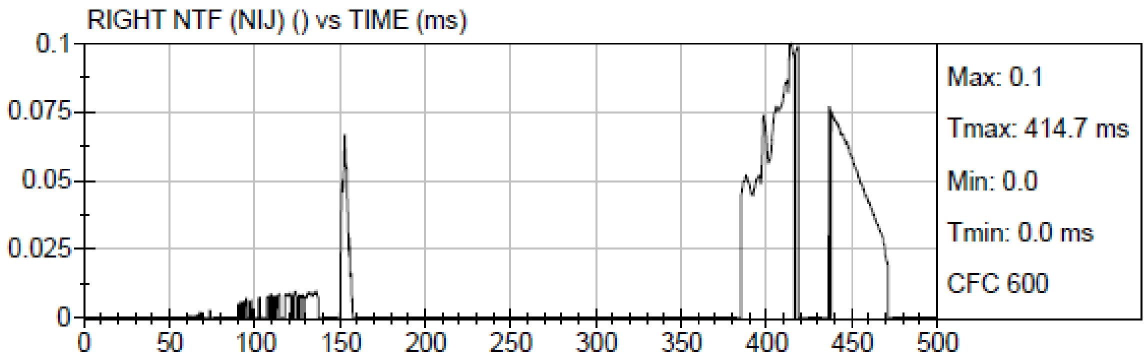


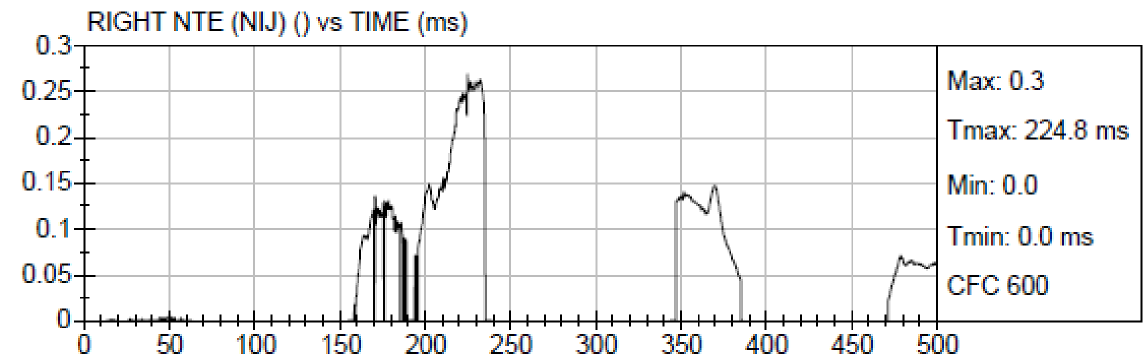
RIGHT NECK MZ (N) vs TIME (ms)

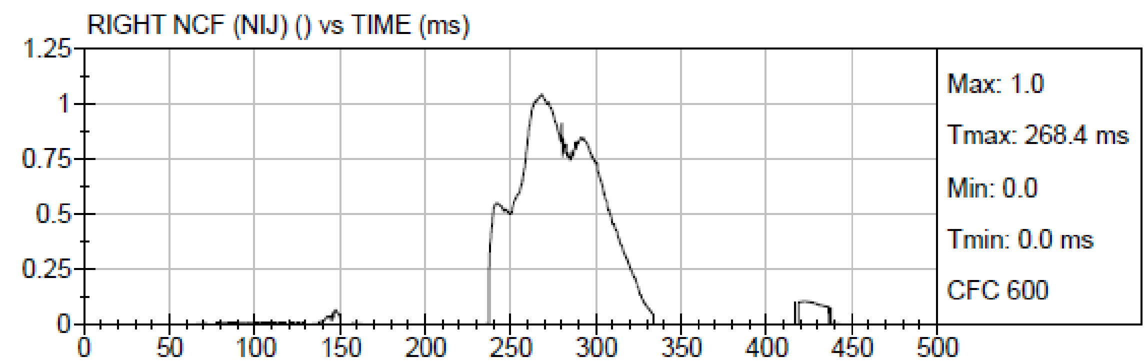


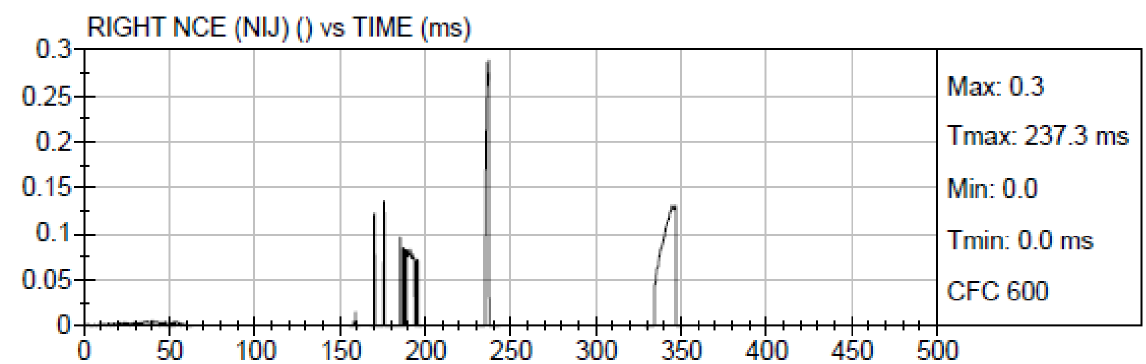
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306





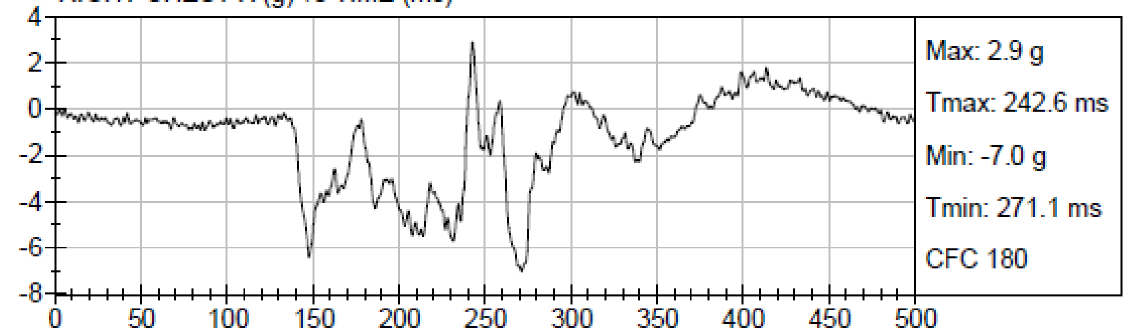




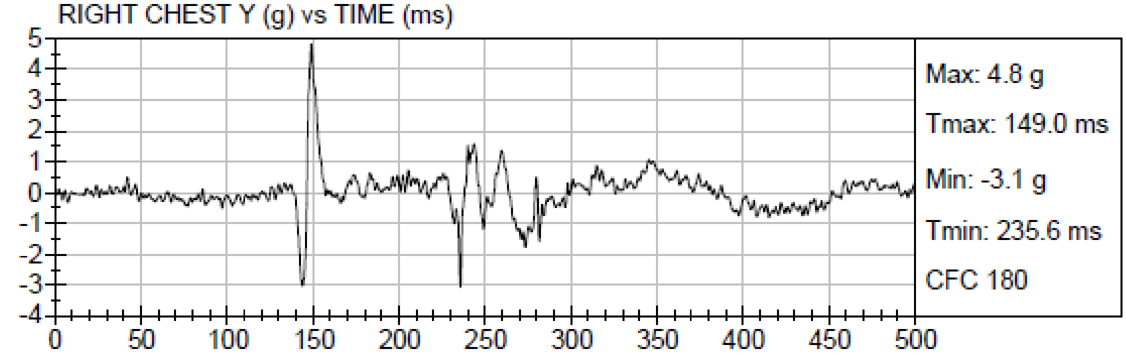
APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306

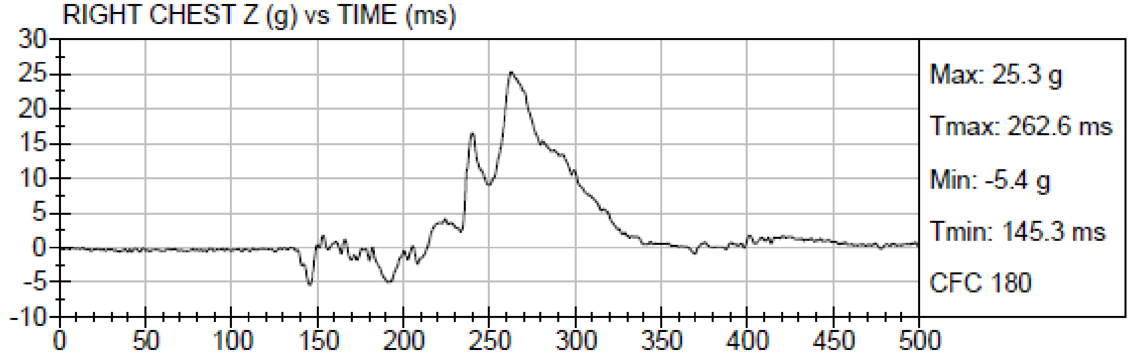
RIGHT CHEST X (g) vs TIME (ms)



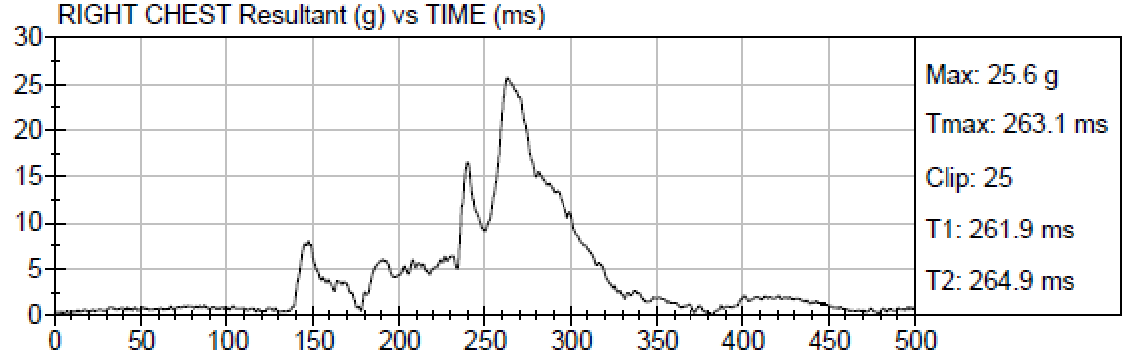
RIGHT CHEST Y (g) vs TIME (ms)



RIGHT CHEST Z (g) vs TIME (ms)

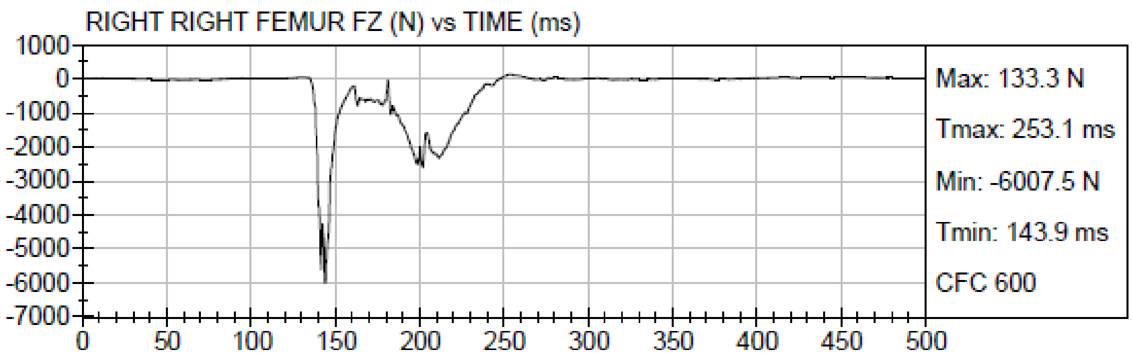


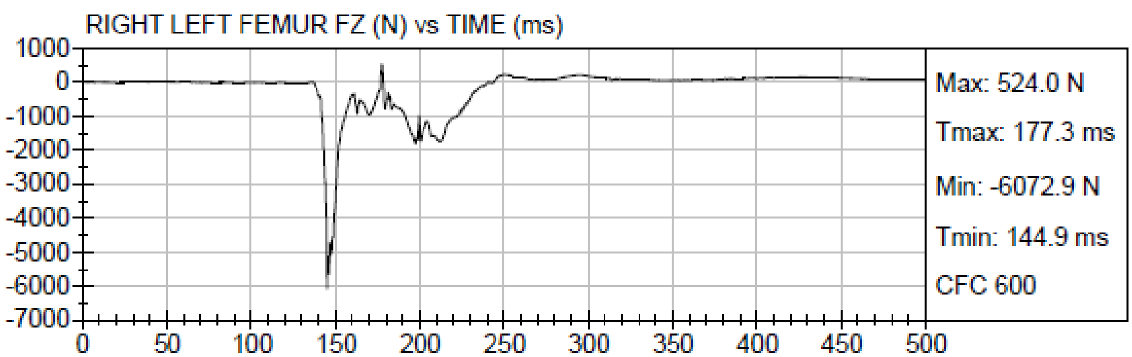
RIGHT CHEST Resultant (g) vs TIME (ms)



APTA RAIL TEST

TEST DATE: 10/26/20
TEST #: S20306





A.4: Test 4 Data

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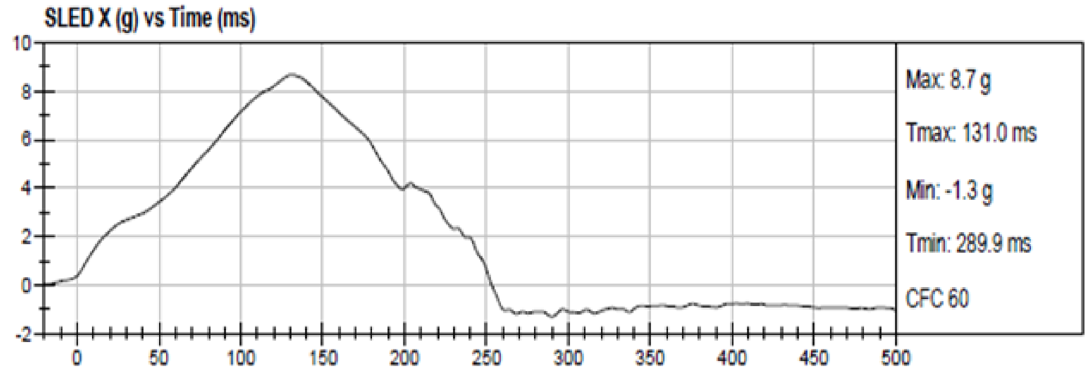
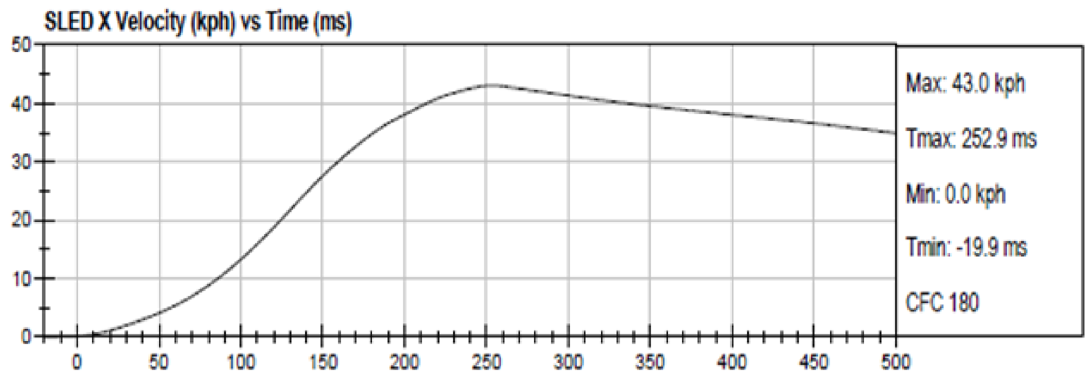
APTA RAIL TEST

Test Date: 05/03/2021

Test #: S21136

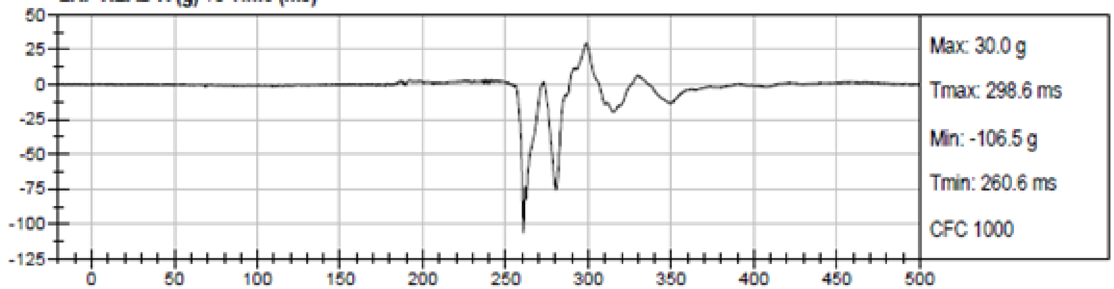




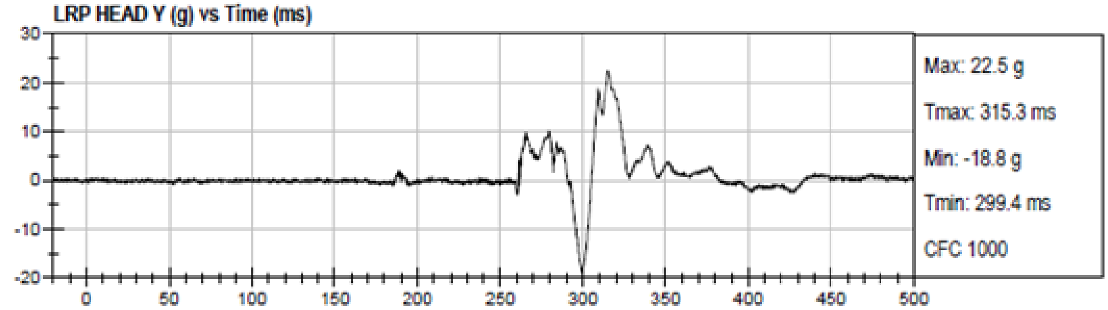
APTA RAIL TEST

Test Date: 05/03/2021
Test #: S21136

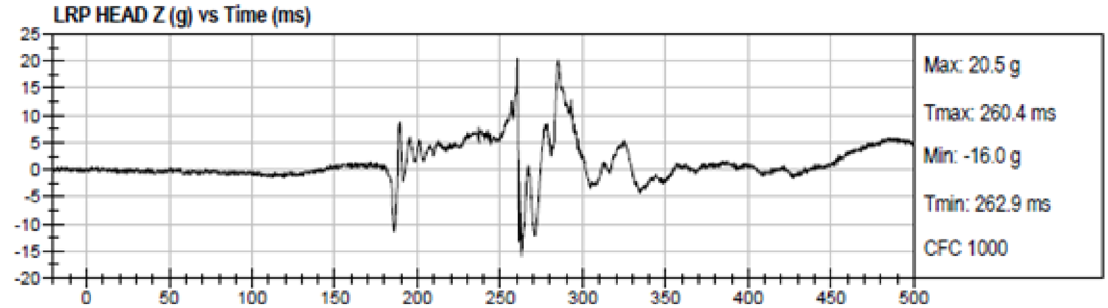
LRP HEAD X (g) vs Time (ms)



LRP HEAD Y (g) vs Time (ms)



LRP HEAD Z (g) vs Time (ms)



LRP HEAD Resultant (g) vs Time (ms)

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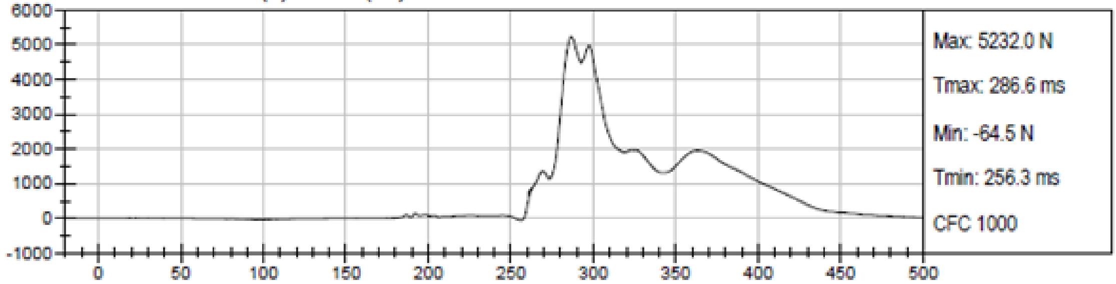
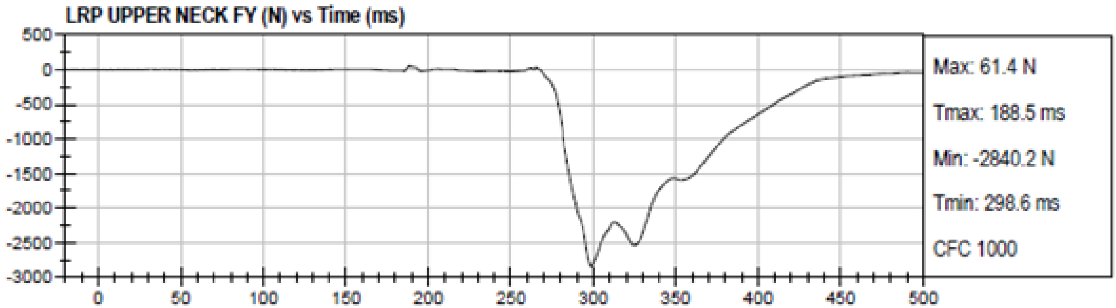
APTA RAIL TEST

Test Date: 05/03/2021
Test #: S21136

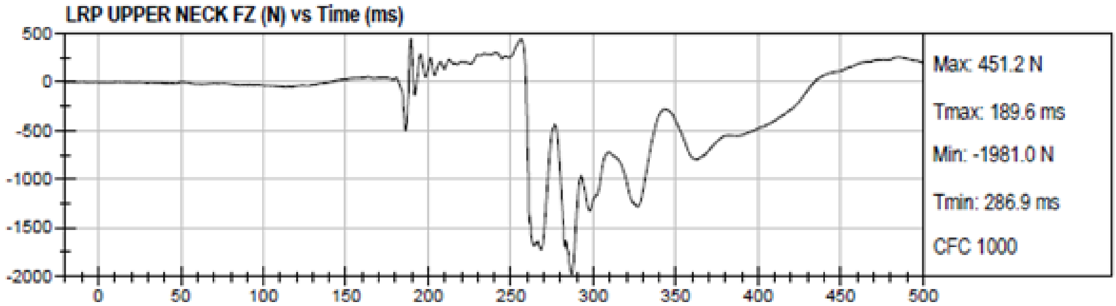
LRP UPPER NECK FX (N) vs Time (ms)



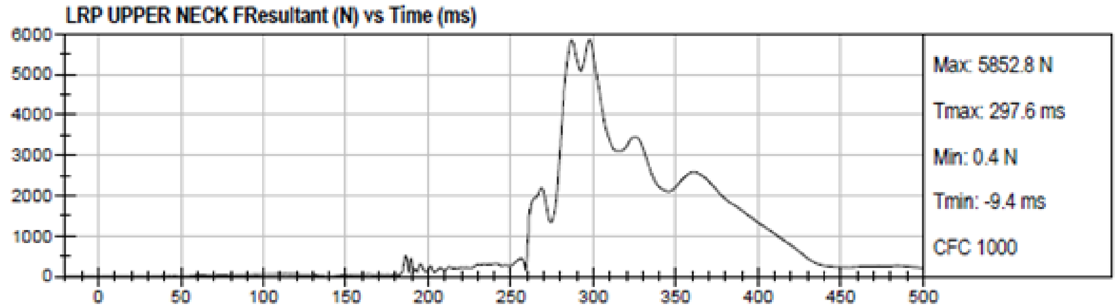
LRP UPPER NECK FY (N) vs Time (ms)



LRP UPPER NECK FZ (N) vs Time (ms)



LRP UPPER NECK FResultant (N) vs Time (ms)

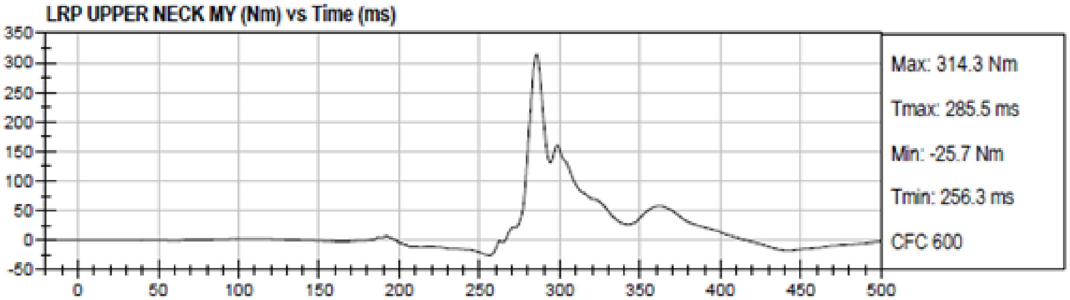


APTA RAIL TEST

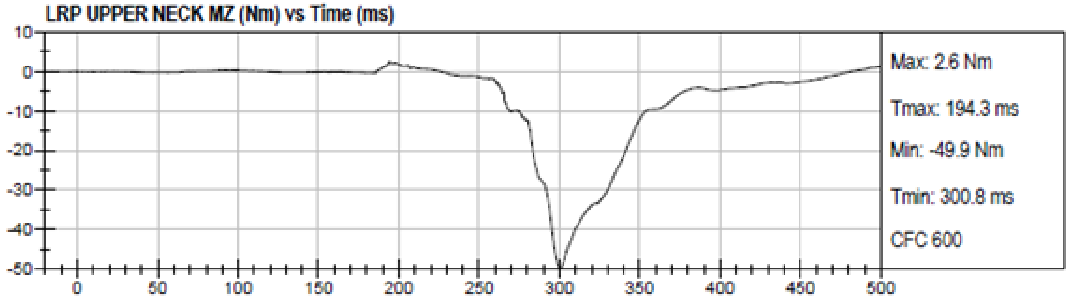
Test Date: 05/03/2021
Test #: S21136

LRP UPPER NECK MX (Nm) vs Time (ms)

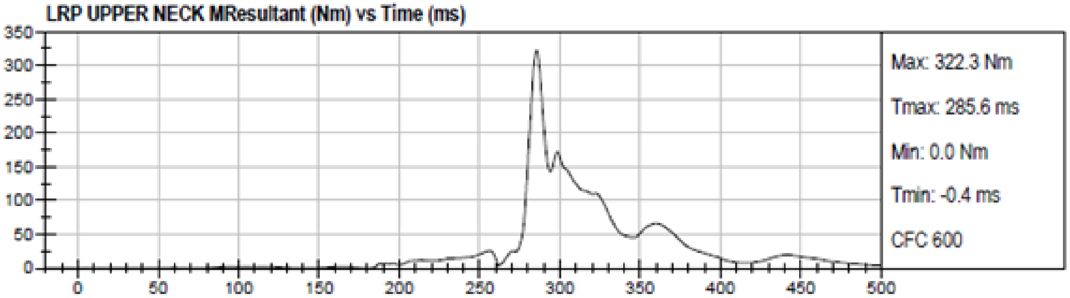
LRP UPPER NECK MY (Nm) vs Time (ms)



LRP UPPER NECK MZ (Nm) vs Time (ms)

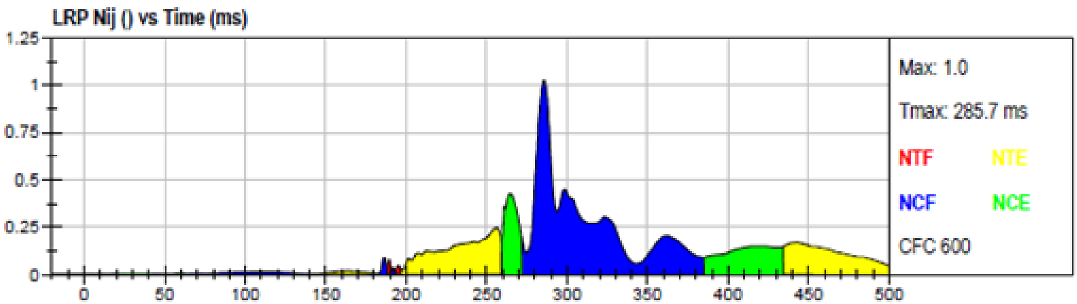


LRP UPPER NECK MResultant (Nm) vs Time (ms)



APTA RAIL TEST

Test Date: 05/03/2021
Test #: S21136



Abbreviations and Acronyms

ACRONYMS	EXPLANATION
APTA	American Public Transportation Association
ATD	Anthropomorphic Test Device
FRA	Federal Rail Administration
HIC	Head Injury Criteria
Nij	Neck Injury Criteria
CFC	Channel Frequency Class
MGA	MGA Research Corporation
RD&T	Research, Development, and Technology
Volpe	Volpe National Transportation Systems Center