To the Graduate Council:

I am submitting herewith a thesis written by Gretchen Marie Hinton entitled "Utilizing an Ultrasonic Device to Model the Lumbar Spine While Driving a Tractor Trailer." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biomedical Engineering.

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Acceptance for the Council:

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____

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

UTILIZING AN ULTRASONIC DEVICE TO MODEL THE LUMBAR SPINE WHILE DRIVING A TRACTOR TRAILER

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Gretchen Marie Hinton
May 2007

DEDICATION

This thesis is dedicated to my husband, Jason, for supporting me through numerous long nights studying and my ongoing education that has been extended more times than we would like to remember.

ACKNOWLEDGEMENTS

My heartfelt thanks are extended to Dr. Jack Wasserman, my major professor. He has provided me with an inexhaustible supply of guidance throughout my undergraduate and graduate career at the University of Tennessee. I would also like to recognize my thesis committee members, Dr. Richard Jendrucko and Dr. J.A.M. Boulet, for their guidance and assistance.

Harini Mangavelli collected the EMG data that is referenced in this study. She also aided in setup and data collection for each test. I give her my thanks for her help in finishing our theses and for providing much needed humor during those early morning testing days.

I would also like to thank Kelly Neal and the Commercial Vehicle Group for supplying me with the equipment and financial support needed to complete this study. Kelly Neal was always available for any help that I needed and provided valuable feedback and brainstorming during the planning and data collection of the experiment. For this I am extremely thankful.

ABSTRACT

Low back pain is a common occupational effect of the long term driving of vehicles. The sonoSens® Monitor ultrasonic device was utilized to model lumbar spinal motions while driving a tractor trailer. Further data was collected to determine if acceleration from a seat pad and EMG data correlated with the driver's movements.

Three testing bouts were completed and analyzed for this study. For each test the driver drove a 1998 Peterbuilt 379 fitted with a National Seating 2000 seat. One driver was used for all three tests.

Data analysis was accomplished with the sonoSens® Analyzer and Microsoft® Excel software. The sonoSens® Analyzer software produced graphs of the spinal motion of the driver. These graphs were visually analyzed for motion trends and increased movement of the lumbar region.

The sonoSens® Monitor is ideal for determining motion and posture of the lumbar region over periods of time. Acceleration and EMG data was found not to correlate with a driver's movements while driving.

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CHAPTER I
INTRODUCTION

Background Information

Musculo-skeletal disorders are a common problem throughout industrialized countries. (20) Low back pain is a very prevalent disorder and has also been the focus of much research. Exposure to conditions that cause back pain is common in many occupations. Occupational effects of driving vehicles and tractors have been well researched. (7, 16) However, most testing of vehicles only measures the movement and vibration of the vehicle seat, not direct measurement of the driver.

Recently, an ultrasonic device has been utilized to capture data directly from the subject in a non-invasive manner. The data captured may be used to determine spinal movements as well as a posture profile of the driver. Analysis of the posture profile can determine overall comfort of the driver during the course of long term testing. This study was conducted to investigate the movements and effects on the spine of workers driving a tractor trailer for periods of several hours.

Device Requirements

Many methods for estimating spinal motions exist in the literature. The validity, reliability, cost, and practicability of each method vary considerably. In order to model the spine throughout a typical 8 hour work day, continuous measurement of the spine is necessary.

Additional considerations should also be met with the chosen method. The method should provide a non-invasive assessment of spinal motion without disrupting the subject's normal work routine. For tractor trailer driver testing the device used should also be compact in size and sturdy enough to survive an accidental fall.

Chosen Device

The device utilized for this investigation was the sonoSens® Monitor manufactured by Friendly Sensors AG of Jena, Germany. The intended use of the device is non-invasive analysis of entire body or body segment movements. It is especially designed to measure movements of the spinal column for long periods of time. Contraindications include allergies to polyethylene, silicon, and polyurethane. Also the device is not to be used with pacemakers. The device has no known side-effects.

Purpose of Study

The goal of this study is to provide an improved understanding of what is happening to the driver's lumbar spine over time. Correlating the results from the sonoSens® with acceleration and EMG data will allow us to evaluate the validity of using the sonoSens® to model a driver's lumbar spine. Future research may then be focused on building upon the results of this study.

CHAPTER II
MATERIALS AND METHODS

Ultrasonic Device

Measurement Principle of Ultrasonic Device

The sonoSens® Monitor uses ultrasound to measure distance. This is accomplished by small ultrasonic sensors (diameter 20 mm), which are placed in pairs on the subject's skin. Each pair consists of a sender and a receiver. The time the ultrasonic signal takes to get from the sending to the receiving sensor is measured by the device. The speed of ultrasound in human tissue is almost constant at 1500 m/s. (18)

The distance between any two sensors is calculated with the following equation:

$$s=v*\Delta t$$

where: s - distance between the sender and receiver
t - traveling time of the signal
v - speed of the ultrasound in the tissue (1500 m/s).

As the body moves, the skin becomes extended causing a change in the distance between sensors. This change in distance is measured by the sonoSens® Monitor as depicted below in Figure 2-1. The device has a maximum measuring distance of 50 cm and a minimum measuring distance of 3 cm, with an accuracy of 0.4 mm. (18)

Application onto Subject

In addition to the sonoSens® Monitor, 8 double-sided stick-on pads and first aid tape were used to apply the device to the subject. The stick-on pads were supplied by the device manufacturer. The sensors were applied in accordance with manufacturer directions, as depicted in Figure 2-2.

Calibration

The device was calibrated before each use as directed by the manufacturer. The patients were asked to stand still while standing upright, facing forward, and with their arms hanging relaxed at their sides. This position was held for 30 seconds. The device software was designed to recognize the first segment of data as the calibration.

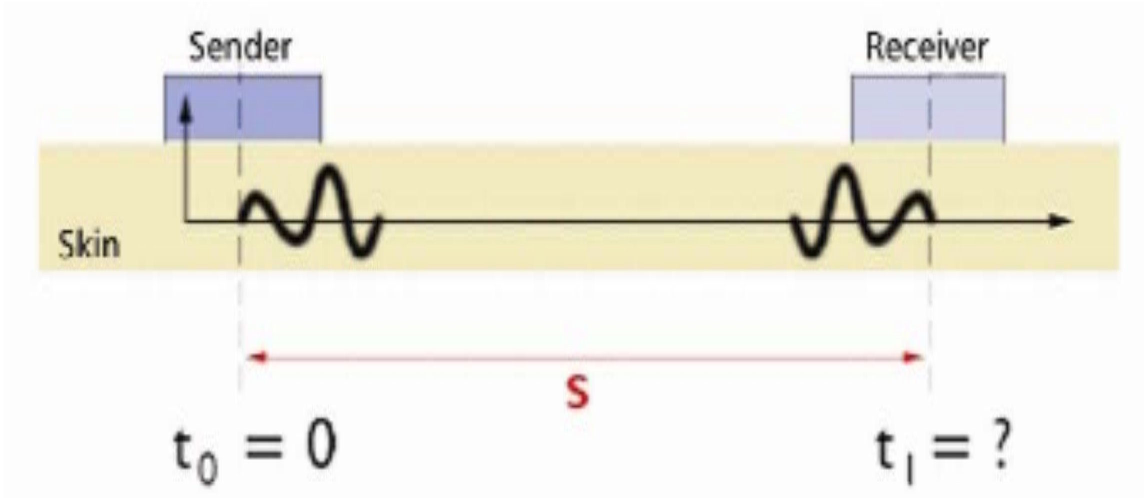

Figure 2-1: The Functioning Principle of the Ultrasonic Distance Measurement. (1)

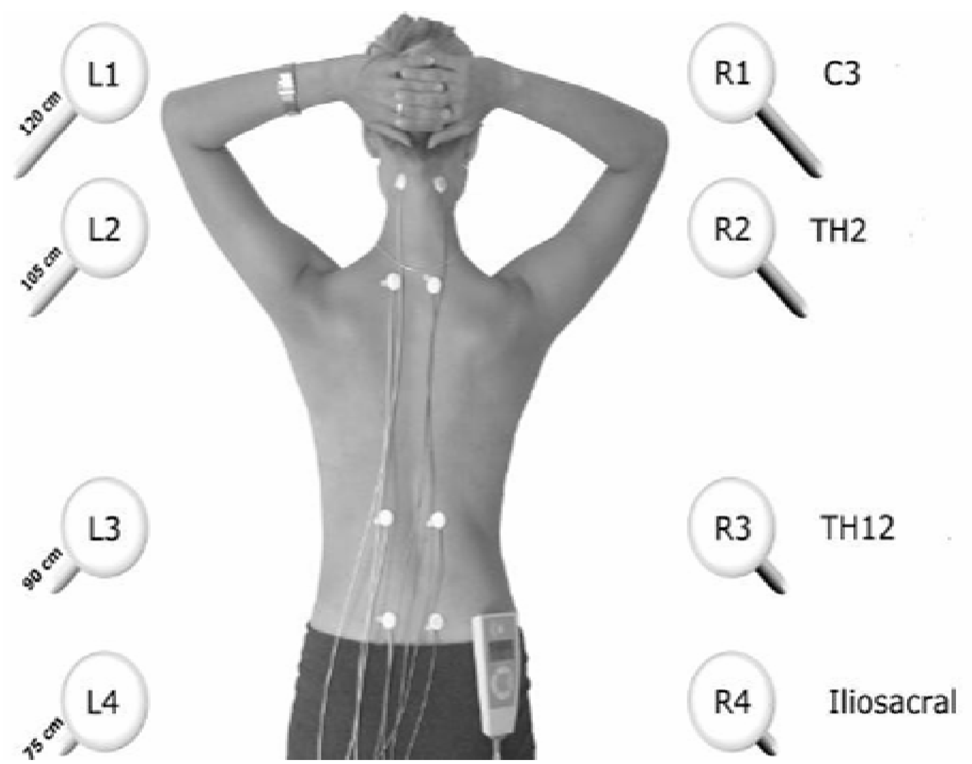

Figure 2-2: Positions of the Sensors along the Spinal Column. (1)

Maximum Range of Motion

After the calibration, the maximum range of motion of the subject is measured. This measurement is used by the analysis software to determine if movement during testing is within maximum ranges. The subject begins in the same upright position as for calibration and then is asked to perform the movements depicted in Figure 2-3. The subject held each position for 10 seconds. The device software was designed to recognize the second segment of data as the maximum range of motion. Since the range of motion of the lumbar spine has been found to increase during the course of the day, all testing was done at approximately the same time of the day. (4)

Study Population

Questionnaire

The driver was asked to provide answers to a questionnaire. The questionnaire contained questions pertaining to both pre and post testing. A copy of the questionnaire may be found in Appendix 1.

Driver Information

The driver utilized for the three bouts of testing for this study was a 31 year old male. He weighed 185 lbs with a height of 5 ft 9in. His body mass index (BMI) was then calculated at 27.3 with the standard BMI equation. A BMI higher than 25 is known to be more likely to lead to errors due to skin motion during movement. (5) The chosen driver had the lowest BMI from the available pool of drivers.

The driver has had chronic intermittent mild back pain since a car accident in 1998. He reported no known back surgeries or abnormalities. The driver has 12 years of experience driving tractor trailers.

The driver was asked after the experiment about discomfort during testing. He reported that wearing the device did not interfere in anyway with his normal work routine, did not limit normal movement, and no discomfort was experienced during the application, wearing, and removal of the device.

Tractor Trailer

The tractor trailer utilized in this study was a 1998 Peterbuilt 379. The actual truck used is depicted in Figure 2-4. The truck had an approximate trailer load of 20,000 lbs for each testing event.

Figure 2-3: Movements for Measurement of the Maximum Range of Motion. (1)

Figure 2-4: 2000 Peterbuilt 376

Seats

The seat used for all testing was manufactured by National Seating, model 2000. It is depicted below in Figure 2-5. The seat was placed in the truck cab prior to testing and removed following testing, thereby allowing for the use of the same seat for all testing. The driver was told to adjust the seat to his comfort and normal use. The driver used the seat with no air; therefore the seat was on the floor with no suspension except of the foam of the seat.

Measuring Procedure

The ultrasonic device was applied as described in a preceding section. The device was calibrated and the maximum range of motion was recorded as described previously and prior to each testing period. The sonoSens® Monitor was clipped to the driver's pant waistband during testing. Just before the truck was leaving all the equipment used for testing was set to record at approximately the same time.

Additional equipment used is described in detail in the following sections.

Accelerometer and Seat Pad Placement

A seat pad was placed on the driver seat's bottom cushion. It was placed such that the driver would be sitting directly on the seat pad. The seat pad was securely attached to the seat with duct tape. The three axes of the coordinate system of the seat pad were fed to a recorder and human vibration monitor (HVM). The HVM setup is described in more detail below.

Three accelerometers were fixed in the cab of the truck. The first accelerometer was affixed at the base of the driver's seat, second at the base of the gear shift, and third at the base of the passenger seat. Great care was taken to ensure that the accelerometers were all at the same height. Measurements of each accelerometer in space were taken for possible future evaluation. The accelerometer data was also fed into a recorder for possible future evaluation.

HVM Data Collection

The HVM's setup was for whole body vibration with 60 second averaging and a store time of 5 minutes. Every 5 minutes during testing the seat pad acceleration in the vertical (z-axis) direction as displayed by the HVM was recorded. This acceleration data was used in conjunction with the movement data of the ultrasound to determine if a correlation exists.

Figure 2-5: National Seating Model 2000

EMG

Another student applied and recorded data simultaneously from an electromyography (EMG) unit. A small, portable EMG was utilized for this purpose. The results of the EMG study and this study will be compared to determine if a correlation between the two exists.

CHAPTER III
PRELIMINARY TESTING

Preliminary testing was done prior to the 3 testing trials analyzed in order to provide practice in device setup and data recording. Several practice tests were required in order to become proficient at fitting the truck and driver with all the equipment in a timely manner. The preliminary tests also allowed for the addressing of unforeseen problems that arose in the field.

Different drivers were used for each preliminary test in order to screen for a subject with a low BMI and no back abnormalities or recent pain. The subject for preliminary test 3 was utilized for the actual testing bouts of this study. He had the lowest BMI of the available drivers and was also willing to complete several additional testing trials.

Preliminary Test 1

Driver Information

The driver of the first preliminary test was a 55 year old male. He weighed 210 lbs with a height of 5 ft 5 in. His BMI was then calculated at 34.9 with the standard BMI equation. The driver had been driving tractor trailers for 33 years. He reported experiencing intermittent, acute back pain for years, but no back surgeries or abnormalities. The truck, seat, and testing procedure were the same as described previously for the actual testing trails. The driver adjusted the seat to his comfort. The driver used the seat with no air suspension, as he normally did.

Results of Preliminary Test 1

The driver reported no discomfort from the testing device. He also reported that the device was not bothersome and did not limit his normal work routine or range of motion. He stated that the worst part of the testing procedure was removing the tape used to secure the ultrasound sensors.

Testing Complications

Fitting of the tractor trailer and driver with all the necessary equipment took about 3 hours. This did not include actual time recording data. It was necessary to decrease the time of equipment setup to about one hour. An approximate one hour setup time was accomplished on subsequent trials through practice and delegating equipment setup responsibilities.

Preliminary Test 2

Driver Information

The driver of the second preliminary test was a 50 year old male. He weighed 240 lbs with a height of 5 ft 8 in. His BMI was then calculated at 36.5 with the standard BMI equation. The driver had been driving tractor trailers for 25 years. He reported no current or past back pain. The driver reported no back surgeries or spine abnormalities. The truck, seat, and testing procedure were the same as described previously for the actual testing trails. The driver adjusted the seat to his comfort. The driver used the seat with no air suspension, as he normally did.

Results of Preliminary Test 2

The driver reported only very minimal discomfort from the testing device. A slight skin discomfort was reported from the pressure of the sensors where his back was against the seat. Despite this he reported that the device was not bothersome and did not limit his normal work routine or range of motion.

Testing Complications

There were no complications with testing for this preliminary trial.

Preliminary Test 3

Driver Information

The driver of the third preliminary test was the same individual as for the actual testing trials. The truck, seat, and testing procedure were the same as described previously for the actual testing trails. The driver used the seat with no air suspension as for the actual trials.

Results of Preliminary Test 3

The driver reported no discomfort from the testing device. He also reported that the device was not bothersome and did not limit his normal work routine or range of motion.

Testing Complications

At some point during the testing procedure, the first-aid tape securing the ultrasound sensors and EMG sensors released on several of the sensors. This lapse produced erroneous results. The modeled spinal motions were unable to be analyzed. This testing trial produced no useful results. For future testing trials greater care was taken to ensure proper adhesion of the sensors to the skin.

CHAPTER IV
DATA ANALYSIS

sonoSens® Analyzer with Report Toolbox

Analysis of the data accumulated from the sonoSens® Monitor involved several steps. The data was first downloaded to the supplied manufacturer's software for initial analysis. The software package includes many different types of automatically generated measurement reports.

For each testing period a long term measurement report was created. This report illustrates with the use of figures and charts the overall activity of the subject during testing. The report also includes the baseline measurements taken during calibration and maximum range of motion. The generated report was very helpful to provide an overall impression of posture and movements of the driver with time. However, the resolution of the flow diagrams of sagittal, frontal, and torsion movements was not sufficient.

Flow diagrams of each movement plane were made by manually changing the x-axis settings as needed to produce 1 minute intervals. This was accomplished by adjusting the table options in the sonoSens® Analyzer software. The 1 minute intervals allowed for more precise flow diagrams. The diagrams were then cut and pasted into a word processor for ease of printing.

After printing the flow diagrams for each movement plane, manual analysis of the graphed movements was possible. The first and last 10 minutes of each testing bout were ignored. For the first few minutes of testing the driver movement was very high due to the driving settling in. The last few minutes of testing also had an abnormal amount of movement due to exiting the highway and parking the truck at a truckstop.

The manufacturer's guide and training received by a company representative was used to analyze the flow diagrams. This was completed by visually looking for motion trends per the manufacturer's training. Areas of interest were recorded in a spreadsheet synchronized with time and acceleration from the HVM.

Microsoft® Excel

Microsoft® Excel software was used to produce a spreadsheet that was used to form a flow chart comparing time, lumbar movement, EMG activity and acceleration. There were no calculations made in the spreadsheet. The spreadsheet was only utilized as an organizational tool.

CHAPTER V
RESULTS

Spinal Motions

The sonoSens® Analyzer was used to generate flow diagrams of the test subject's spinal motion versus time. The x-axis of all the flow diagrams is the time elapsed in minutes. The motions for each spinal segment are depicted. Cervical region motion (CR) is depicted at the top third of the figure. Thoracic region motion (TR) is depicted in the middle of the figure. Lumber region motion (LR) is depicted in the lower third of the figure. Each region's center line, denoted 0%, is the neutral posture for that spinal region. The neutral posture for the subject was determined from the calibration data. It is simply the position of the spine while standing upright. Only the lumbar region was of interest for this study. The flow diagrams were visually analyzed for motion trends and increased movement of the lumbar region. Flow diagrams of frontal, torsional, and sagittal motion for each test were analyzed.

The frontal flow diagrams depict the subject's motion over time as viewed from the frontal plane. The y-axis is the percentage the motion is changed from the neutral position. Motion to the right of neutral is denoted ®, motion to the left is denoted (l) on the y-axis.

The sagittal flow diagrams depict the subject's motion over time as viewed from the sagittal plane. The y-axis is the percentage the motion is changed from the neutral position. Motion of the extension from neutral is denoted (Ext), motion of the flexion from neutral is denoted (Flex) on the y-axis.

The torsional flow diagrams depict the subject's motion in torsion over time. The y-axis is the percentage the motion is changed from the neutral position. Motion of torsion to the right of neutral is denoted (r), motion of torsion to the left of neutral is denoted (l) on the y-axis.

Test 1

Figures 5-1 to 5-6 are the frontal flow diagrams for test 1.

Figures 5-7 through 5-12 are the sagittal flow diagrams for test 1.

Figures 5-13 through 5-18 are the torsional flow diagrams for test 1.

Test 2

Figures 5-19 to 5-25 are the frontal flow diagrams for test 2.

Figures 5-26 through 5-32 are the sagittal flow diagrams for test 2.

Figures 5-33 through 5-39 are the torsional flow diagrams for test 2.

Test 3

Figures 5-40 to 5-46 are the frontal flow diagrams for test 3.

Figures 5-47 through 5-53 are the sagittal flow diagrams for test 3.

Figures 5-54 through 5-60 are the torsional flow diagrams for test 3.

Flow Charts of Spinal Movements, Acceleration, and EMG

A spreadsheet was created in Microsoft® Excel to compare: elapsed time during testing, movement of the lumbar region, acceleration values from the HVM, and muscle activity as denoted by the EMG. No calculations were made in the spreadsheet. It was only utilized as an organizational tool for comparison of the data from all the devices. Specifically, it was used to determine if a correlation existed between the lumbar movement and EMG data or acceleration data from the HVM.

Test 1

The flow chart comparing the spinal movements, acceleration, and EMG normalized to elapsed time for test 1 is displayed in Table 1.

Test 2

The flow chart comparing the spinal movements, acceleration, and EMG normalized to elapsed time for test 2 is displayed in Table 2.

Test 3

The flow chart comparing the spinal movements, acceleration, and EMG normalized to elapsed time for test 3 is displayed in Table 3.

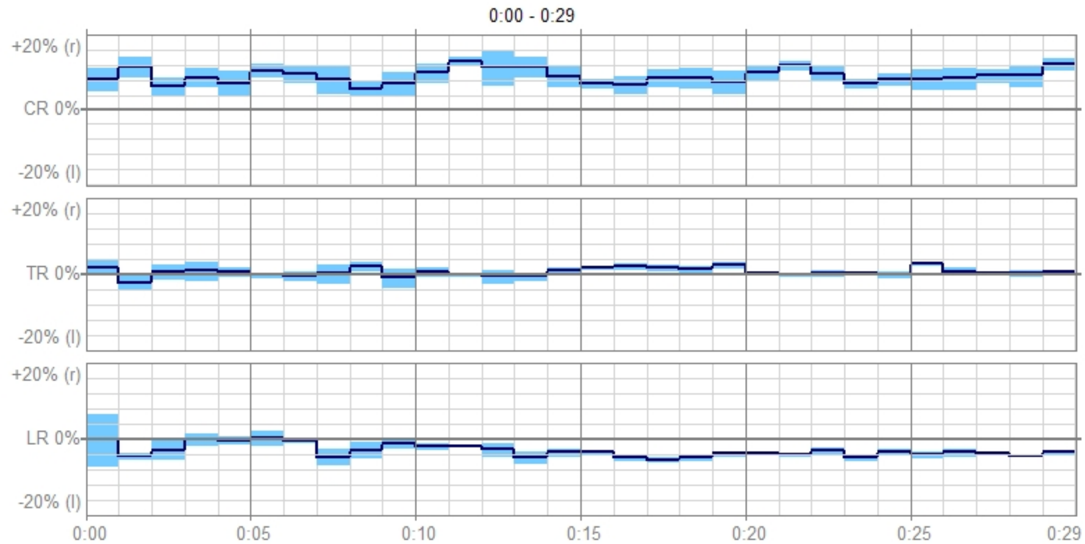

Figure 5-1: Frontal flow diagram of 0:00-0:29 minutes of Test 1.

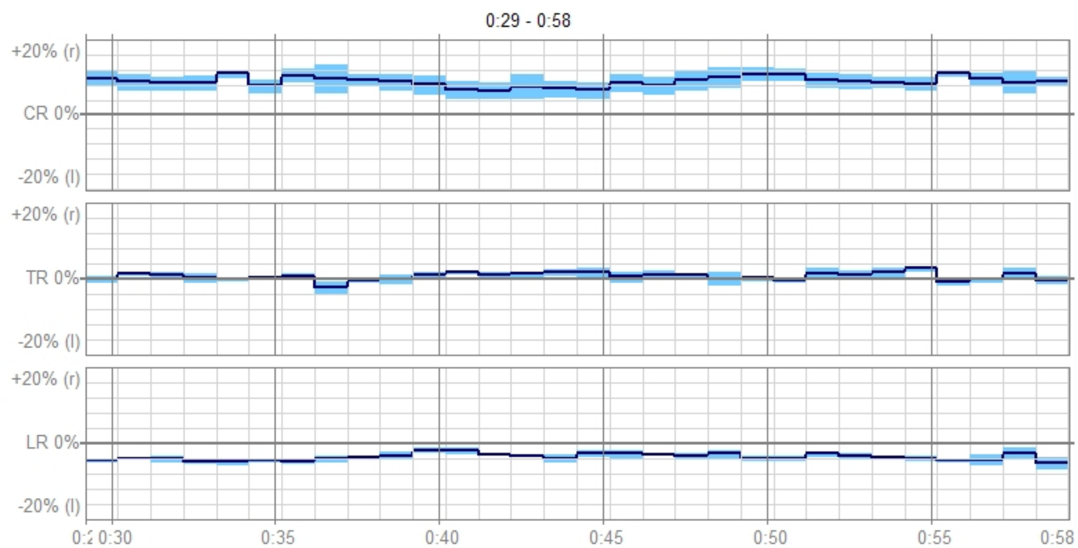

Figure 5-2: Frontal flow diagram of 0:29-0:58 minutes of Test 1.

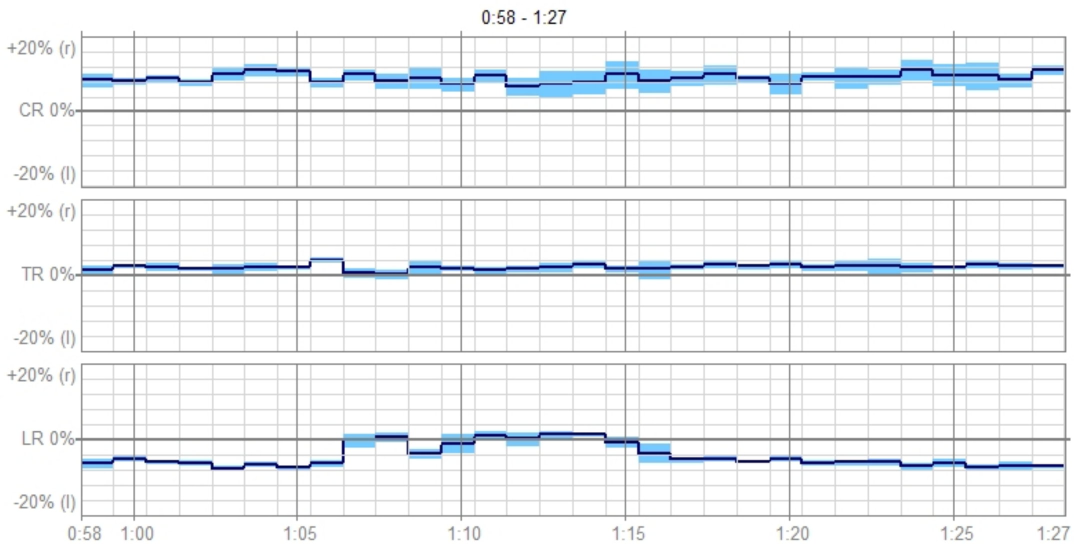

Figure 5-3: Frontal flow diagram of 0:58-1:27 minutes of Test 1.

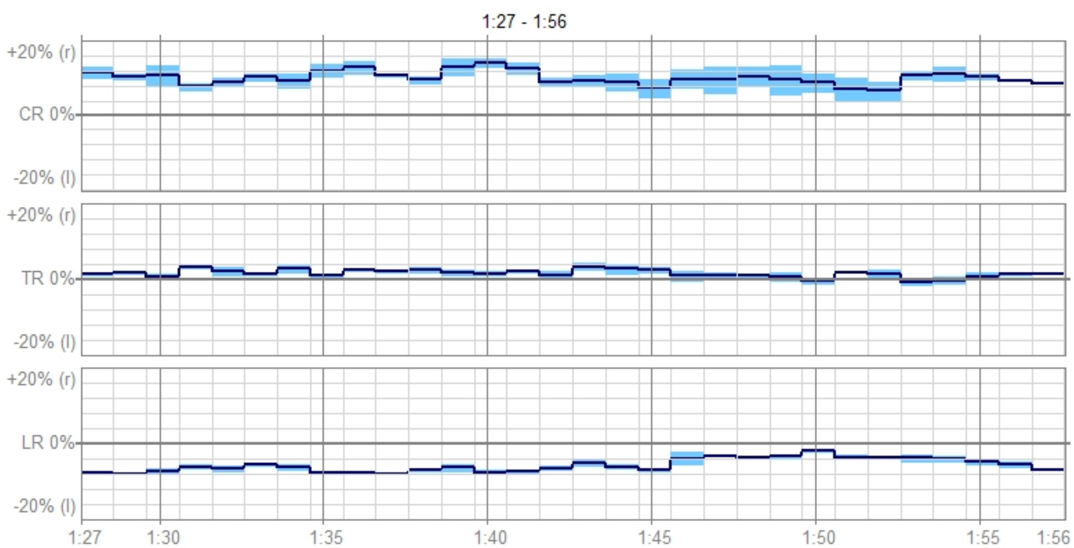

Figure 5-4: Frontal flow diagram of 1:27-1:56 minutes of Test 1.

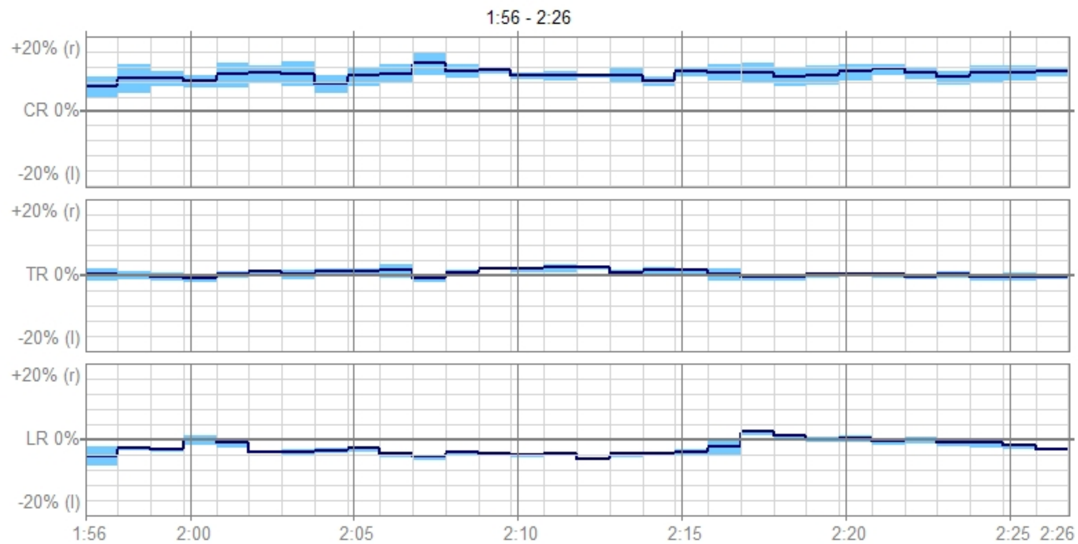

Figure 5-5: Frontal flow diagram of 1:56-2:26 minutes of test 1.

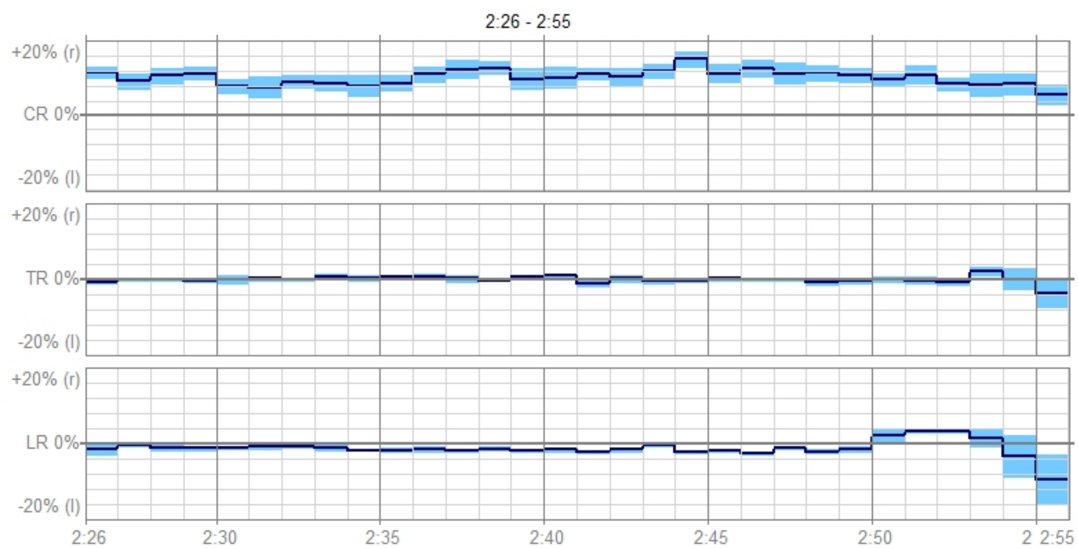

Figure 5-6: Frontal flow diagram of 2:26-2:55 minutes of Test 1.

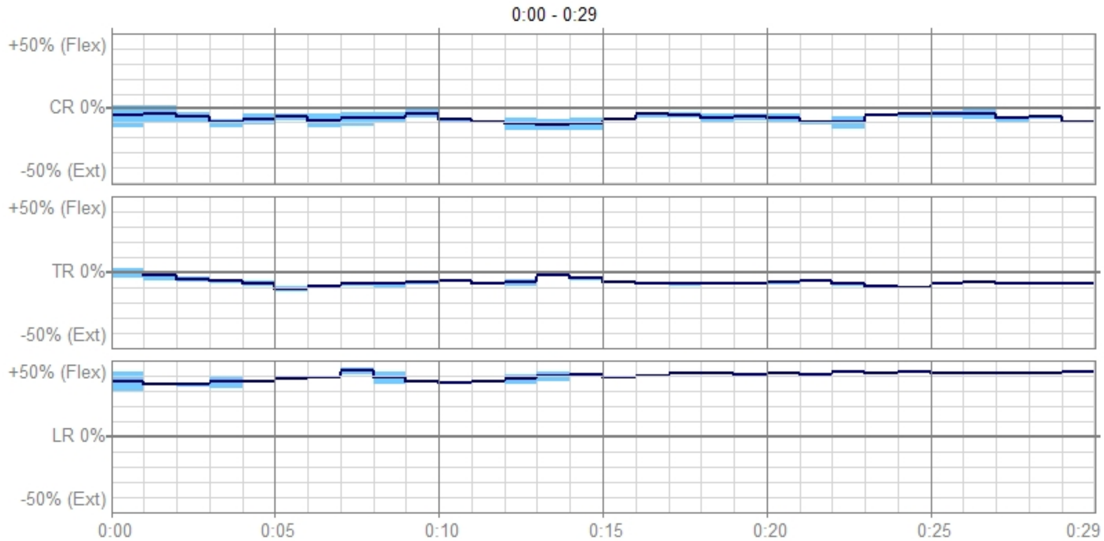

Figure 5-7: Sagittal flow diagram of 0:00-0:29 minutes of Test 1.

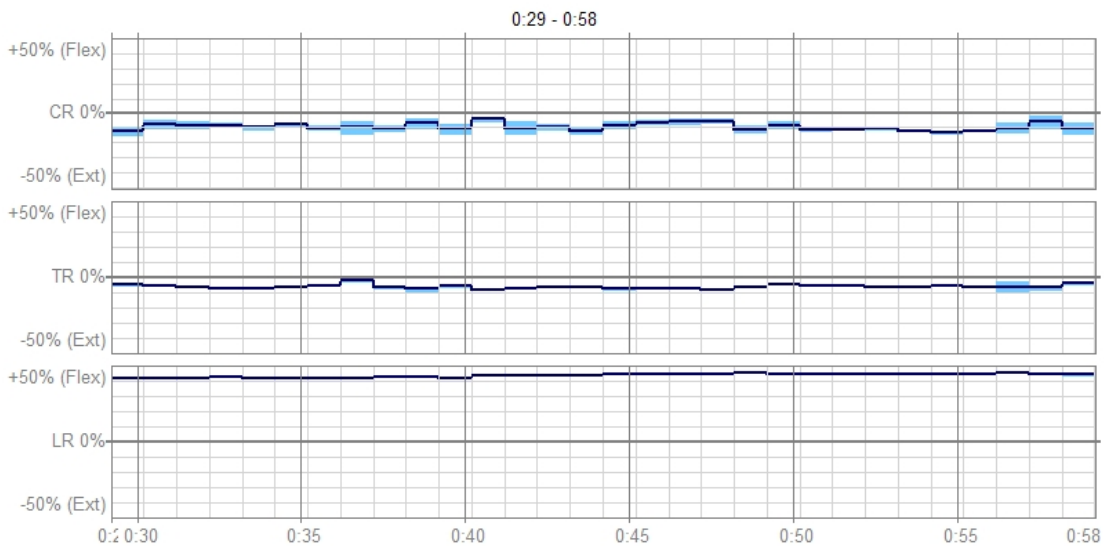

Figure 5-8: Sagittal flow diagram of 0:29-0:58 minutes of Test 1.

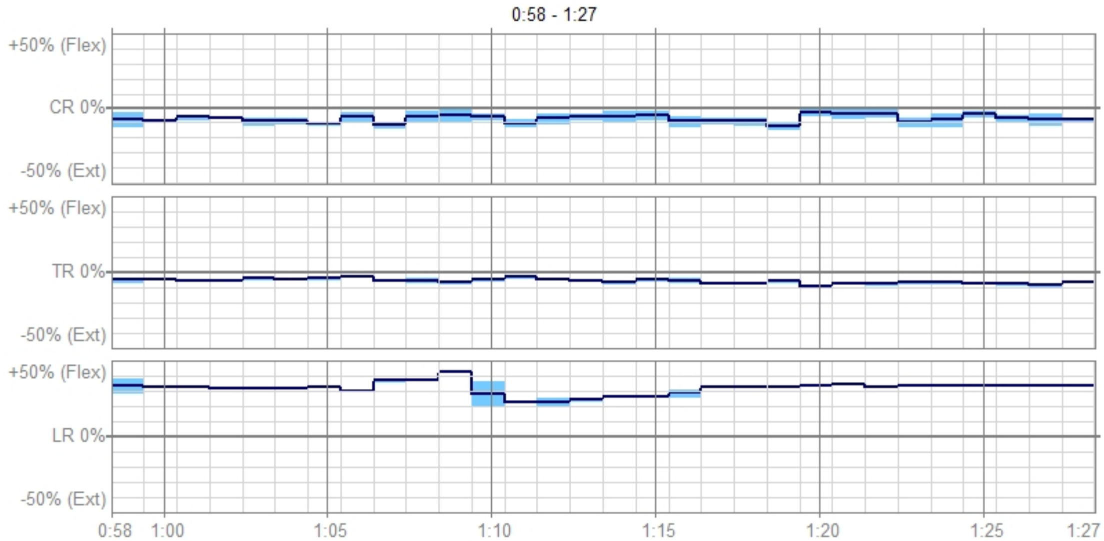

Figure 5-9: Sagittal flow diagram of 0:58-1:27 minutes of Test 1.

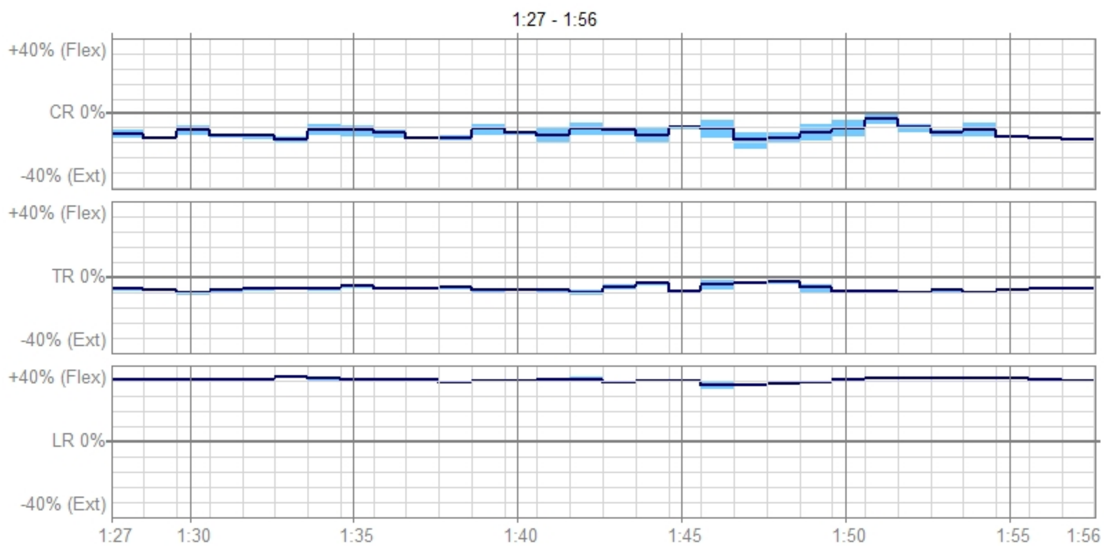

Figure 5-10: Sagittal flow diagram of 1:27-1:56 minutes of Test 1.

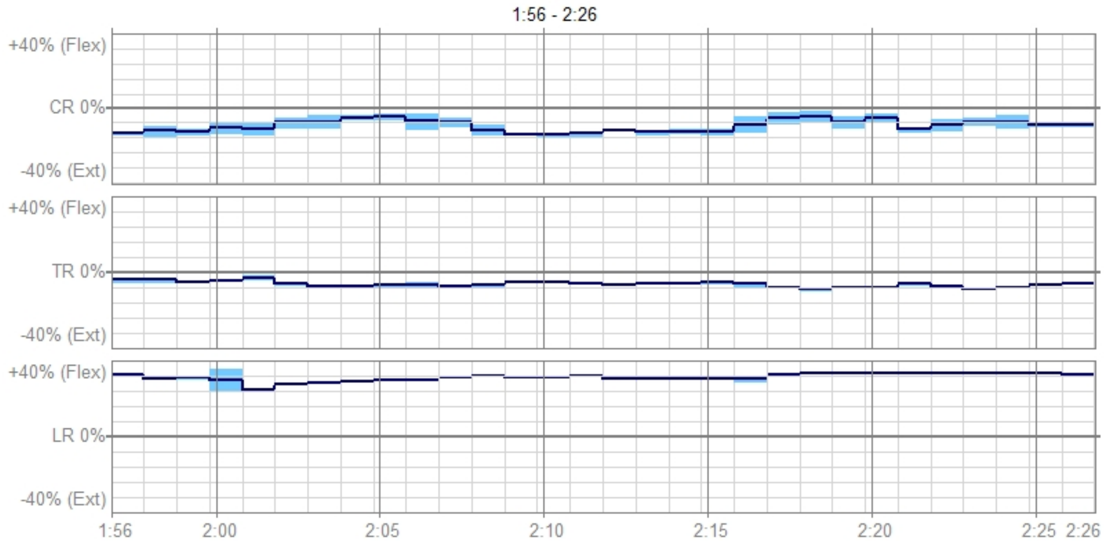

Figure 5-11: Sagittal flow diagram of 1:56-2:26 minutes of Test 1.

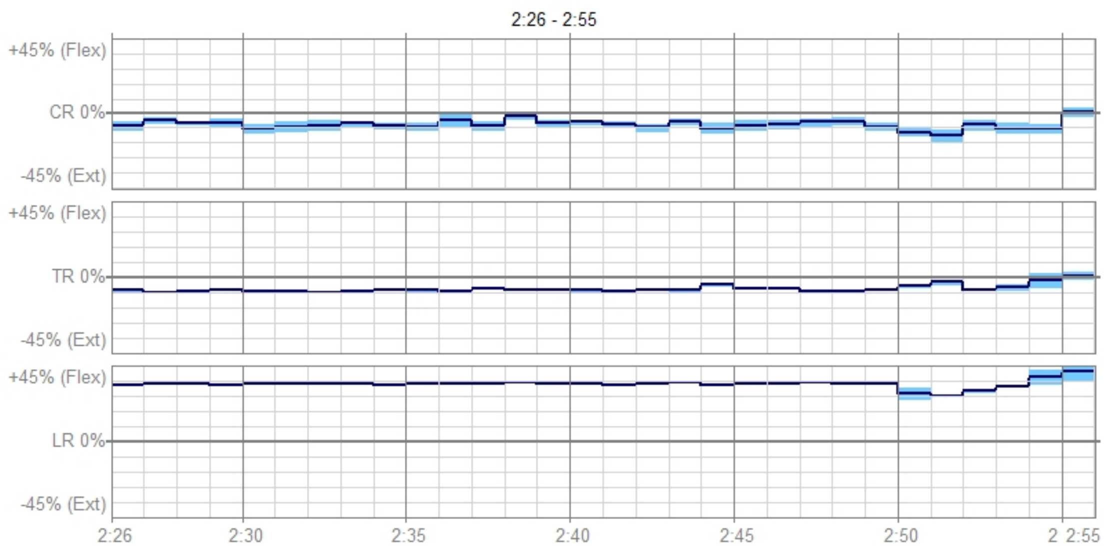

Figure 5-12: Sagittal flow diagram of 2:26-2:55 minutes of Test 1.

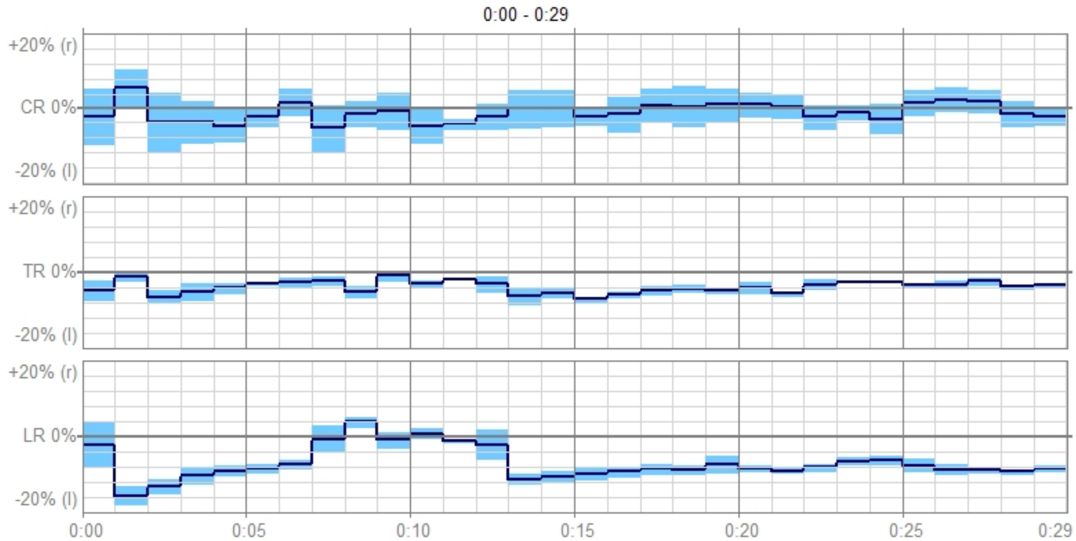

Figure 5-13: Torsional flow diagram of 0:00-0:29 minutes of Test 1.

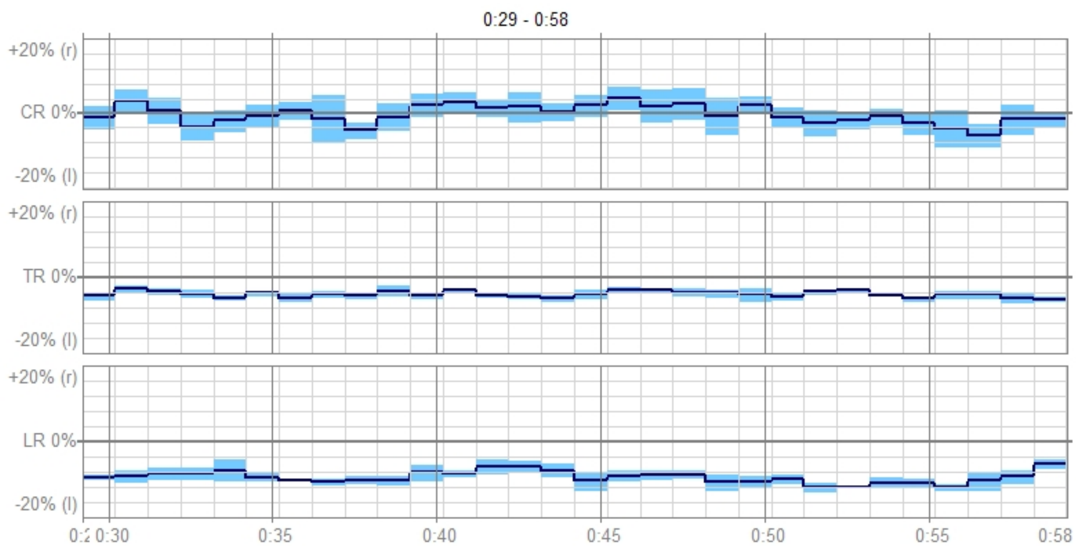

Figure 5-14: Torsional flow diagram of 0:29-0:58 minutes of Test 1.

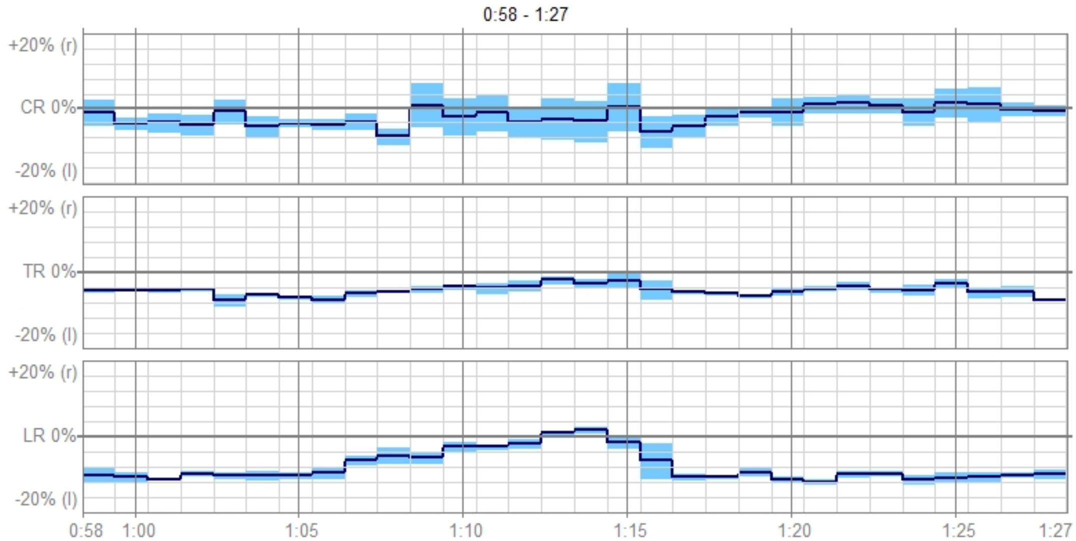

Figure 5-15: Torsional flow diagram of 0:58-1:27 minutes of Test 1.

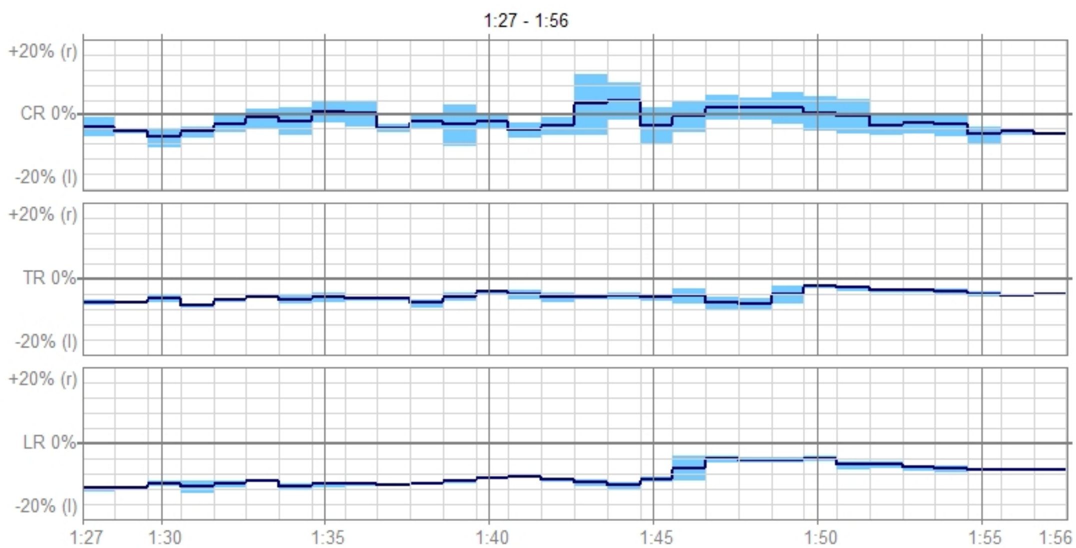

Figure 5-16: Torsional flow diagram of 1:27-1:56 minutes of Test 1.

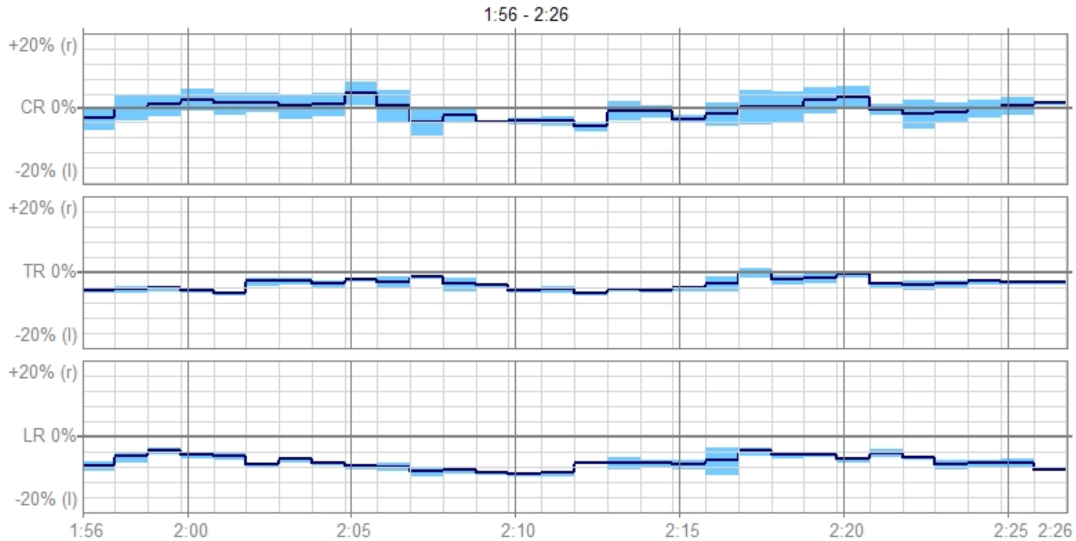

Figure 5-17: Torsional flow diagram of 1:56-2:26 minutes of Test 1.

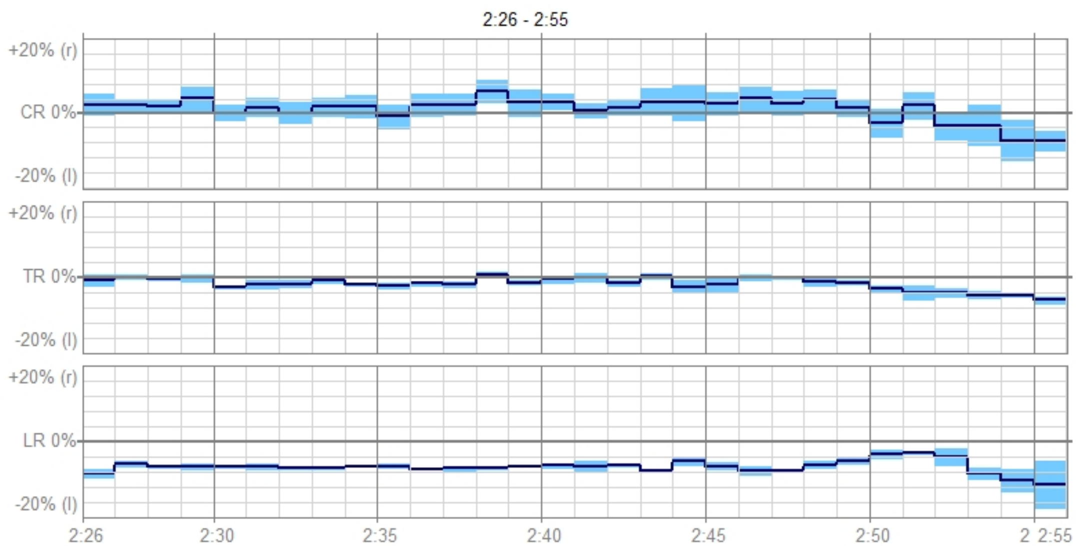

Figure 5-18: Torsional flow diagram of 2:26-2:55 minutes of Test 1.

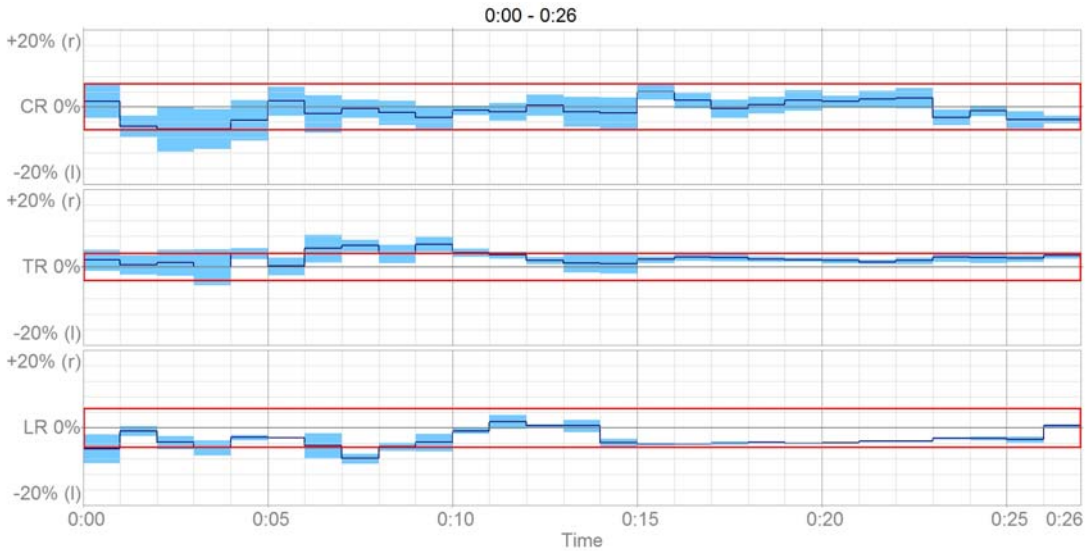

Figure 5-19: Frontal flow diagram of 0:00-0:26 minutes of Test 2.

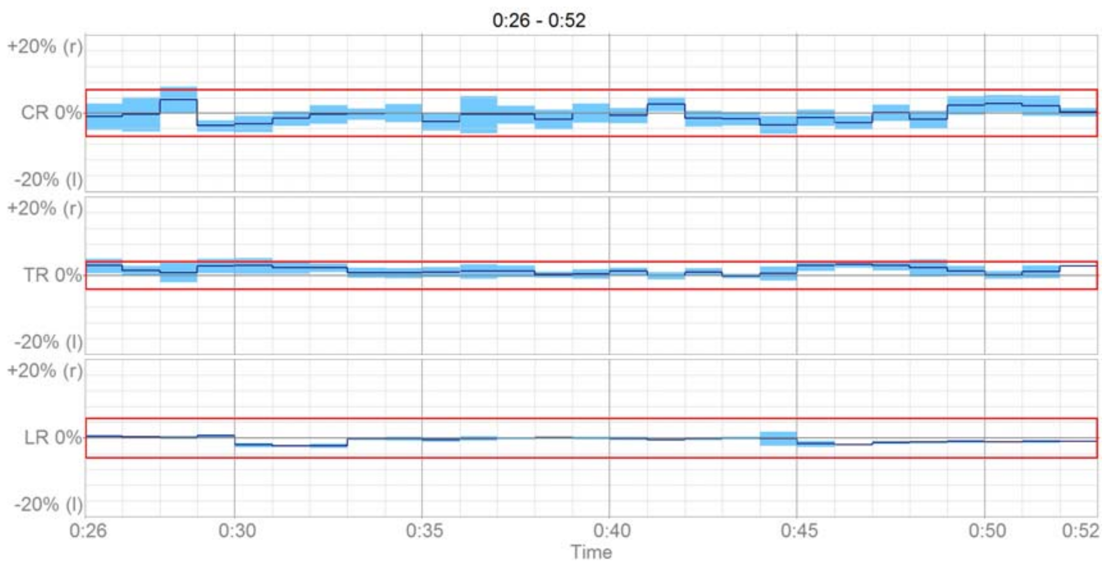

Figure 5-20: Frontal flow diagram of 0:26-0:52 minutes of Test 2.

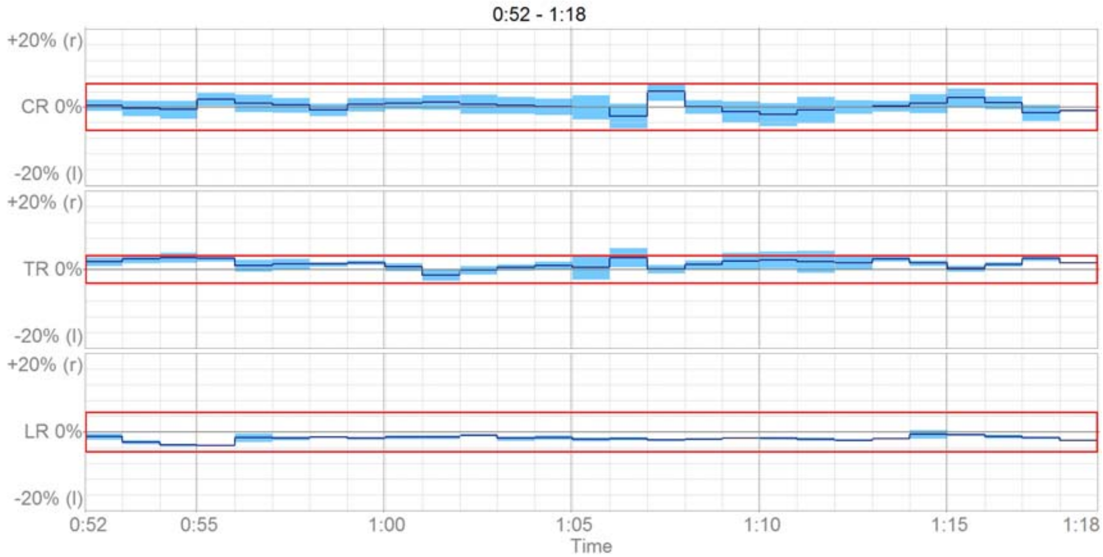

Figure 5-21: Frontal flow diagram of 0:52-1:18 minutes of Test 2.

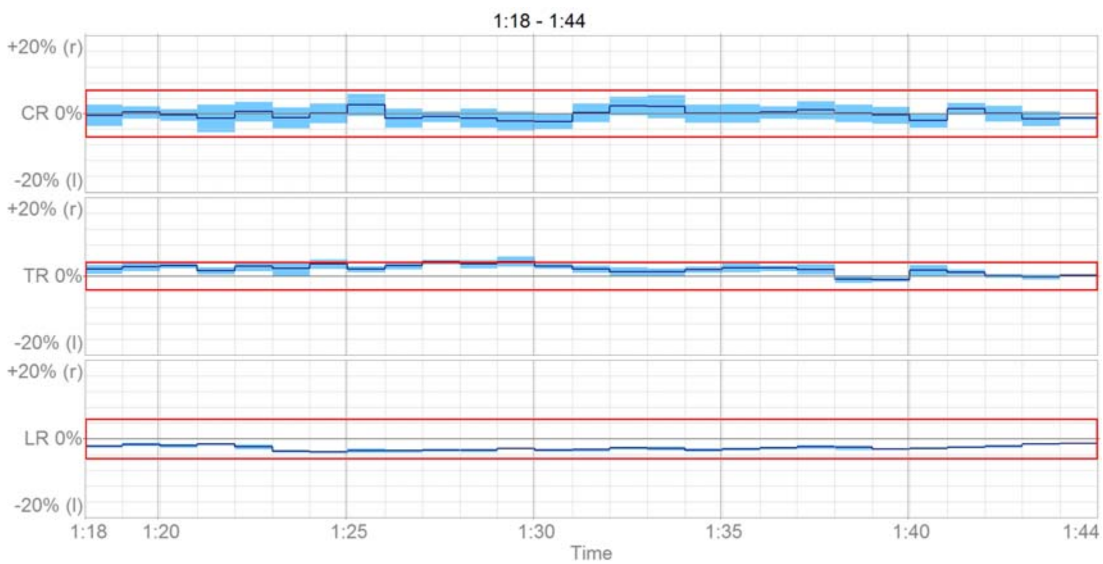

Figure 5-22: Frontal flow diagram of 1:18-1:44 minutes of Test 2.

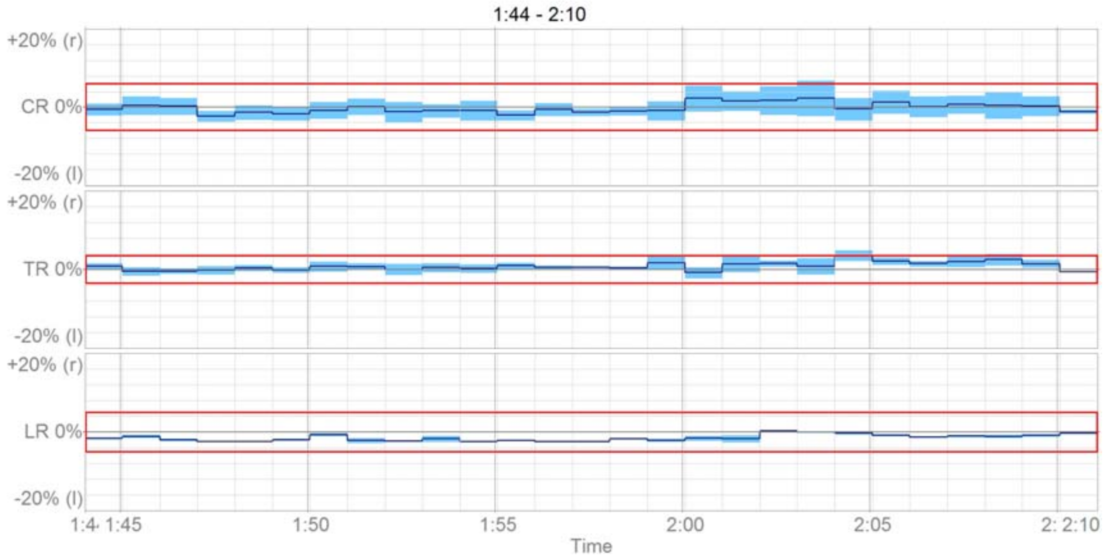

Figure 5-23: Frontal flow diagram of 1:44-2:10 minutes of Test 2.

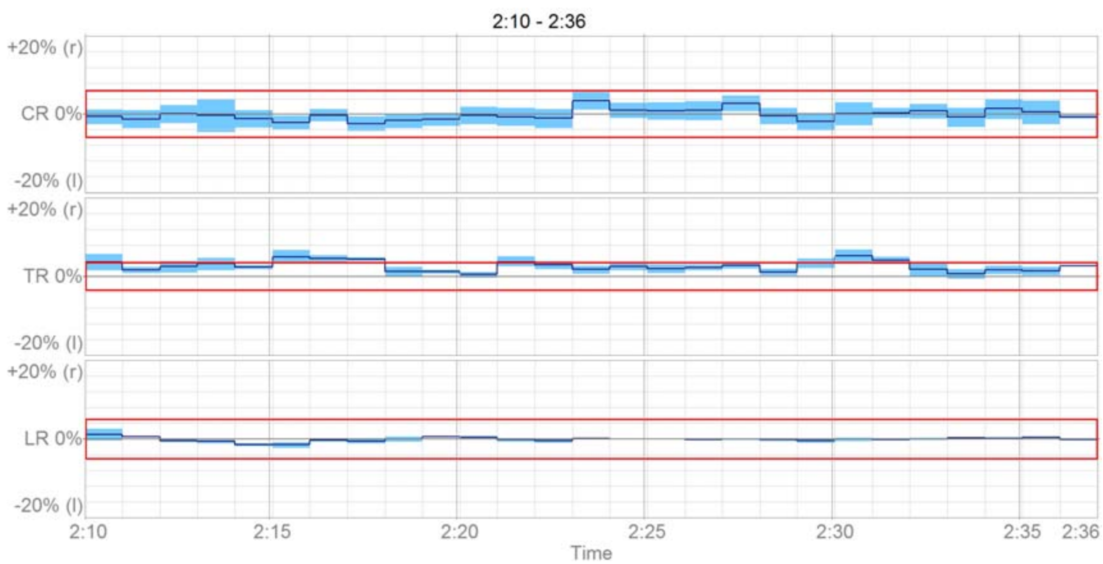

Figure 5-24: Frontal flow diagram of 2:10-2:36 minutes of Test 2.

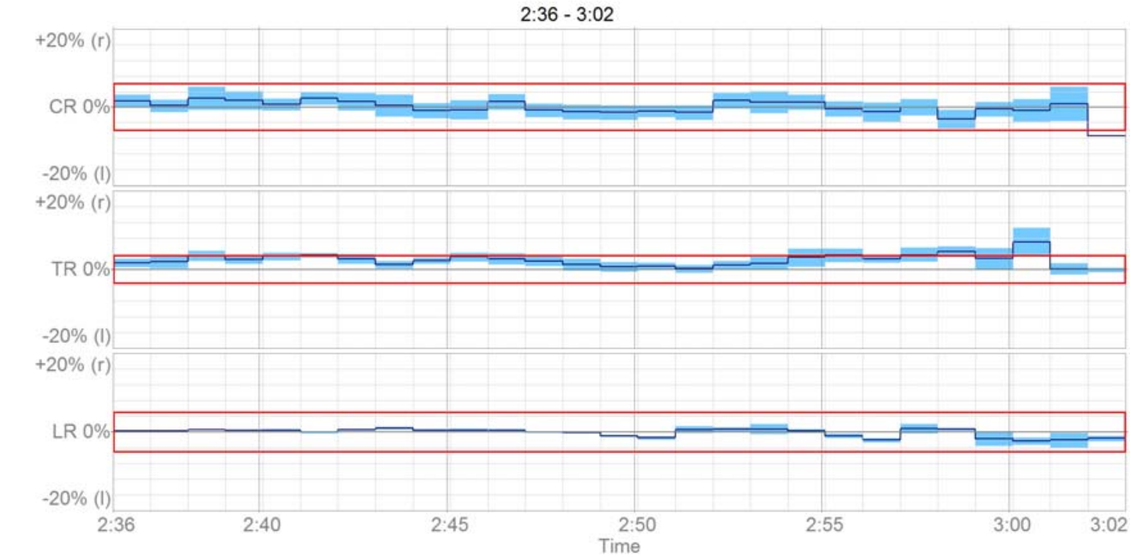

Figure 5-25: Frontal flow diagram of 2:36-3:02 minutes of Test 2.

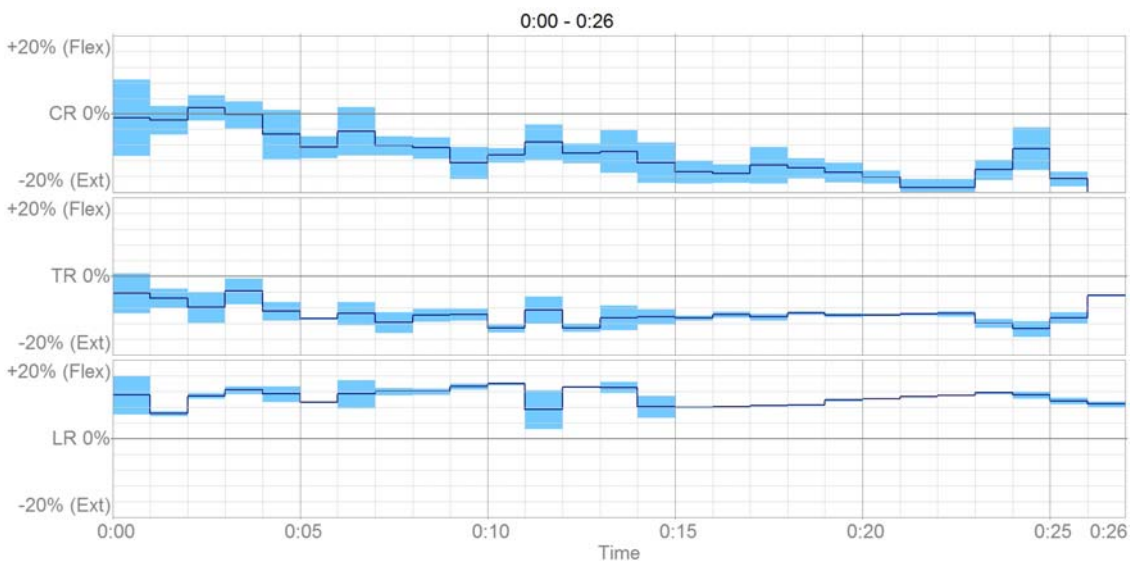

Figure 5-26: Sagittal flow diagram of 0:00-0:26 minutes of Test 2.

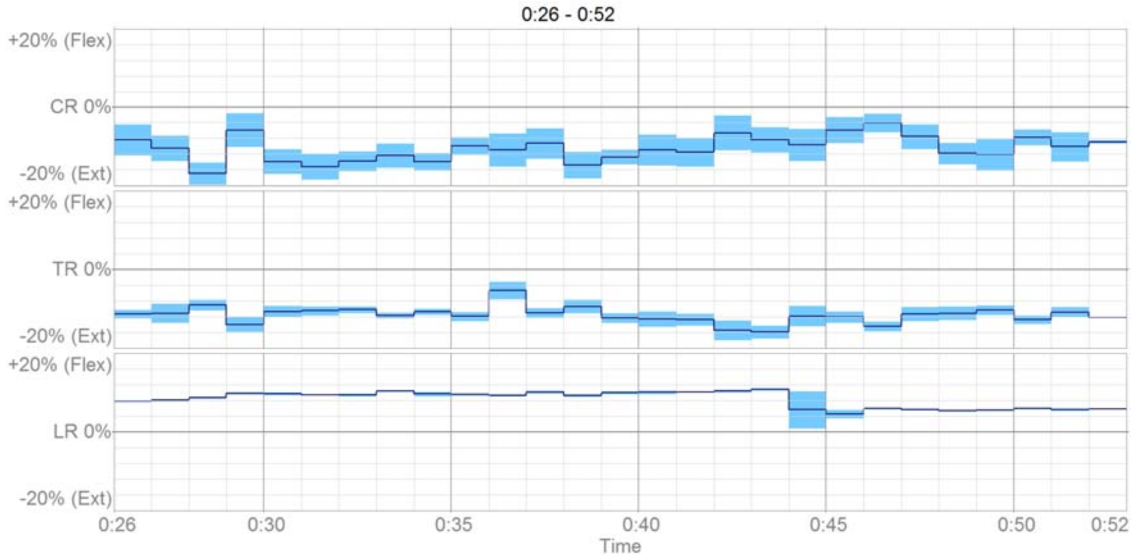

Figure 5-27: Sagittal flow diagram of 0:26-0:52 minutes of Test 2.

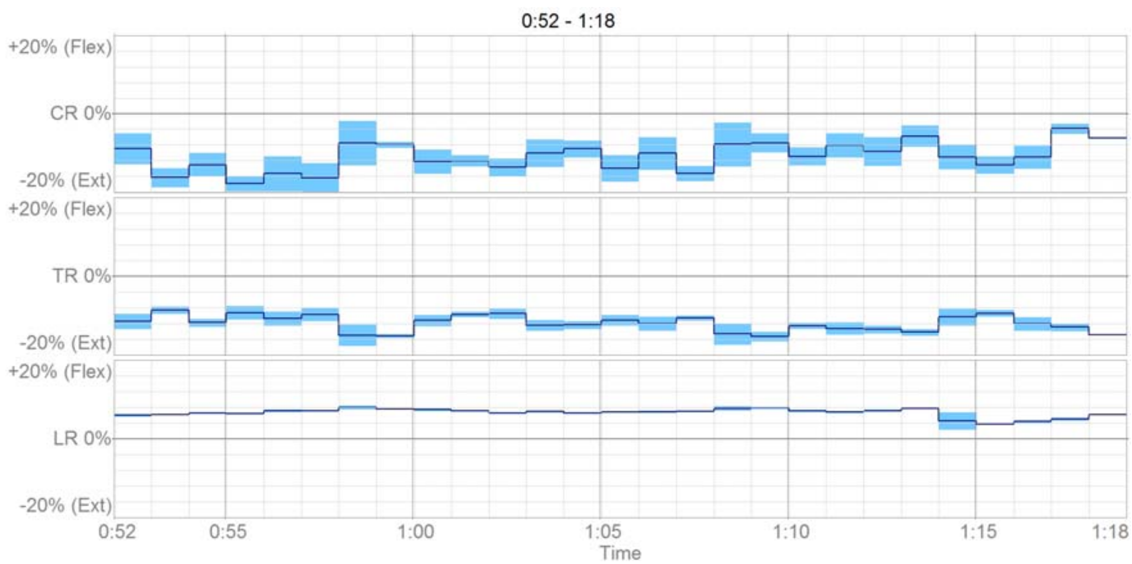

Figure 5-28: Sagittal flow diagram of 0:52-1:18 minutes of Test 2.

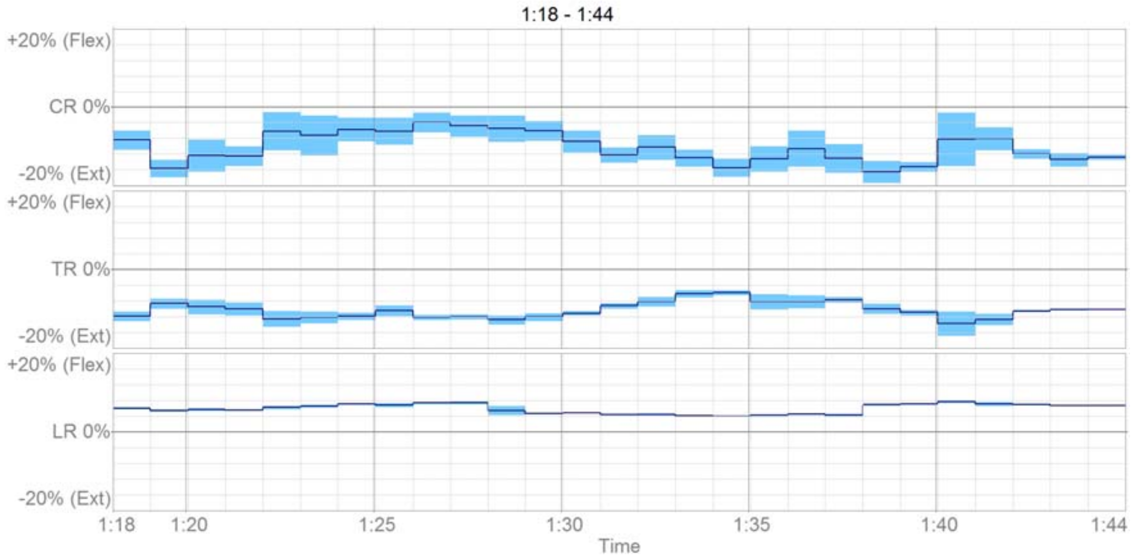

Figure 5-29: Sagittal flow diagram of 1:18-1:44 minutes of Test 2.

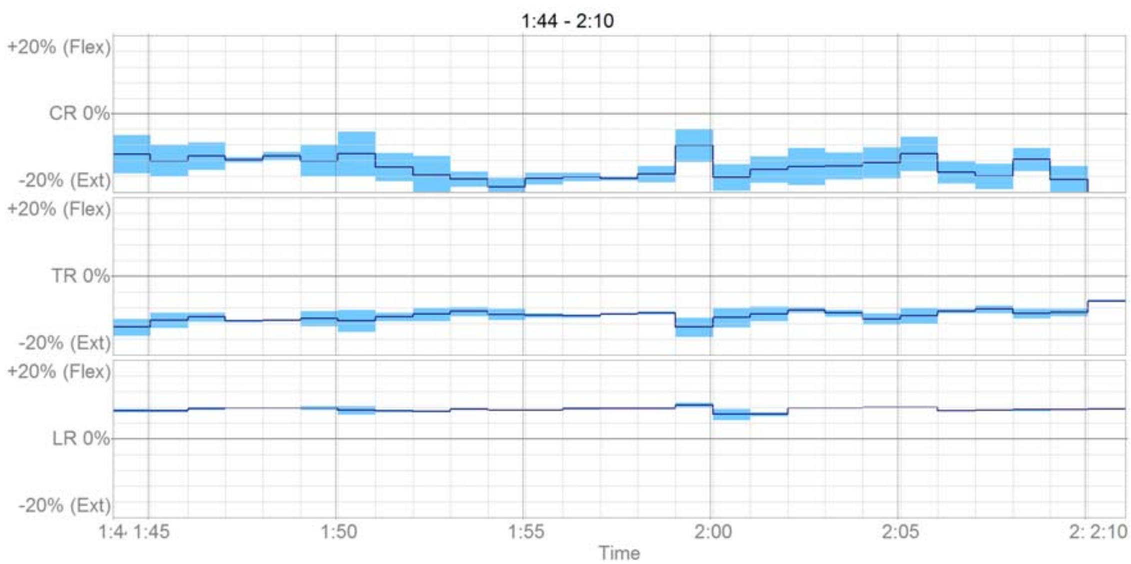

Figure 5-30: Sagittal flow diagram of 1:44-2:10 minutes of Test 2.

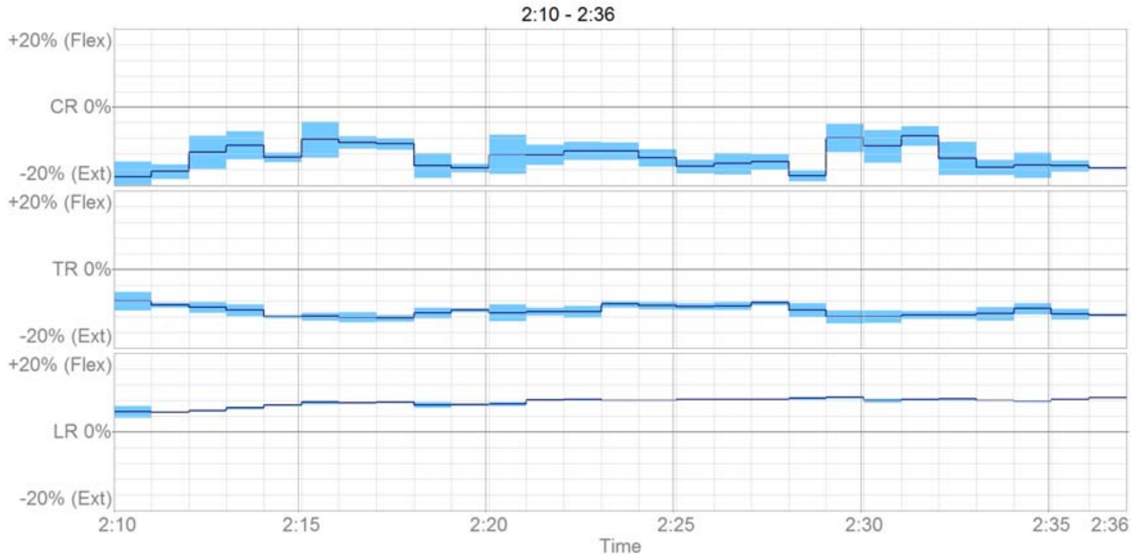

Figure 5-31: Sagittal flow diagram of 2:10-2:36 minutes of Test 2.

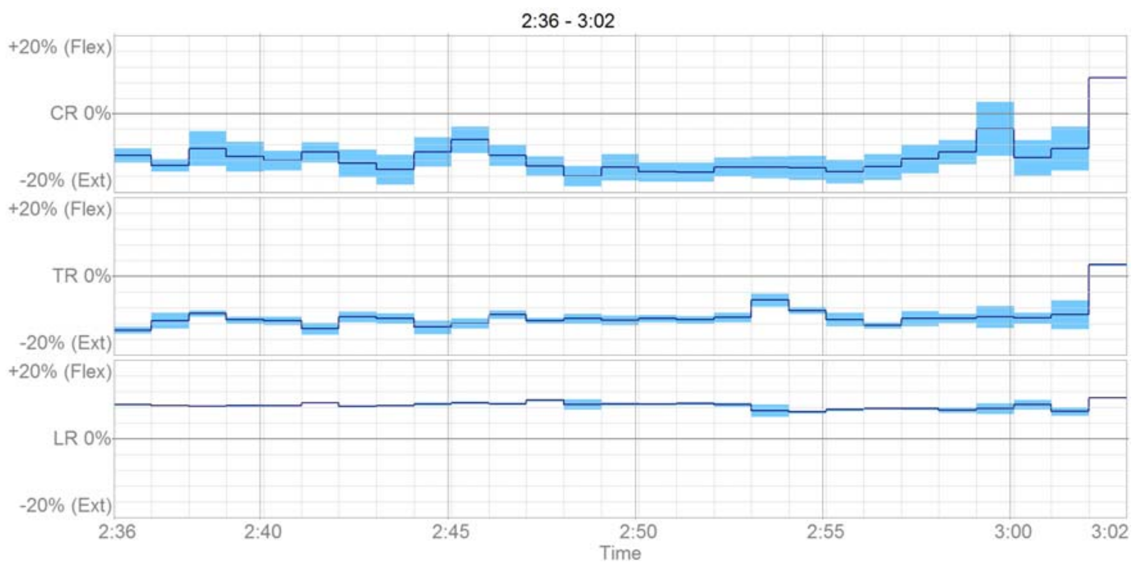

Figure 5-32: Sagittal flow diagram of 2:36-3:02 minutes of Test 2.

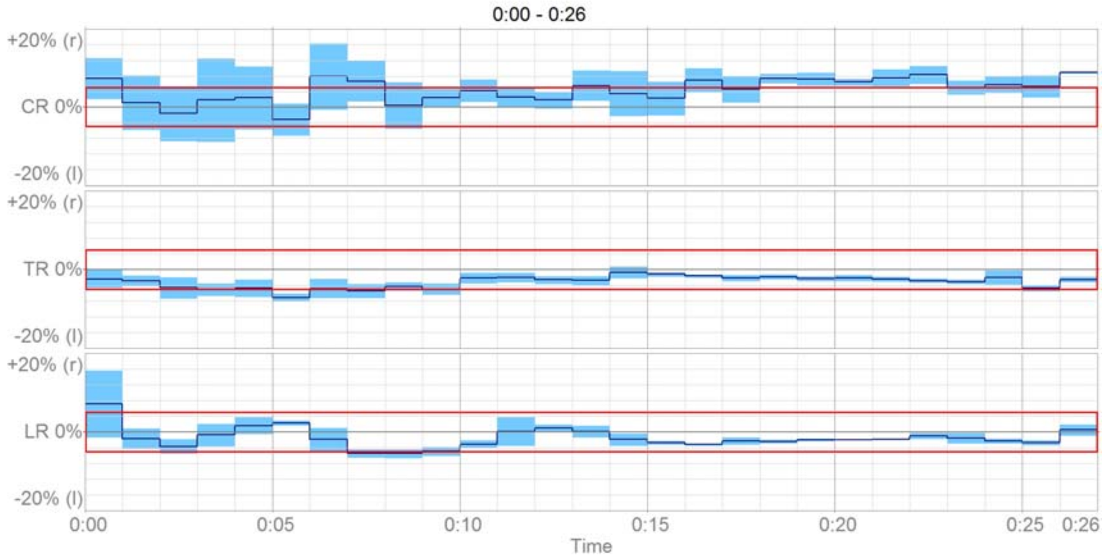

Figure 5-33: Torsional flow diagram of 0:00-0:26 minutes of Test 2.

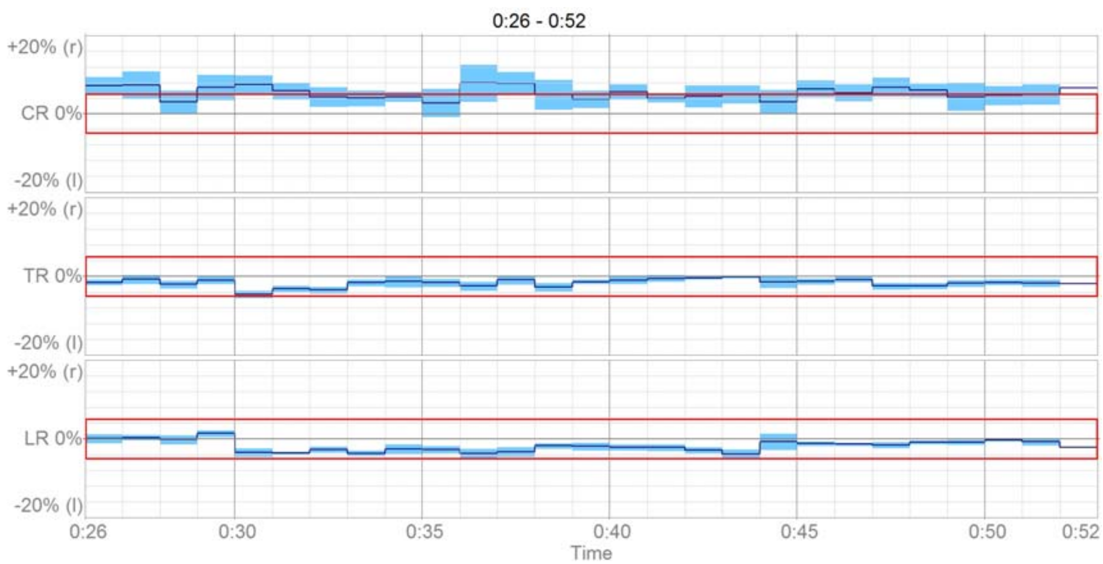

Figure 5-34: Torsional flow diagram of 0:26-0:52 minutes of Test 2.

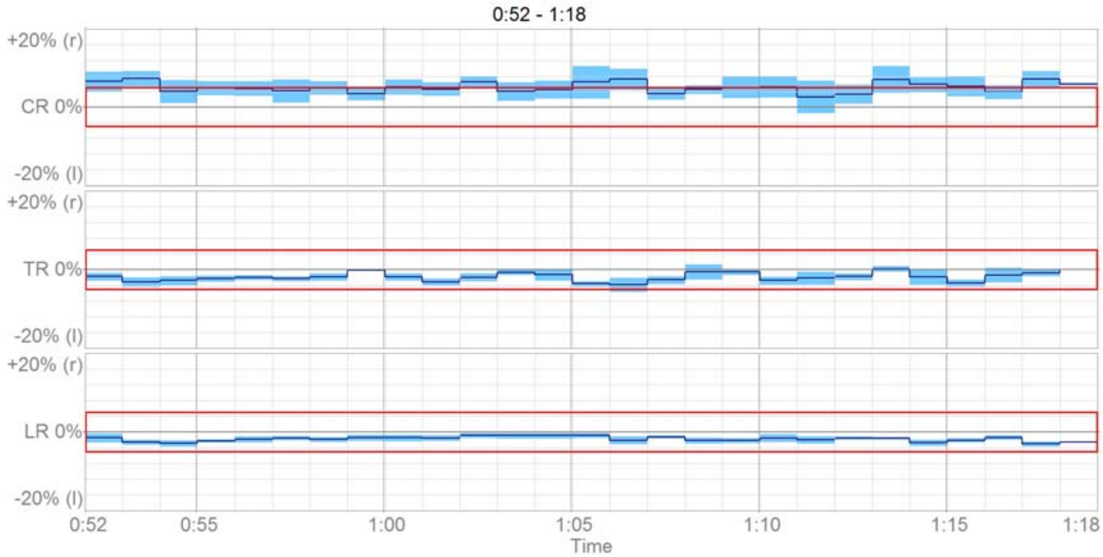

Figure 5-35: Torsional flow diagram of 0:52-1:18 minutes of Test 2.

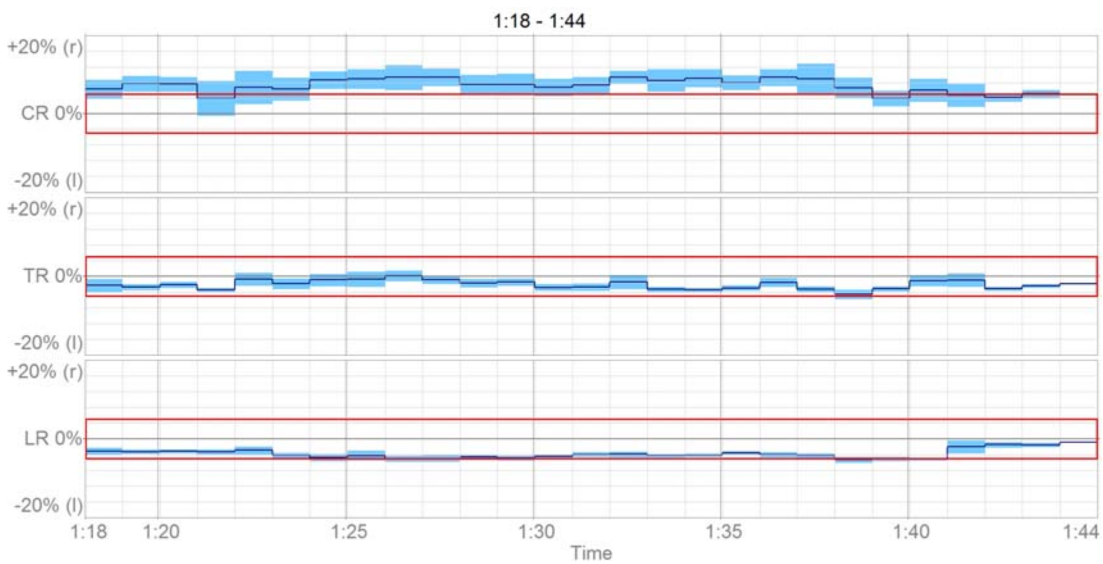

Figure 5-36: Torsional flow diagram of 1:18-1:44 minutes of Test 2.

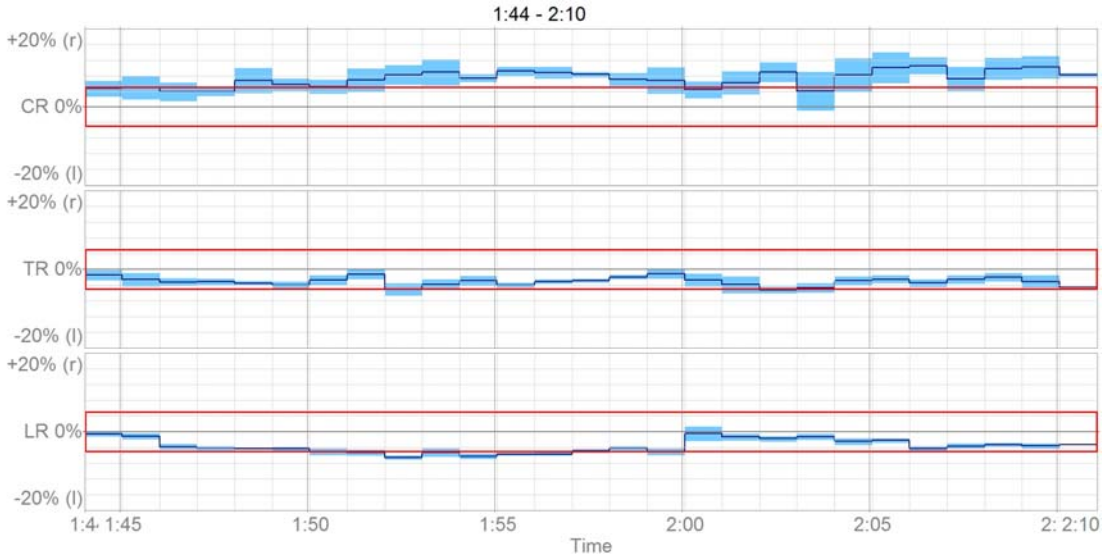

Figure 5-37: Torsional flow diagram of 1:44-2:10 minutes of Test 2.

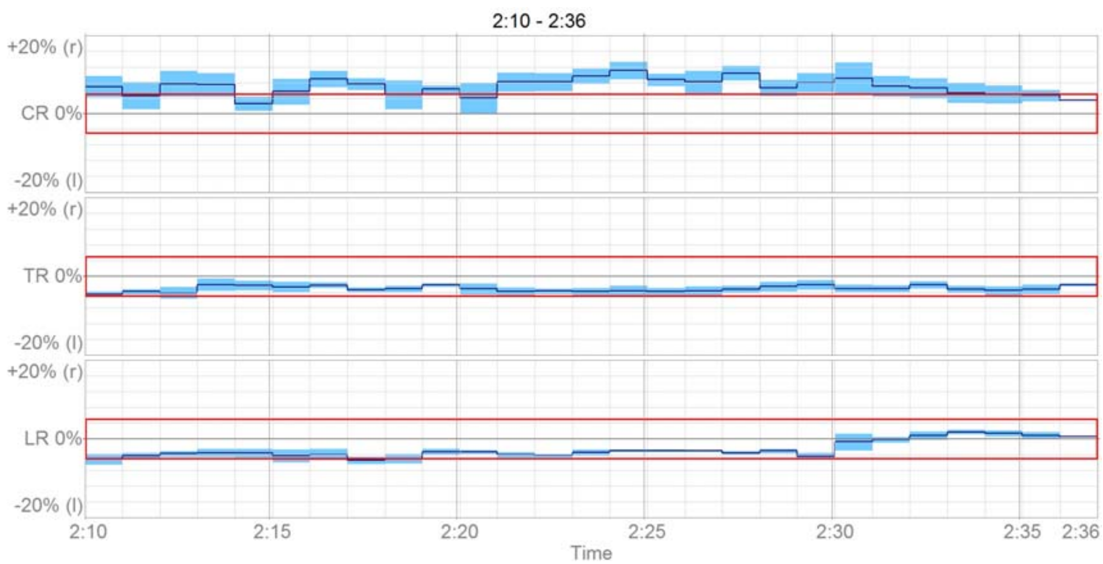

Figure 5-38: Torsional flow diagram of 2:10-2:36 minutes of Test 2.

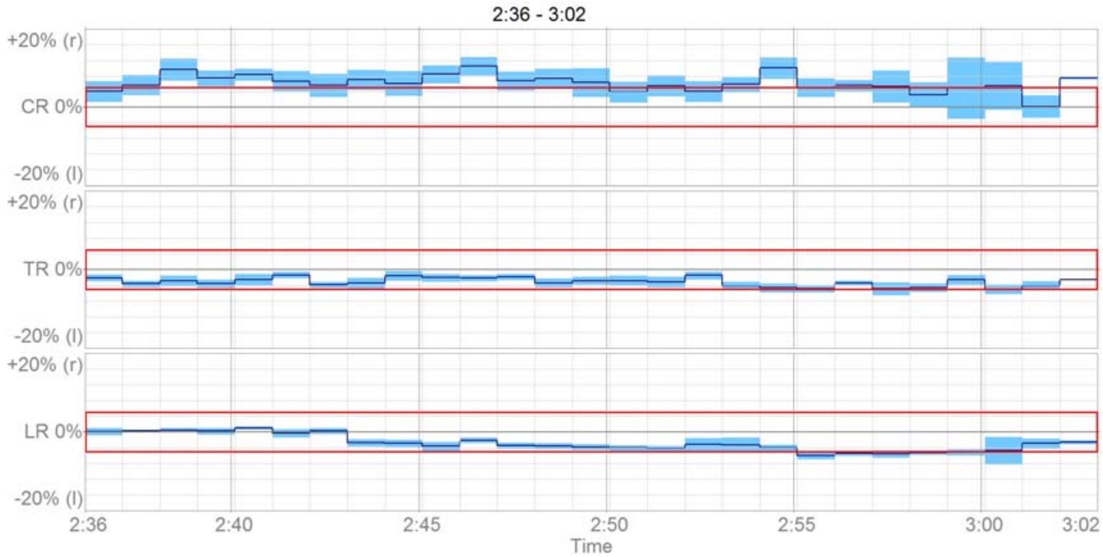

Figure 5-39: Torsional flow diagram of 2:36-3:02 minutes of Test 2.

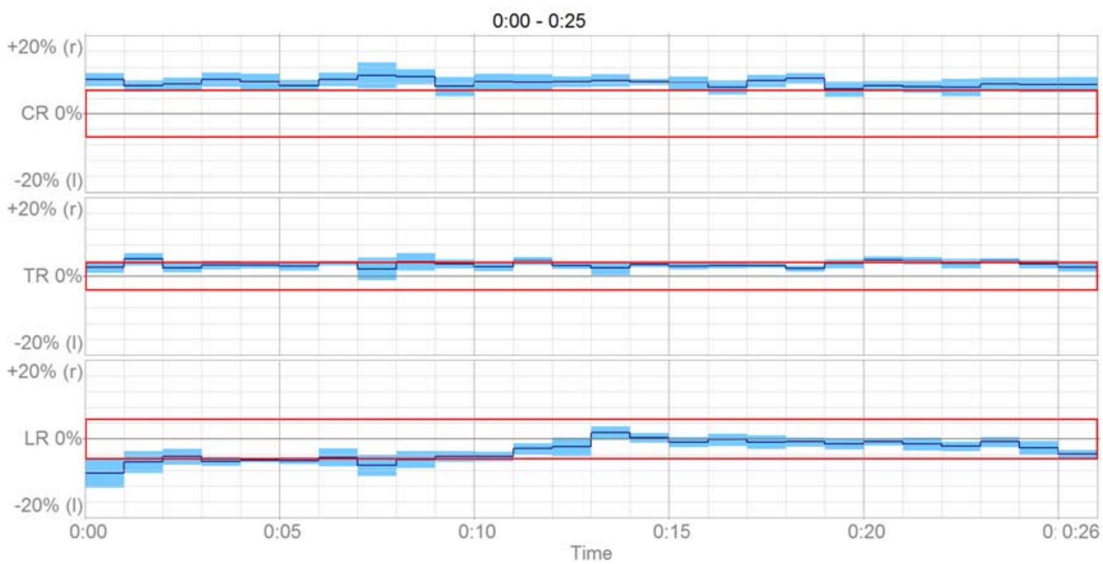

Figure 5-40: Frontal flow diagram of 0:00-0:25 minutes of Test 3.

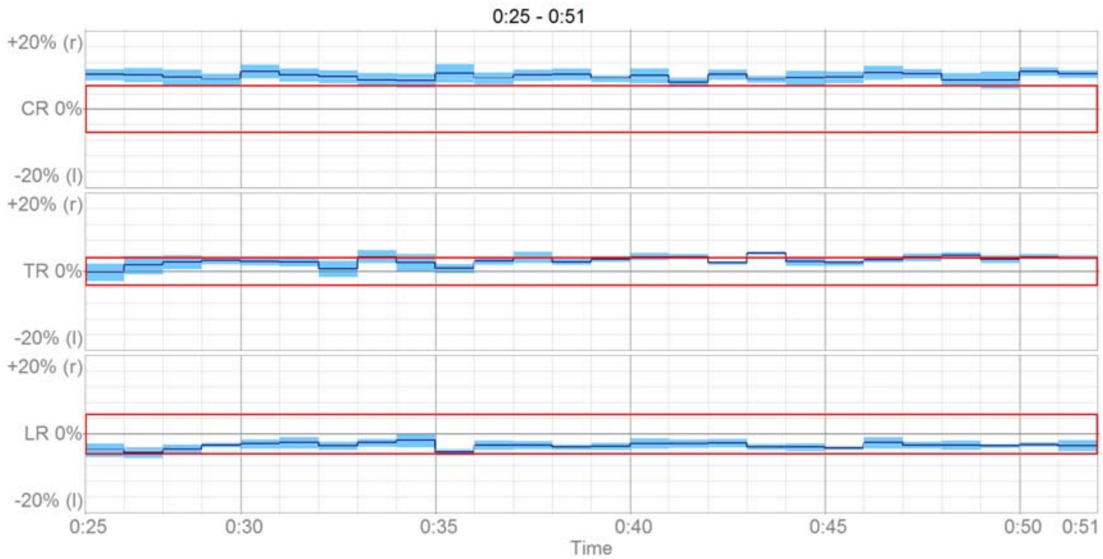

Figure 5-41: Frontal flow diagram of 0:25-0:51 minutes of Test 3.

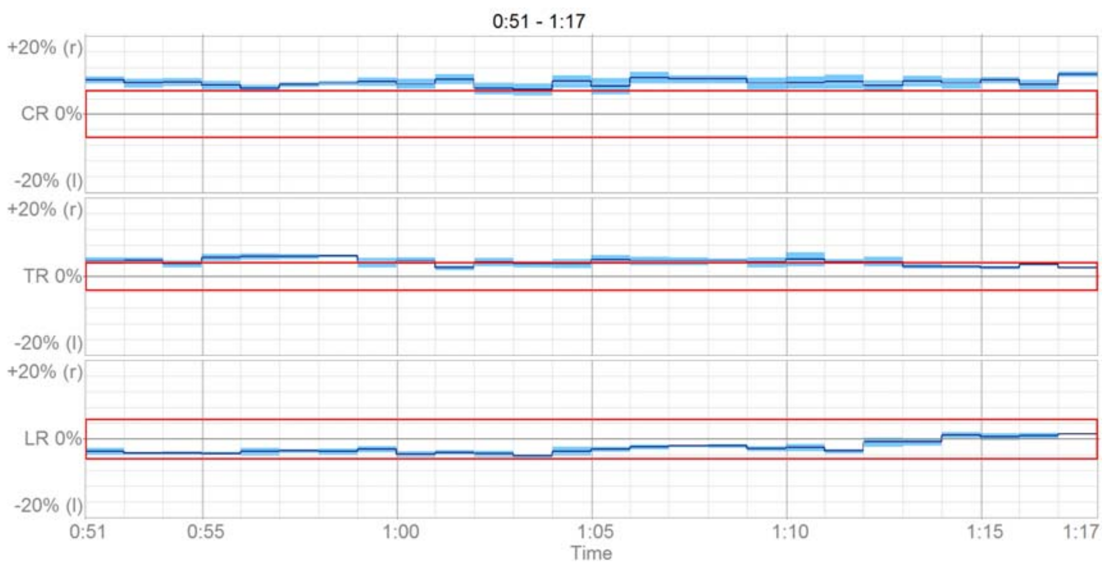

Figure 5-42: Frontal flow diagram of 0:51-1:17 minutes of Test 3.

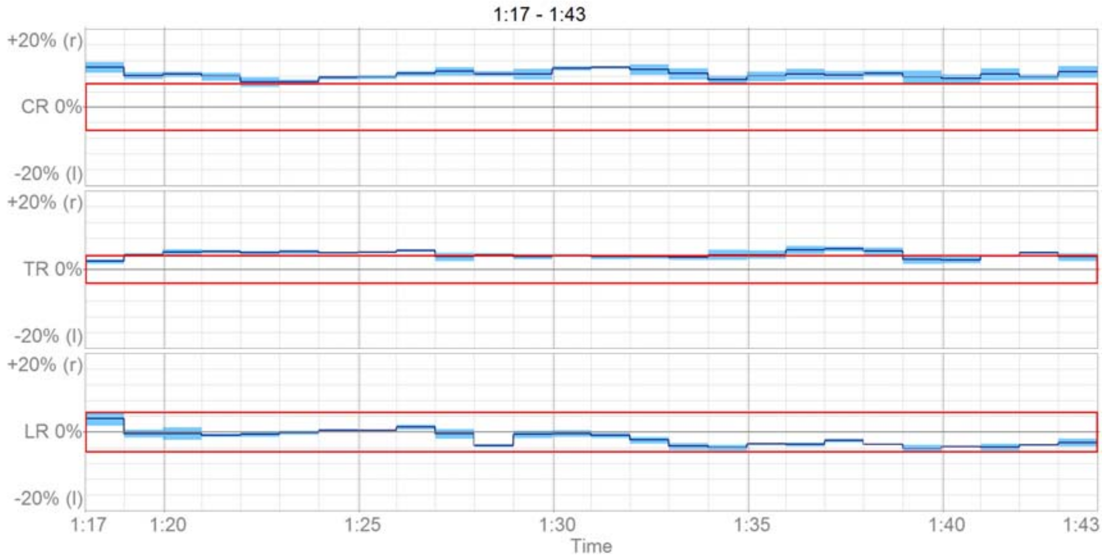

Figure 5-43: Frontal flow diagram of 1:17-1:43 minutes of Test 3.

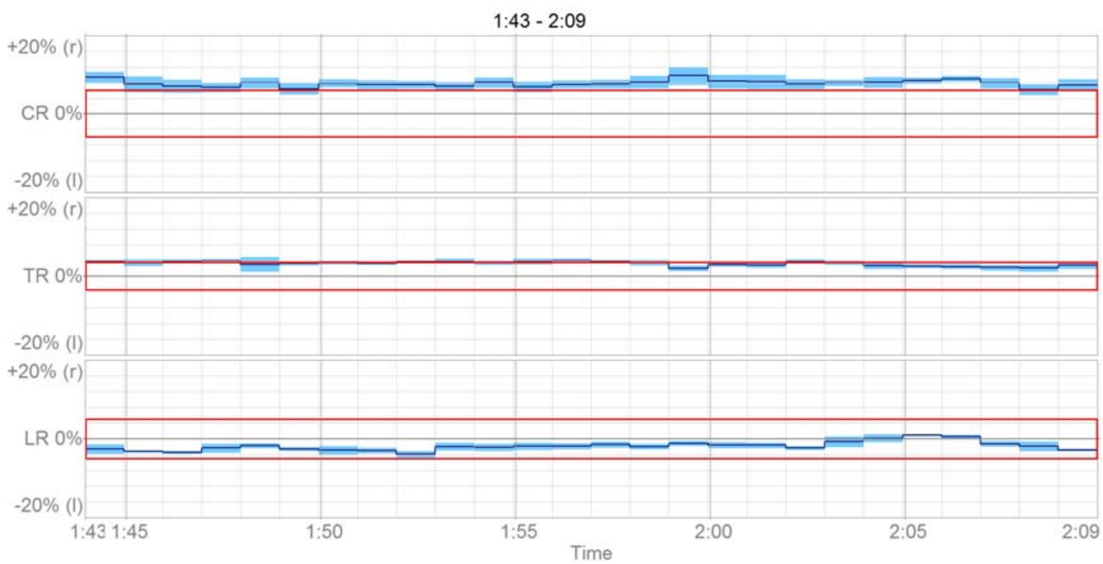

Figure 5-44: Frontal flow diagram of 1:43-2:09 minutes of Test 3.

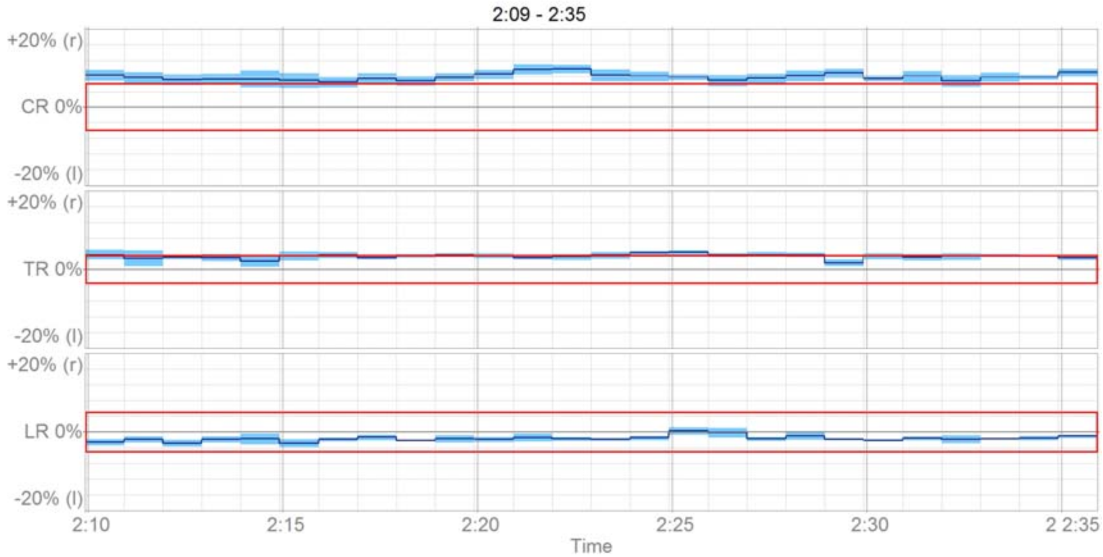

Figure 5-45: Frontal flow diagram of 2:09-2:35 minutes of Test 3.

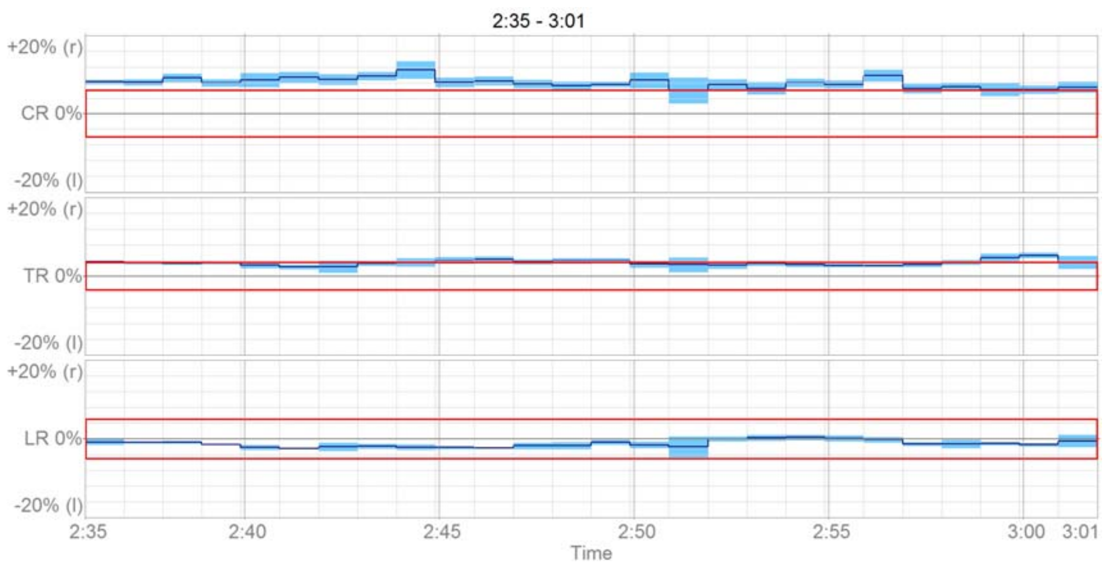

Figure 5-46: Frontal flow diagram of 2:35-3:01 minutes of Test 3.

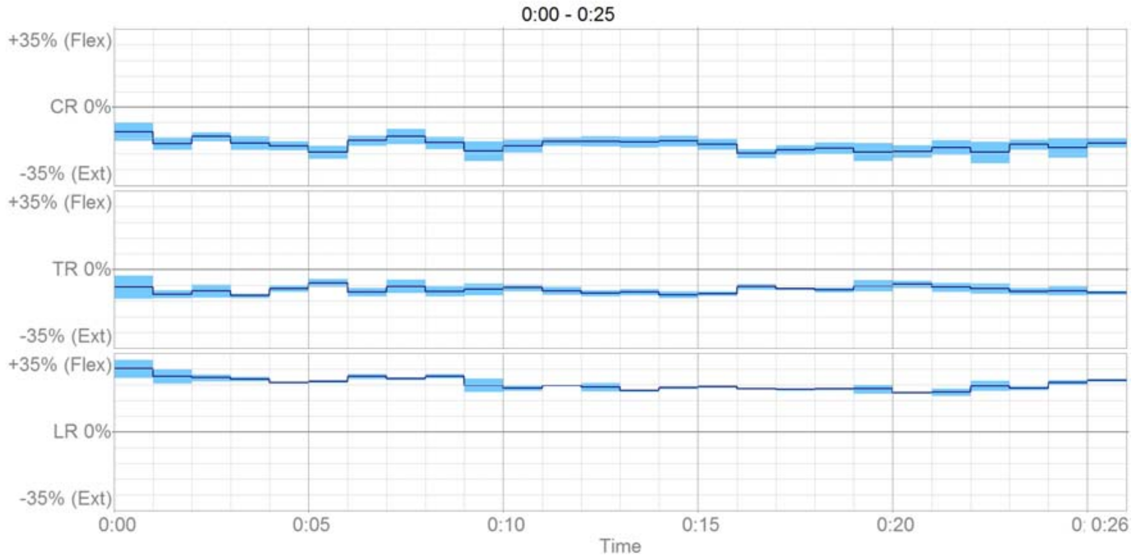

Figure 5-47: Sagittal flow diagram of 0:00-0:25 minutes of Test 3

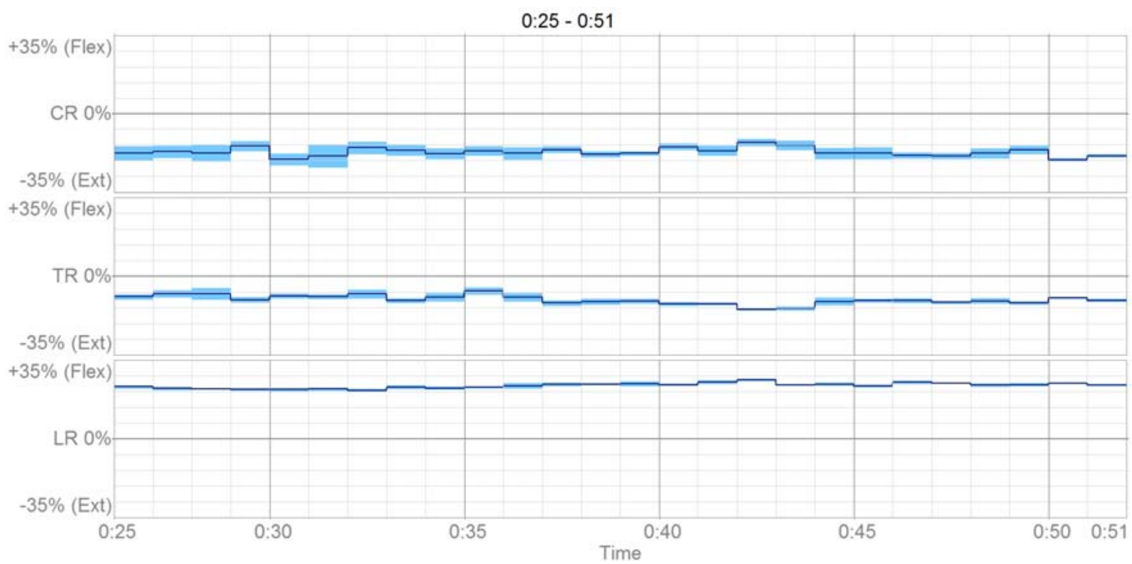

Figure 5-48: Sagittal flow diagram of 0:25-0:51 minutes of Test 3.

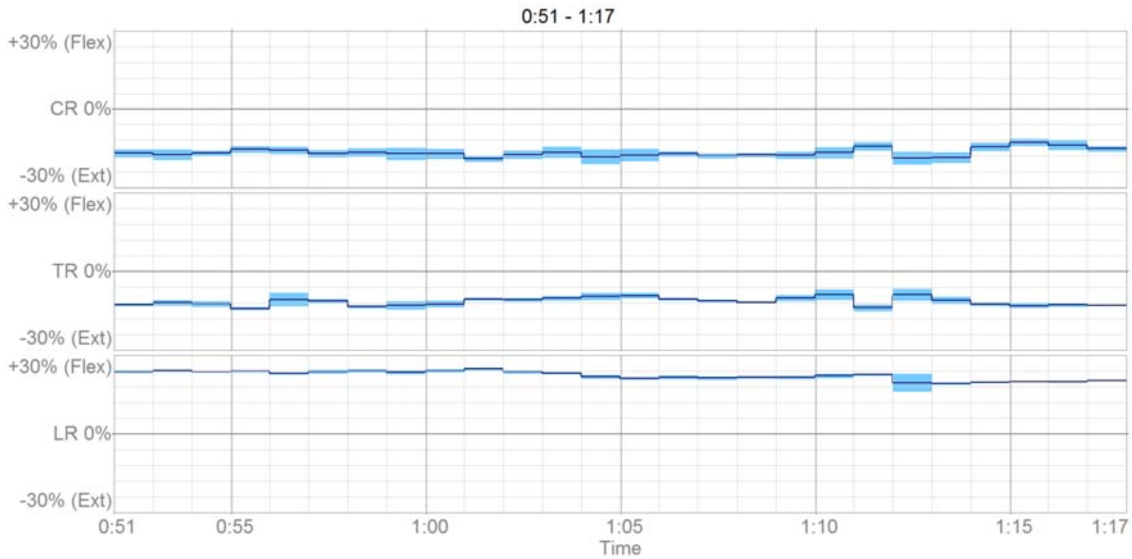

Figure 5-49: Sagittal flow diagram of 0:51-1:17 minutes of Test 3.

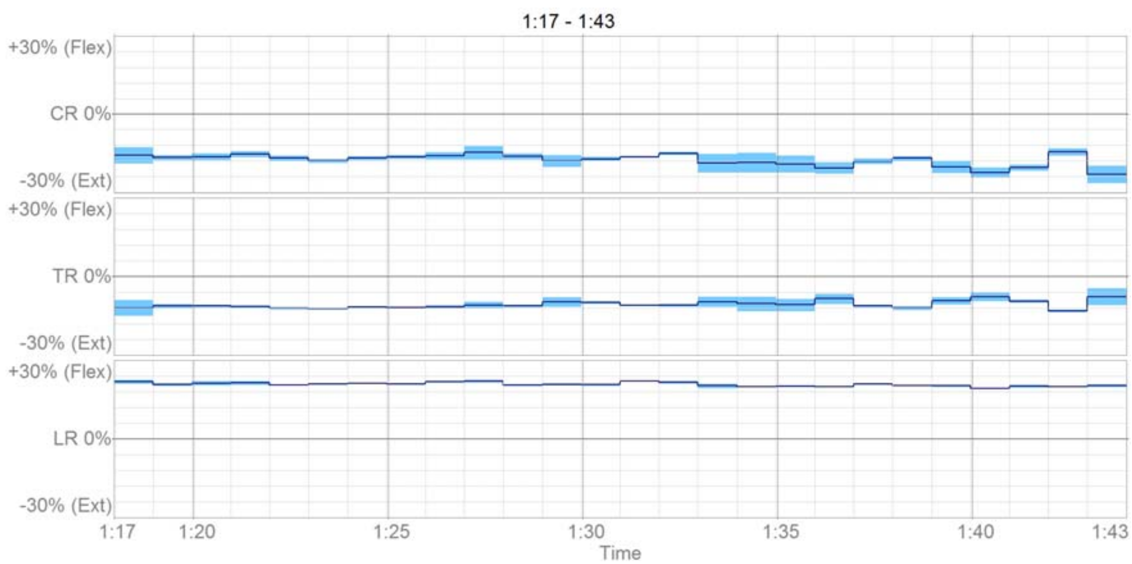

Figure 5-50: Sagittal flow diagram of 1:17-1:43 minutes of Test 3.

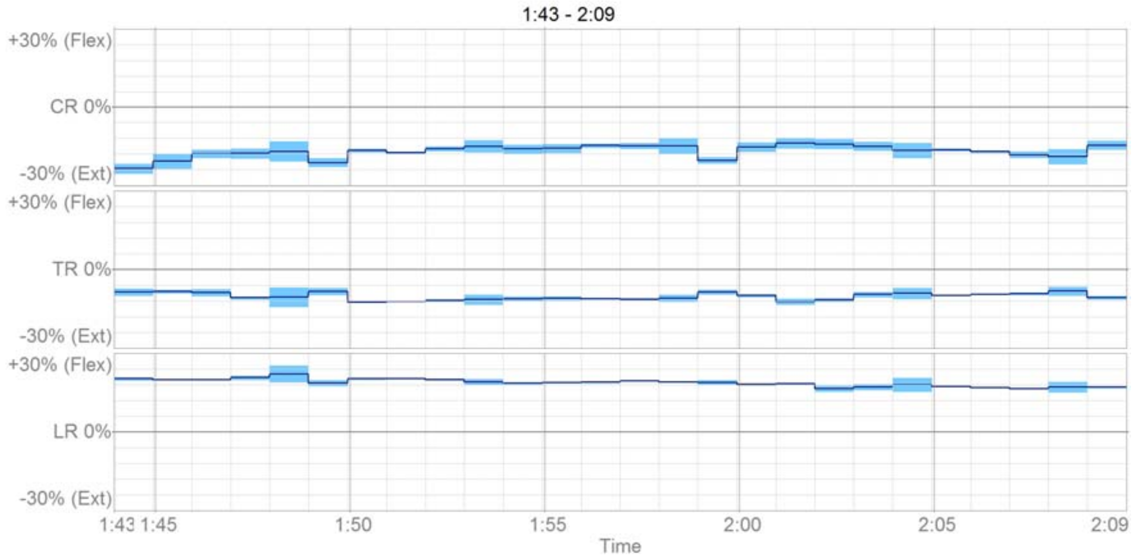

Figure 5-51: Sagittal flow diagram of 1:43-2:09 minutes of Test 3.

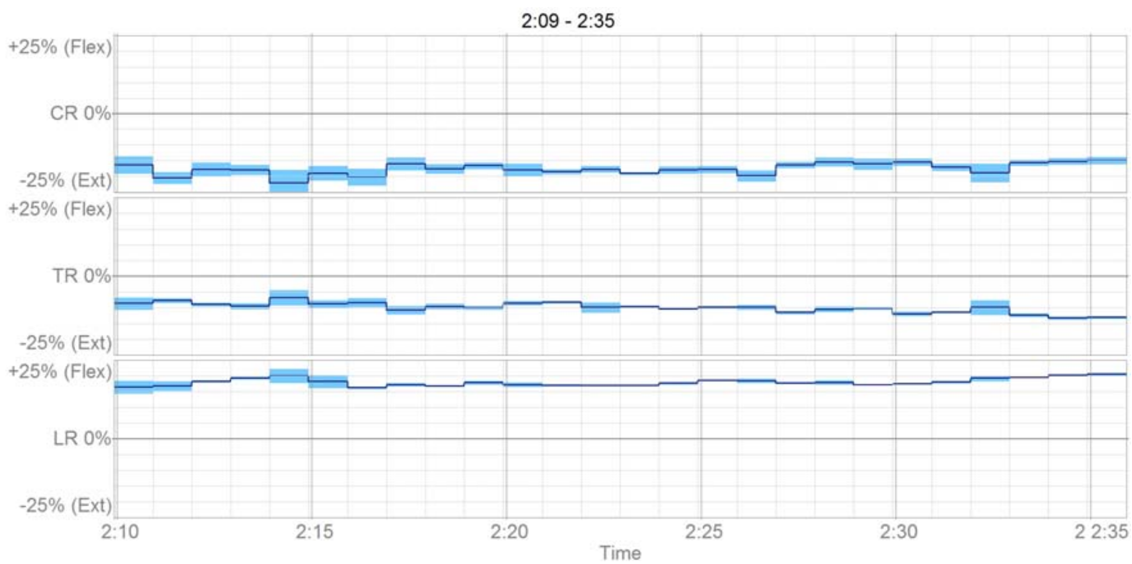

Figure 5-52: Sagittal flow diagram of 2:09-2:35 minutes of Test 3.

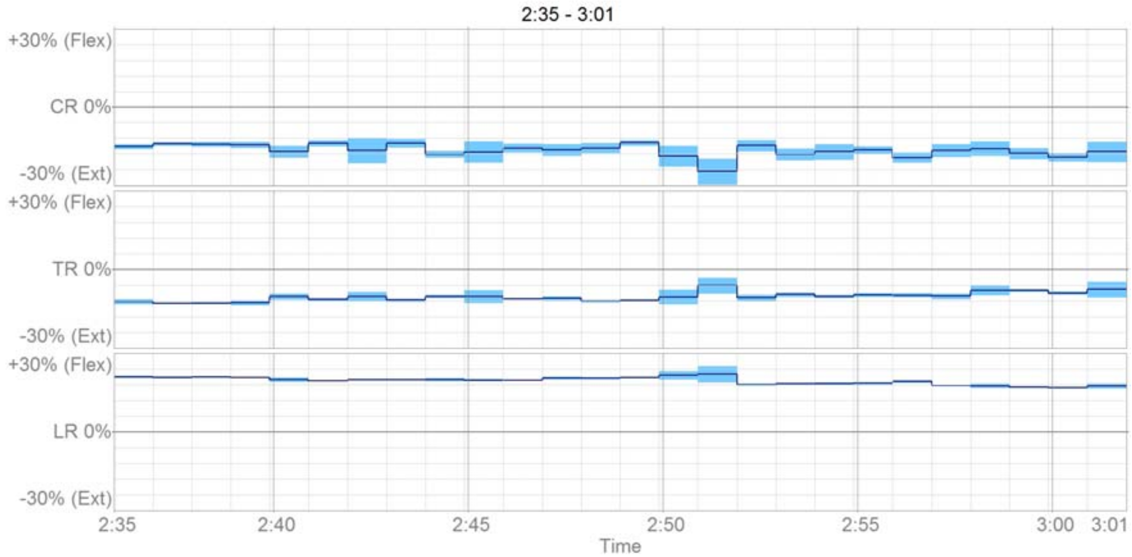

Figure 5-53: Sagittal flow diagram of 2:35-3:01 minutes of Test 3.

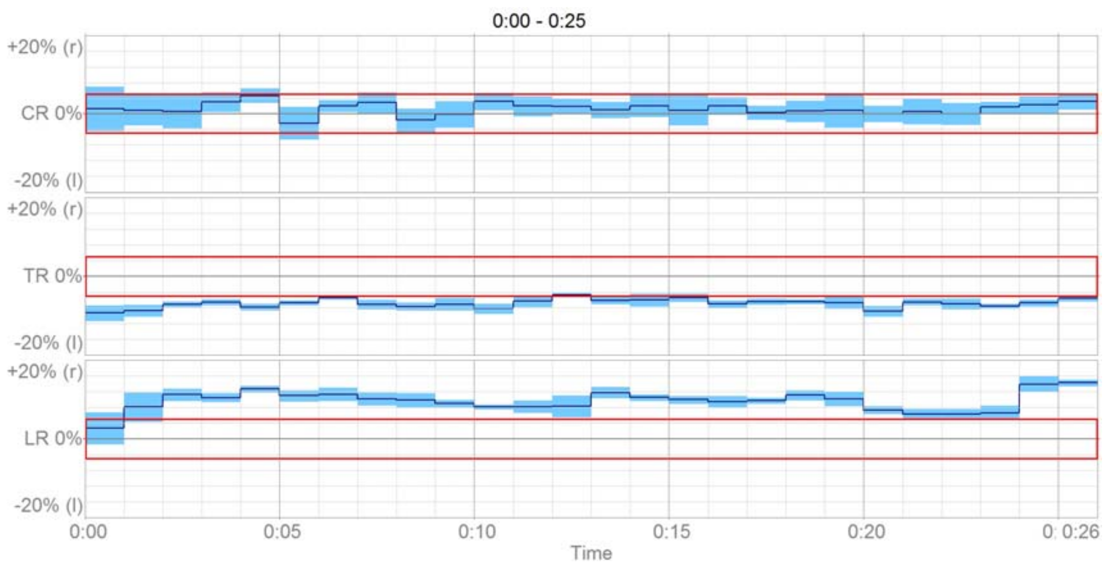

Figure 5-54: Torsional flow diagram of 0:00-0:25 minutes of Test 3

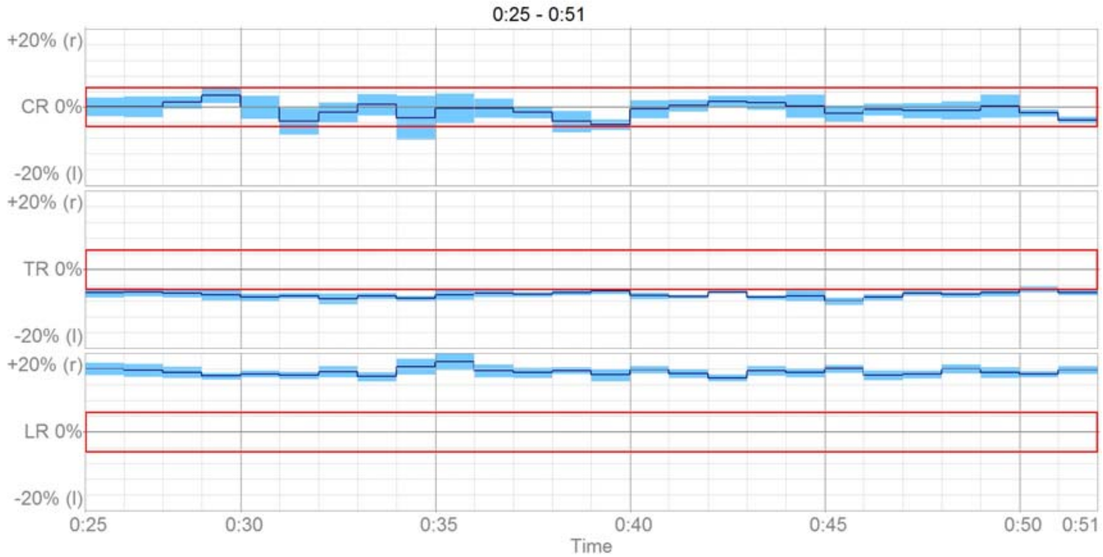

Figure 5-55: Torsional flow diagram of 0:25-0:51 minutes of Test 3.

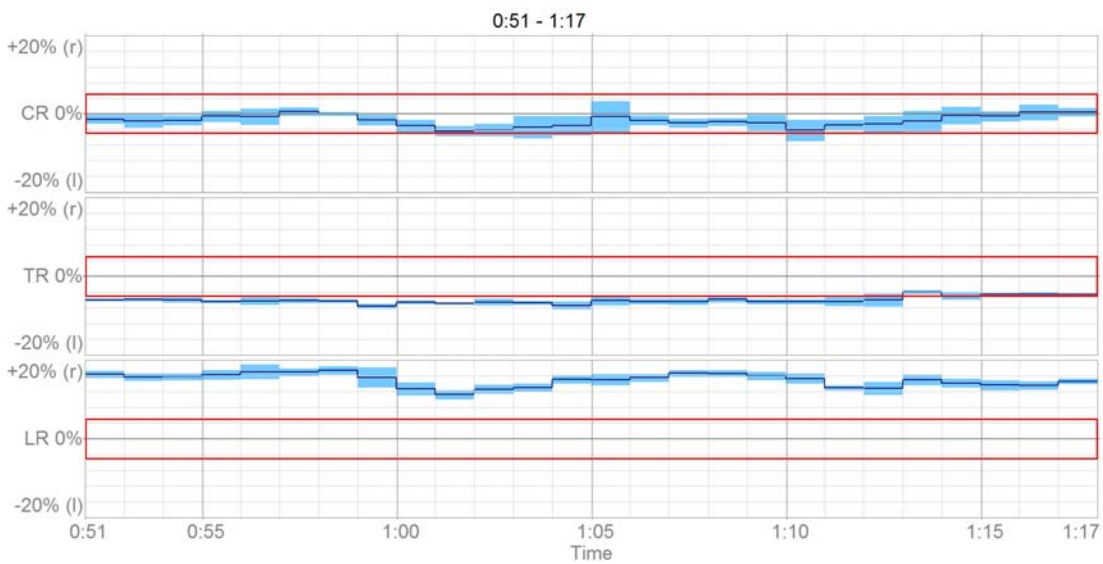

Figure 5-56: Torsional flow diagram of 0:51-1:17 minutes of Test 3.

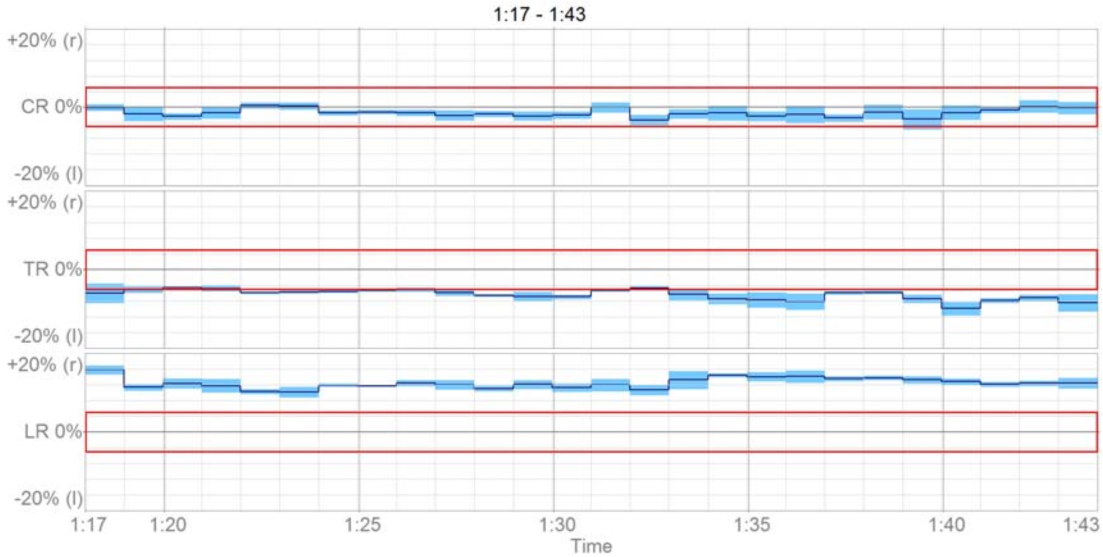

Figure 5-57: Torsional flow diagram of 1:17-1:43 minutes of Test 3.

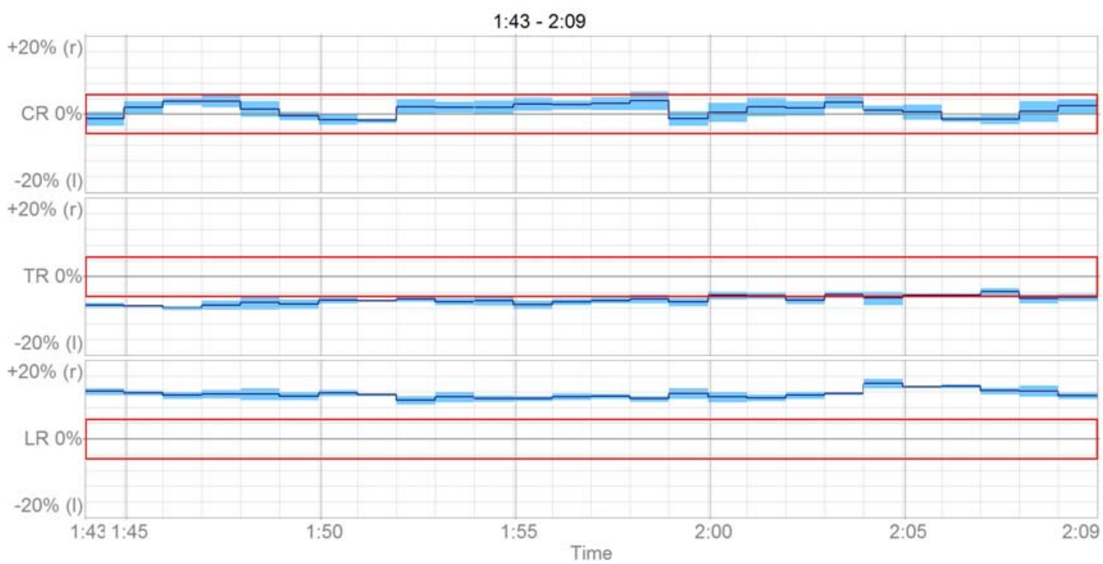

Figure 5-58: Torsional flow diagram of 1:43-2:09 minutes of Test 3.

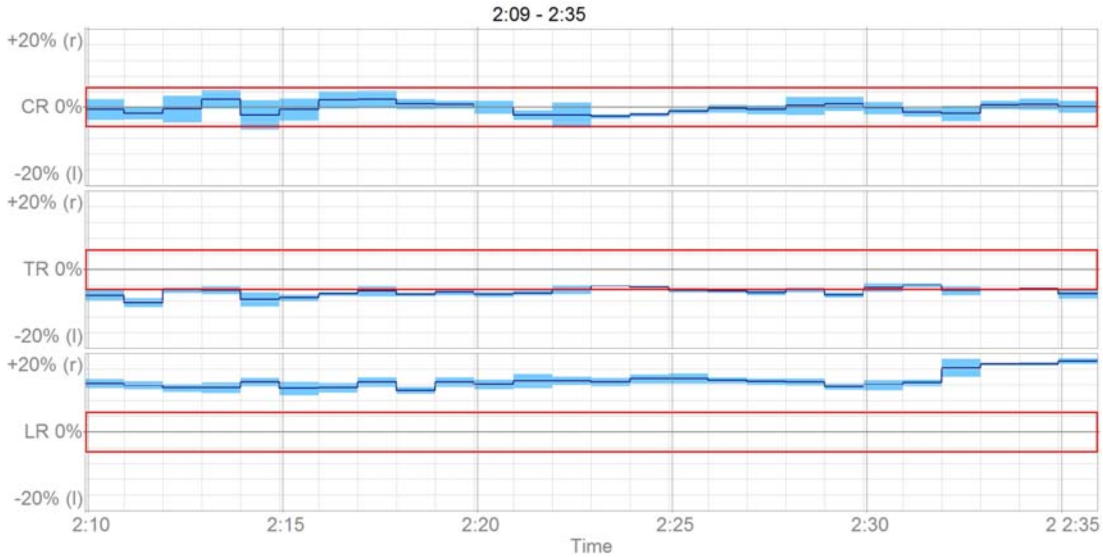

Figure 5-59: Torsional flow diagram of 2:09-2:35 minutes of Test 3.

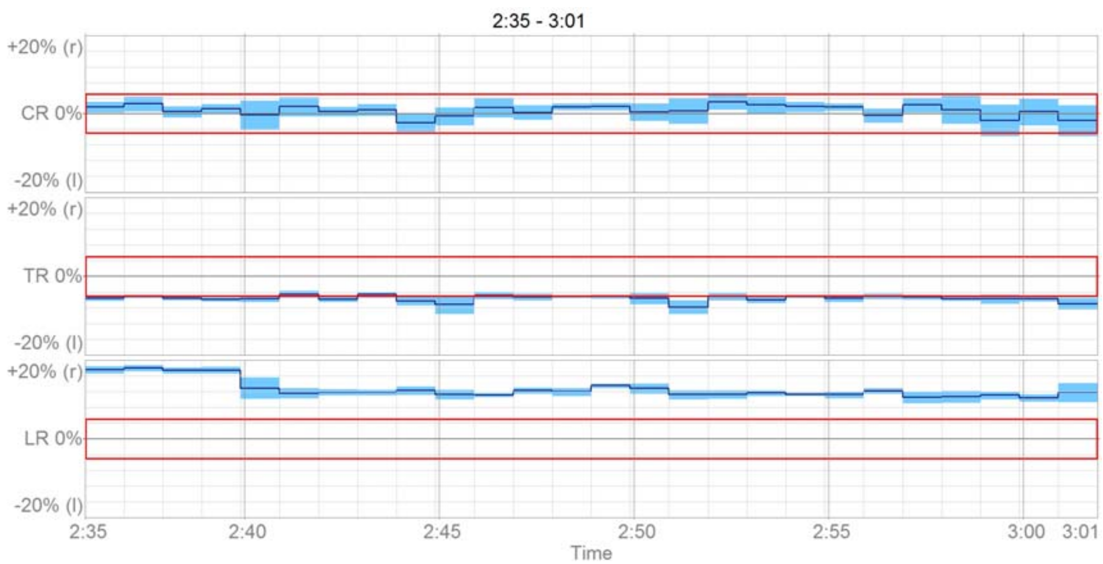

Figure 5-60: Torsional flow diagram of 2:35-3:01 minutes of Test 3.

Table 1. Flow chart of spinal movements, acceleration, and EMG of Test 1.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
0.0					
0.1					
0.2					
0.3					
0.4					
0.5					0.405
0.6					
0.7					
0.8					
0.9	Start	Start	Start		
0.10					0.618
0.11					
0.12	Increased Motion	Increased Motion	Some increased motion.	Yes	
0.13		Lg posture change to L		Yes	
0.14			Very static until 0:58		
0.15					0.508
0.16					
0.17					
0.18					
0.19					
0.20					0.48
0.21					
0.22					
0.23					
0.24					
0.25					0.463
0.26					
0.27					
0.28					
0.29					
0.30		Increasing motion			0.572
0.31				Yes	
0.32				Yes	
0.33		Lg motion inc			

Table 1 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
0.34					
0.35					0.892
0.36					
0.37					
0.38					
0.39					
0.40					0.66
0.41					
0.42					
0.43					
0.44					
0.45					0.437
0.46					
0.47					
0.48					
0.49					
0.50					0.46
0.51					
0.52					
0.53					
0.54					
0.55					0.2266
0.56	Increased Motion	Posture change towards N		Yes	
0.57		with inc motion		Yes	
0.58			Increased motion	Yes	
0.59				Yes	
1.0					0.356
1.1					
1.2					
1.3					
1.4					
1.5	Posture change to N	Posture change to N			0.259
1.6	Increased Motion	with inc motion	Posture change towards Flexed		

Table 1 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
1.7					
1.8	Posture change to L				
1.9	Posture change to N		Posture change towards N		
1.10			Lg inc in motion	Yes	0.547
1.11			Posture change towards Flexed	Yes	
1.12				Yes	
1.13				Yes	
1.14	Decreasing posture to L	Posture change towards L		Yes	
1.15				Yes	0.446
1.16		Lg inc in motion		Yes	
1.17					
1.18					
1.19					
1.20					0.574
1.21					
1.22					
1.23					
1.24					
1.25					0.323
1.26					
1.27					
1.28					
1.29					
1.30					0.473
1.31					
1.32					
1.33					
1.34					
1.35					0.184
1.36					
1.37					

Table 1 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
1.38					
1.39					
1.40					0.37
1.41					
1.42					
1.43					
1.44					
1.45	Posture towards N	Posture towards N	small inc in motion		0.624
1.46	Increased Motion	Increased Motion			
1.47					
1.48					
1.49					
1.50				Yes	0.5
1.51				Yes	
1.52					
1.53					
1.54					
1.55					0.295
1.56	Increased Motion				
1.57					
1.58					
1.59					
2.0	Posture towards N		Lg inc in motion	Yes	0.407
2.1	Increased Motion			Yes	
2.2					
2.3			Very static to END		
2.4					
2.5					0.418
2.6					
2.7					

Table 1 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
2.8					
2.9					
2.10					0.388
2.11					
2.12					
2.13		Inc motion			
2.14					
2.15					0.446
2.16	Increased Motion	Lg inc in motion		Yes	
2.17	Posture to R of N			Yes	
2.18				Yes	
2.19				Yes	
2.20	Static and close to N				0.428
2.21	until END				
2.22					
2.23					
2.24					
2.25					0.522
2.26					
2.27					
2.28					
2.29					
2.30					0.352
2.31					
2.32					
2.33					
2.34					
2.35					0.373
2.36					
2.37					
2.38					
2.39					

Table 1 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
2.40					0.48
2.41					
2.42					
2.43					
2.44					
2.45					

Table 2. Flow chart of spinal movements, acceleration, and EMG of Test 2.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
0.0					
0.1					
0.2					
0.3					
0.4					
0.5					
0.6					
0.7					
0.8					
0.9	Start	Start	Start		
0.10	Still settling in	Still settling in	Still settling in		
0.11					
0.12					
0.13					
0.14					
0.15					
0.16					
0.17			Motion trend to inc Flex		
0.18					
0.19					
0.20					0.234
0.21					
0.22		Increased motion			
0.23		Posture change towards L			
0.24					
0.25	Posture change towards N	Posture change to N	Motion trend towards N		0.347
0.26		Increased motion	Inc in motion		
0.27			Motion trend to inc Flex	Max	
0.28			until 0:43	Max	
0.29	Posture change L of N and	Posture change from R of N			
0.30	back to N	to L of N			0.771

Table 2 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
0.31					
0.32					
0.33					
0.34					
0.35					0.34
0.36					
0.37					
0.38					
0.39					
0.40					0.297
0.41					
0.42					
0.43		Posture change towards N	Posture change towards N		
0.44	Increased movement.	Increased motion	Very large inc in motion	Yes	
0.45	Posture change slightly to L	Very static until 1:05		Yes	0.241
0.46				Yes	
0.47					
0.48					
0.49					
0.50					0.372
0.51					
0.52	Posture change more to L				
0.53					
0.54					
0.55					0.177
0.56					
0.57	Movement inc, Posture				
0.58	moves back towards N				
0.59					
1.0					0.237
1.1					

Table 2 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
1.2					
1.3					
1.4					
1.5		Posture becomes progressively			0.289
1.6		more L of N.			
1.7					
1.8					
1.9					
1.10					0.252
1.11					
1.12					
1.13	Movement inc, Posture		Posture change towards N		
1.14	moves back towards N		Increased motion	Yes	
1.15	Motion trend towards L		Motion trend towards inc Flexed	Yes	0.434
1.16					
1.17	Very static posture				
1.18	until 2:00				
1.19					
1.20					0.288
1.21					
1.22					
1.23					
1.24					
1.25					0.25
1.26					
1.27					
1.28					
1.29					
1.30					0.316
1.31					
1.32					

Table 2 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
1.33					
1.34					
1.35					0.319
1.36			Posture change to more Flexed		
1.37					
1.38					
1.39		Posture change towards N			
1.40		Increased movement			0.411
1.41					
1.42					
1.43					
1.44		Becomes much more to L of N			
1.45		until 1:59			0.199
1.46					
1.47					
1.48					
1.49					
1.50					0.362
1.51					
1.52					
1.53					
1.54					
1.55					0.339
1.56					
1.57					
1.58		Posture goes to N		Yes	
1.59	Increased movement.	Increased movement	Increased motion	Yes	
2.0				Yes	0.375
2.1	Posture goes to N				
2.2		Posture returns to L of N			

Table 2 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
2.3		quite quickly.			
2.4					
2.5		Posture static and to L of N			0.975
2.6		until 2:30			
2.7					
2.8					
2.9	Increased movement @ N		Increased motion	Yes	
2.10	Movement trend to L			Yes	0.399
2.11			Motion trend toward Flexed	Yes	
2.12					
2.13					
2.14	Movement trend back to N				
2.15					0.174
2.16					
2.17					
2.18					
2.19			Static until 2:48		
2.20					0.347
2.21					
2.22					
2.23					
2.24					
2.25					0.487
2.26					
2.27					
2.28		Posture changes back to N			
2.29		Increased motion			
2.30					0.307
2.31					
2.32					
2.33					

Table 2 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
2.34					
2.35					0.538
2.36					
2.37					
2.38					
2.39					
2.40					0.425
2.41					
2.42		Posture moves to L and stays			
2.43					
2.44					
2.45					0.316
2.46					
2.47			Increased motion	Yes	
2.48	Motion trend towards L				
2.49					
2.50	Posture change back to N				
2.51	Increased movement @ N				0.462
2.52			Increased motion	Yes	
2.53					
2.54					

Table 3. Flow chart of spinal movements, acceleration, and EMG of Test 3.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
0.0					
0.1					
0.2					
0.3					
0.4					
0.5					0.372
0.6					
0.7					
0.8					
0.9	Start	Start	Start		
0.10					0.361
0.11	Posture from L of N to R of N.	Increased motion			
0.12				Max	
0.13	Inc Motion	Posture change to R		Max	
0.14					
0.15					0.43
0.16					
0.17					
0.18		Posture gradually			
0.19		towards N			
0.20					0.437
0.21	Posture gradually to L		Posture gradually more flexed		
0.22	of N				
0.23		Lg posture change to R			
0.24				Max	
0.25				Max	0.445
0.26	Stays L of N until 1:14			Max	
0.27			Very static until 1:12		
0.28					
0.29					
0.30					0.342

Table 3 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
0.31					
0.32					
0.33					
0.34		Increased motion			
0.35					0.312
0.36					
0.37					
0.38					
0.39					
0.40					0.267
0.41					
0.42					
0.43					
0.44					
0.45					0.359
0.46					
0.47					
0.48					
0.49					
0.50					0.459
0.51					
0.52					
0.53					
0.54					
0.55					0.43
0.56					
0.57				Yes	
0.58		Posture change to R		Yes	
0.59		Lg inc motion		Yes	
1.0					0.405
1.1					
1.2					
1.3					
1.4					
1.5					0.367

Table 3 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
1.6					
1.7					
1.8					
1.9					
1.10					0.376
1.11					
1.12	Posture moves to N	Increased motion	Lg increase of motion		
1.13			Very static until 1:48		
1.14					
1.15					0.33
1.16					
1.17	Increased Motion				
1.18	Posture change R to N	Posture change towards N			
1.19		Increased motion			
1.20					0.322
1.21					
1.22					
1.23					
1.24					
1.25					0.347
1.26					
1.27	Posture change N to L				
1.28	and back to N				
1.29					
1.30		Increased motion			0.343
1.31	Posture moves to L of				
1.32	N				
1.33					
1.34					
1.35		Increased motion			0.383

Table 3 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
1.36	Remains L of N until 2:04				
1.37					
1.38		Very static to 2:04			
1.39					
1.40					0.391
1.41					
1.42					
1.43					
1.44					
1.45					0.341
1.46					
1.47					
1.48			Increased motion		
1.49					
1.50					0.361
1.51				Yes	
1.52					
1.53					
1.54					
1.55					0.381
1.56					
1.57					
1.58					
1.59					
2.0					0.375
2.1					
2.2					
2.3	Posture from L to N				
2.4		Sm posture change to R			
2.5			Increased motion		0.397
2.6	Posture from N to L			Yes	
2.7				Yes	

Table 3 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
2.8			Increased motion	Yes	
2.9				Yes	
2.10	Relatively static until end.		Increased motion	Yes	0.77
2.11			Posture becomes more flexed		
2.12					
2.13					
2.14					
2.15			Increased motion		0.396
2.16					
2.17			Very static until end.		
2.18					
2.19					
2.20					0.45
2.21					
2.22					
2.23					
2.24					
2.25					0.351
2.26					
2.27					
2.28					
2.29					
2.30					0.378
2.31		Posture change to R			
2.32		Increased motion			
2.33					
2.34					
2.35					0.439
2.36				Yes	
2.37					
2.38					

Table 3 Continued.

Time (hr.min)	Frontal Motions	Torsional Motions	Sagittal Motions	EMG	Az (m/s^2)
2.39		Posture change towards N			
2.40		Lg increase of motion			0.476
2.41					
2.42					
2.43					
2.44					
2.45				Yes	0.474
2.46					
2.47					
2.48					
2.49					
2.50					0.448

CHAPTER VI
DISCUSSION

Driver Posture Profiles

The sonoSens® ultrasound was used to determine the overall posture of the driver while sitting in the National Seating 2000 tractor trailer seat. The driver's modeled posture may be used to instruct drivers on ways to correct poor posture in the hope of reducing long term injuries.

The neutral posture of the driver was determined by the sonoSens® Analyzer software. The software uses the calibration and range of motion measurements to generate a neutral posture reference frame. Any movements outside of this reference frame are of interest because of their deviation away from the neutral posture. Several figures denote the posture profile and reference frame for the driver for each test. Figure 6-1 displays the profile for test 1, Figure 6-2 for test 2, and Figure 6-3 for test 3.

Each person's posture profile will be different due to anatomical variations. It is very unlikely that a person would have an "ideal" posture. An ideal posture would have the cervical, thoracic, and lumbar regions all in the neutral position.

The posture profiles of the driver are similar for each test. A slight variation from day to day for the same driver is expected. For all tests, the cervical and thoracic regions of the driver are dorsal to the anatomical, neutral, position. The lumbar region is placed very ventrally for tests 1 and 3. Only a small ventral shift was noted for test 2. This data illustrates that the driver was leaned back in the seat with his lumbar region forward and off the seat back.

Predicting Discomfort

When sitting in a static position for a period of time, the subject will begin to feel discomfort and change his/her posture to alleviate this discomfort. Often this change of posture is done unconsciously. Everyone whom has been on a long car ride or sat in a chair for a long period has experienced this. Looking for posture changes after areas of static movement in the flow diagrams (Figures 4-1 through 4-60) has allowed for the prediction of discomfort. Prediction of driver discomfort was achieved by looking for motion trends in the flow diagrams with the characteristics described below.

Long term, very static areas were generally followed by an increasing motion trend, leading to a posture change. During the static areas, posture moved very gradually away from N, with this process repeating itself throughout the testing

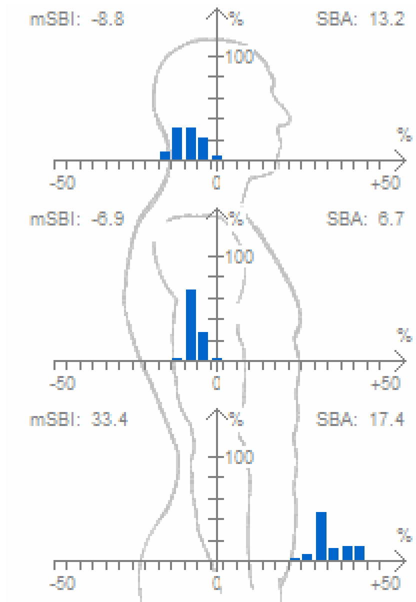

Figure 6-1: The posture profile for Test 1.

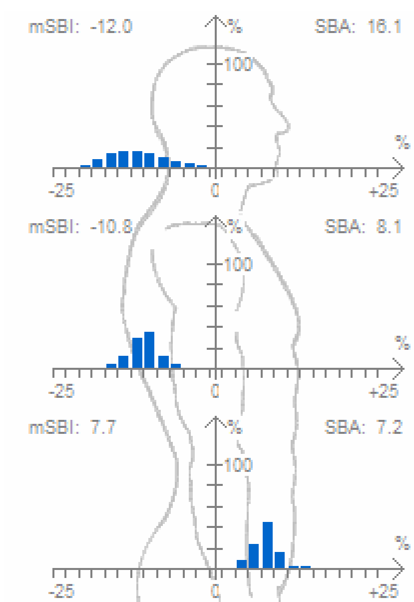

Figure 6-2: The posture profile for Test 2.

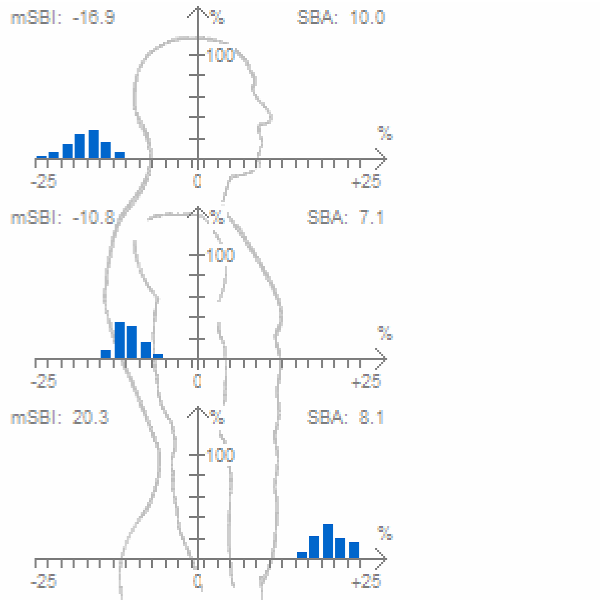

Figure 6-3: The posture profile for Test 3.

period. A change in posture generally moved toward the neutral position (N). Examples illustrating this include Figures 5-27 and 5-28.

Discomfort may be caused by many different factors. The seat type, posture, road conditions, length of sitting, and vibrations felt by the driver may all contribute to the driver's discomfort. Determining specific factors that cause discomfort may lead to the development of seats and truck suspensions that improve the long term comfort of the driver. Table 4 displays the time and presence of posture changes of the driver for each test. X denotes the presence of a posture change.

Only frontal motion was used to determine the posture changes in Table 4. Ventral and dorsal motions of the lumbar vertebrae were of the most interest. Torsional movements were not considered in-depth due to the constant, conscious torsional movements of the driver. The driver often twisted and turned to reach a cell phone, drink, radio, and Citizens' Band (CB) radio. These movements were not from environmental inputs to the truck, and were difficult to record accurately.

As depicted in Table 4, the posture changes occurred in no pattern from tests 1 through 3. Test 2 had posture changes centered about the first hour of testing, while Test 3 did not denote any posture changes until 1 hour and 5 minutes into testing. Comparatively, Test 3 had about half the posture changes of the other tests. This coincides with the very static posture of the driver during the course of Test 3.

Data like that in Table 4 could be compared for testing trials with different variables. For instance, to determine the relative long term comfort of a model of seat, three testing bouts with seat A could be compared with three tests with seat B. The comfort of a given seat could then be ascertained and facilitated by seat designers to determine which seat features promote comfort.

Driver-Device Discomfort and Interference

The driver was asked about any discomfort experienced during the testing period. No limitations on natural movement or normal work routine were reported. The driver stated that the device was not bothersome and after several minutes forgot about wearing it. Upon removal of the device, no evidence of skin inflammation or injury was observed.

Many electronic devices were in close proximity of the ultrasound. Besides the EMG and acceleration recording equipment, a cellular phone and CB radio were used intermittently during testing. No interference was noted between any of the devices at anytime during testing. The driver made and received several cellular phone calls during testing, but no interference with the testing equipment was noted.

Table 4. The time and presence of posture changes of the driver for each test.

	Posture Change		
Time (hr.min)	Test 1	Test 2	Test 3
0.11	0	0	X
0.25	0	X	0
0.29	0	X	0
0.52	0	X	0
1.5	X	0	0
1.13	0	X	0
1.14	X	0	0
1.18	0	0	X
1.27	0	0	X
1.45	X	0	0
2.0	X	0	0
2.1	0	X	0
2.17	X	0	0
2.50	0	X	0

Correlation with Acceleration Data

A correlation between the motion data and acceleration data was not found. It was thought that accelerations of high magnitude (>5 m/s^2) may produce increased movement of the lumbar region. Areas of high acceleration (>5 m/s^2) were no more likely than accelerations of low (<3 m/s^2) or midrange magnitudes to be accompanied with driver movement. Table 5 displays the acceleration and presence of movement of the driver for each test. The accelerations are displayed in descending value to aid in the determination of a pattern. The presence of driver movement is denoted by an X, and no movement by a 0.

One of the purposes of this study was to determine if the sonoSens® ultrasound could be correlated with acceleration areas of interest. Acceleration at and above 5 Hz is of interest in whole body vibration studies. (10) Since no correlation was found the ultrasound may not be used to estimate acceleration ranges experienced by a driver.

Correlation with EMG

A correlation between the motion data and EMG activity was not found. Table 6 displays EMG activity and the presence of movement of the driver for each test. The presence of driver movement or EMG activity is denoted by an X, and no movement or EMG activity by a 0.

For test 1: 75% (6/9 occurrences) of the time movement accompanied EMG activity, 22% (2/9) movement occurred with no EMG activity, and 11% (1/9) EMG activity occurred with no movement. For test 2: 50% (5/10) of the time movement accompanied EMG activity, 50% (5/10) movement occurred with no EMG activity. For test 3: 29% (4/14) of the time movement accompanied EMG activity, 50% (7/14) movement occurred with no EMG activity, and 21% (3/14) EMG activity occurred with no movement. Overall, only 45% (15/33) of the time movement accompanied EMG activity.

Several possible reasons for the lack of correlation of the EMG data and lumbar motion exist. The EMG may have shown an increased muscle tension from some of the inputs (i.e. traveling over a rough road), but resulted in decreased spinal motion. This may have occurred if the input was too rapid for the brain to respond to, so the muscles tightened up and were converted into springs. Tightened muscles (springs) would move less than relaxed muscles (dampers). The relaxed muscles would move as the input was absorbed. It is also possible that a lag occurred between the acceleration input and movement of the spine. Future research would be beneficial in these areas.

Table 5. The acceleration and presence of movement of the driver for each test.

Test 1		Test 2		Test 3	
Accel (m/s^2)	Movement	Accel (m/s^2)	Movement	Accel (m/s^2)	Movement
0.892	0	0.975	X	0.77	X
0.66	0	0.771	X	0.52	0
0.624	X	0.538	0	0.476	X
0.618	X	0.487	X	0.474	0
0.574	0	0.462	X	0.459	0
0.572	X	0.434	X	0.456	0
0.547	X	0.425	X	0.45	0
0.522	0	0.411	X	0.448	0
0.508	0	0.399	X	0.445	X
0.5	0	0.375	X	0.439	X
0.48	0	0.372	X	0.437	X
0.48	0	0.362	0	0.43	X
0.473	0	0.347	0	0.43	X
0.463	0	0.347	X	0.405	X
0.46	0	0.34	X	0.397	X
0.446	X	0.339	X	0.396	X
0.446	X	0.319	X	0.391	0
0.437	0	0.316	0	0.383	X
0.428	0	0.316	X	0.381	0
0.418	0	0.307	0	0.378	X
0.407	X	0.299	0	0.376	X
0.405	0	0.297	X	0.375	X
0.388	X	0.289	0	0.372	0
0.373	0	0.288	0	0.367	0
0.37	0	0.252	X	0.361	X
0.356	0	0.25	0	0.361	0
0.352	0	0.241	X	0.359	0
0.323	0	0.237	0	0.351	0
0.295	X	0.234	X	0.347	X
0.259	X	0.199	0	0.343	X
0.2266	X	0.177	X	0.342	X
0.184	0	0.174	X	0.341	X
				0.33	X
				0.322	X

Table 5 Continued.

Test 1		Test 2		Test 3	
Accel (m/s^2)	Movement	Accel (m/s^2)	Movement	Accel (m/s^2)	Movement
				0.312	X
				0.267	0

Table 6. The EMG and presence of movement of the driver for each test.

Test 1		Test 2		Test 3	
Movement	EMG	Movement	EMG	Movement	EMG
X	X	X	X	X	X
X	X	X	0	X	X
X	X	X	X	X	0
X	X	X	0	X	X
X	0	X	0	X	0
0	X	X	X	X	0
X	0	X	X	X	0
X	X	X	0	X	0
X	X	X	0	0	X
		X	X	X	X
				X	0
				0	X
				X	0
				0	X

CHAPTER VII
CONCLUSIONS AND RECOMMENDATIONS

The sonoSens® Monitor is ideal for determining motion and posture of the lumbar region over periods of time. The advantage of this system is that it can measure posture without interference and during the whole day under everyday conditions. In contrast to laboratory set-ups which primarily analyze artificial situations, this method can be used to monitor the movements of the spinal column continuously while driving.

This study has illustrated the feasibility of using the device for modeling lumbar motions while driving a vehicle. The sonoSens® Monitor successfully modeled the spinal movements of a driver while driving a tractor trailer over approximately 3 hour period. The device appears to receive no interference with commonly used electronic devices (i.e. radios and cell phones). The subject of this study found the device well tolerated, with no discomfort reported. Acceleration data from a seat pad was found not to correlate with a driver's movement while driving. The EMG data was also not found to correlate with the movement of the driver.

The sonoSens® Monitor may be used for many applications pertaining to the testing of subjects driving a tractor trailer. Driver posture profiles may aid in the correction of poor posture. Instructing drivers on ways to correct poor posture may reduce the incidence of long term injuries. Further research would be useful in this area.

An area of further testing may involve varying the seat for each test to see if posture improves and discomfort decreases with certain seat models. Information obtained from this type of study would be helpful in designing future seats. Additional studies could investigate varying other variables as well (i.e. load weight, drivers, or truck model type).

Further study may improve the accuracy of the correlation between movement and EMG activity. Test 1 had promising results with a correlation of 75%. Tests 2 (50%) and 3 (29%) decreased that correlation drastically. Completing many more bouts of testing may show that the correlation of movement and EMG activity is closer to test 1. Further testing may also confirm no existence of correlation.

In reviewing this study, it would have been beneficial to perform a whole system verification prior to each testing trial. With all devices in place, a standardized motion could have been performed by the driver. This motion could have verified that the EMG and sonoSens® Monitor were working together. The use of a trigger to simultaneously start all the devices for testing would also have been helpful.

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APPENDIX

Subject Questionnaire

Pre-experiment

1. Sex

2. Age

3. Height

4. Weight

5. Back Pain History
   A. Do you now or have you had any ongoing back pain in the last 6 months?

   B. Have you had any back surgery or any back abnormalities (scoliosis, slipped disc, etc)?

Post-experiment

1. Did the testing interfere with your normal work routine?

2. Did the testing device limit your normal movement?

3. Was the testing device uncomfortable in any way?

Equipment Information

1. Truck make and model

2. Seat make and model

3. Load weight

Figure A-1. Subject Questionnaire.

VITA

Gretchen Marie (Illikman) Hinton was born in Saginaw, MI on January 4, 1978. She was raised in the small farming community of Spaulding Twp, MI. She graduated from Bridgeport-Spaulding High School in 1996. After high school she attended Michigan State University and received a Bachelor of Science in Animal Science in 2000, becoming the first in her family to graduate from college.

After moving to Morristown, TN with her husband, Gretchen attended the University of Tennessee in Knoxville and received a Bachelor of Science in Biomedical Engineering in 2005 and a Master of Science in Biomedical Engineering with a concentration in Biomechanics in 2007.