# SENIORS

SAFETY ENHANCED INNOVATIONS FOR OLDER ROAD USERS

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## EXECUTIVE SUMMARY

This report documents Electromyography (EMG) measurements carried out during the low-speed frontal crash sled tests. The objective was to quantify muscle onset times and the relative activity of volunteer's trunk and lower extremity muscles during sled tests compared to their individual maximal voluntary activity.

In particular, this report states technical details about the EMG tests and provides the test matrix and procedures that the recording of the volunteer's maximum voluntary contraction (MVC) and sled tests were based on. Volunteer characteristics are described. Processed experimental data is presented and discussed in terms of test setup, muscle latency, and the level of activity during low-speed frontal impacts.

In general, the test setup used in the experiments has been found suitable for quantifying electromyography responses of volunteers in low-speed frontal impacts. MVC assessment worked well for all measured muscles, with the exception of the Sternocleidomastoid muscle. In terms of muscle onset latency following the impact no clear tendency of a sequential activation of muscles has been observed. Also, regarding the magnitude of muscular activation as a result of the impact no uniform way of reacting could be observed across several sled runs or between volunteers. Habituation of volunteers with repeated sled runs was not supported by onset latency or level of activation data.

**Contributions of the partners:**

| | |
|---|---|
| LMU | EMG measurement and processing of volunteer muscle activity during maximum voluntary contraction and low-speed frontal sled tests |

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# 1 Introduction

## 1.1 Objectives of this Deliverable

Positioning and pre-crash motion of vehicle occupants can have a significant interaction with the performance of current safety systems. Additionally, the effect of active safety systems can have a significant effect on occupant positioning immediately prior to a collision occuring. The effect of this is not fully studied, and especially the information regarding elderly is limited. However, the effect of these pre-collision kinematics on the performance of the restraint systems can be significant; in order to develop more advanced restraint systems, the understanding of this pre-collision motion is key. For these reasons, this report aims to assess the influence of muscular activity for the future/following comparison of the kinematics of restrained elderly volunteers in low-speed non-injurious frontal sled tests.

## 1.2 Structure of this Deliverable

In section 2 of this report methods are described. Section 2.1 presents volunteer characteristics, section 2.2 describes the sled test setup and section 2.3 states the technical details of the EMG system and recording parameter of muscle activity measurement. Section 2.4 presents the test matrix for the recording of volunteer's muscle activity during maximum voluntary contraction and low-speed frontal sled tests and provides detailed information about the test procedure of recording the Maximum Voluntary Contraction (MVC) of each muscle. Section 2.5 specifies EMG data digital processing. Results of volunteer's electromygraphy responses to low-speed frontal impact, more precisely muscle activity onset (chapter 3.1) and level of activity (chapter 3.2), are presented in Section 3. In Section 4 the EMG test setup and way of data processing are being evaluated (section 4.1 and 4.2), and muscle baseline activity (4.3.1) and latency (4.3.2) and level of activation (4.3.3) are discussed. Here, conclusions are drawn and recommendations for future EMG measurements are presented.

Abbreviations used in this report are listed in the Glossary. MVC test postures are presented in Appendix 6.1. Appendix 6.2 shows processed EMG signals as a function of time including onset times. Appendix 6.3 gives a tabular overview of muscle onset times. Raw MVC data can be found in Appendix 6.4. Static and dynamic normalized EMG activity is depicted in Appendix 6.5.

# 2 METHOD

Muscle activity has been quantified with an Electromyography system (EMG) during dynamic sled tests and maximum voluntary contraction (MVC) tests for 7 muscle(s) (group) bilaterally. The objective was to detect the onset and to quantify the level of activity during sled tests with normalizing the dynamic activity to the maximum voluntary isometric contraction activity of each muscle (group).

## 2.1 VOLUNTEER CHARACTERISTICS

Volunteers were chosen to represent two age groups. As this EMG study was conducted as part of WP2.3 sled tests, but only started in the middle of this series of tests, here, the younger group consisted of only one volunteer younger than 25 years old, while the older group was formed by four subjects older than 65 years old. Volunteers did not show any health conditions susceptible of being aggravated because of the tests and were chosen as close as possible in height and weight to the 50th male percentile (175 cm; 78 kg). Volunteer's main anthropometric characteristics can be found in Table 1. Volunteers were exposed to three trials (e.g. sled runs). Volunteer 8 stopped the trials after the second run due to discomfort. None of the volunteers experienced any pain or non-bearable discomfort during the experiments.

Table 1: Volunteer ID and main characteristics (age, stature, weight)

| Subject ID | Age (years) | Stature (cm) | Weight (kg) |
|---|---|---|---|
| **Volunteer 5** | 22 | 167.0 | 75.3 |
| **Volunteer 6** | 71 | 164.0 | 81.0 |
| **Volunteer 7** | 71 | 176.5 | 99.1 |
| **Volunteer 8** | 85 | 165.3 | 78.2 |
| **Volunteer 9** | 67 | 169.0 | 88.2 |

Although volunteer 5 was the first test subject volunteer IDs start with number 5. Reason for this is that sled tests with volunteers 1-4 had already been completed in Work Package 2.3 sled tests when the EMG measurements were included. To be consistent with Deliverable 2.3 volunteer names were kept the same.

## 2.2 SLED TEST SETUP

As this study was part of sled tests run in Work Package 2.3, characteristics of the sled configuration are summarized here and explained more detailed in Deliverable 2.3.

The test fixture was designed to represent the seating posture of a passenger car occupant. It was conceptualized in a generic way, so it can easily be reproduced in any workshop and reconstructed as finite element computer model. The fixture consisted of a rigid seat (Pipkorn et al., 2016). Additionally, a rigid footrest and a wired back support were incorporated.

The seating procedure consisted of aligning the occupant pelvis to the midline of the seat and adjusting the footrest for the femur (~ 11°) and tibia angle (~ 50°). The volunteer's upper body was stabilized in the sitting position by back wires that were adjusted so that the angle measured over the sternum was about 60° (Figure 1). The seating protocol was followed in each test.

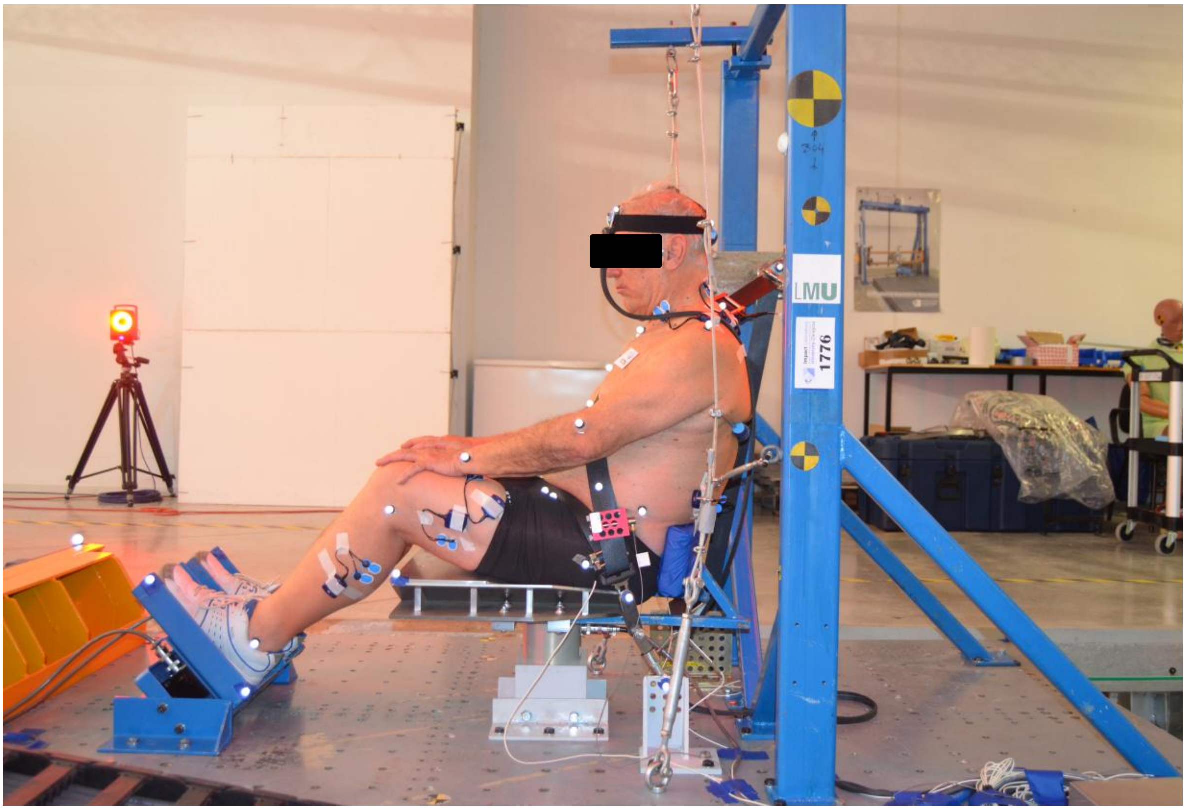



Figure 1: Volunteer sitting in the sled after positioning (lateral view)

The restraint system consisted of a lap and shoulder belt (passenger configuration). For further description please refer to Deliverable 2.3.

In each sled trial volunteers were exposed to a low-speed crash test pulse with a nominal change of velocity of 9 km/h as presented in Table 2. The crash test pulse was selected to ensure a safe environment to the volunteers. Please see D2.3 for the derivation of the safe crash pulse. EMG measurements were synchronized with the sled test instrumentation used in Work package 2.3 sled tests (e.g. with motion tracking system). Before each sled test a static measurement of muscle activity (e.g. baseline activity during sitting in sled chair) was performend. This way it was possible to distinguish reflex and response activity from activity necessary for postural stability. Lateral and frontal high-speed video footage (1000 Hz) have been used to detect possible mechanical interactions with the EMG electrodes or transmitters that can lead to artefacts. In total, 5 MVC and 14 sled trials have been performed.

Table 2: Test matrix for volunteers 5-9

| Occupant type | Speed (km/h) | Trial numbers |
|---|---|---|
| **Young volunteer** | 9 | 1767-1769 |
| **Elderly volunteers** | 9 | 1771-1773 |
| | | 1774-1776 |
| | | 1778-1789 |
| | | 1780-1782 |

## 2.3 Technical and Software Specifications (EMG)

Muscle activity during MVC and sled tests has been detected with a 16 channel wireless EMG system (12 bit resolution) *(Myon 320, Myon AG,* Schwarzenberg*).* Analog signals were converted to digital signals with an analog digital converter (16 bit resolution, ± 10V range) *(NI USB-6210, National Instruments,* Austin*)*. The digital activity has been recorded, stored and exported with *ProEMGApplication, Version 2.1.2.5* for the MVC measurements and *NIDAQ Plug-in for Vicon Nexus 1.8.5., Version 1.0.0.2* (*National Instruments,* Austin*)* for the frontal sled tests. Dynamic activity recording during sled tests was triggered simultaneously with the video capture of volunteer motion.

Bioelectric signals were detected using Ag/AgCl wet electrodes with a sensor area of 15 mm² (*BlueSensor N, Ambu GmbH,* Bad Nauheim*)* and an interelectrode distance of 2 cm. The EMG system works with a floating ground, so no reference electrode was needed. All MVC and dynamic sled tests were measured with a sample frequency of 2,000 Hz and exported in ASCII and C3D format.

## 2.4 Muscle Activity Assessment

### 2.4.1 Test Setup

For the muscle activity analysis 7 muscle(s) (groups) were recorded bilaterally, using 14 EMG channels overall (Table 3).

The selected muscles or muscle groups were considered to be most appropriate with regard to the frontal sled test configuration without steering wheel (Mathews, 2013). As the test setup did not include a steering wheel upper extremity muscles were not taken into consideration. The use of cables instead of a seat with backrest allowed measurement of the lower back muscles.

Table 3: Overview of measured muscles or muscle groups during isometric maximum voluntary contraction and dynamic sled tests. Abbreviation, origin and insertion and main function are listed for each muscle separately

| Muscle (group) | Abbreviation | Origin | Insertion | Function |
|---|---|---|---|---|
| **Sternocleidomastoid muscle (Putz & Pabst, 2007)** | SCM | Sternum, Clavicula | Mastoid process of temporal bone | Cervical rotation and head flexion |
| **Cervical paravertebral muscles* (Putz & Pabst, 2007)** | CPVM | Transverse processes (and others*) | Occipital head region | Head extension |
| **Rectus abdominis muscle, upper part (Putz & Pabst, 2007)** | RA | Costal cartilage $5^{th}$-$7^{th}$ rib and sternum | Pubic bone | Flexion upper body |
| **Erector spinae muscle, lower part (Seniam, 2016)** | ES | Iliocostalis lumborum, transverse process lumbar vertebrae and thoracolumbar fascia | Transverse process thoracic vertebrae | Back extension |
| **Rectus femoris muscle (Seniam, 2016)** | RF | Anterior inferior iliac spine | Proximal patella | Knee extension, hip flexion |
| **Biceps femoris muscle (Seniam, 2016)** | BF | Sacrotuberous ligament and posterior tuberosity | Lateral condyle of tibia | Flexion of knee joint |
| **Gastrocnemius muscle, lateral part (Seniam, 2016)** | GC | Lateral condyle of femur, capsule knee joint | Posterior surface of calcaneus | Plantar flexion ankle joint |

* known crosstalk phenomenons of multiple muscles in that region

Electrodes have been attached according to international standard (Seniam, 2016; Konrad, 2006). Placement of the two electrodes was done parallel to the muscle fiber orientation, and, if possible (subject to sled test configurations), on the mid-point of the muscle belly (Table 4).

Table 4: Definition of electrode placement location including literature reference

| Muscle (group) | Electrode placement | Reference |
|---|---|---|
| **SCM** | 1/3 length between the suprasternal notch and the mastoid process | Falla et al., 2002 |
| **CPVM** | C4 level, 2 cm lateral to the proximal half of the direct line between the spinal process of C7 and the occipital head | Blouin et al., 2003 |
| **RA** | 2 cm lateral to the proximal third of the direct line between the navel and the xiphoid process | Lehman & McGill, 2001 |
| **ES** | 2 cm lateral to the spinous process of L5-S1 | Anderson & Behm, 2005 |
| **RF** | On the direct line between origin and insertion, in the last third proximal to the patella | Ebersole et al., 1999 |
| **BF** | On the direct line between origin and insertion, in the last third proximal to the insertion | Rainoldi et al., 2004 |
| **GC** | On the lateral muscle part, in the first 4th of the direct line between the origin and insertion | Rainoldi et al., 2004 |

Electrode placement procedures included localizing the respective muscle on the volunteer, shaving the skin if necessary, and cleaning the skin with alcohol before attaching the electrodes (Figure 2). EMG transmitters were connected to the electrodes, with the transmitter cable attached laterally on the body for best possible signal quality. Before measurement of MVC, a signal quality check was conducted.

A firm adhesion of electrodes was ensured before every MVC and sled test. Loose electrodes were exchanged with new ones if necessary.

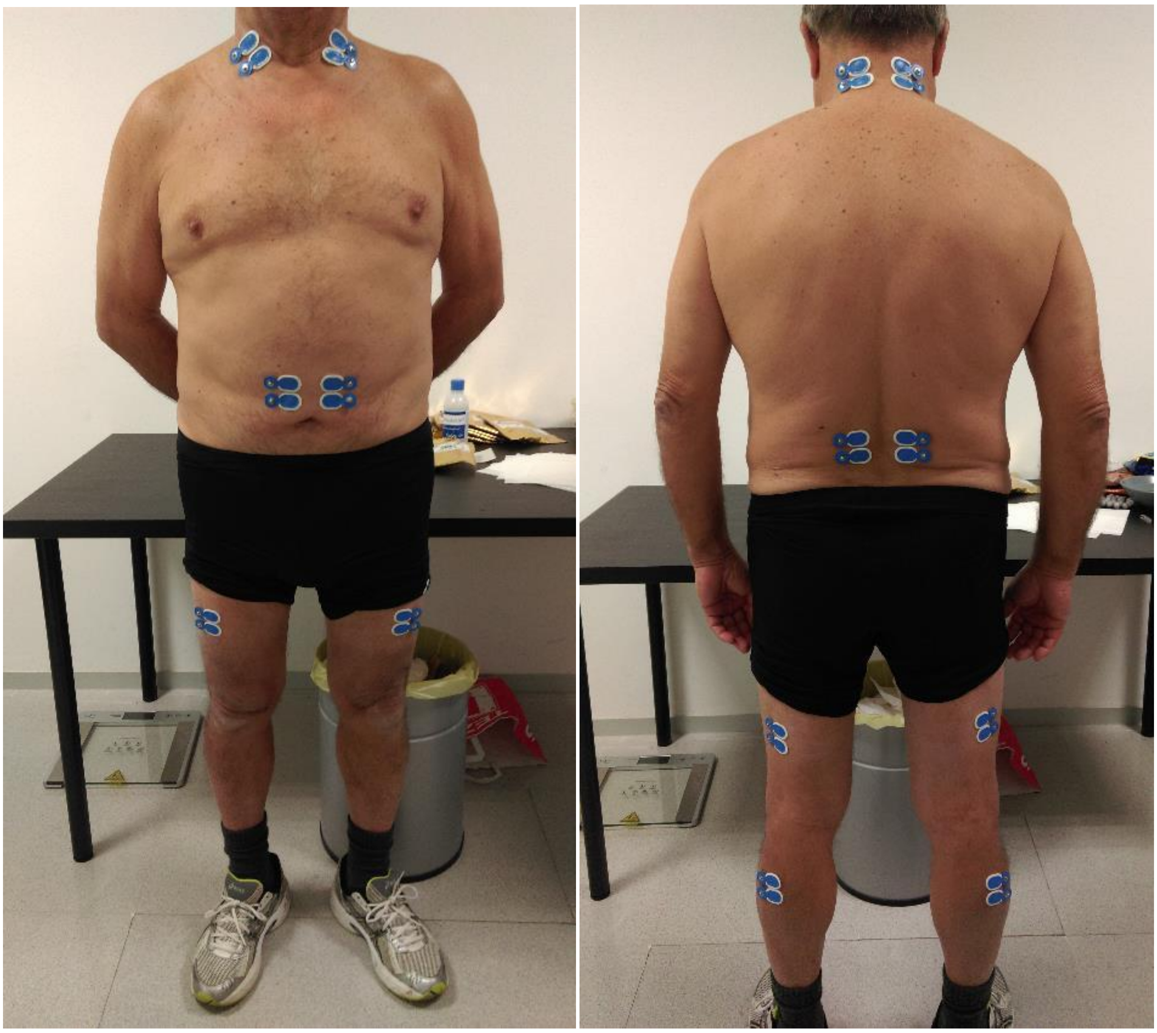


Figure 2: Electrode placement on Sternocleidomastoid, Rectus abdominis, and Rectus femoris muscle (left) and Cervical paravertebral muscle group, Erector spinae, Biceps femoris and Gastrocnemius muscle (right)

### 2.4.2 Measurement of Maximum Voluntary Contraction (MVC)

In order to quantify muscle activity during dynamic sled tests maximum voluntary isometric contractions (MVC) of each muscle (group) were recorded bilaterally. For each test the volunteer adopted a specific posture and performed exercises that aim at producing the maximal possible isometric strength (Table 5 and Appendix 6.1). It was monitored visually if muscle length changed undesirably during MVC. The MVC exercises for the SCM and CPVM muscles were specifically designed in order to minimize the risk of neck injuries for the elderly volunteers.

Table 5: Test procedure for isometric maximum voluntary contraction tests. Each test aims at gaining maximum possible muscle strength for 5 seconds

| Muscle (group) | Test procedure | Reference |
|---|---|---|
| **SCM** | Try to turn the head to the left/right as far as possible, sitting up straight. | LMU |
| **CPVM** | Lower the head about 30°, try to lift up head again with the head's backward motion restrained, sitting up straight | LMU |
| **RA** | Bend knees at around 90°, flex spine by around 30°and try to lift up upper body with manually restrained upper body and feet, lying on a stretcher in supine position | Konrad, 2006 |
| **ES** | Extend spine about 20° and try to lift up upper body with manually restrained upper body and legs, lying on a stretcher in prone position | Konrad, 2006 |
| **RF** | Single leg knee extension at 90° to 70° knee flexion position with restrained leg, sitting up straight | Konrad, 2006 |
| **BF** | Unilateral knee flexion at 20-30° knee flexion with the hip fastened manually, lying on a stretcher in prone position | Konrad, 2006 |
| **GC** | Unilateral plantar flexion at 90° ankle position with restrained hip, sitting up straight | Konrad, 2006 |

According to the test matrix below the MVC tests were performed 3 times at 5 seconds for each muscle (group), with an interval of at least 2 minutes between two consecutive exercises to allow for relaxation of the muscles (Table 6).

Table 6: Test matrix for maximum voluntary contractions tabularizing test posture, tested muscle (group) and number of repetitions. For each muscle or muscle group, 3 repetitive MVC exercises at 5 seconds were conducted with an interval of at least 2 minutes

| Exercise posture | Muscle (group) | Exercise number |
|---|---|---|
| **Sitting on bench** | SCM | 1 |
| | CPVM | 1 |
| | RF | 1 |
| | SCM | 2 |
| | CPVM | 2 |
| | RF | 2 |
| | SCM | 3 |
| | CPVM | 3 |
| | RF | 3 |
| **Sitting in chair** | GC | 1 |
| | GC | 2 |
| | GC | 3 |
| **Prone position** | ES | 1 |
| | BF | 1 |
| | ES | 2 |
| | BF | 2 |
| | ES | 3 |
| | BF | 3 |
| **Supine position** | RA | 1 |
| | | 2 |
| | | 3 |

## 2.5 Data Processing

Data was processed with *ProEMGApplication, Version 2.1.2.5 (Vicon Motion Systems,* Oxford*)* and *MS Excel 2013* (*Microsoft Corporation*, Redmond). Raw data, both from MVC and sled recordings, has been digitally filtered using a Butterworth filter with cutoff frequencies at 20 Hz (high pass) and 500 Hz (low pass), full-wave rectified, and smoothed using Root Mean Square (RMS) method with a 25 ms sliding window, where RMS is defined as the square root of the mean square value.

Latency of muscle activity onset was defined as the time difference between time of impact (t=0) and beginning of the EMG signal with the criterion of the signal either exceeding 3 times the standard deviation of the baseline activity (within a window of 100 ms) for at least 50 ms or exceeding 10 % of the maximum value before rising up to the maximum value (modified methods based on Hodges & Bui,1996, Solnik et al., 2010, and Balasubramanian et al., 2008). The criteria based onset times were finally confirmed or corrected visually and/or set manually where there was no onset found by the criteria mentioned above (Boxtel, 1993).

Apart from deriving onset times, dynamic data from the sled tests was also put in reference to MVC data to quantify the level of activation. MVC was designated as 100 % of the maximum activity (measured in [V]) of the 3 MVC exercises for each muscle and volunteer after signal processing, and dynamic sled test data was expressed as fractions thereof.

To quantify the baseline activity needed for stabilization while sitting in the sled the static recording for each volunteer and before each sled test were processed in the same manner as the dynamic sled and MVC data.

Muscle activity was only considered from about 30 ms after impact until about 300 ms after impact. Onsets indicated earlier, e.g. after 5 ms, could be related to activity that startet already before the impact and is therefore not directly related to the impact response. Lateral high-speed videos from every sled trial showed that beyond about 300 ms activity was not related to the impact response anymore and was therefore not taken into account for discussion. Activation of muscles following the main reaction is viewed to serve stabilization and regaining of control, may be induced intentionally and is individual according to the preceeding action or kinematic.

Data measured by transmitters that did not record activity properly or lost signal to the receiver entirely have been excluded from processing and marked as “N/A” hereafter.

# 3 RESULTS

## 3.1 MUSCLE ONSET LATENCY

Muscular activity for each sled trial and muscle (group) after impact of the sled has been processed according to the processing pipeline explained in section 2.5 and plotted over time, including onset time(s) (see Appendix 6.2 for all figures). Each plot shows muscular activity measured in Volts over time in seconds. Sled impact occured at time t=0. Onsets defined by the criteria mentioned in section 2.5 are indicated by solid lines, onsets defined visually by dotted lines, e.g. in Figure 3 for the left Biceps femoris muscle, trial 1767. Here, the onset found by the criteria occurs at about 80 ms after impact, a second onset found visually after almost 290 ms.

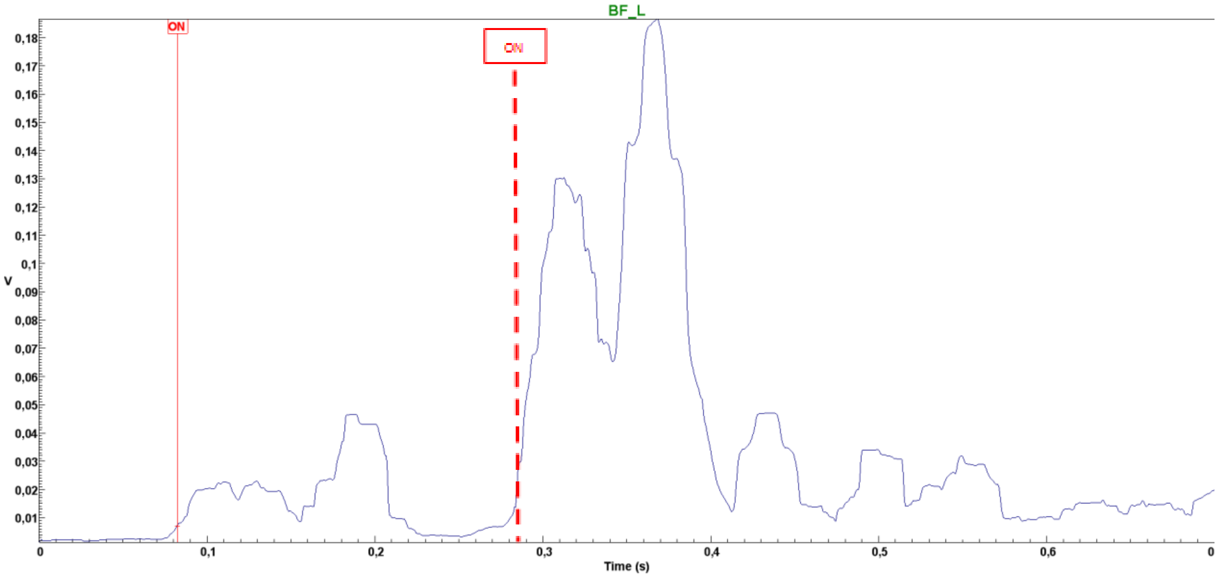



Figure 3: Muscular activity of the left Biceps femoris muscle after impact (t=0) measured in [V] over time in [s] (trial 1767); onset found by criteria is marked with a solid red line, onset found visually with a dotted red line

All onset times as well as their median value defined by criteria and/or visually for each trial and muscle can be found tabularized in Appendix 6.3. In many cases several onsets have been found by the criteria and visually. In few cases, where no onset could be found by the onset criteria, only a visually determined onset is given. A summarized overview of the onset data is presented in Table 7 for every volunteer. Here, the tabularized onsets represent the first, median, and latest onsets that have been found, regardless of how they had been defined. Onset times indicated between impact and about 30 ms and after about 300 ms were not considered in this summary. Nevertheless, it should be noted that all volunteers showed muscle onsets as early as 0 or 5 ms in some channels and trials.

Table 7: First, latest, and median muscle onset times found by onset criteria or visually between about 30 ms and 300 ms after impact (t=0) for every volunteer and each muscle (group) in seconds (s)

| Volunteer | onset | SCM_R* | SCM_L | CPVM_R | CPVM_L | RA_R | RA_L | ES_R | ES_L | RF_R | RF_L | BF_R | BF_L | GC_R | GC_L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | first (s) | 0,144 | 0,087 | 0,162 | 0,139 | 0,187 | 0,177 | 0,175 | 0,162 | 0,039 | 0,154 | 0,105 | 0,032 | 0,076 | 0,055 |
| 5 | median (s) | 0,174 | 0,230 | 0,190 | 0,195 | 0,189 | 0,187 | 0,197 | 0,173 | 0,107 | 0,180 | 0,229 | 0,083 | 0,188 | 0,219 |
| | latest (s) | 0,214 | 0,255 | 0,211 | 0,218 | 0,209 | 0,217 | 0,215 | 0,267 | 0,135 | 0,209 | 0,232 | 0,277 | 0,266 | 0,268 |
| | first (s) | 0,144 | 0,184 | 0,118 | 0,051 | 0,135 | 0,045 | 0,088 | 0,053 | 0,130 | 0,132 | 0,191 | 0,172 | 0,053 | 0,161 |
| 6 | median (s) | 0,182 | 0,223 | 0,173 | 0,162 | 0,164 | 0,171 | 0,154 | 0,125 | 0,163 | 0,162 | 0,221 | 0,237 | 0,171 | 0,246 |
| | latest (s) | 0,198 | 0,233 | 0,178 | 0,205 | 0,184 | 0,217 | 0,277 | 0,178 | 0,180 | 0,180 | 0,251 | 0,301 | 0,289 | 0,276 |
| | first (s) | 0,042 | 0,062 | 0,039 | 0,070 | 0,158 | 0,149 | 0,080 | 0,038 | 0,102 | 0,066 | 0,062 | 0,092 | 0,052 | 0,036 |
| 7 | median (s) | 0,140 | 0,070 | 0,159 | 0,146 | 0,170 | 0,168 | 0,197 | 0,074 | 0,109 | 0,092 | 0,094 | 0,172 | 0,082 | 0,037 |
| | latest (s) | 0,239 | 0,142 | 0,180 | 0,186 | 0,172 | 0,177 | 0,283 | 0,128 | 0,177 | 0,168 | 0,141 | 0,247 | 0,116 | 0,085 |
| | first (s) | 0,123 | 0,120 | 0,116 | 0,030 | 0,083 | 0,132 | 0,056 | 0,083 | 0,068 | 0,157 | | 0,197 | 0,045 | 0,211 |
| 8 | median (s) | 0,146 | 0,154 | 0,228 | 0,128 | 0,128 | 0,239 | 0,063 | 0,152 | 0,068 | 0,157 | N/A | 0,197 | 0,150 | 0,227 |
| | latest (s) | 0,179 | 0,188 | 0,283 | 0,283 | 0,180 | 0,253 | 0,069 | 0,221 | 0,068 | 0,157 | | 0,197 | 0,156 | 0,243 |
| | first (s) | 0,076 | 0,164 | 0,129 | 0,088 | 0,064 | 0,114 | 0,078 | 0,064 | 0,069 | 0,172 | 0,079 | 0,148 | 0,073 | 0,120 |
| 9 | median (s) | 0,141 | 0,198 | 0,149 | 0,159 | 0,138 | 0,179 | 0,129 | 0,170 | 0,231 | 0,233 | 0,155 | 0,197 | 0,204 | 0,147 |
| | latest (s) | 0,194 | 0,199 | 0,169 | 0,169 | 0,202 | 0,307 | 0,248 | 0,287 | 0,305 | 0,280 | 0,230 | 0,246 | 0,259 | 0,159 |

* Muscle abbreviations: SCM: Sternocleidomastoid, CPVM: Cervical paravertebral muscles, RA: Rectus abdominis, ES: Erectos spinae, RF: Rectus femoris, BF: Biceps femoris, GC: Gastrocnemius, with R: right muscle, L: left muscle

No tendency towards an early onset of certain muscle (groups) can be found in the data. Also, no clear tendency can be found across the three sled trials supporting habituation of the volunteers as a function of an increased or decreased onset time in trial 2 or 3.

In order to quantify differences between muscle onset of the right and left muscle (group) the difference between the median onsets has been calculated by subtracting the left onset time from the right for every volunteer and each muscle (Table 8).

There is no clear tendency towards one side of the body reacting first throughout the tests, except the left SCM muscle being activated after the right in 4 out of 5 volunteers. For volunteer number 7, the right side always reacted before the left with exception of the Biceps femoris muscle. Volunteer number 9 shows a tendency to react with the left muscles first. The absolute differences between the right and the left muscles range from 2 ms for the CPVM muscles to 146 ms for the BF.

Table 8: Median differences between right and left muscle onsets for every volunteer in (s). Values are calculated by subtracting the left median value from the right median value, so that a negative value indicates a later median activity onset of the left muscle in comparison with the right muscle and vice versa

| Volunteer | SCM (s) | CPVM (s) | RA (s) | ES (s) | RF (s) | BF (s) | GC (s) |
|---|---|---|---|---|---|---|---|
| 5 | -0,056 | -0,005 | 0,002 | 0,024 | -0,073 | 0,146 | -0,031 |
| 6 | -0,041 | 0,011 | -0,007 | 0,029 | 0,001 | -0,016 | -0,075 |
| 7 | 0,070 | 0,013 | 0,002 | 0,123 | 0,017 | -0,078 | 0,045 |
| 8 | -0,008 | 0,100 | -0,111 | -0,089 | -0,089 | N/A | -0,077 |
| 9 | -0,057 | -0,010 | -0,041 | -0,041 | -0,002 | -0,042 | 0,057 |

First, median, and latest onset times for each muscle (group) with regard to age group can be found in Table 9, where the young age group is represented by the young volunteer and the elderly age group is comprised of onset times of the 4 elderly men.

Table 9: First, median, and latest onset times found by onset criteria or visually found between about 30 ms and 300 ms after impact for each age group and muscle (group) in (s). The young group is comprised of one young volunteer, the elderly age group represents onset times from 4 elderly volunteers

| age group | onset range | SCM_R | SCM_L | CPVM_R | CPVM_L | RA_R | RA_L | ES_R | ES_L | RF_R | RF_L | BF_R | BF_L | GC_R | GC_L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| young | first (s) | 0,144 | 0,087 | 0,162 | 0,139 | 0,187 | 0,177 | 0,175 | 0,162 | 0,039 | 0,154 | 0,105 | 0,032 | 0,076 | 0,055 |
| | median (s) | 0,174 | 0,230 | 0,190 | 0,195 | 0,189 | 0,187 | 0,197 | 0,173 | 0,107 | 0,180 | 0,229 | 0,083 | 0,188 | 0,219 |
| | latest (s) | 0,214 | 0,255 | 0,211 | 0,218 | 0,209 | 0,217 | 0,215 | 0,267 | 0,135 | 0,209 | 0,232 | 0,277 | 0,266 | 0,268 |
| elderly | first (s) | 0,042 | 0,062 | 0,039 | 0,030 | 0,064 | 0,045 | 0,056 | 0,038 | 0,068 | 0,066 | 0,062 | 0,092 | 0,045 | 0,036 |
| | median (s) | 0,142 | 0,189 | 0,166 | 0,153 | 0,151 | 0,175 | 0,142 | 0,139 | 0,136 | 0,160 | 0,155 | 0,197 | 0,161 | 0,187 |
| | latest (s) | 0,239 | 0,233 | 0,283 | 0,283 | 0,202 | 0,307 | 0,283 | 0,287 | 0,305 | 0,280 | 0,251 | 0,301 | 0,289 | 0,276 |

Comparing the median of the young volunteer versus the elderly muscle onset occurs later for the young volunteer for all muscles except the Rectus and Biceps femoris muscles.

The very first muscle onset also happened later in the young volunteer than in the elderly except for RF_R and BF_L. In terms of the latest onset no clear difference can be found between young and elderly volunteers.

## 3.2 Magnitude of Muscular Activity

Processed MVC data for every volunteer is presented in Appendix 6.4, with muscular activity referring to excercises for maximum voluntary contraction highlighted with red boxes, as in Figure 4 for volunteer 5.

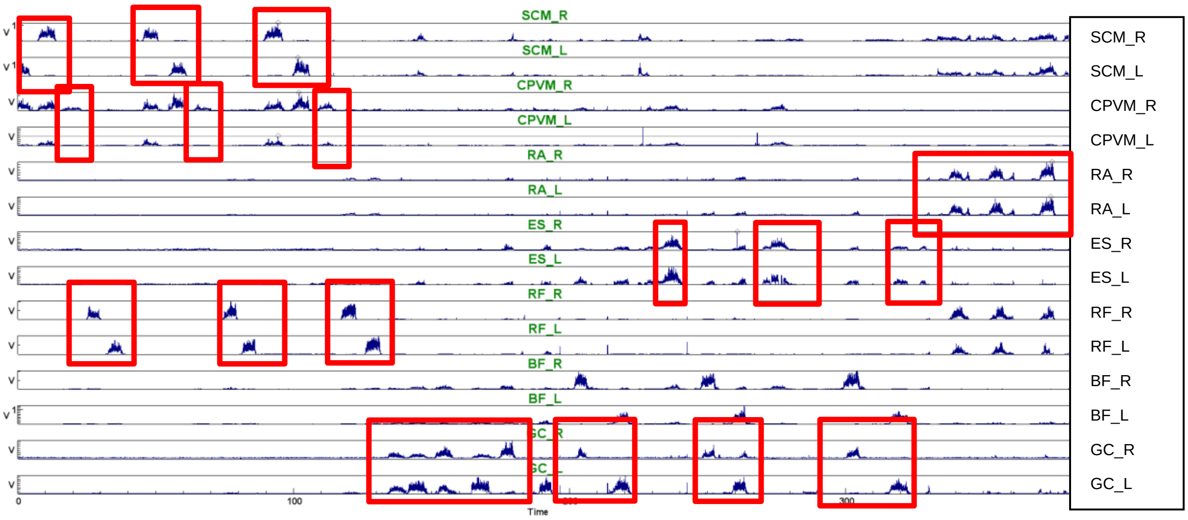



Figure 4: Overview of rectified MVC activity measured in (V) of volunteer 5. MVC measurement is highlighted with red boxes

Normalized muscle activity during a static trial and during each sled trial has been plotted over time for each trial and muscle (group) and can be found in Appendix 6.5. It is important to note that the time between onset of sled acceleration and sled impact there was no recording of EMG possible. The figures will be explained using the example of the right Erector spinae muscle (trial 1767) (Figure 5):

The first half of the graph presents normalized activity while sitting relaxed in the sled with no sled movement, after the volunteer has been positioned correctly. The second half shows muscle activity following the impact at t=0 (marked with two black bars to indicate interrupted time scale) with regard to the MVC value [%]. After volunteer 5 has been positioned in the sled correctly his right Erector spinae muscle shows activation of up to 3 % of MVC (static trial 1767). After the impact muscle activity first stays at a baseline level similar to the static trial before increasing up to 81 % of MVC after about 160 ms (dynamic trial 1767).

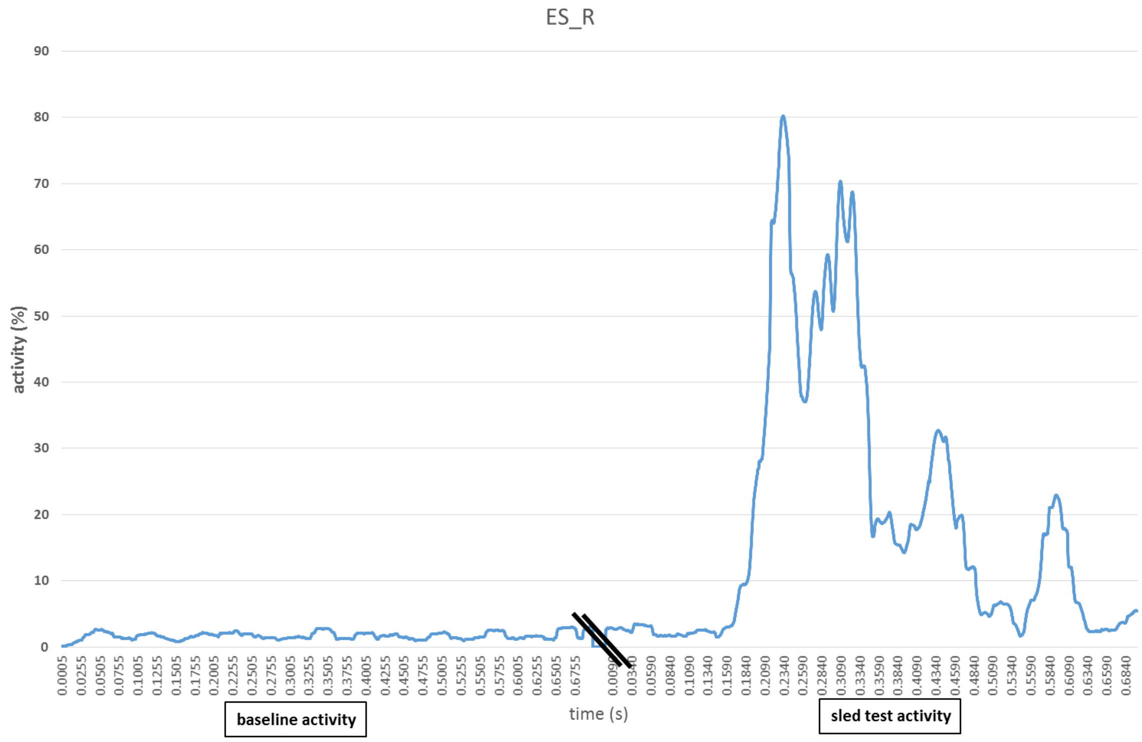



Figure 5: Static and dynamic trial 1767 showing normalized baseline activity of the right Erector spinae muscle while volunteer 5 was seated in the sled with no sled movement (left side) and normalized activity as a reaction to the impact (right side) in (%) of MVC over time in (s). The impact is marked with two black bars. Relaxed baseline activity is below 5 % of MVC compared to activity as a reaction to the impact with up to 81 % of MVC

In most cases baseline activity during relaxed sitting in the sled was very low with activity between 0.3 % and 5 % of MVC. Slightly elevated activity has been found with 15-20 % of MVC for GC_R of volunteer 5 and with 15-20 % of MVC for CPVM_R in sled trials 1778 through 1782.

The level of muscle activity during sled tests has been classified according to the following categories and marked in Table 10 as follows:

- x < 100 % of MVC, light yellow
- 100 %< x <110 % of MVC, yellow
- 110 %< x <200 % of MVC, orange
- 200 % < x of MVC, red

Table 10: Overview of categorized sled data normalized to the highest MVC value (V) for every volunteer and each muscle;. Light yellow: x<100 % of MVC, yellow: 100<x<110 % of MVC; orange: 110<x<200 % of MVC; red: 200<x % of MVC; framed MVC values highlight right channels that show MVC activity about a potence of ten less than the left channel respectively

| volunteer | Trial number | Trial type | Channels | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SCM_R | SCM_L | CPVM_R | CPVM_L | RA_R | RA_L | ES_R | ES_L | RF_R | RF_L | BF_R | BF_L | GC_R | GC_L |
| 5 | | MVC (V) | 1,143 | 1,591 | 0,243 | 0,449 | 0,689 | 0,851 | 0,740 | 0,890 | 2,019 | 1,917 | 2,046 | 1,260 | 0,061 | 0,649 |
| | 1767 | Sled | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | 1768 | | x | x | x | x | x | x | x | x | N/A | x | N/A | N/A | x | x |
| | 1769 | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| 6 | | MVC (V) | 0,182 | 0,354 | 0,244 | 0,353 | 0,487 | 0,460 | 0,244 | 0,267 | 0,634 | 0,690 | 0,292 | 1,200 | 0,709 | 0,883 |
| | 1771 | Sled | x | x | x | x | x | x | x | x | x | x | N/A | x | N/A | x |
| | 1772 | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | 1773 | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| 7 | | MVC (V) | 0,231 | 0,335 | 0,317 | 0,306 | 0,323 | 0,265 | 0,252 | 0,212 | 0,281 | 0,242 | 1,035 | 0,573 | 0,450 | 0,400 |
| | 1774 | Sled | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | 1775 | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | 1776 | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| 8 | | MVC (V) | 0,301 | 0,478 | 0,085 | 0,280 | 0,747 | 0,213 | 0,281 | 0,218 | 0,959 | 0,446 | 0,848 | 0,810 | 0,918 | 0,567 |
| | 1778 | Sled | x | x | x | x | x | x | x | x | x | x | N/A | x | x | x |
| | 1779 | | x | x | x | x | x | x | x | x | N/A | N/A | N/A | N/A | x | x |
| 9 | | MVC (V) | 0,397 | 0,442 | 0,059 | 0,184 | 0,226 | 0,106 | 0,284 | 0,134 | 0,267 | 0,204 | 0,806 | 0,888 | 0,646 | 0,194 |
| | 1780 | Sled | x | x | x | x | x | x | x | x | x | x | N/A | N/A | x | x |
| | 1781 | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | 1782 | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |

The level of sled muscle activity stayed below 100 % of MVC mainly for muscles CPVM_L, ES, RF, BF, and GC. The level of activity exceeded 100 % of MVC in some sled trials in muscles SCM and RA. CPVM and SCM also show values above 200 % in several sled runs.

A tendency between the right and left muscles can be seen in the CPVM muscle, where the right muscle group went above 110 % and 200 % of MVC in considerably more trials than the left muscle group. Right MVC values for CPVM of volunteers 8 and 9, and GC of volunteer 5 show activity more than a potence of ten lower than the left side in each case.

A clear trend for habituation of volunteers across the three consecutive sled tests and all muscles in terms of magnitude can not be observed. Volunteer 5 tends to increase activity with each sled run for CPVM_L, RA_R and ES_R while volunteer 6 shows signs of lower activity for some muscles SCM_L, CPVM, RA_R and ES in consecutive sled trials. Volunteers 7 and 9 react at different levels of magnitude in each trial. Volunteer 8 experienced two trials where an adjustment of muscle activity level can only be hypothesized for the RA_R muscle in the second dynamic sled recording.

# 4 Conclusions and Recommendations

## 4.1 EMG Test Setup in Low-Speed Frontal Impacts

General phenomena affecting EMG data such as crosstalk of muscles, noise from skin and fat, or the number of recruited motor units evoking the summarized muscle potential will not be evaluated here in detail but should be kept in mind when drawing conclusions. Crosstalk phenomena will have occured in the CMPV muscle group by its definition. Also, the superficial Erector spinae and Rectus abdominis muscles are other muscles that might have influenced the summarized superficial electromyographic potential. By applying the smallest inter-electrode distance possible, using electrodes with small areas, and filtering frequencies lower than 20 Hz the attempt was made to reduce the influence of crosstalk phenomena (Chowdhury, 2013).

Given the seated position of the volunteers in the test rig the Rectus femoris muscle signal quality could have been affected by the volunteers' hands resting nearby the electrode location. Such interaction of the hands with the electrodes or transmitters was not seen throughout the left-lateral high-speed videos of all trials. The same accounts for the Biceps femoris and Gastrocnemius muscles, where no interaction with the seat pan was observed in the left-lateral high-speed videos.

Interaction of the seatbelt with the right SCM electrodes or cables cannot be ruled out according to the frontal high speed videos of each trial (e.g. Figure 6). Unfortunately, there are no optimization measures that could keep the seat belt from interacting with the electrodes in future tests without changing the whole test setup. Apart from this, the EMG test setup seems to have worked well for frontal impact tests.

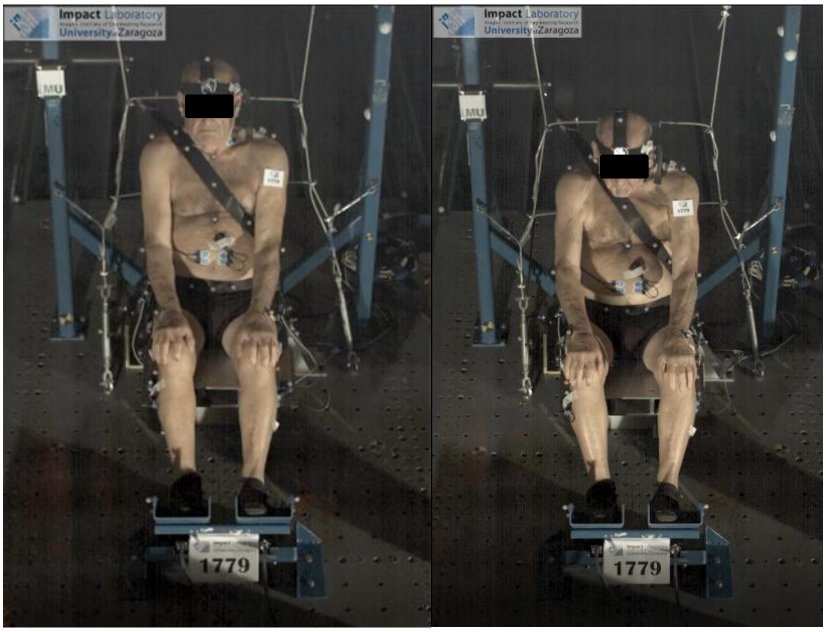



Figure 6: Stills from frontal high-speed video before impact (left) and after impact (right). Interaction of the seat belt with the right SCM muscle cannot be ruled out as seat belt is very close to the SCM muscle after impact (trial 1779)

## 4.2 Processing of Data

Muscle activity has been evaluated in terms of muscle onset latency following sled impact and levels of activation, with sled activity normalized to MVC. In terms of comparison of EMG data between young and elderly volunteers or right and left muscles, other than smoothing the filtered and rectified EMG data with the RMS method a frequency spectrum analysis could be performed, possibly revealing shifts in frequencies between young and old volunteers if more young volunteers were available.

Muscle onset times have been defined based on two criteria and visually when found appropriate. Several onset methods have been compared with each other and the raw signals in order to find criteria fitting the raw data most. Even though these onset criteria were fitting well with large parts of the data for some sled trials onsets had to be defined visually as well. Reasons for missing onsets are assumed to be associated with missing baseline activity passages in some sled trials, when the muscle has been activated all the time, paired with low maximum peak activity, as baseline activity or a minimum difference between baseline activity and peak activity are required for the onset critera. Further adaption of applied onset methods could lead to an increase in onset sensitivity.Nevertheless, missing baseline activity cannot be compensated.

## 4.3 Electromyography Responses of Volunteers in Low Speed Frontal Sled Impacts

This study quantified muscle responses of the cervical spine, torso, and lower extremities for one young and 4 elderly volunteers in low-speed frontal impacts. Baseline activity, muscle onset latency, and the magnitude of muscle activity will be discussed in the following sections.

### 4.3.1 Baseline Activity

In general, the normalized static trials show that only little muscular activation was needed in order to stabilize the body in the sitting position. It suggests that volunteers were relaxed before each sled trial, which implies that seating position was not causing too much discomfort and did not exert the volunteers beyond normal levels prior to impact testing.

### 4.3.2 Muscle Onset Latency

In general, no clear tendency for a certain muscle (group) to react to the impact rather early or late can be found in the data. Tendencies for the right muscle to react before the left muscle are rather dependent on the subject, except partly for the SCM muscle, which could be associated with the seat belt contact on the right SCM. The absolute difference between onset times for the left and right muscles shows a wide range, and indicates that differences are rather individually than muscle dependent, too.

The comparison of medians shows that for most of the muscles the young volunteer reacted with a longer latency to the onset of impact as the elderly group. Drawing conclusions from comparisons between the two age groups should be limited here as the young group only exists of one individual, and this possible age difference needs to be evaluated with more young volunteer tests.

Studying electromyographic responses of children and young adults in low-speed frontal impacts, Mathews et al. measured activity of the SCM, CPVM, Upper Trapezius, ES, and RF muscles (Mathews et al., 2013). Here, volunteers had shorter latencies for the CPVM muscles compared with SCM, Upper trapezius, ES, and RF muscles, which was explained by the neck stabilizing the head in relation to the torso after its sudden acceleration due to impact. In present data, no such tendency can be detected. Also, no tendencies towards habituation can be supported by the onset times. Habituation was found for onset and amplitude of neck muscles in rear impacts by Siegmund et al. visible in the last 5 of 11 tests in comparison to the first test (Siegmund, 2003). Onset times varied across all individuals and trials.

There was no recording possible of pre-activation of muscles as a function of anticipation or bracing. Still, some volunteers already entered the impact phase with an increased muscle activity above baseline activity, or even with onsets indicated as early as 0 ms or 5 ms after the impact with a muscle activity not related to the impact but maybe to the sled acceleration.

Therefore, for future assessment of low speed frontal sled test muscle activity onset, recording of at least 100 ms before the impact is highly recommended to differentiate between muscle onset as reaction to the impact and pre-activated muscle activity as a way of anticipation or bracing.

### 4.3.3 Magnitude of Muscular Activity

The level of muscular activity while sitting relaxed in the sled and as reaction to the impact has been quantified in relation to individual Maximum Voluntary Contraction activity. From observation, volunteers were highly motivated to exert maximum effort during all MVC exercises. Volunteers did not show any issues performancing the exercises nor experienced any pain during or after exercising.

During impact testing the torso was restrained with a three-point belt, and the legs were firmly resting on a footrest. Thereby, trunk and lower extremity motion was minimized. After normalizing dynamic sled activity, SCM, CPVM, and RA generally experienced higher muscle activity than ES, RF, BF and GC muscles, which is conform to Mathews et al.’s findings (Mathews et al., 2013). SCM and CPVM reacting with higher activity indicates that in relation to the torso and lower extremities a bigger muscle response of the neck muscles is required to resist the sudden involuntary head and neck motion, which was also observed in lateral high-speed videos.

Even though habituation of volunteers in terms of magnitude could not be observed clearly throughout the data, it could have taken place in the pre-impact phase that was not recorded. Also, as there was only one young volunteer involved no trends with age concerning the level of musclular activity were assessed.

Considerung absolute normalized peak values as reaction to the impact, some muscular activities overshoot 100 % of the MVC value. Possible causes for these outliers will be discussed as follows.

As the exercise for the SCM muscles has been designed specifically to diminish the risk of cervical injuries it should be evaluated in more detail. For some volunteers the MVC for the SCM muscle shows higher activity during the RA exercise, leading to the assumption that this exercise might be better to obtain a maximum contraction in the SCM muscles as well. The above mentioned interaction of the right SCM muscle with the shoulder belt should be mentioned here as well.

Also, the exercise for MVC of CPVM was hard to obtain as it required manual resistance of the volunteer's head by the examiner. This could have led to unwanted motion, thus, a change of muscle length during the exercise when resistance was not constant. Also, the resistance by the examiner was always given from the volunteer's left side as the examiner stood on the volunteer's left side, which could have led to a biased exercise and different resisting forces for the right and left muscle group. Volunteers 5, 6, 8, and 9 showed higher maximum activity of CPVM_L during MVC than CPVM_R, and as consequence higher normalized sled activity in the right CPVM. Volunteer 7 produced almost simliar MVC values for the left and right CPVM and sled activity did not go beyond 100 % of MVC. This observation supports assumptions that the applied CPVM exercise should be improved in future measurements.

During medical examination before the MVC tests, volunteer 5 showed signs of impairment in the right lower leg. This could have led to the much lower MVC peaks for the right GC muscle compared with the left one, thus, leading to a higher normalized activity level in the first place and exceeding normalized sled activity. Also, during examination both volunteers 8 and 9 were observed to have a slight tilt of the head to the left, possibly due to a slightly rotational malposition of the cervical spine. An elevated normalized baseline and sled activity in the CPVM_R muscle group due to the lower MVC activity for both volunteers could be hypothesized as being the result of this misalignement as well.

The Rectus abdominis activity after impact also often shows higher values than the corresponding MVC values, but in contrast to SCM and CPVM they mostly stay lower than 200% of MVC. Since the MVC exercise for the RA is widely accepted, and volunteers committed to this exercise well, reason for these overshoots possibly lies elsewhere. Placing of the RA electrodes had been defined intentionally to avoid contact of electrodes with the lap belt. This is also confirmed by frontal high-speed video data, where no interaction of the lap belt with the RA electrodes can be seen. Other sources for these elevated sled activities could not be found. This phenomenon remains unsolved. Future measurements of the RA muscle should be taken very carefully and might contribute to solving this issue.

Since the MVC exercises measure the maximum isometric contraction of muscles that can be raised voluntarily by the subject, activity as a reaction to a sudden stimulus can still result in a higher value. Also, the magnitude of muscle response is dependent on muscle recruitment, firing rate and muscle length. A more suitable test setup for dynamic sled tests would therefore be an isokinetic based MVC. However, this type of MVC is very challenging to obtain under controlled conditions.

The isolated maximal activation of specific muscles is not an easy exercise and should therefore be practised before measuring of MVC. Unfortunately, no preliminary training with the volunteers was possible as it requires a lot of time on site. Without practising, MVC values can be up to 30 % less than obtained with practising (Merletti, 1999). Given this discrepancy, some of the overshooting magnitudes in sled activity could possibly be lower when including training before MVC measurement.

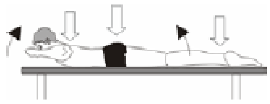
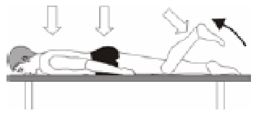
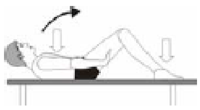
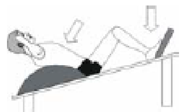
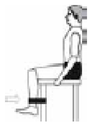
For future measurement of low speed frontal sled test muscle activity with elderly volunteers different MVC exercises for SCM and CPVM should be evaluated capable of measuring the isometric maximum voluntary contraction better while preventing unwanted sudden motions threating to hurt the cervical spine at the same time. Also, some preliminary training should be included in future measurements.

# 5 GLOSSARY

| Term | Definition |
|---|---|
| **BF** | Biceps femoris muscle |
| **CPVM** | Cervico-paravertebral muscles |
| **EMG** | Electromyography |
| **ES** | Erector spinae muscle |
| **GC** | Gastrocnemius muscle |
| **LMU** | Ludwig-Maximilians-Universität |
| **MVC** | Maximum Voluntary Contraction |
| **RA** | Rectus abdominis muscle |
| **RF** | Rectus femoris muscle |
| **SCM** | Sternocleidomastoid muscle |
| **SENIORS** | Safety ENhanced Innovations for Older Road userS |

# 6 Appendix

## 6.1 MVC Postures

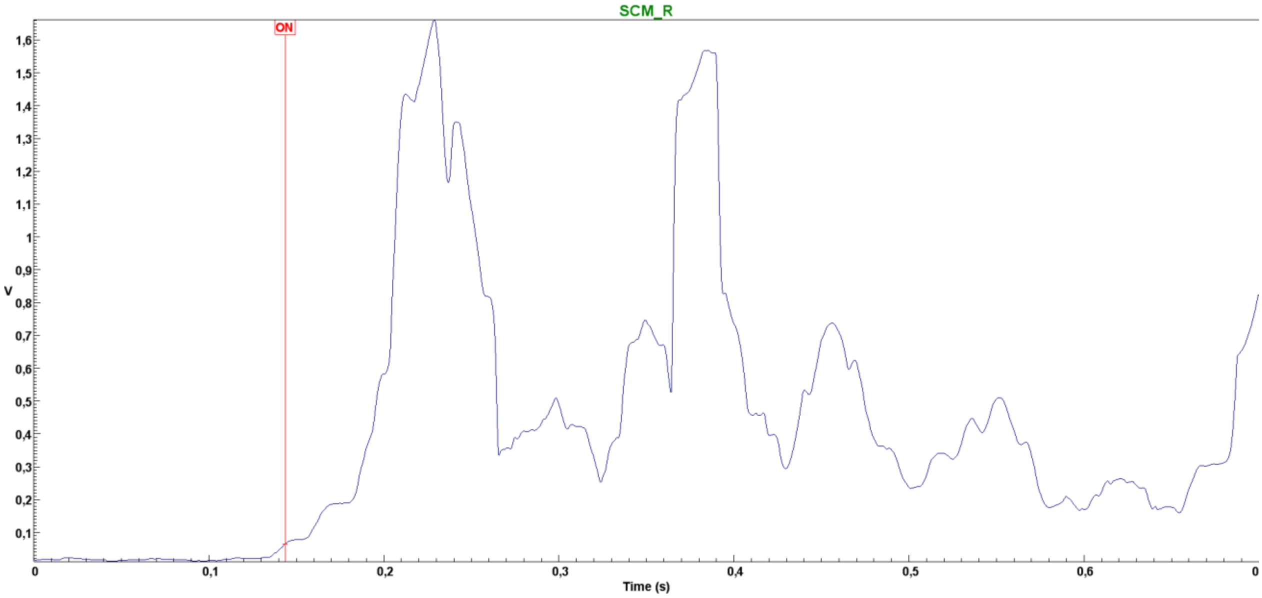
| | | |
|---|---|---|
| Erector spinae / Multifidii |   | The prone lying position on a bench is a very productive MVC test position because all back muscles are facilitated within a muscle chain. MVCs for the erector spinae, the gluteus and the hamstrings are found here. A check exercise is the isolated back extension at a machine |
| Gastrocnemius |  | Being one of the strongest human muscles, the triceps surae group requires a very rigid (machine) resistance against the restrained hip. Perform an unilateral plantar flexion at 90° ankle position |
| Mm ischiocrurales **(M. biceps femoris)** |  | Isolated test for the hamstrings. Fasten the hip securely (belt/heavy person) and perform a unilateral knee flexion at ~ 20-30° knee flexion. An important check exercise is the prone lying MVC test for the erector spinae |
| Rectus abdominis / Obliquus internus abdominis |   | A valid MVC test for the abdominals is difficult to arrange. Sit-up styled movements with the legs securely fastened work the best. Let the spine flex by around 30° and use a belt or manual restraint for that position. The obliques may fire more when an additional trunk rotation is added to the flexion |
| Rectus femoris |  | An easy and beneficial exercise for all quadriceps muscles is a single leg knee extension between 90 and 70° knee flexion position. |

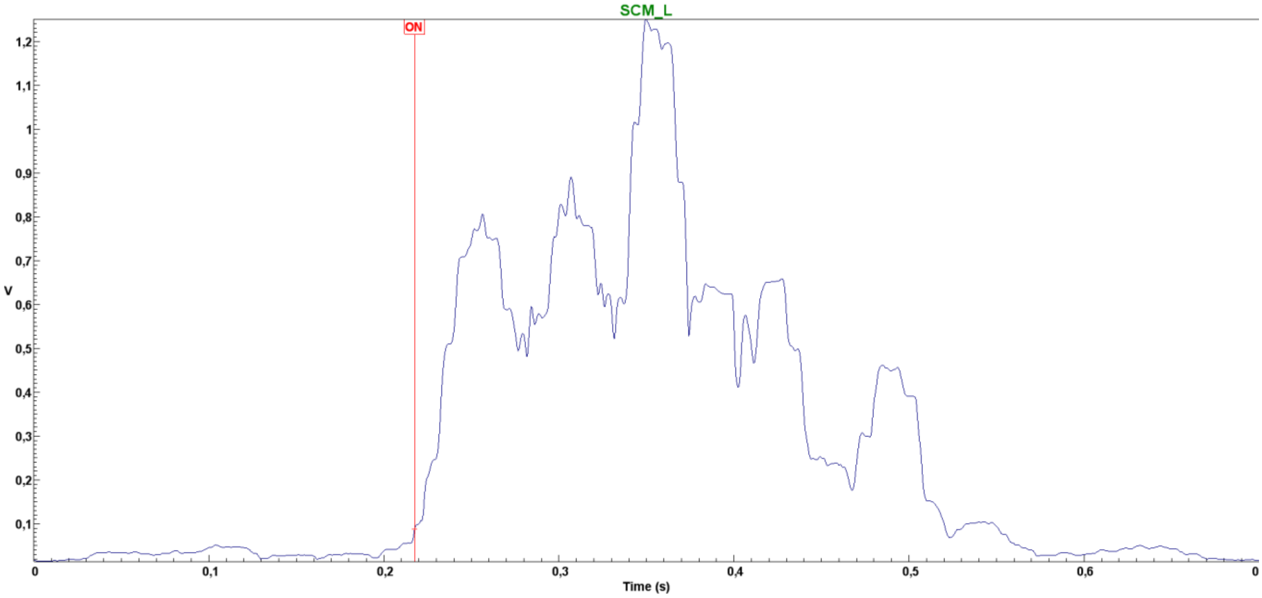
Excerpt from: Konrad, 2006

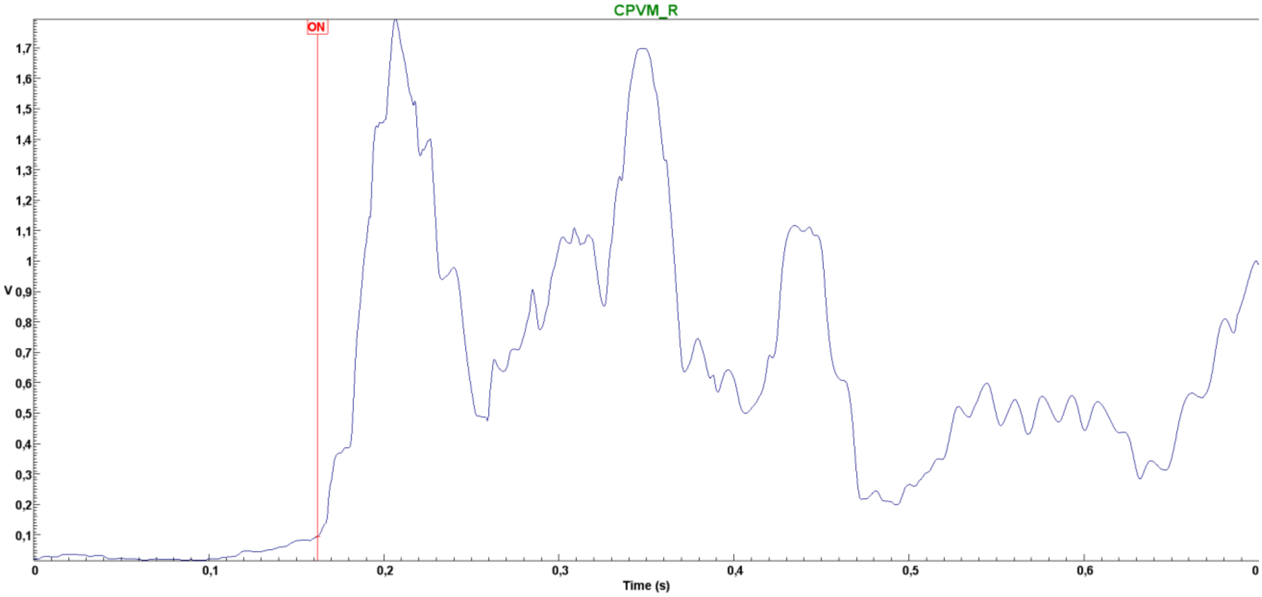
## 6.2 Processed Muscle Activity and Onset Times

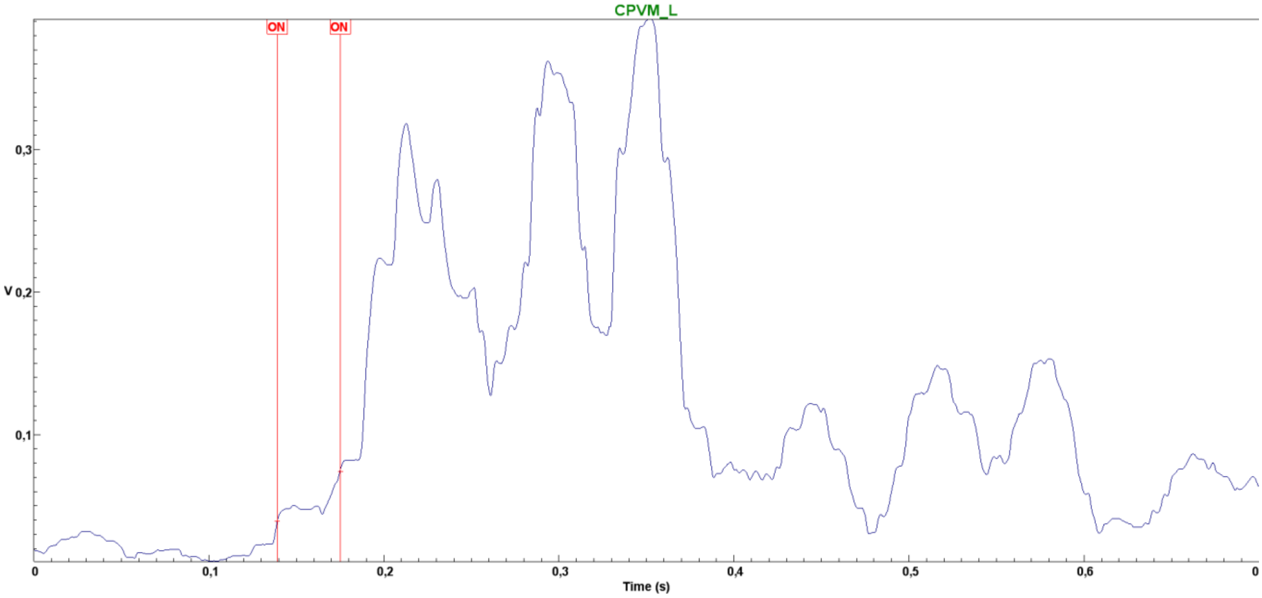
The following figures show muscular activity after processing for each dynamic sled trial and every muscle in (V) over time (s) as well as muscle onsets found by onset criteria (solid red lines) and/or visually (dotted red lines).

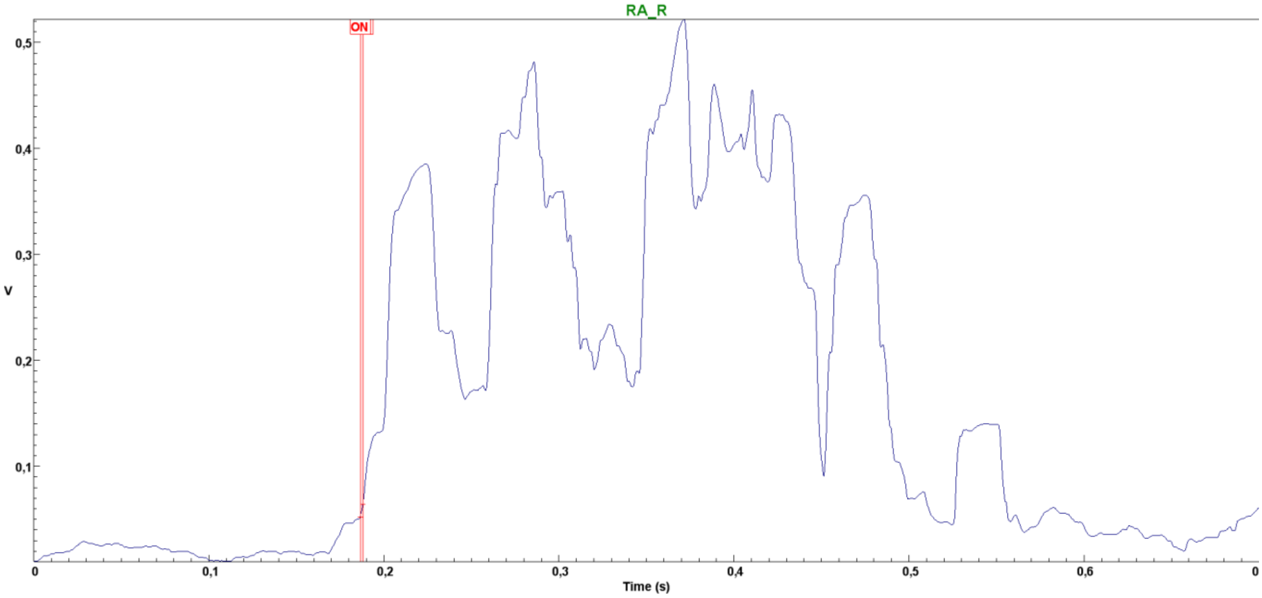
Trial 1767:

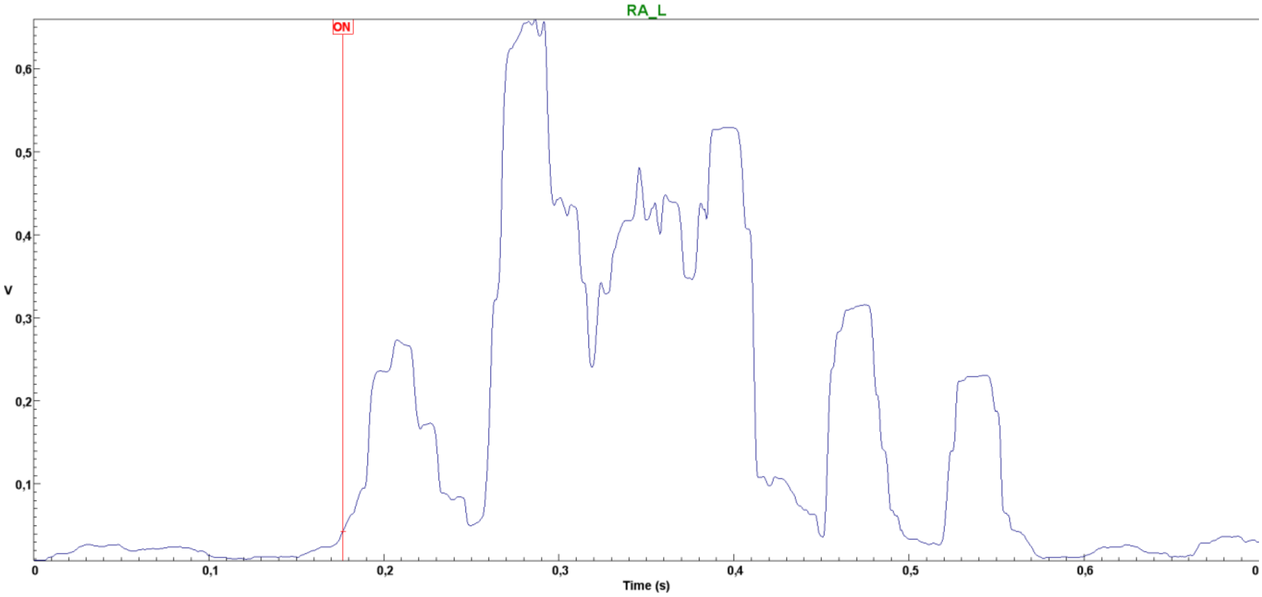

SCM_R
ON
V
Time (s)

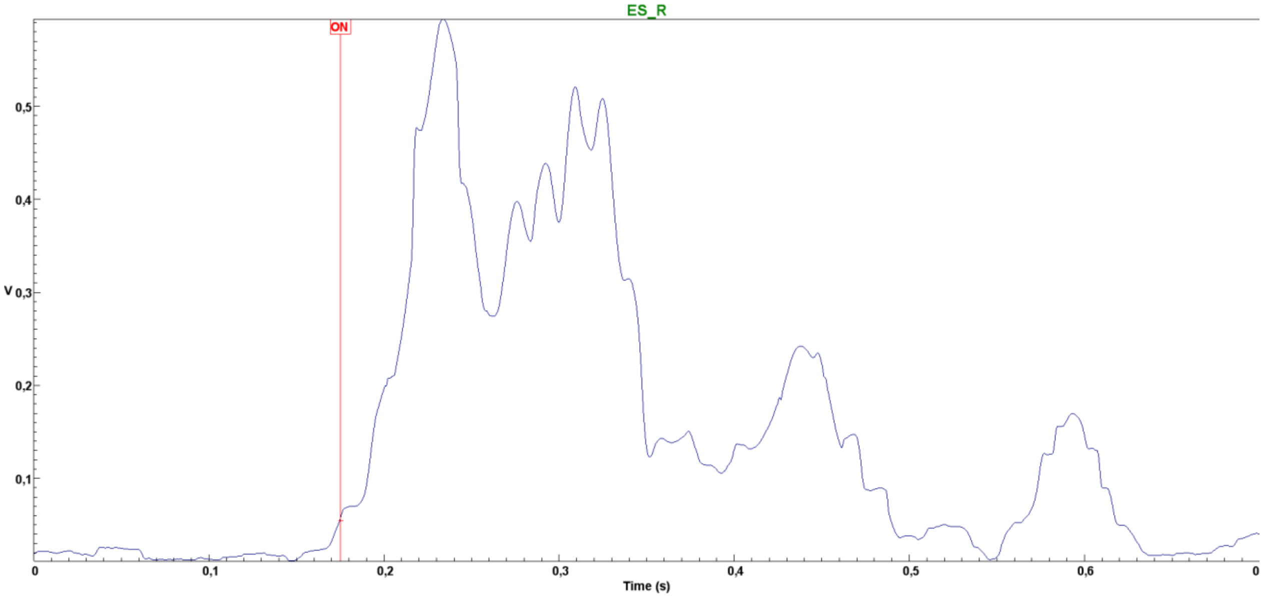

SCM_L
ON
V
Time (s)

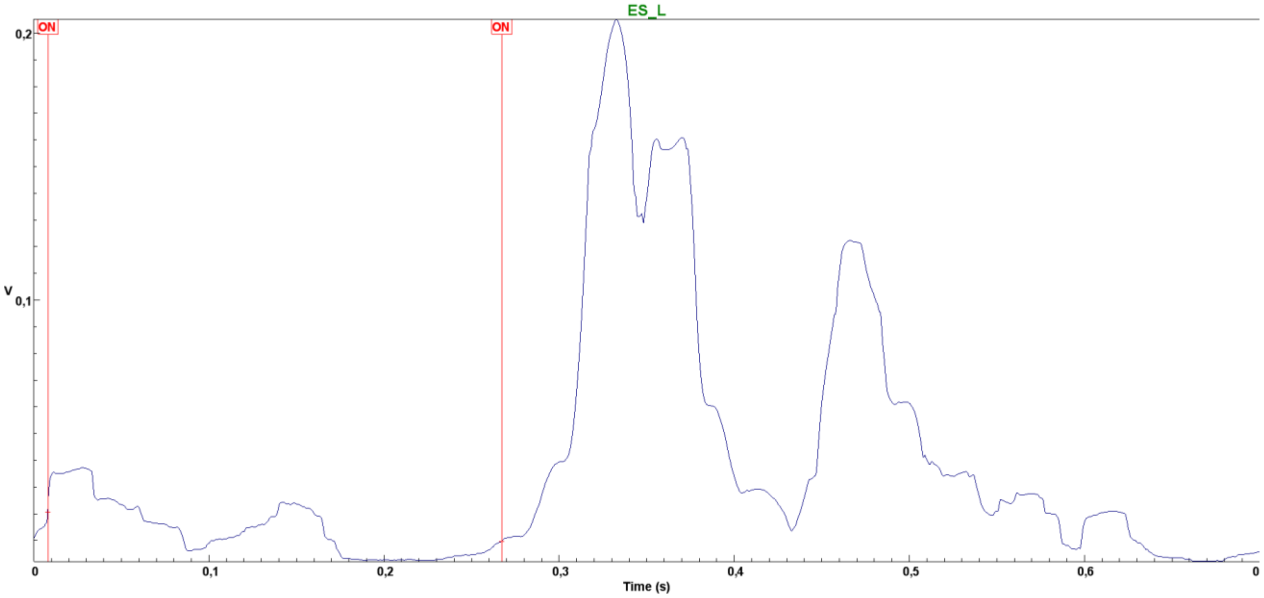

CPVM_R
ON
V
Time (s)

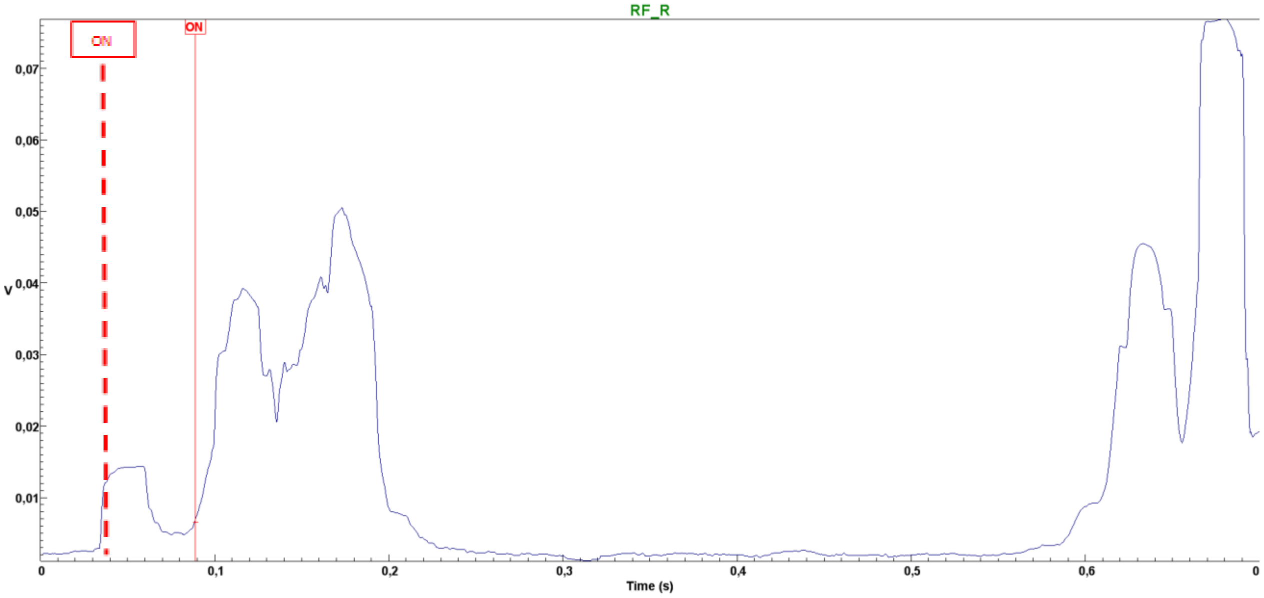

CPVM_L
ON
ON
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time (s)

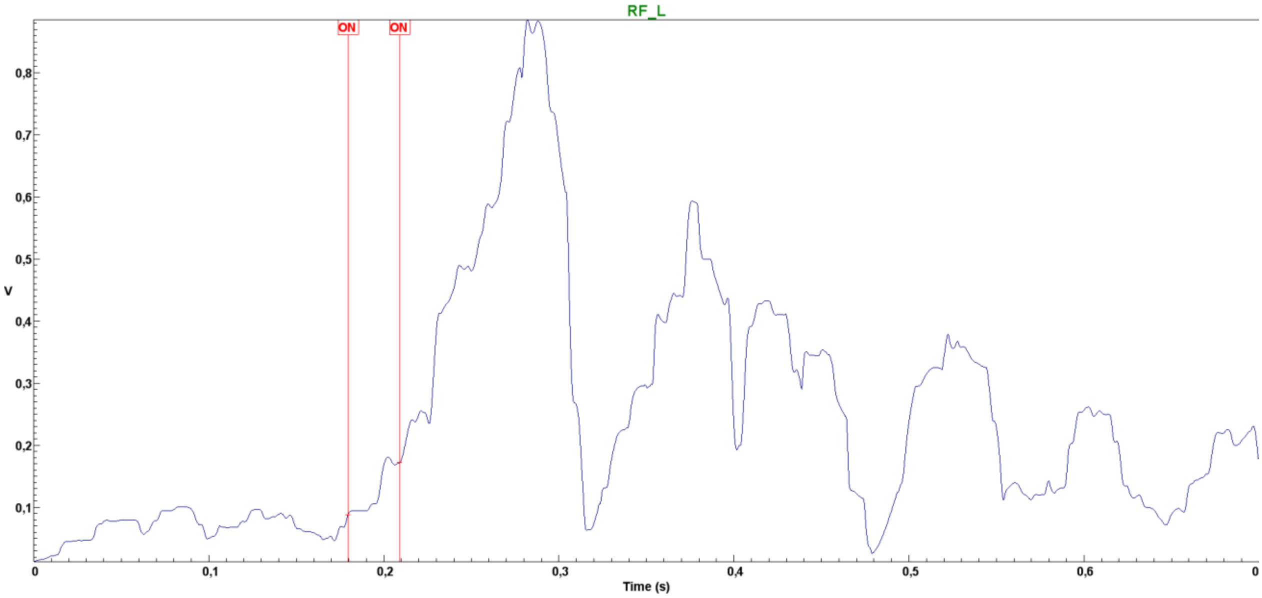

RA_R
ON
V
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time (s)

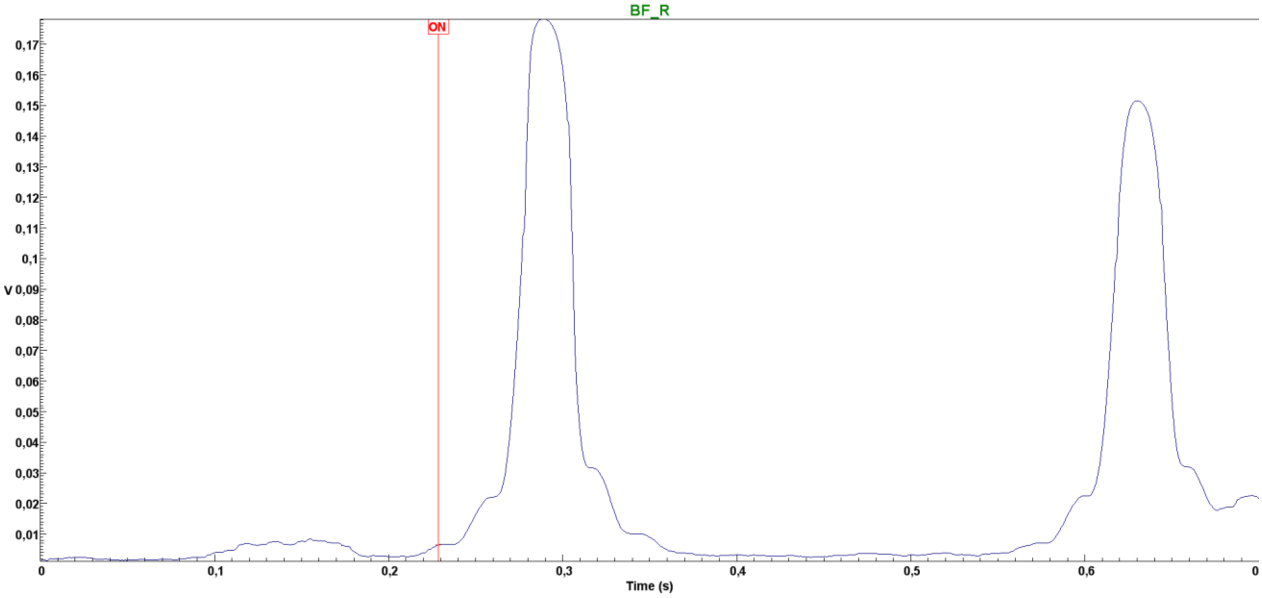

RA_L
ON
V
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time (s)

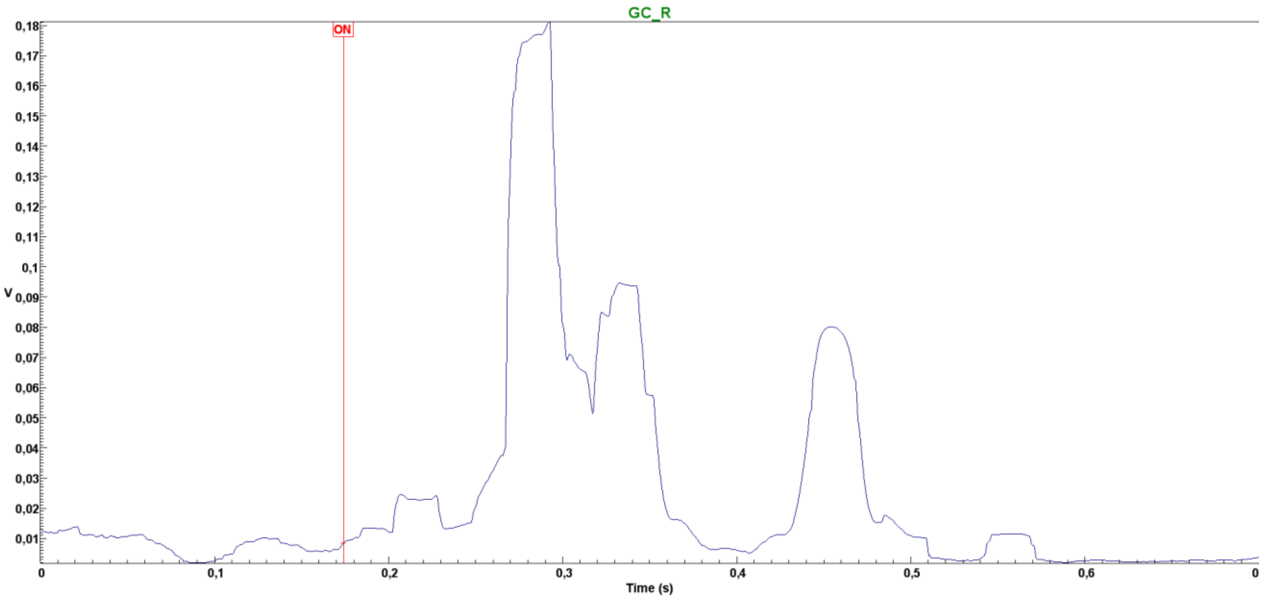

ES_R
ON
V
Time (s)

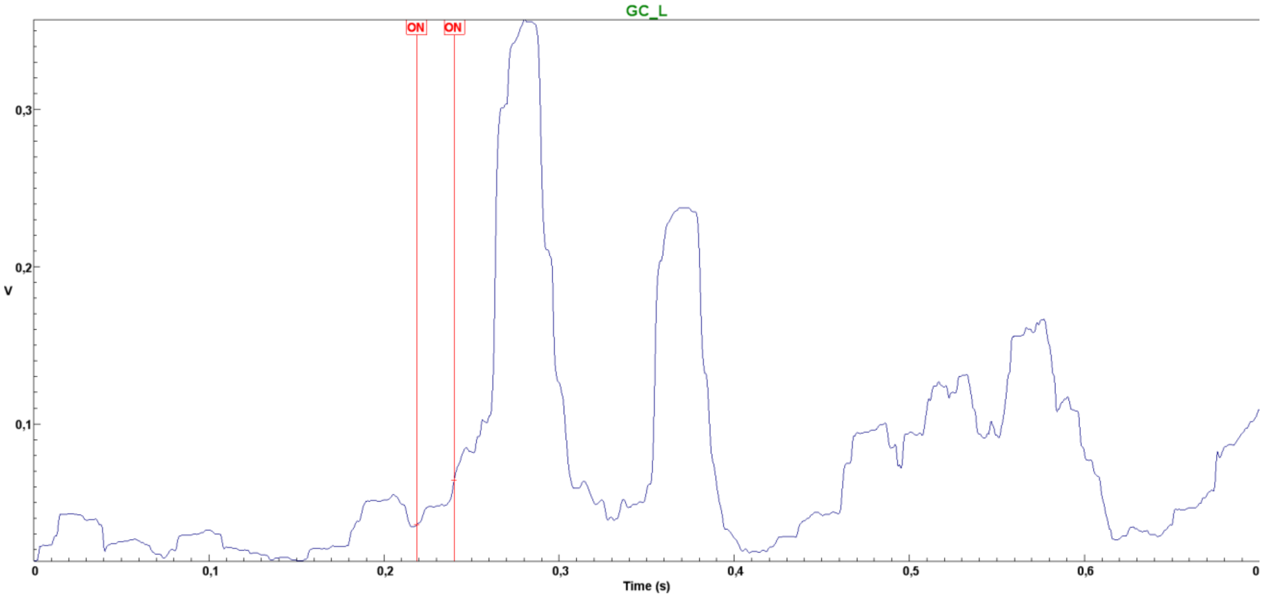

ES_L
ON
ON
V
Time (s)


RF_R
ON
ON
V
Time (s)

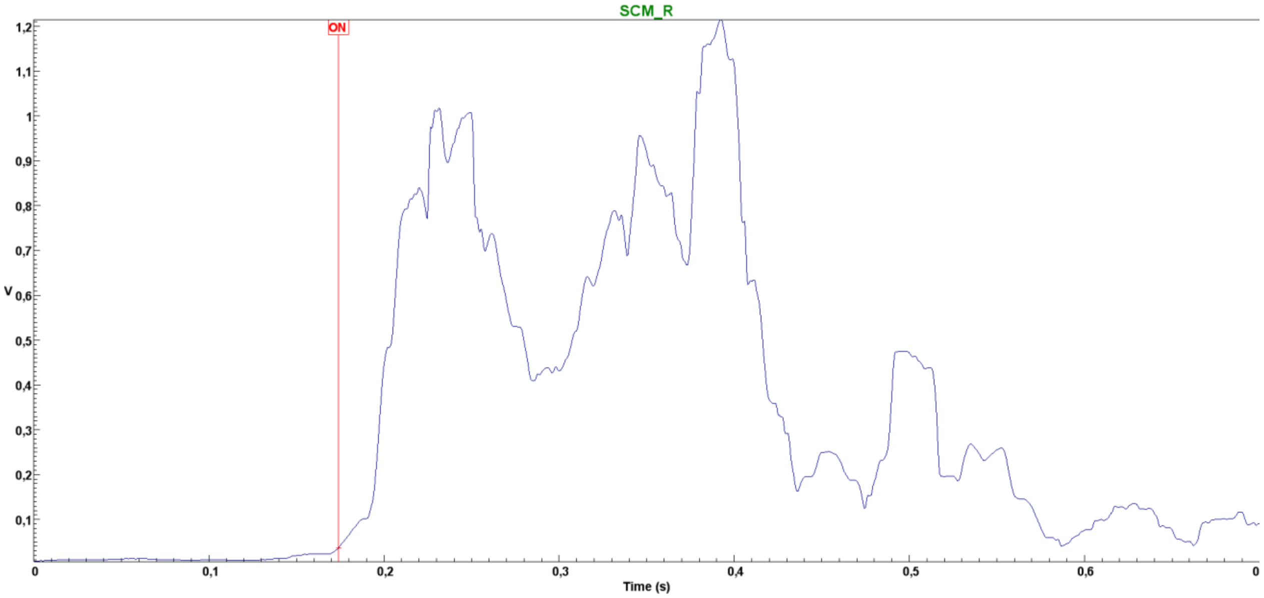

RF_L
ON
ON
V
Time (s)

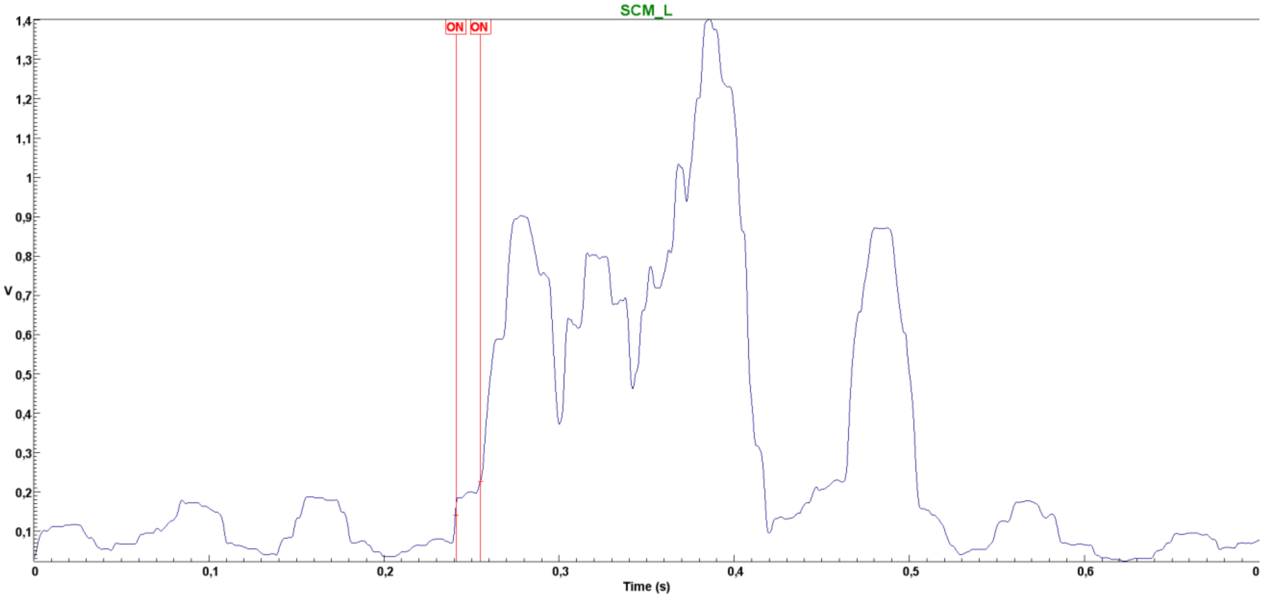

BF_R
ON
V
Time (s)

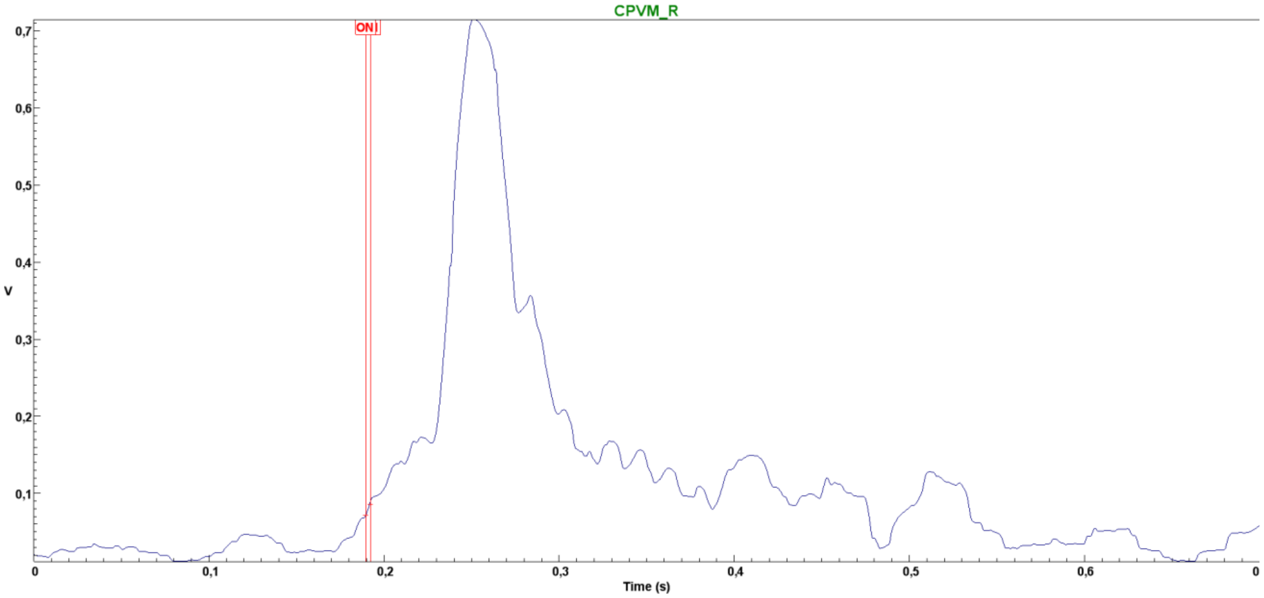

GC_R
ON
V
Time (s)

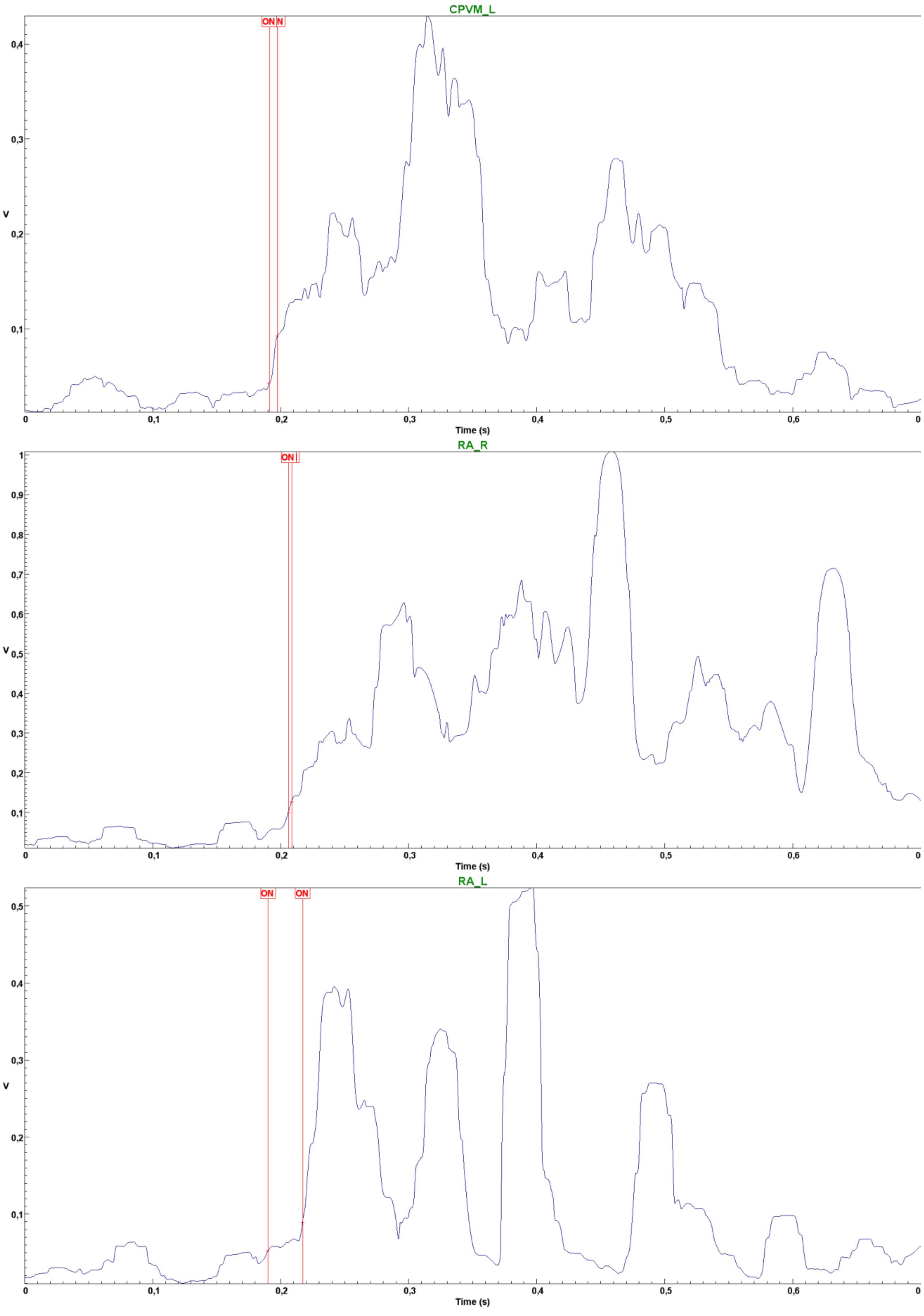

GC_L
ON
ON
0,3
0,2
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

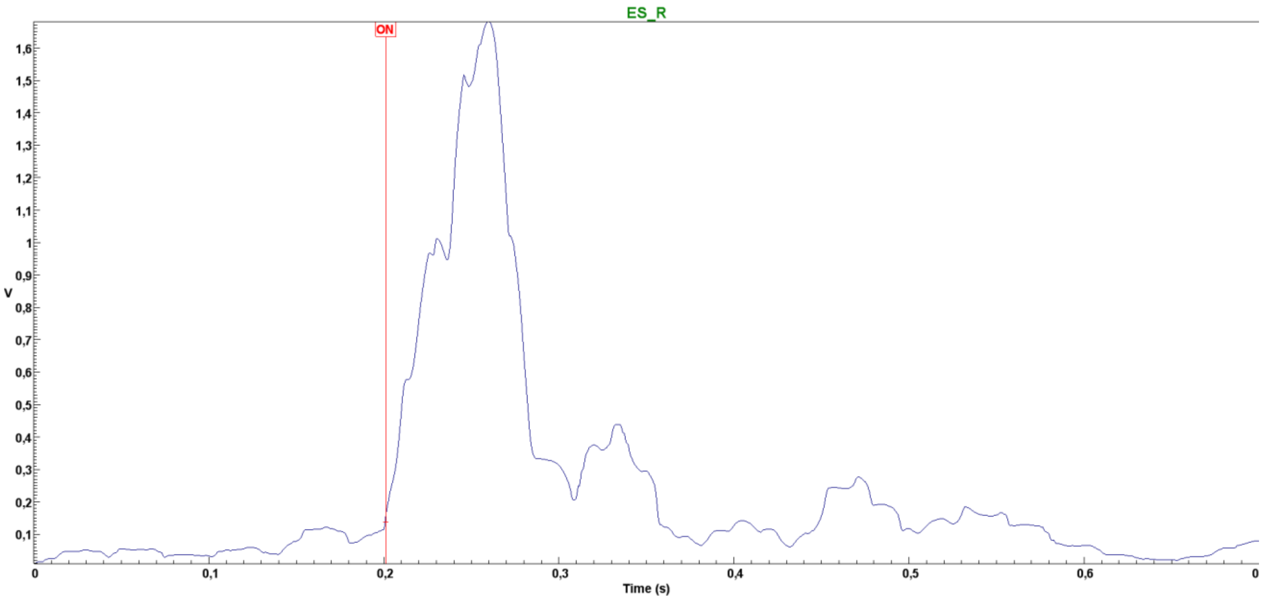
Trial 1768:

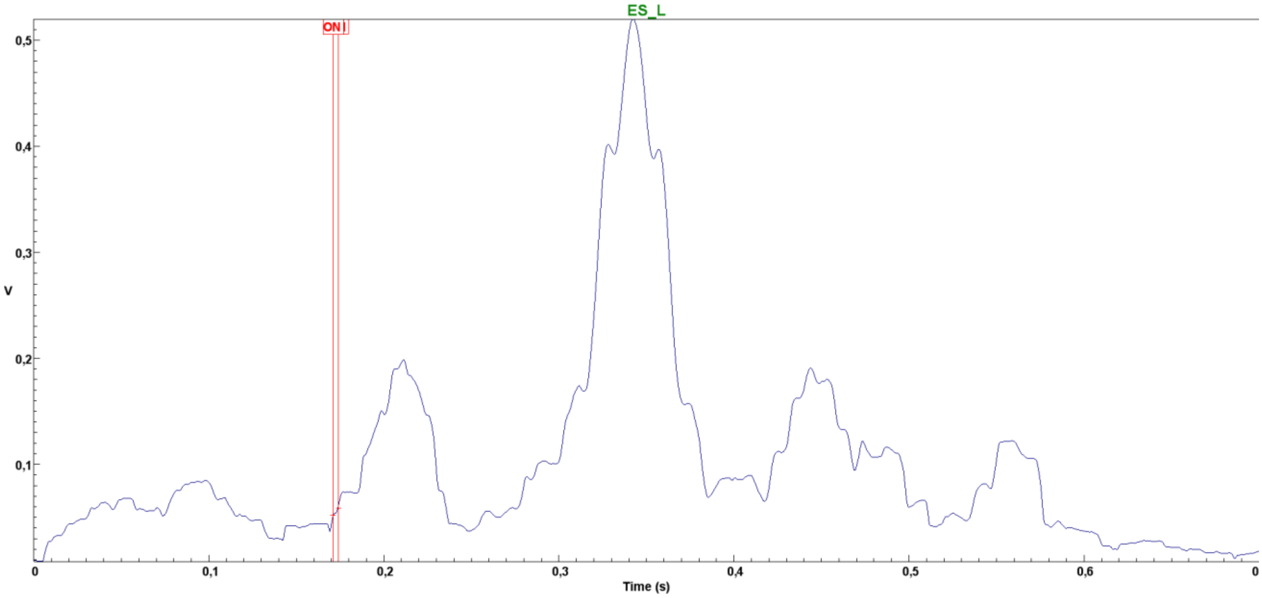

SCM_R
ON
V
Time (s)
1,2
1,1
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0

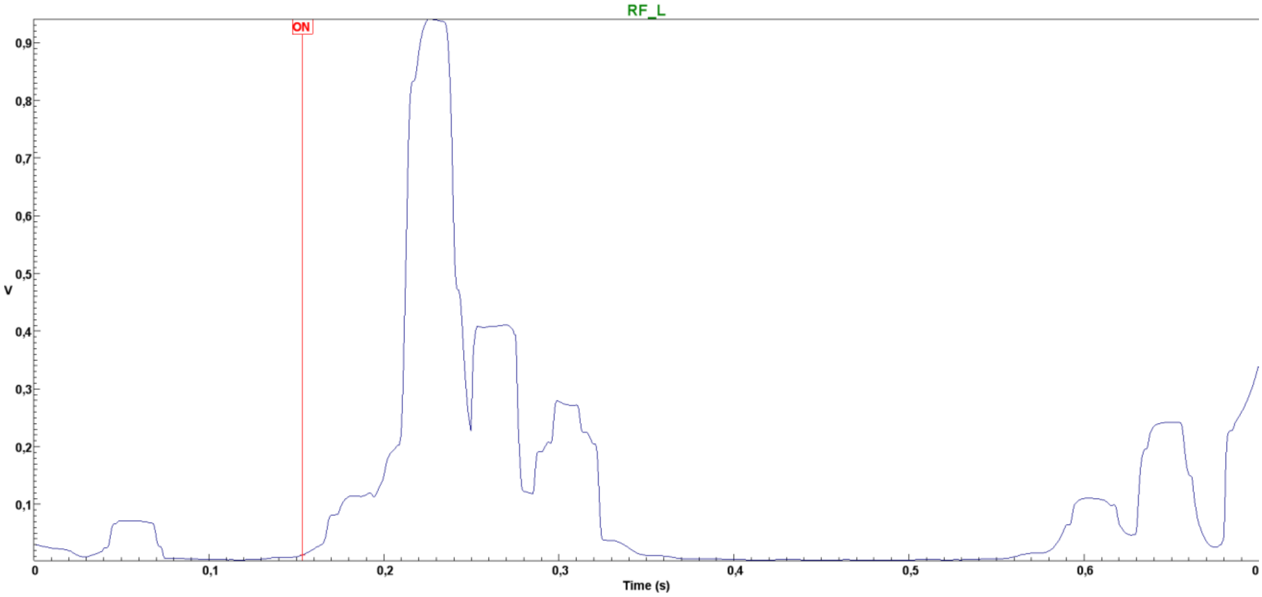

SCM_L
ON
ON
V
Time (s)
1,4
1,3
1,2
1,1
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0

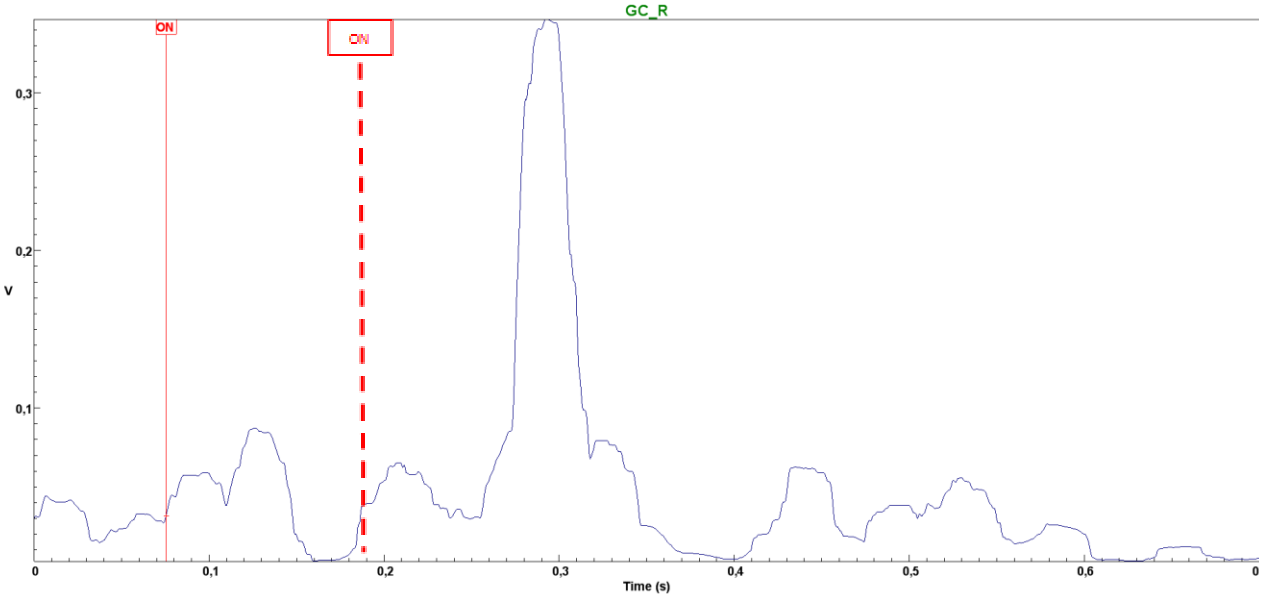

CPVM_R
ON
V
Time (s)
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0

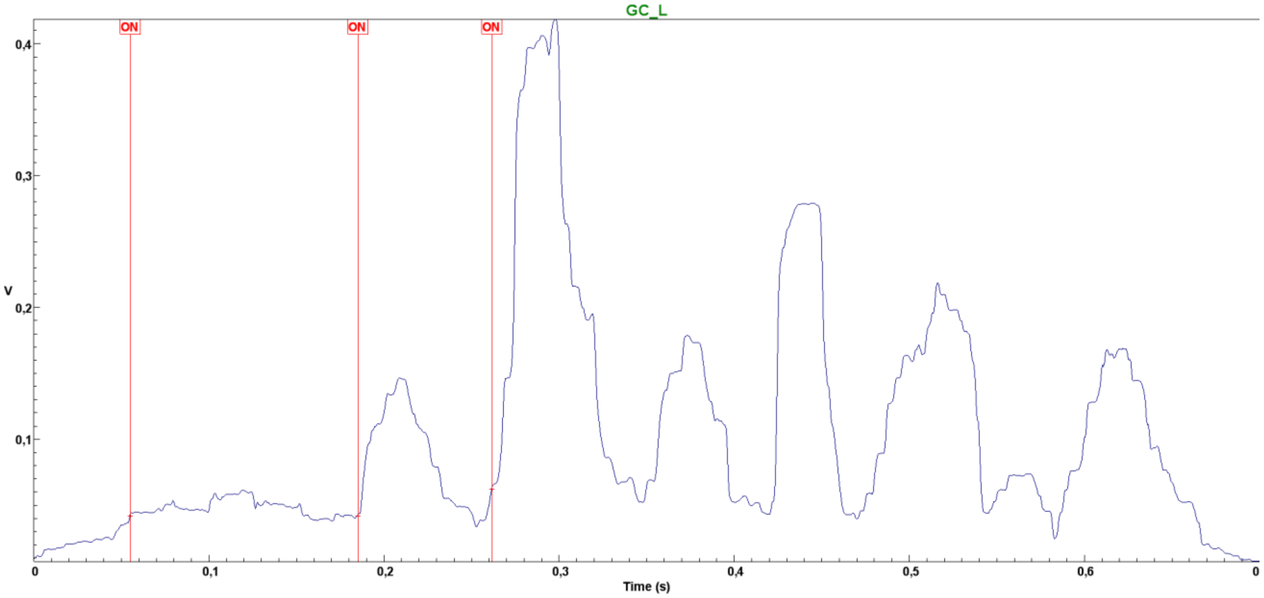

CPVM_L
ON
N
0,4
0,3
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)
RA_R
ON
1
0,9
0,8
0,7
0,6
V 0,5
0,4
0,3
0,2
0,1
Time (s)
RA_L
ON
ON
0,5
0,4
0,3
V
0,2
0,1
Time (s)


ES_R
ON
V
Time (s)

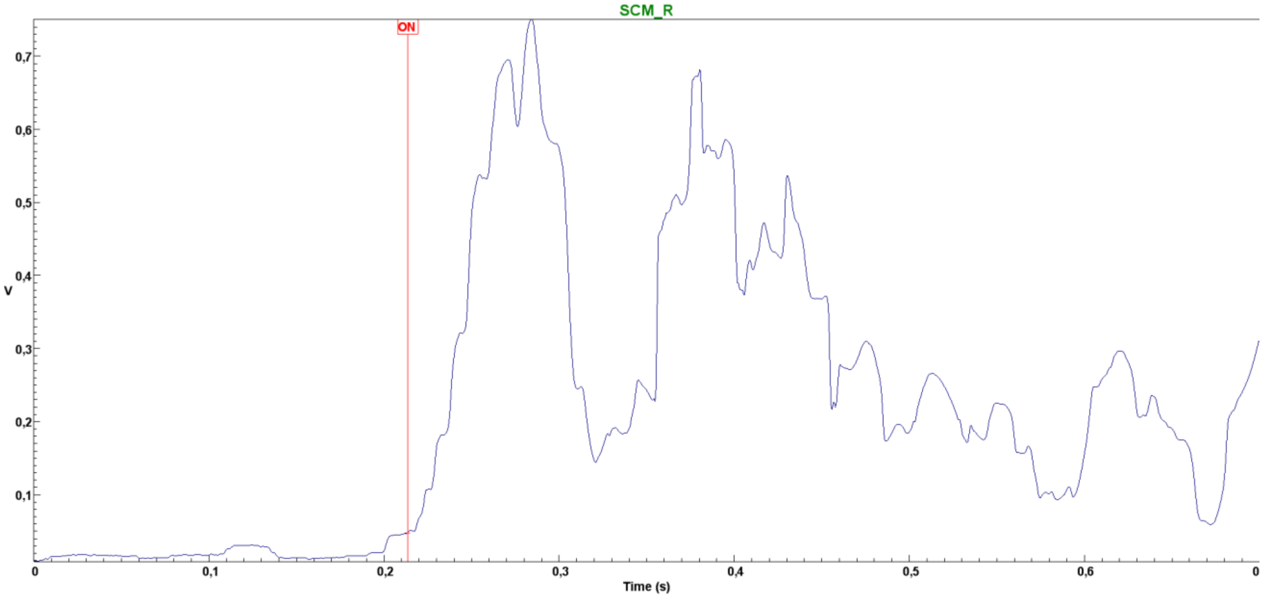

ES_L
ON
V
Time (s)

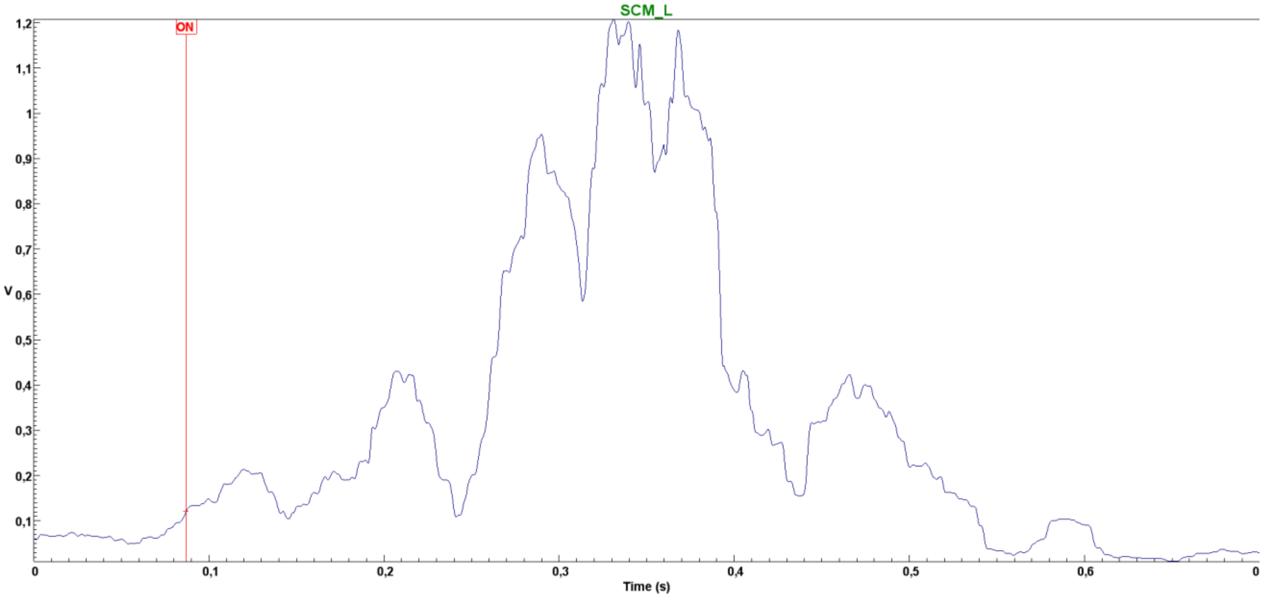

RF_L
ON
V
Time (s)

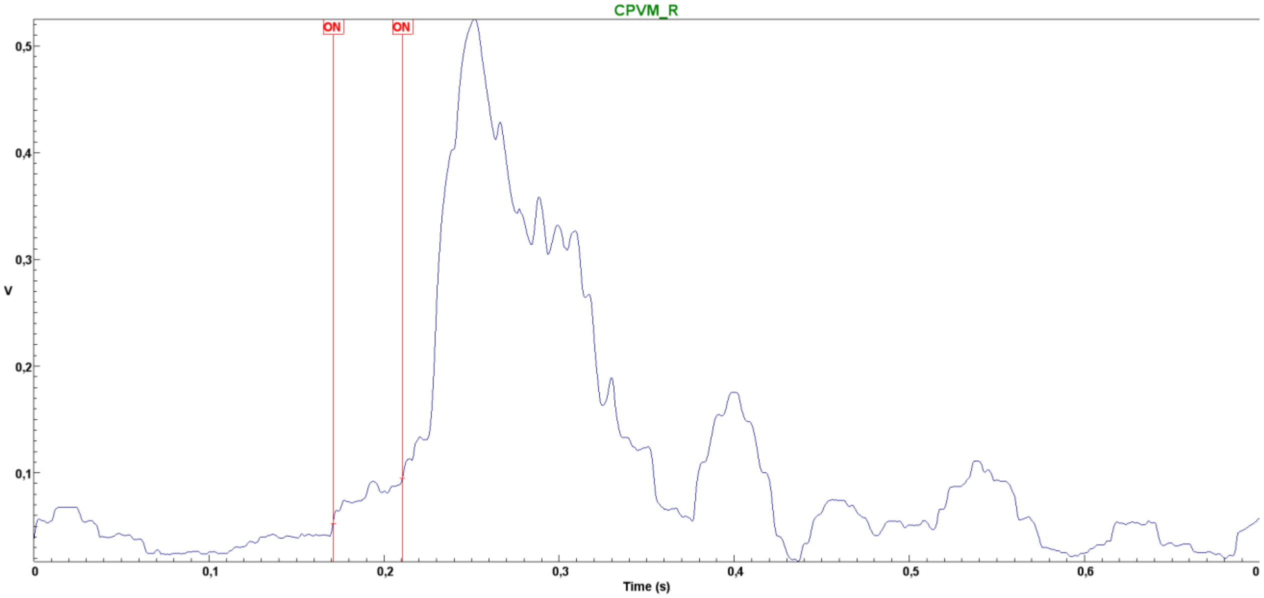

GC_R
ON
ON
0,3
0,2
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

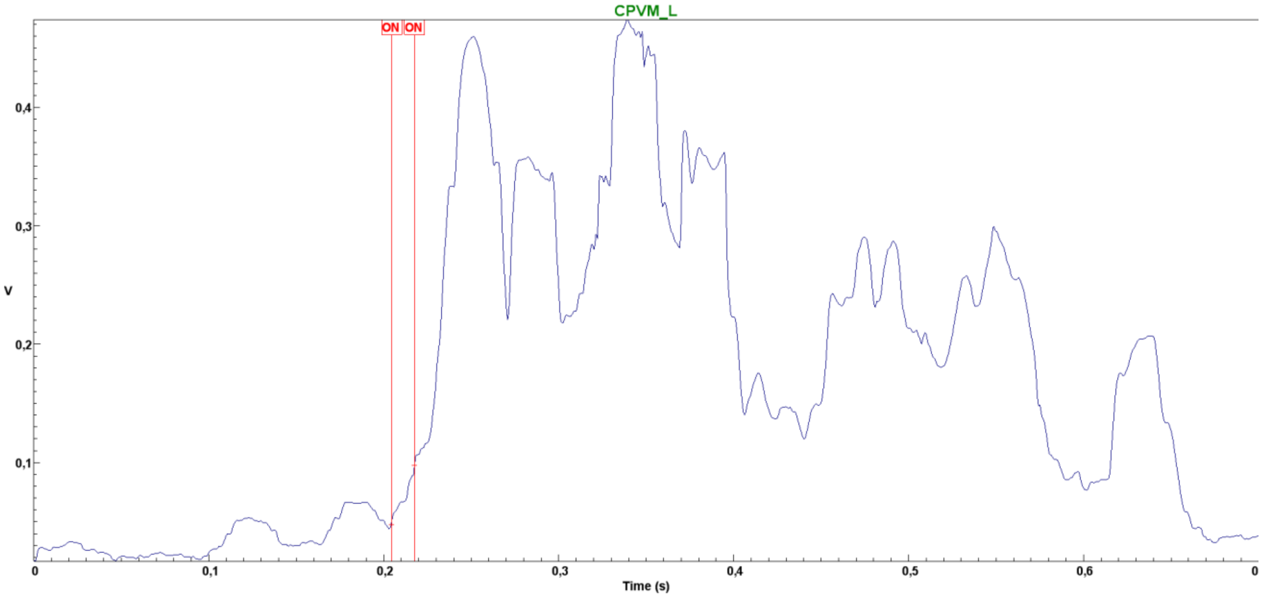

GC_L
ON
ON
ON
0,4
0,3
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

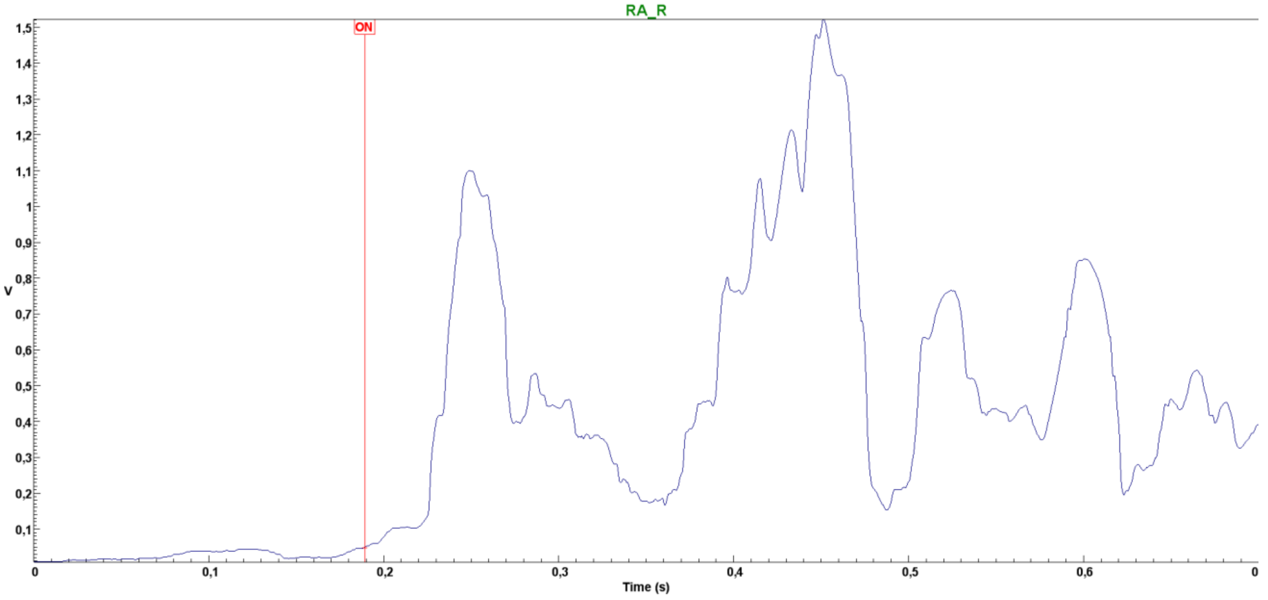
Trial 1769:

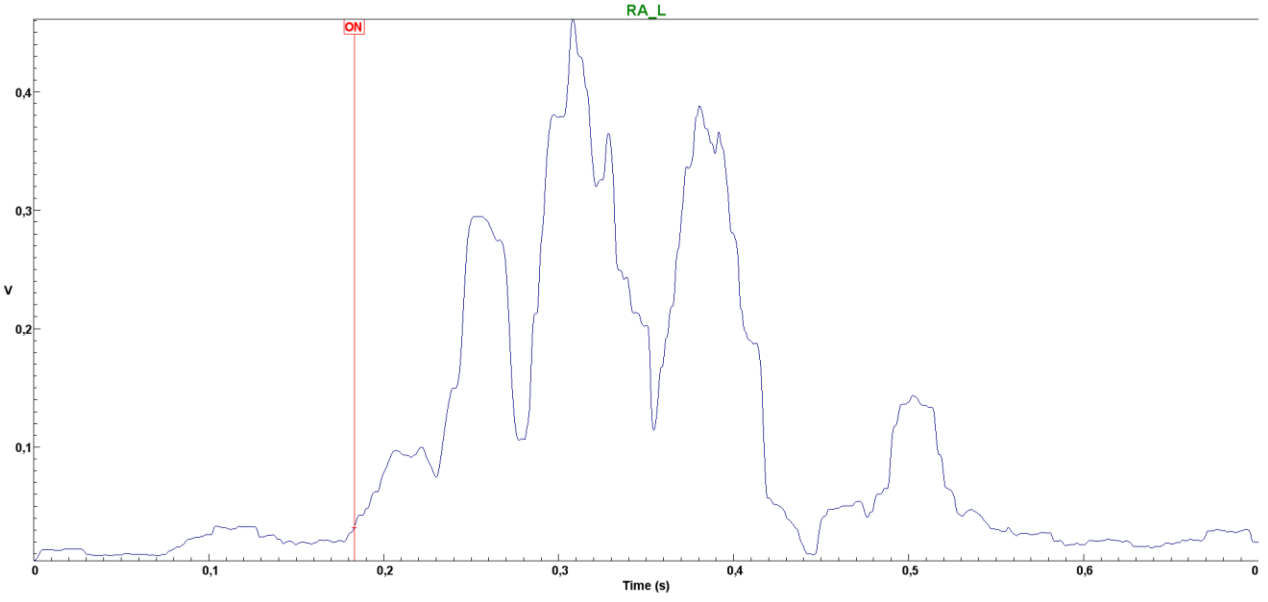

SCM_R
ON
0,7
0,6
0,5
0,4
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

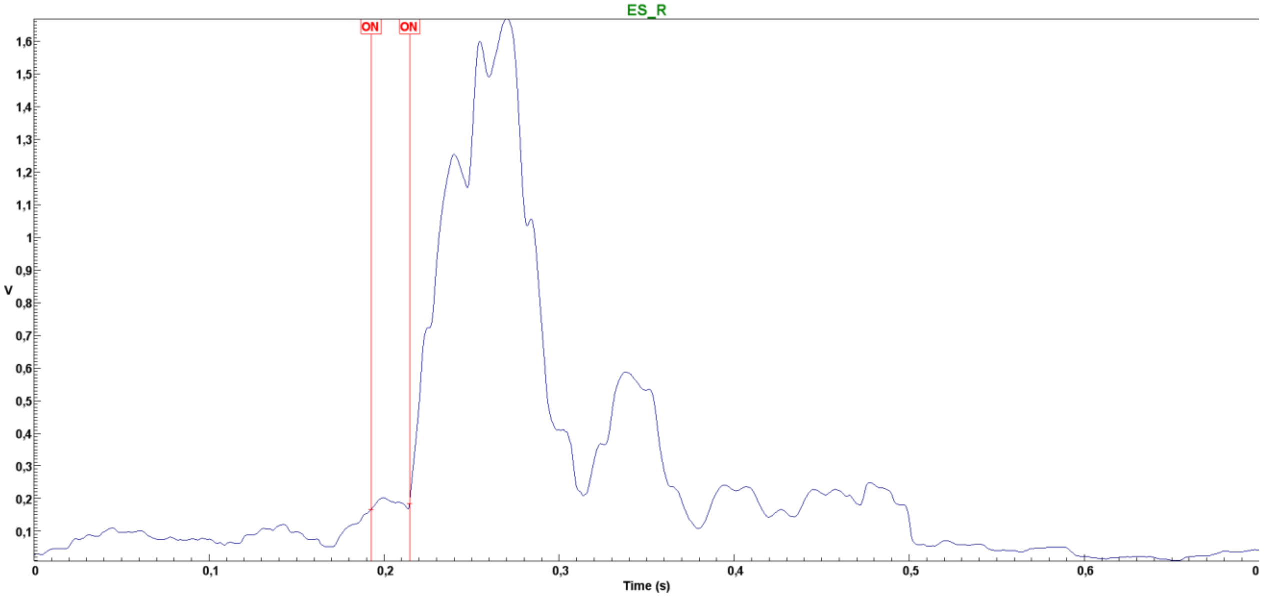

SCM_L
ON
1,2
1,1
1
0,9
0,8
0,7
V 0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

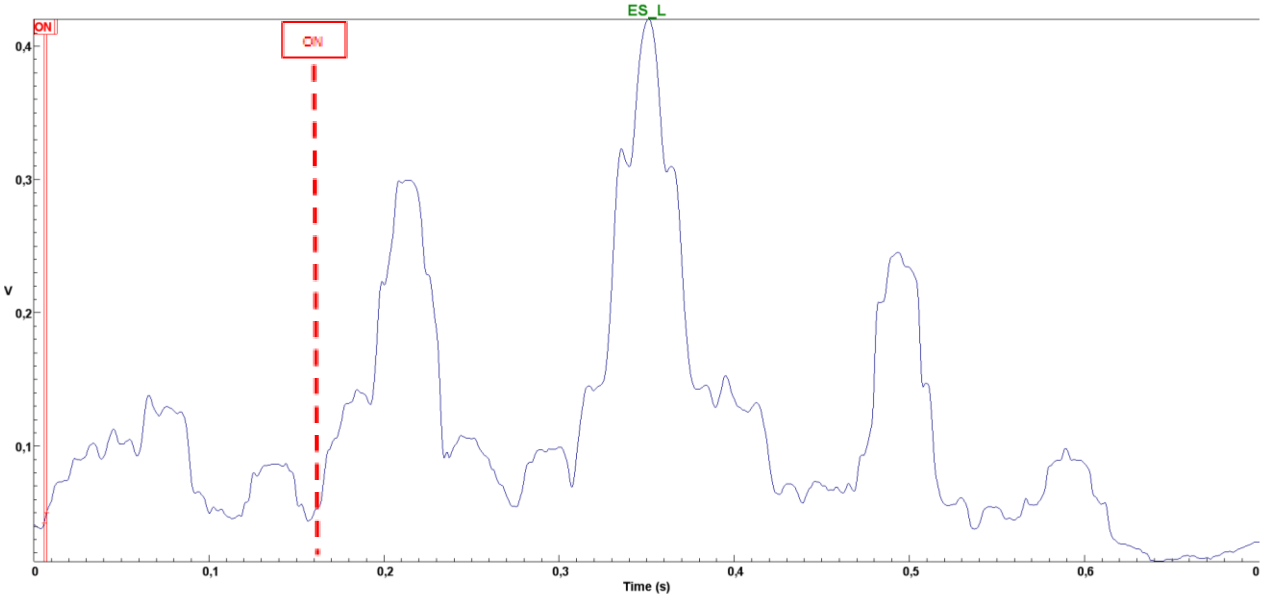

CPVM_R
ON
ON
0,5
0,4
0,3
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

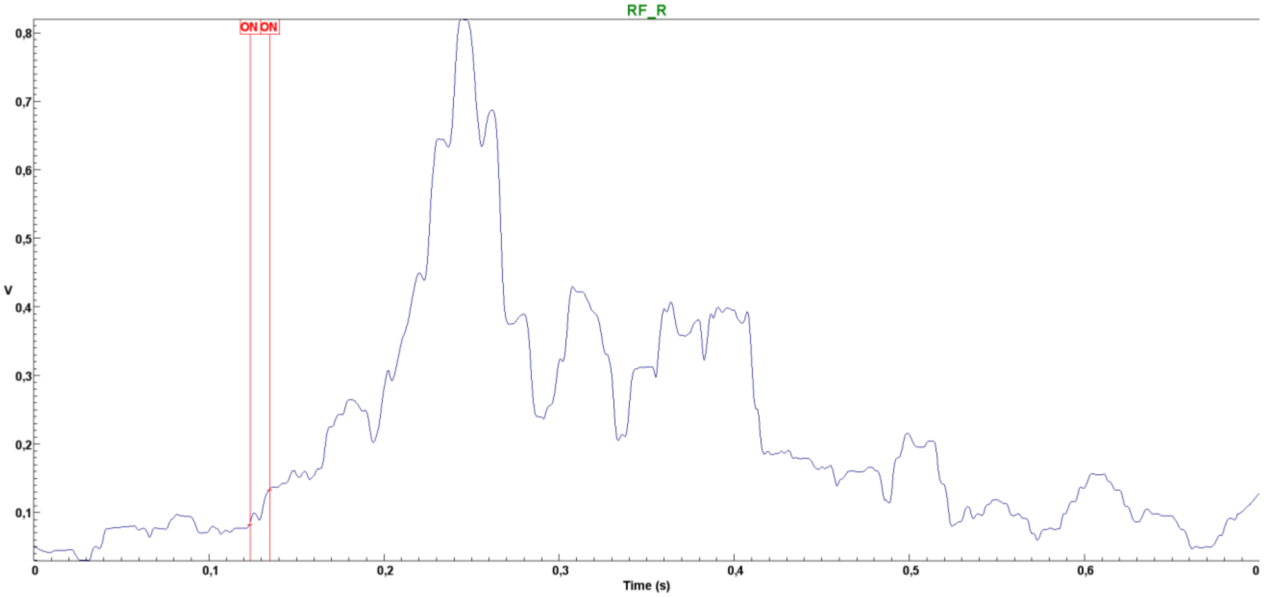

CPVM_L
ON
ON
V
Time (s)

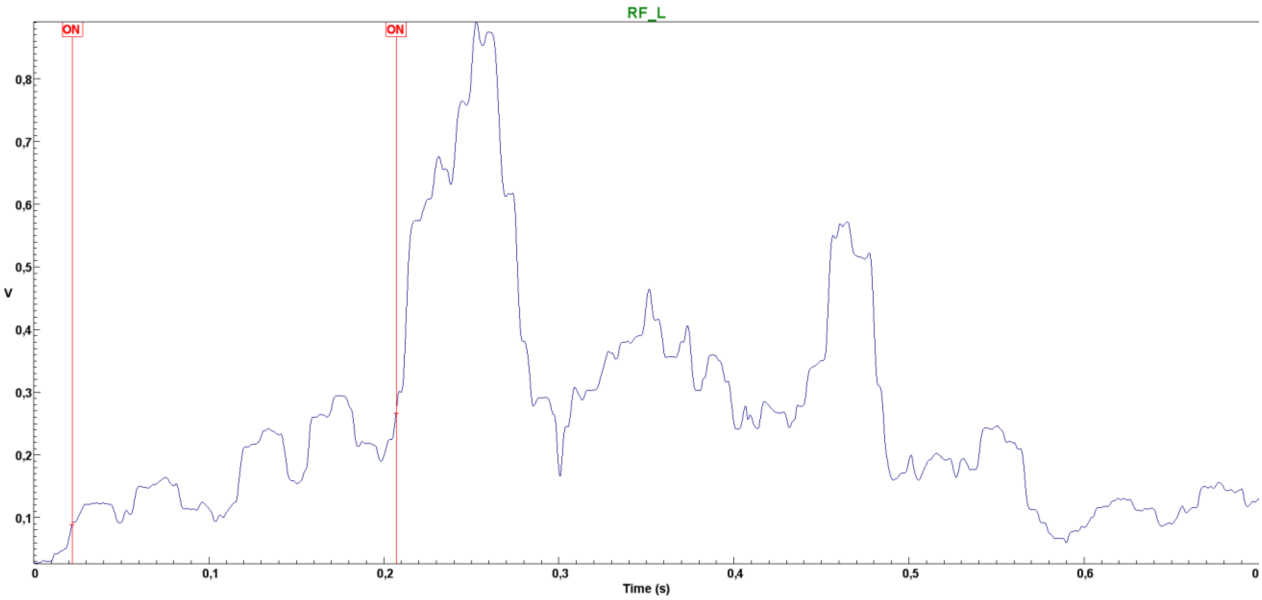

RA_R
ON
V
Time (s)

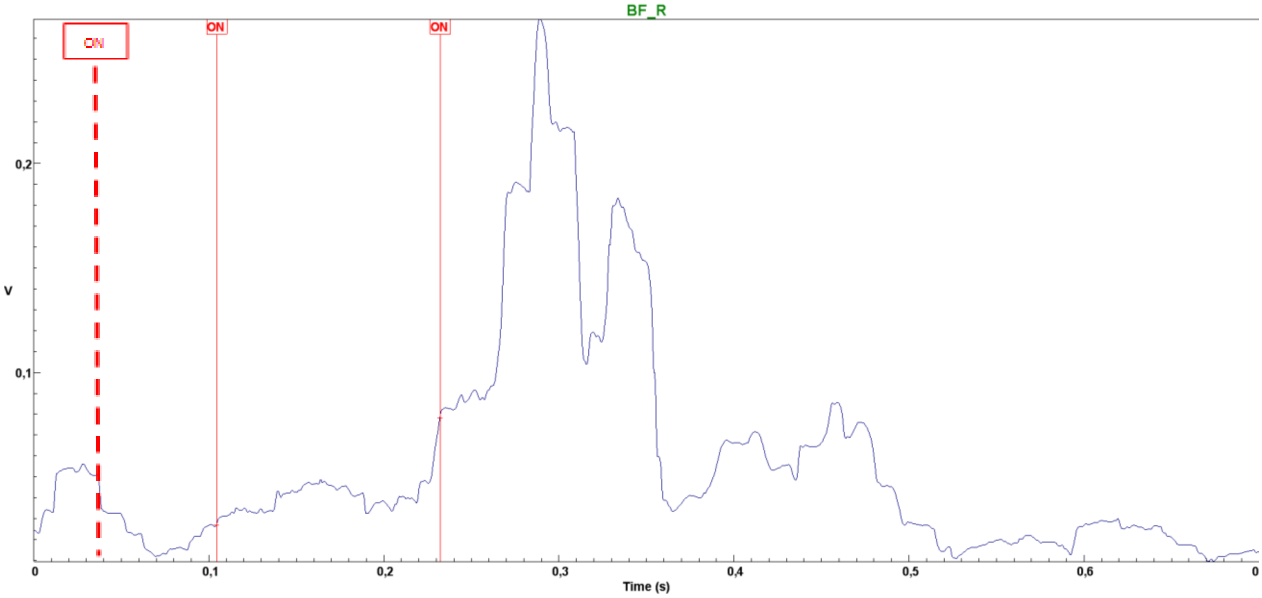

RA_L
ON
V
Time (s)

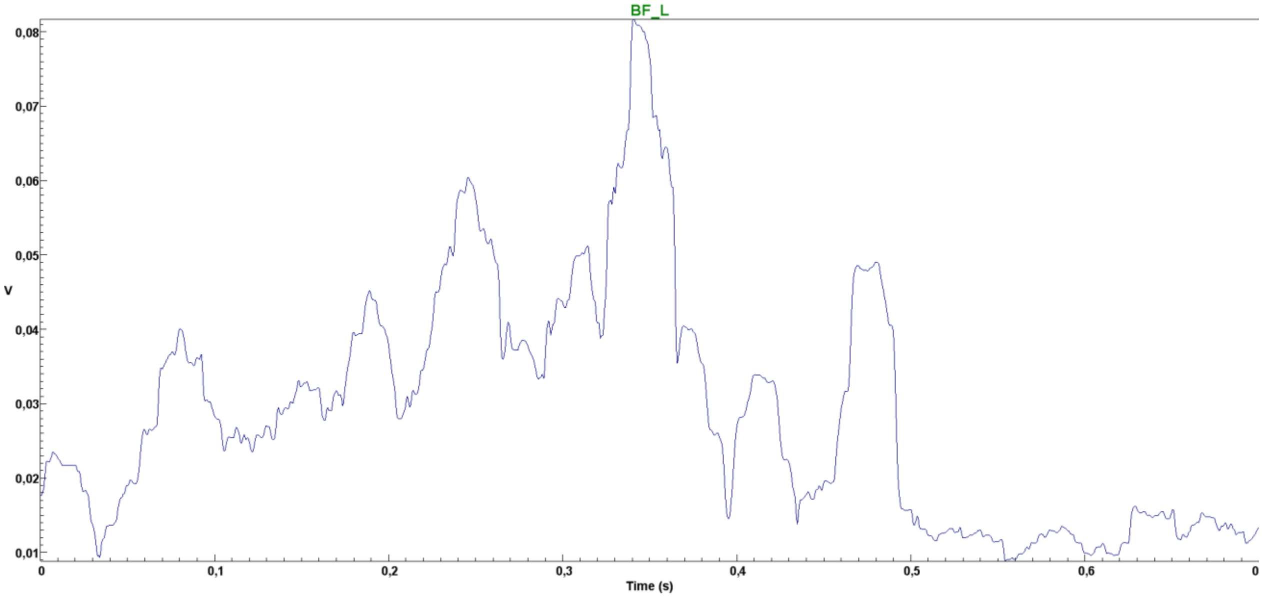

ES_R
ON
ON
V
Time (s)

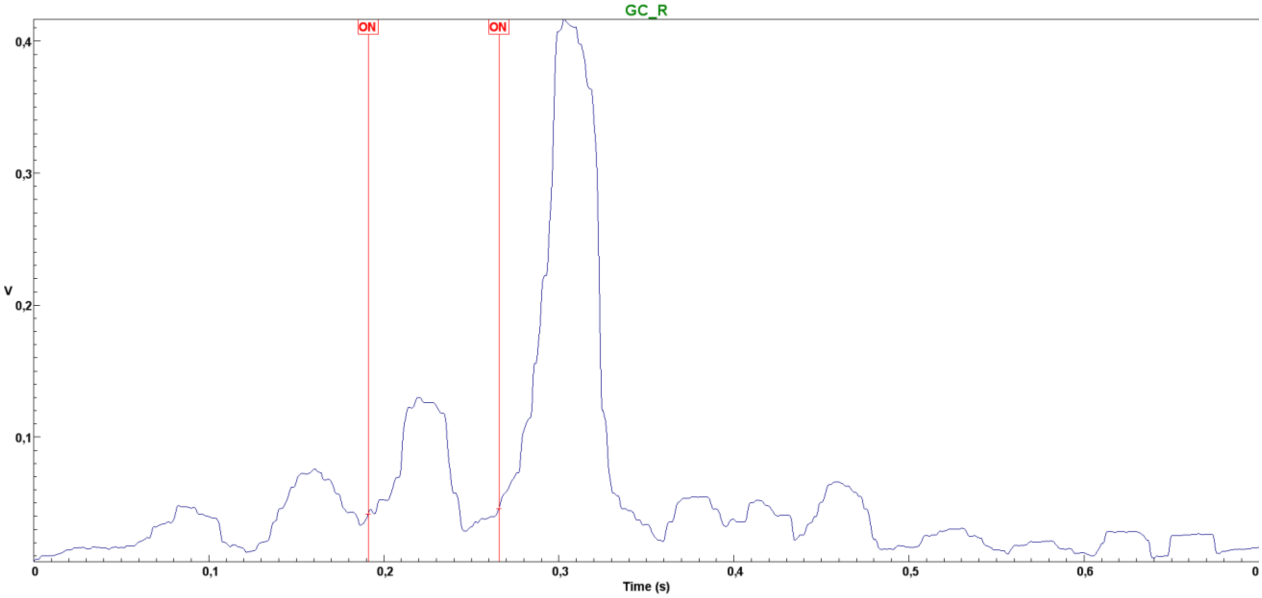

ES_L
ON
ON
V
Time (s)

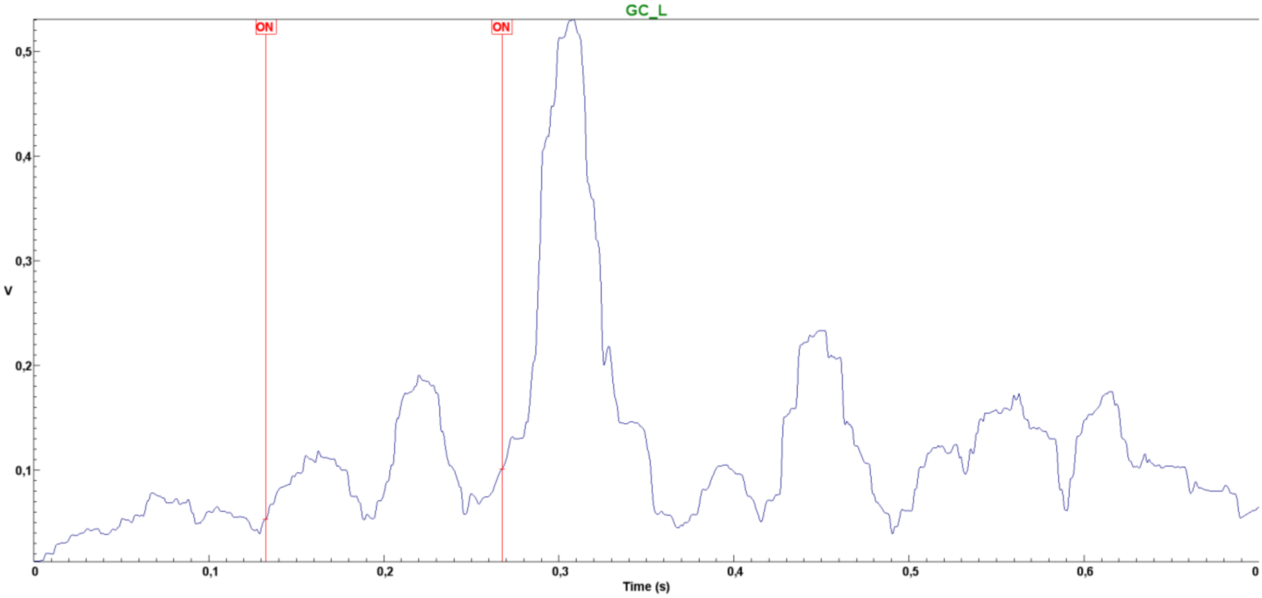

RF_R
ON
ON
V
Time (s)


RF_L
ON
ON
V
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

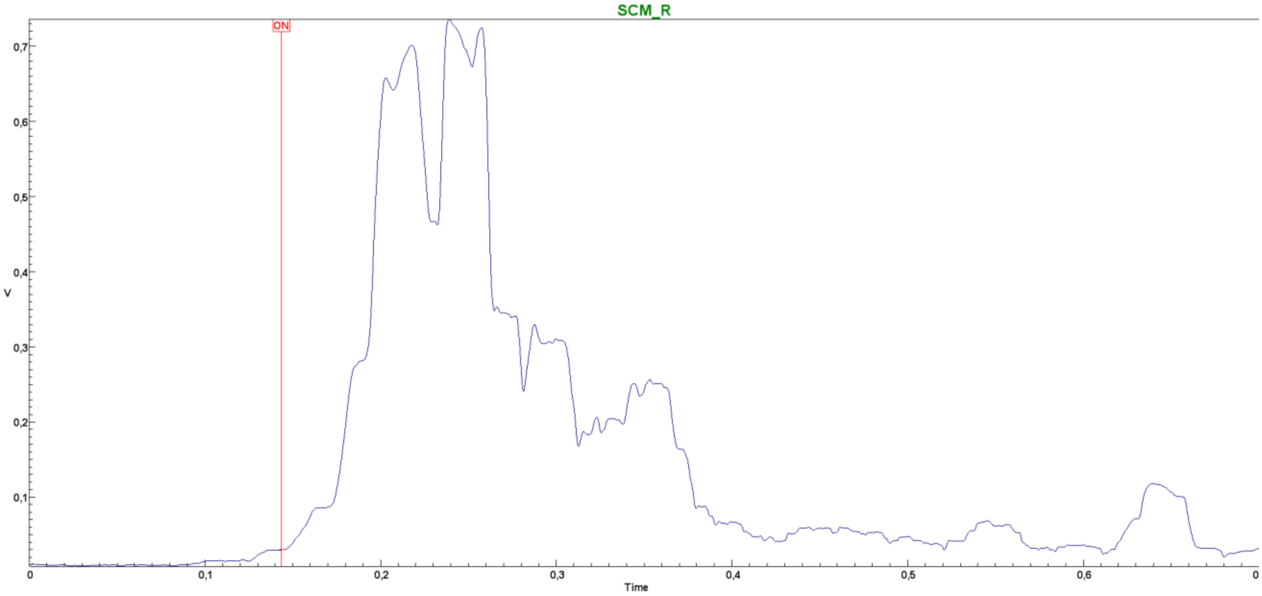

BF_R
ON
ON
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

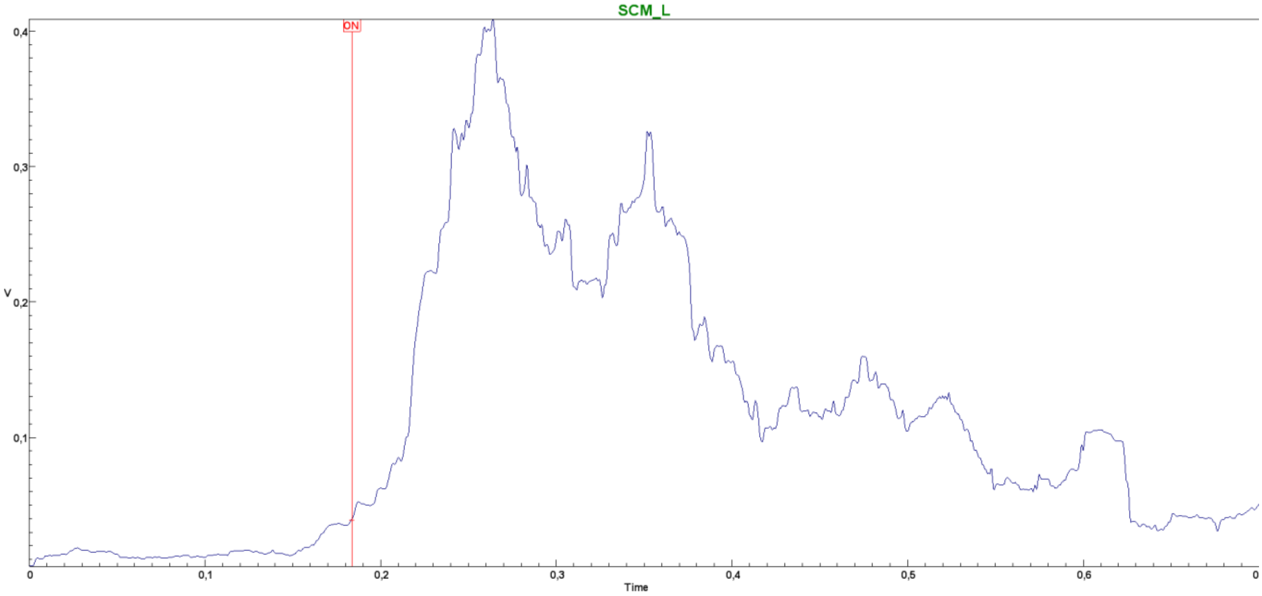

BF_L
V
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

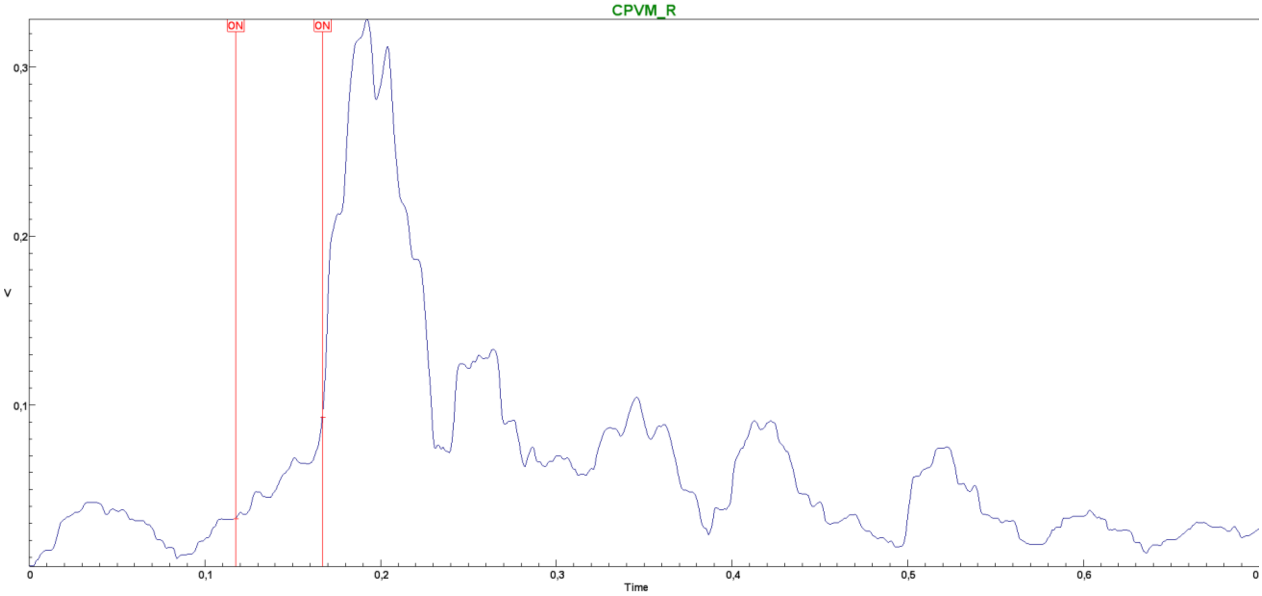

GC_R
ON
ON
0,4
0,3
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

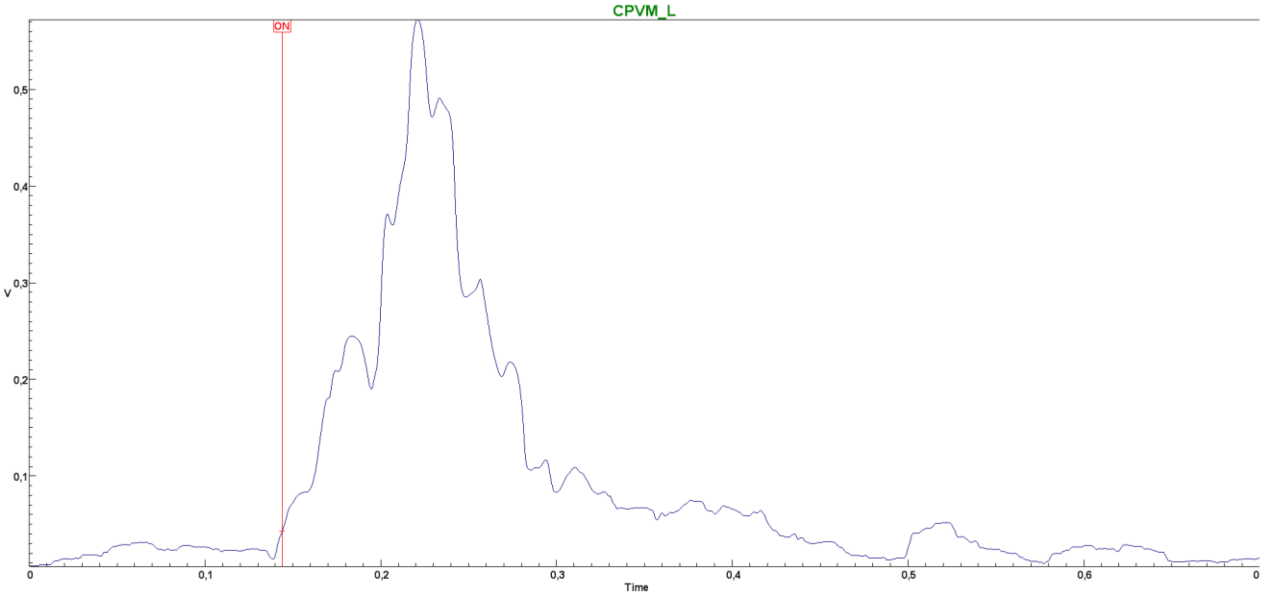

GC_L
ON
ON
0,5
0,4
0,3
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time (s)

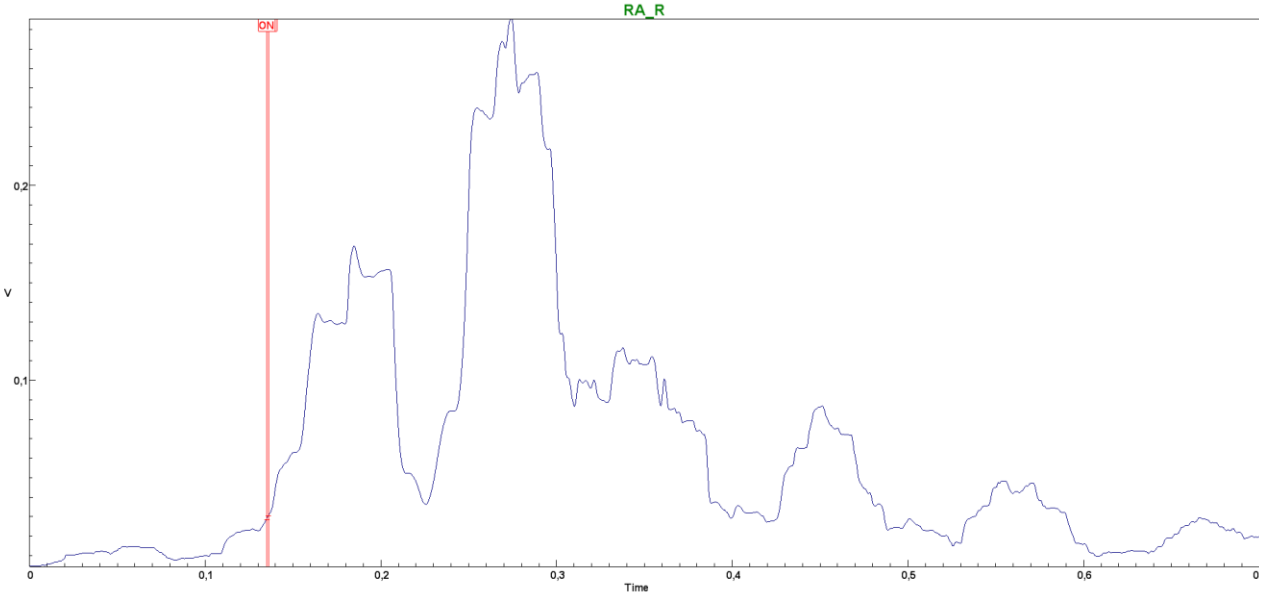
Trial 1771:

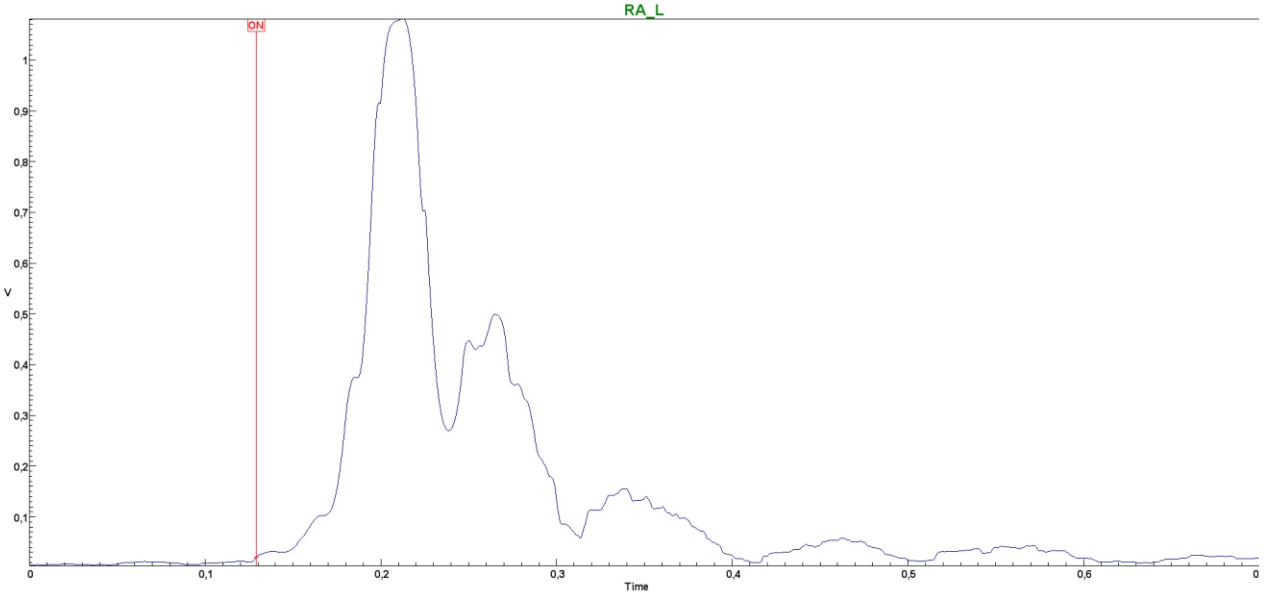

SCM_R
ON
0,7
0,6
0,5
0,4
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

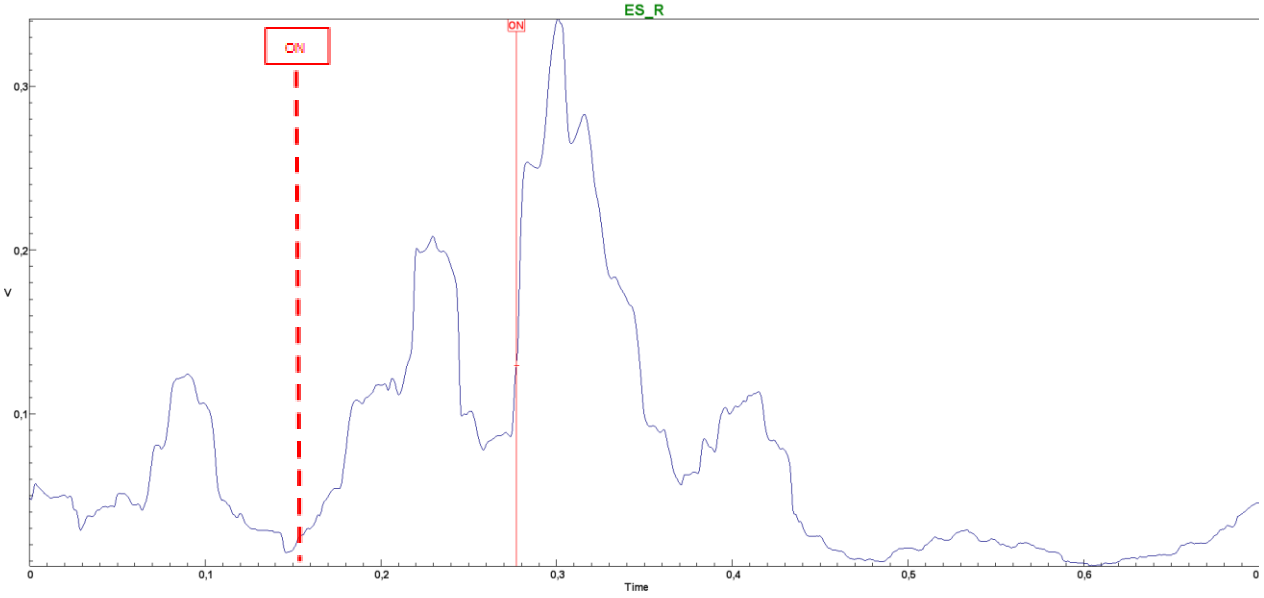

SCM_L
ON
0,4
0,3
V 0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

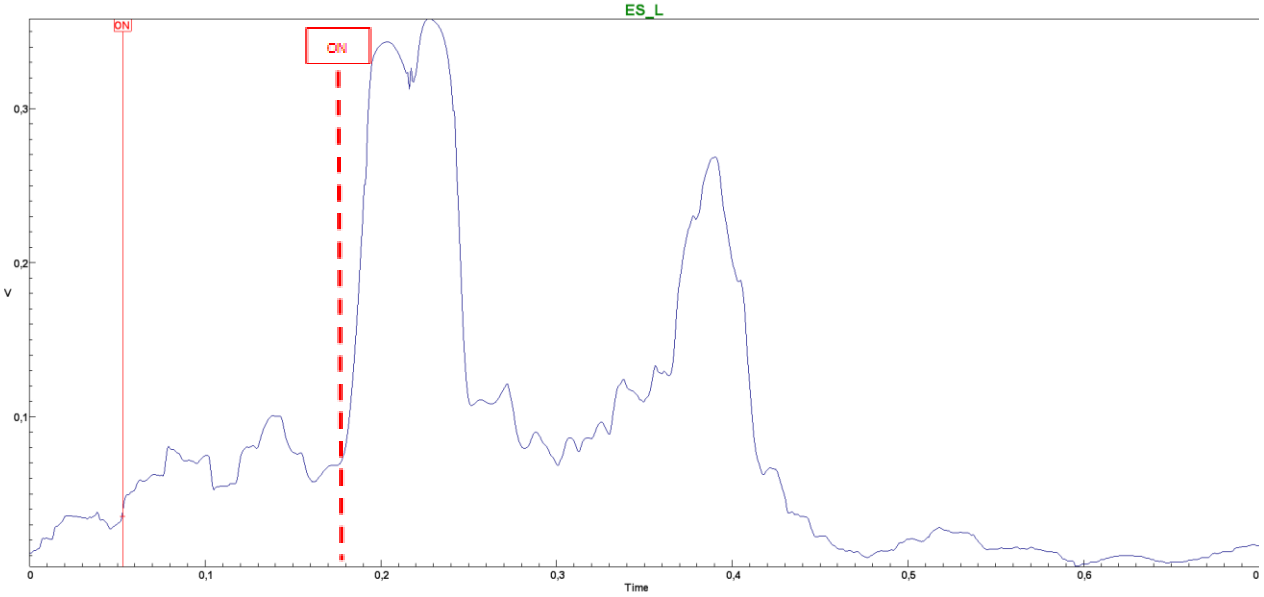

CPVM_R
ON
ON
0,3
0,2
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

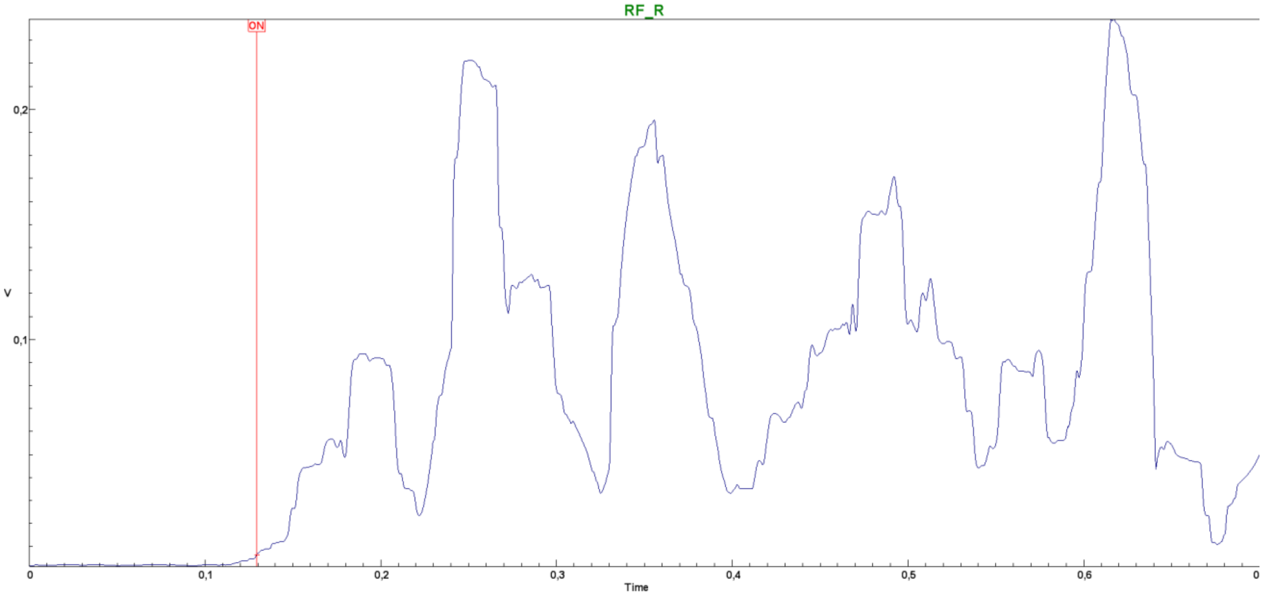

CPVM_L
ON
V
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

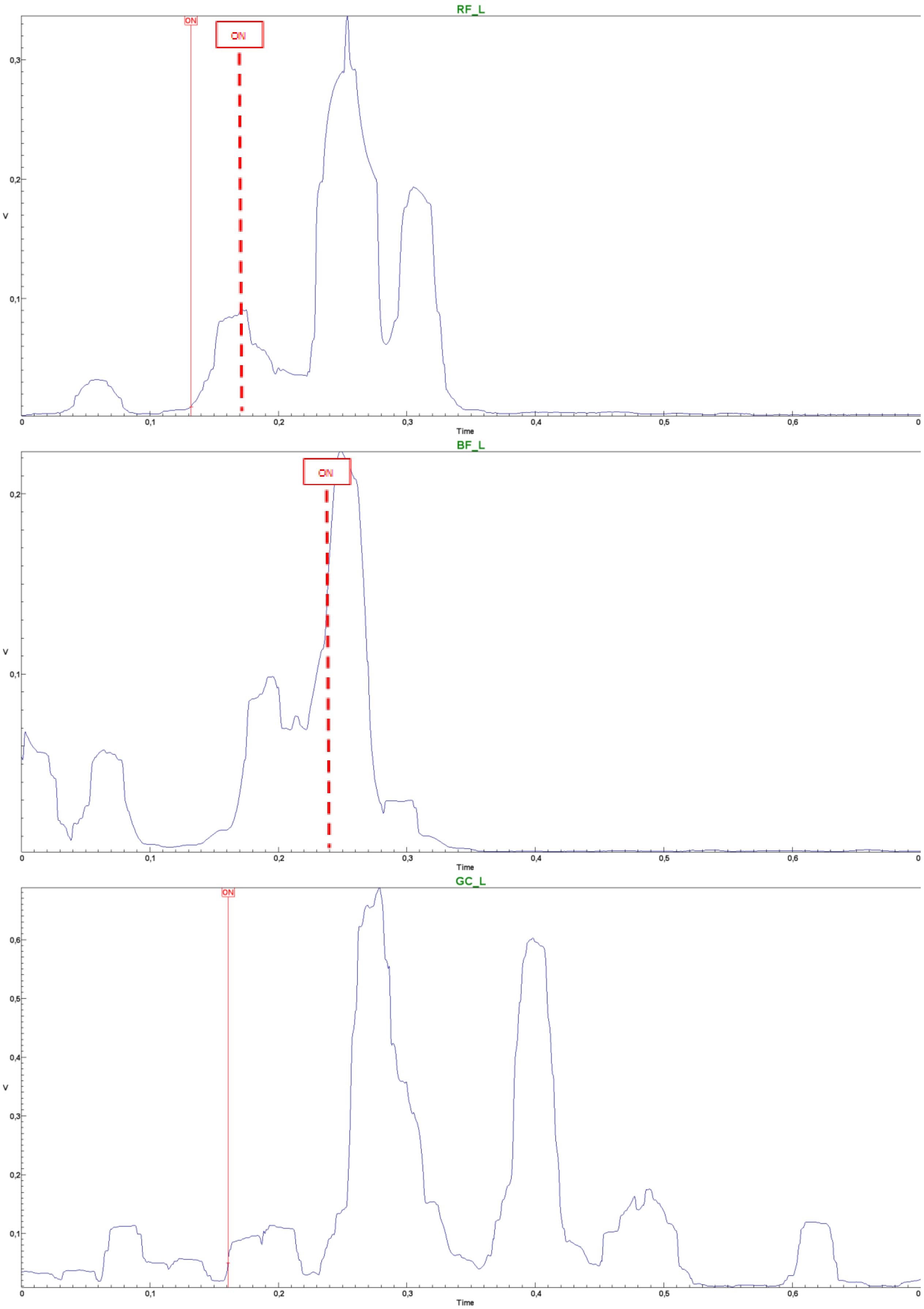

RA_R
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time


RA_L
ON
V
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

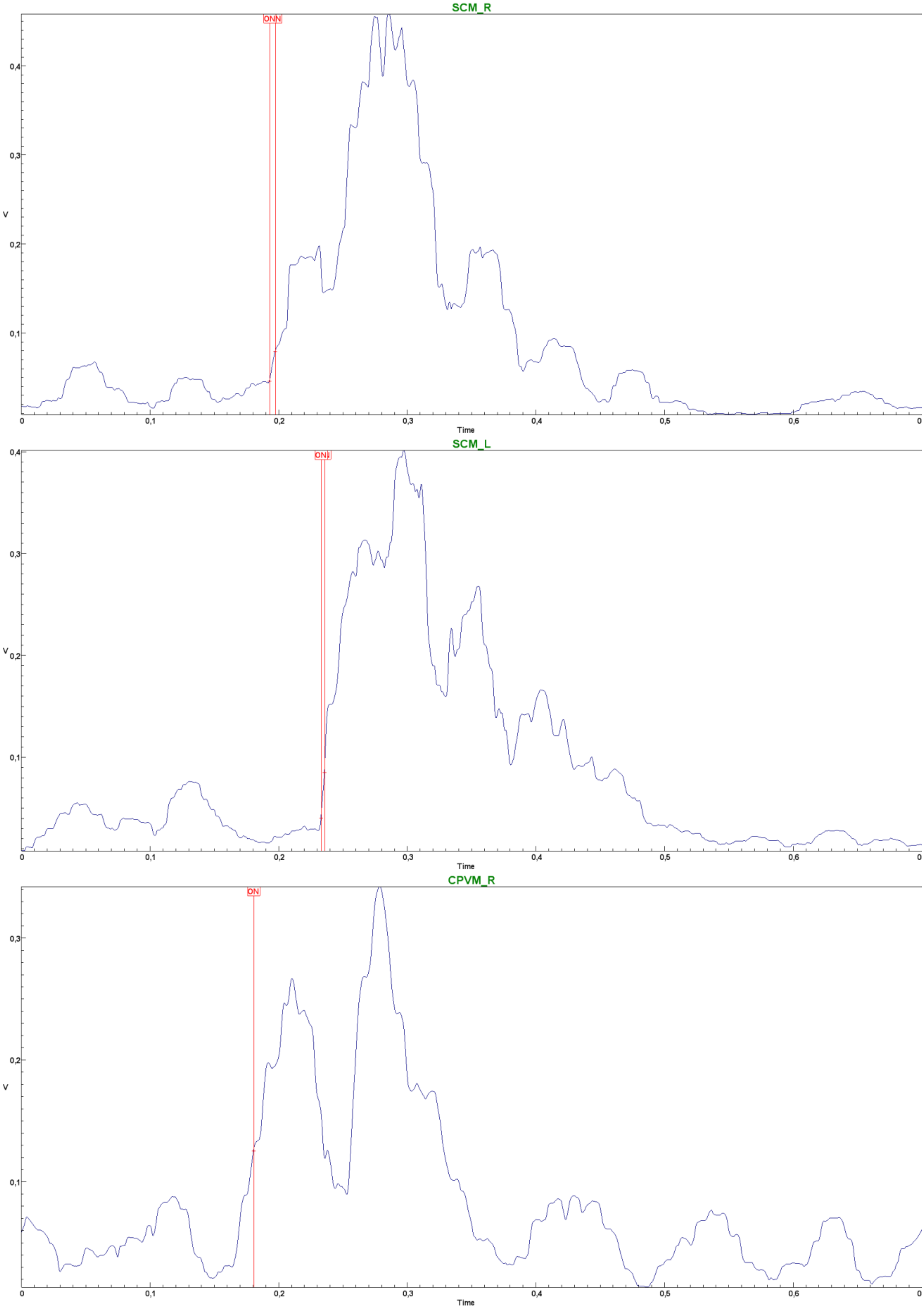

ES_R
ON
ON
0,3
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

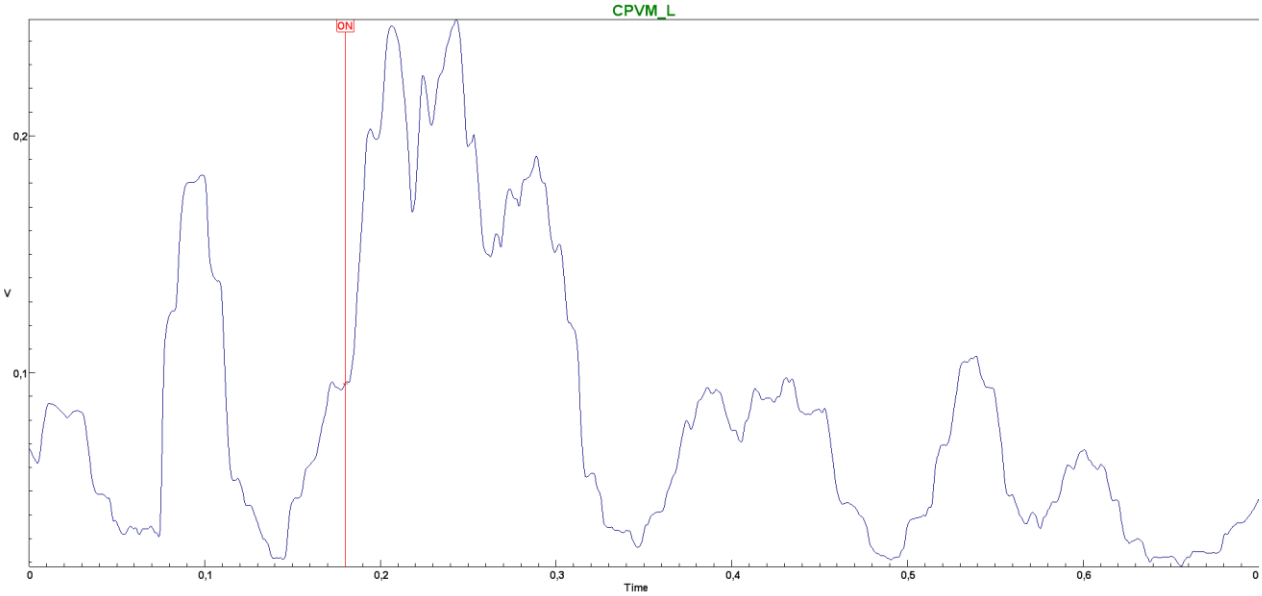

ES_L
ON
ON
0,3
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

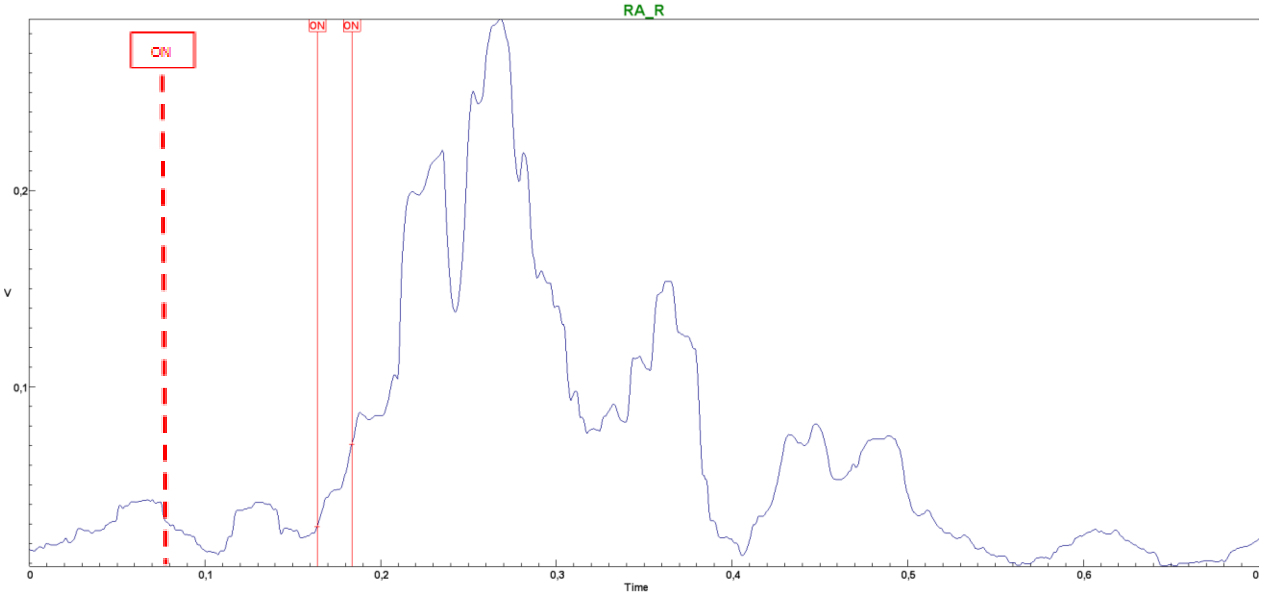

RF_R
ON
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

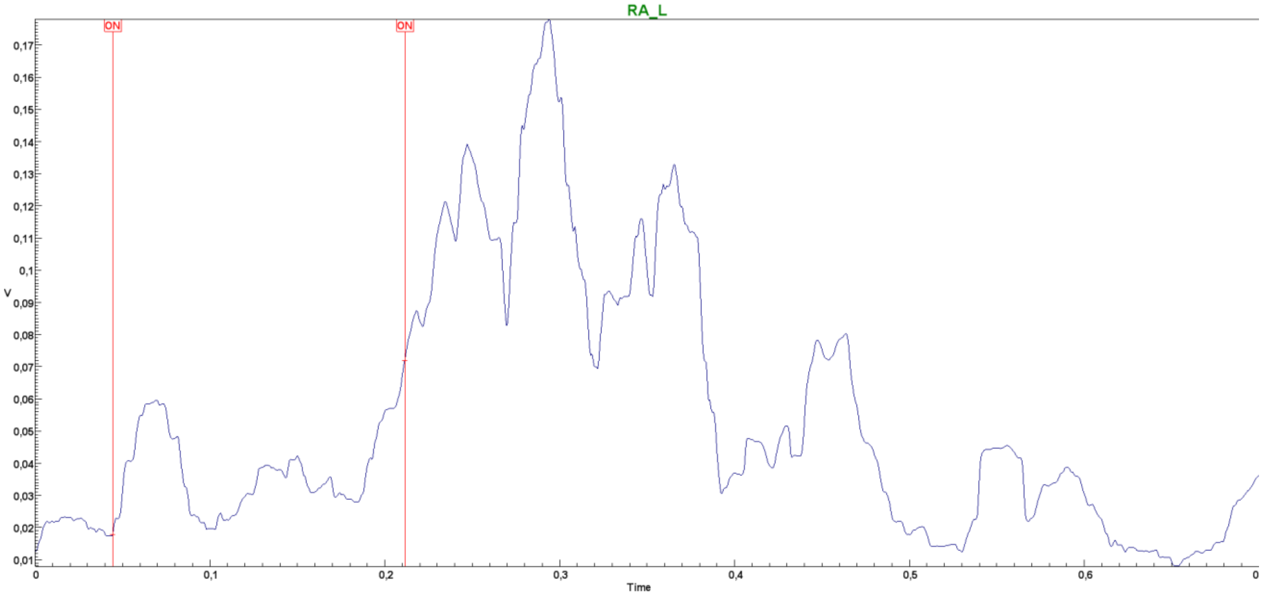

RF_L
ON
ON
0,3
0,2
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time
BF_L
ON
0,2
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time
GC_L
ON
0,6
0,5
0,4
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

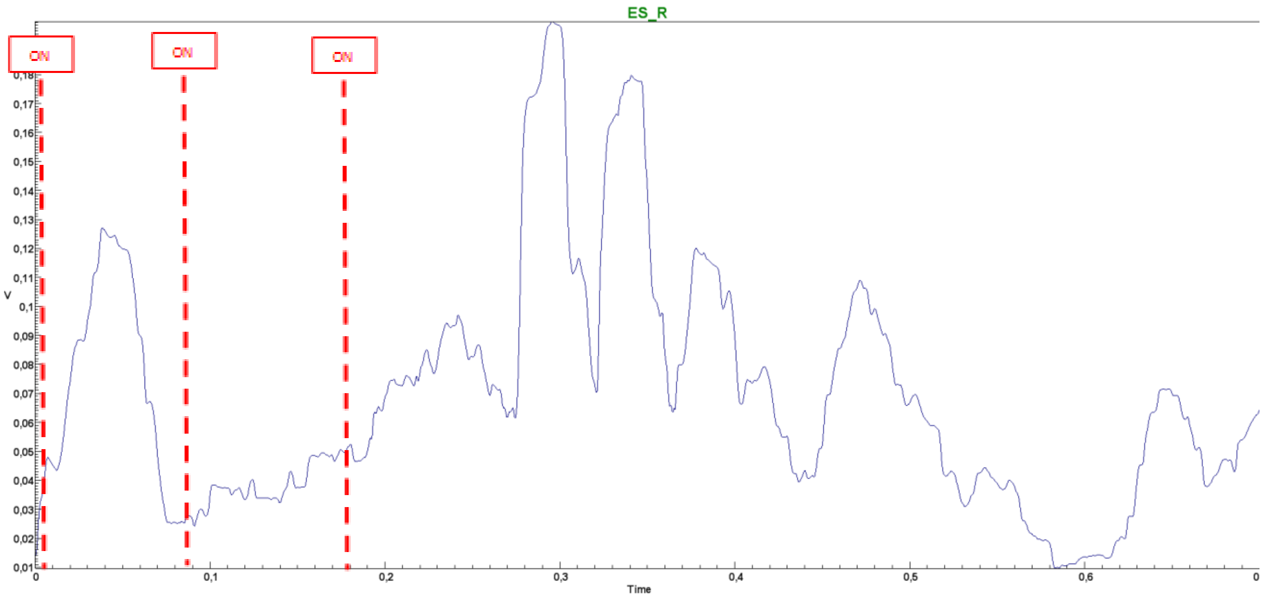
Trial 1772:

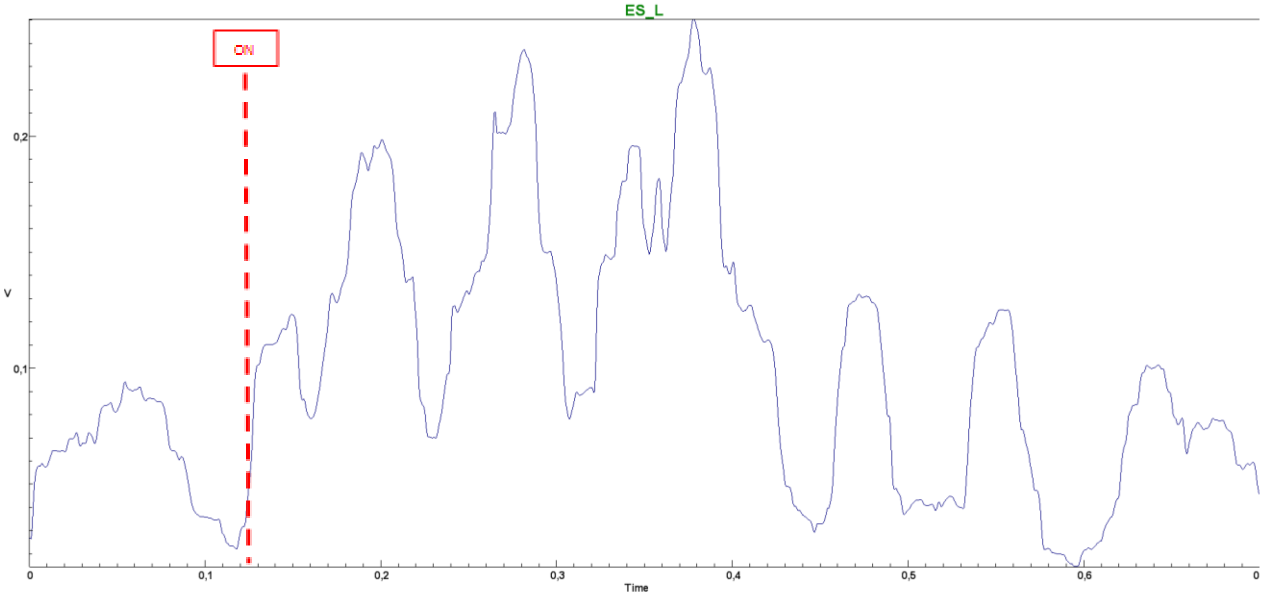


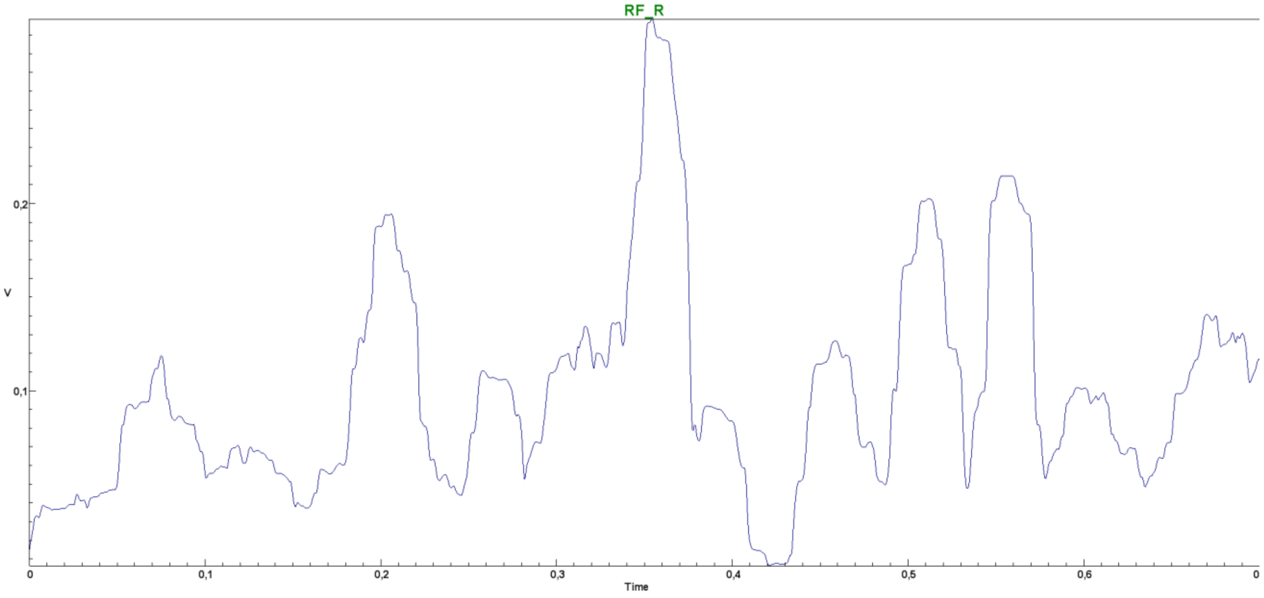

CPVM_L
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

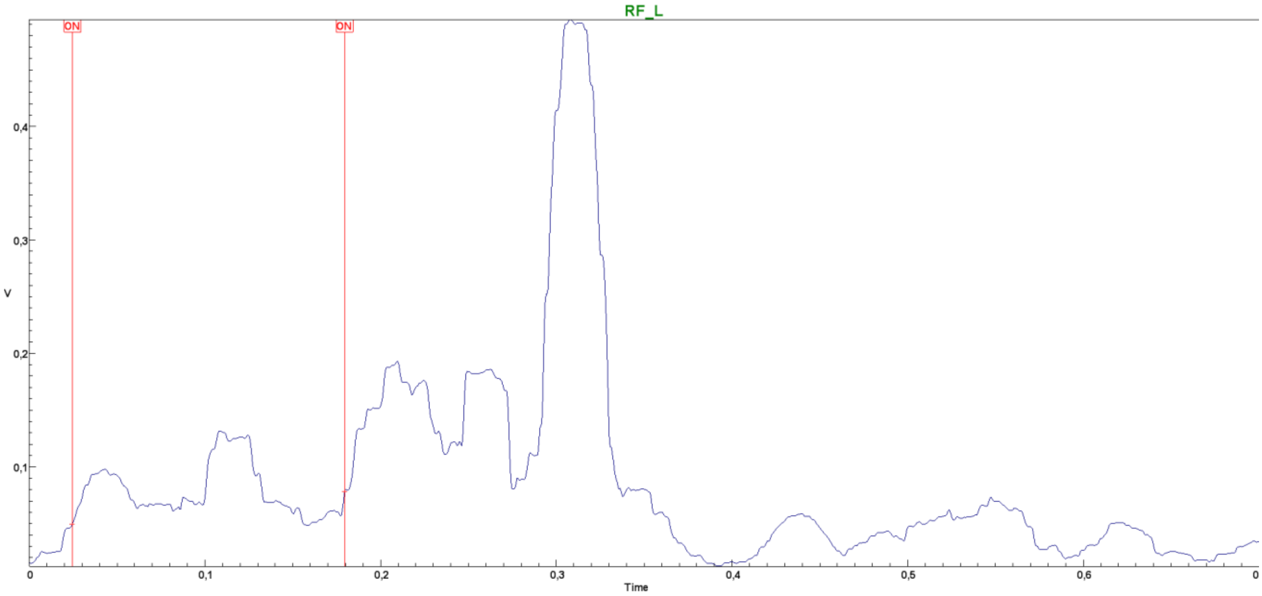

RA_R
ON
ON
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

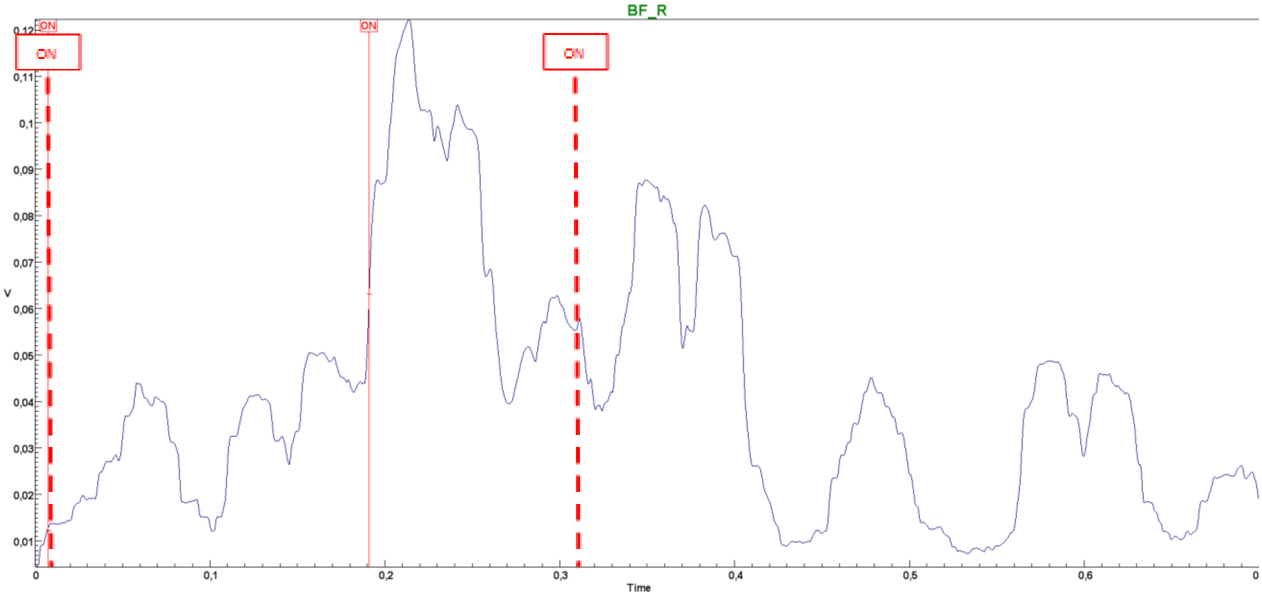

RA_L
ON
ON
V
0,17
0,16
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

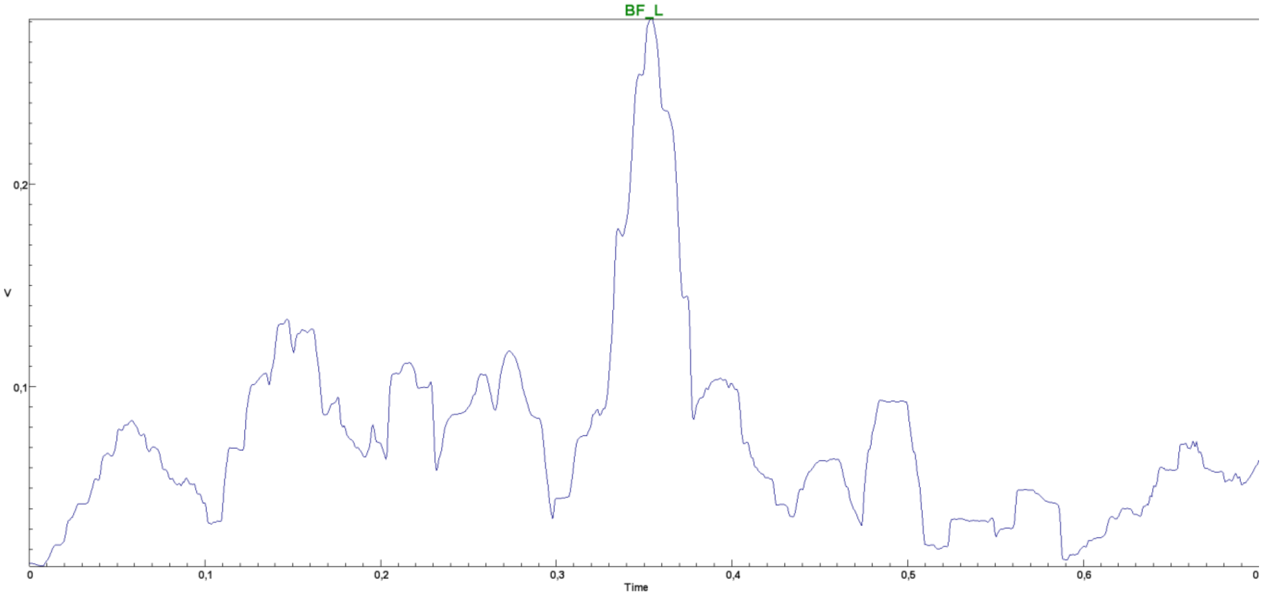

ES_R
ON
ON
ON
V
Time

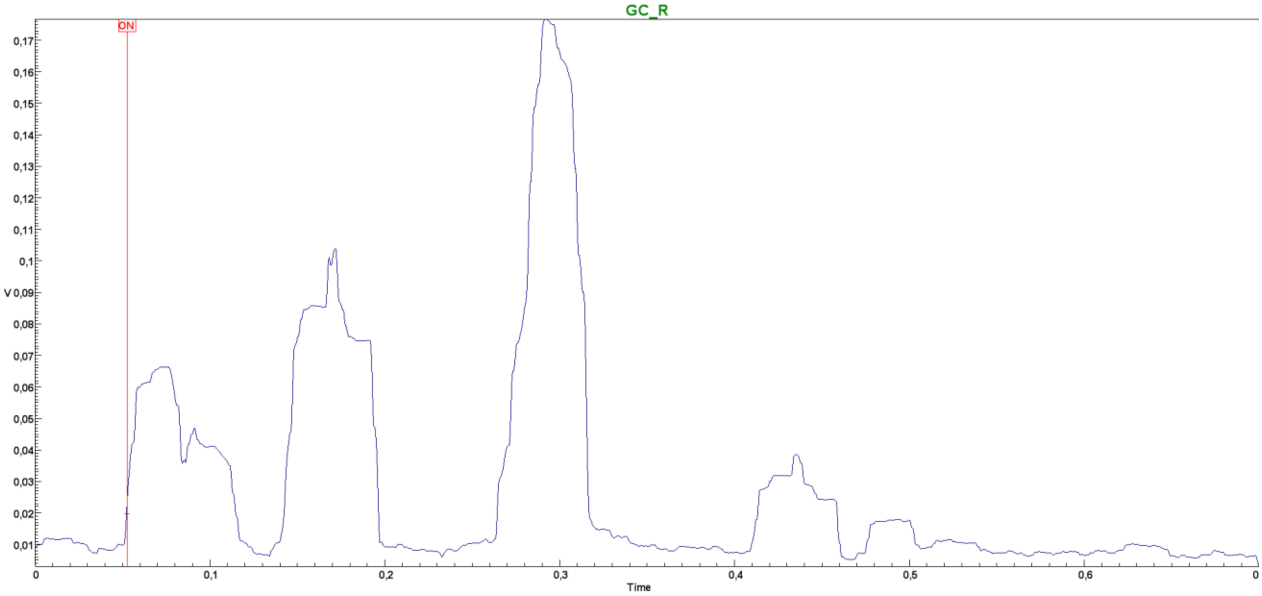

ES_L
ON
V
Time

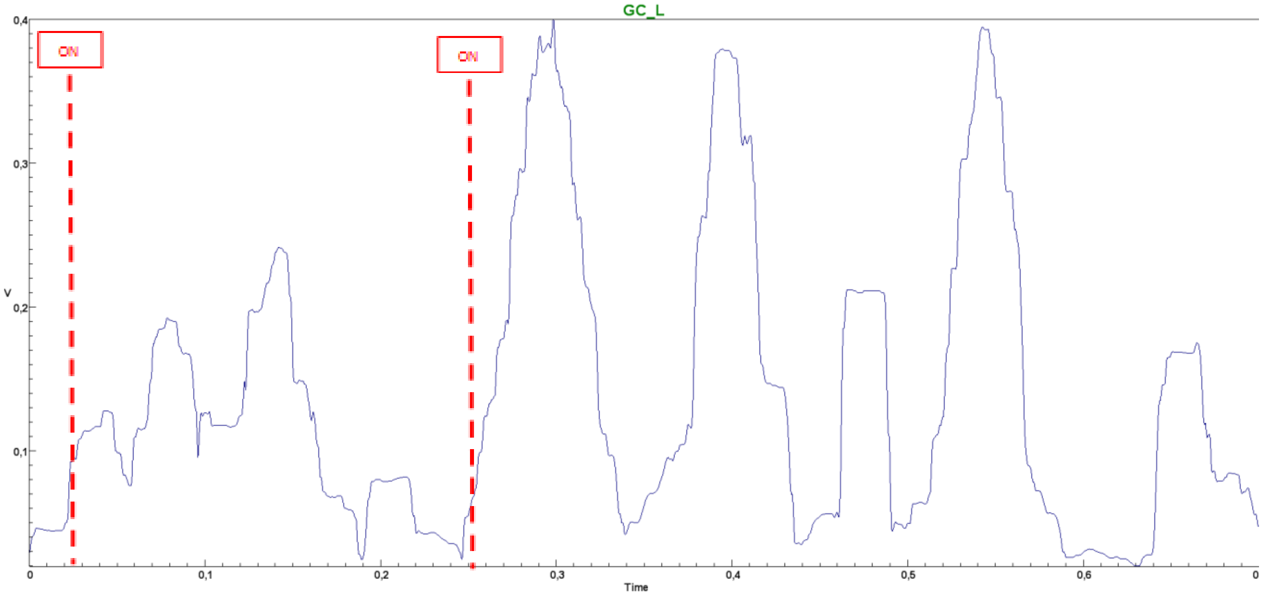

RF_R
V
Time


RF_L
ON
ON
V
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

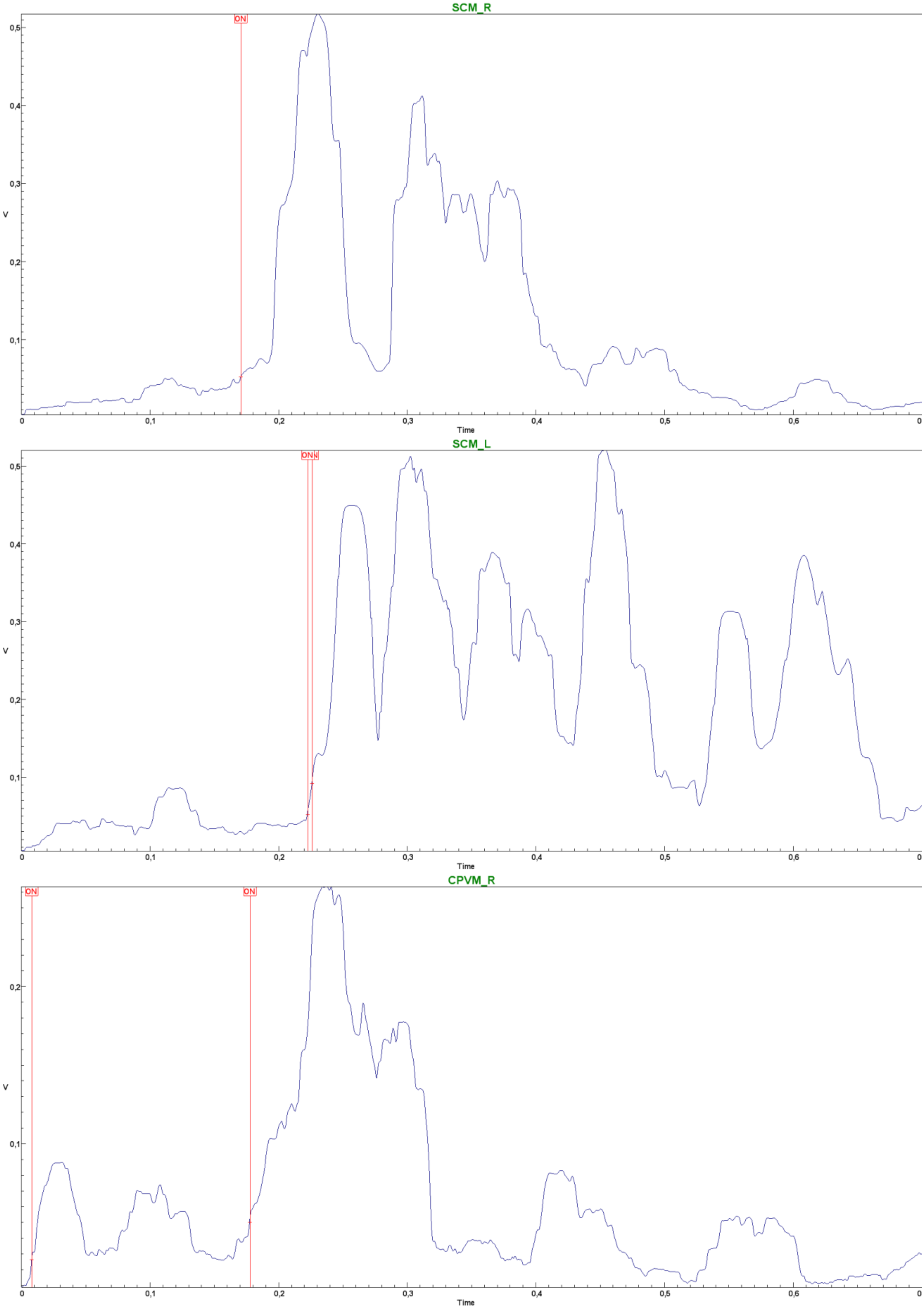

BF_R
ON
ON
ON
ON
V
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

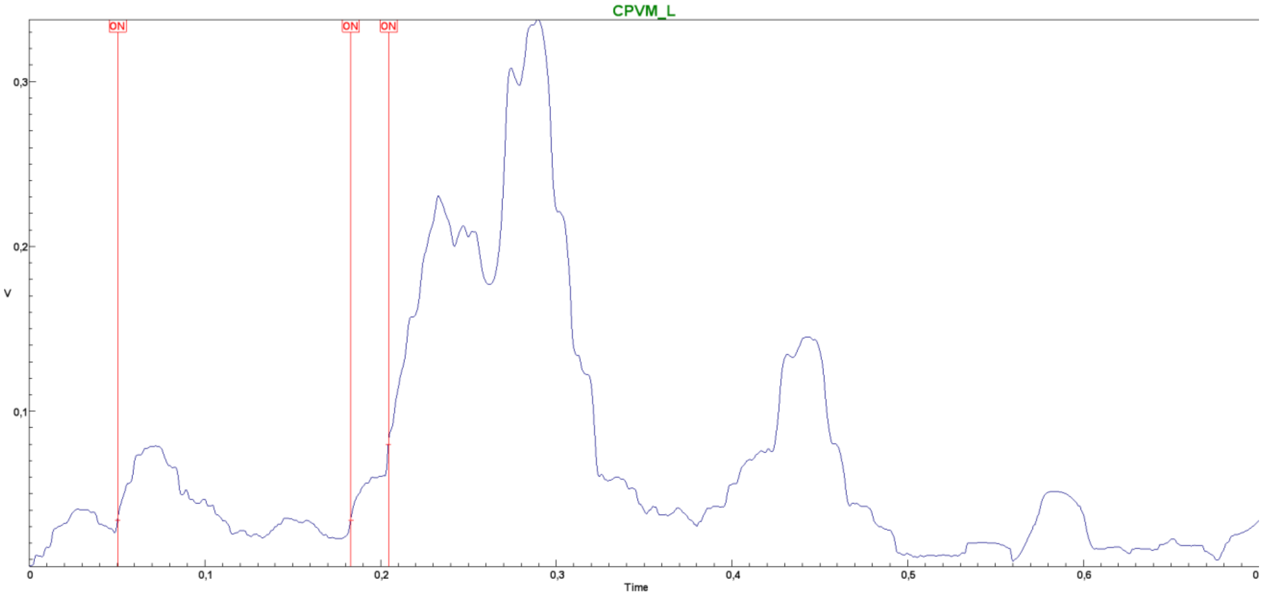

BF_L
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

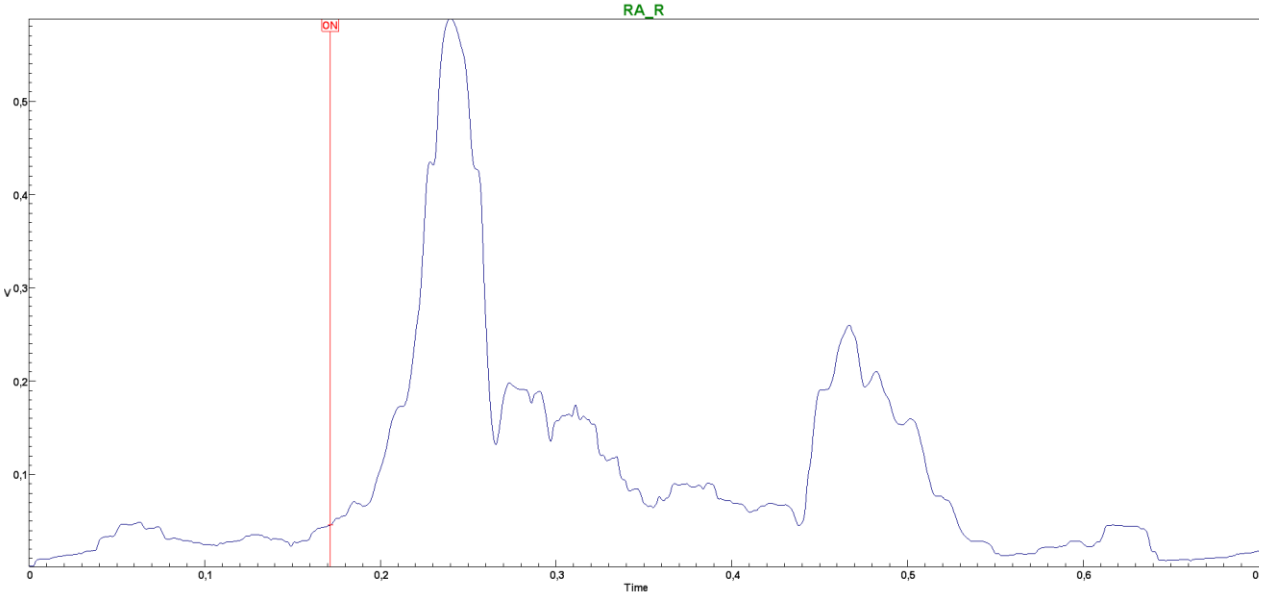

GC_R
ON
V
0,17
0,16
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

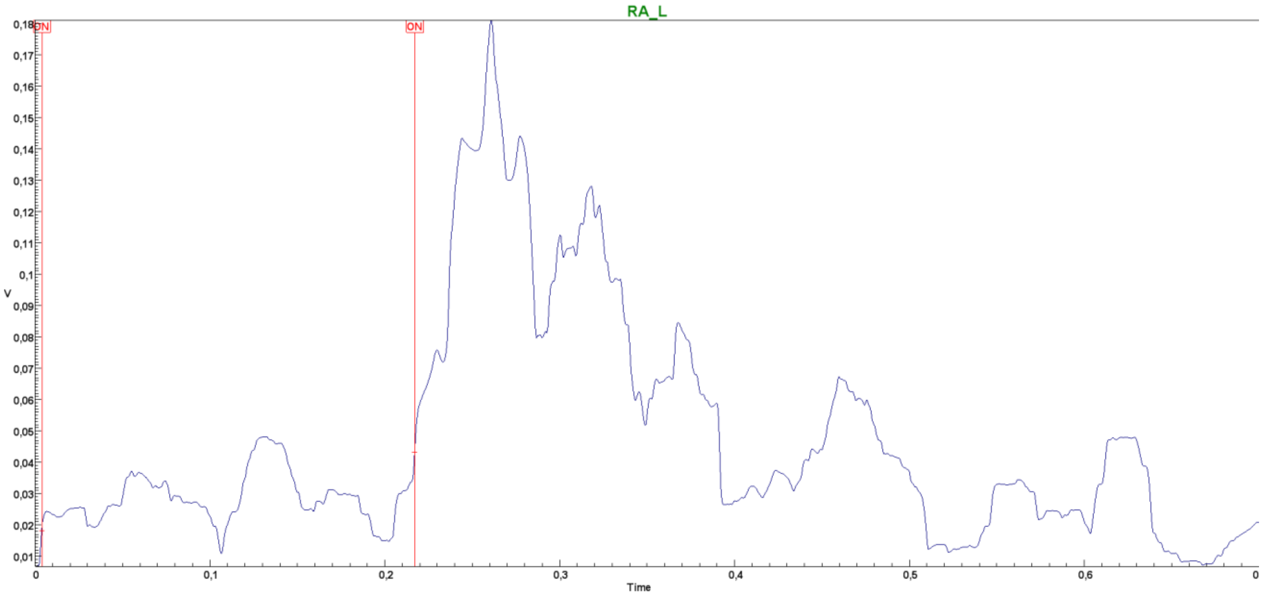

GC_L
ON
ON
V
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

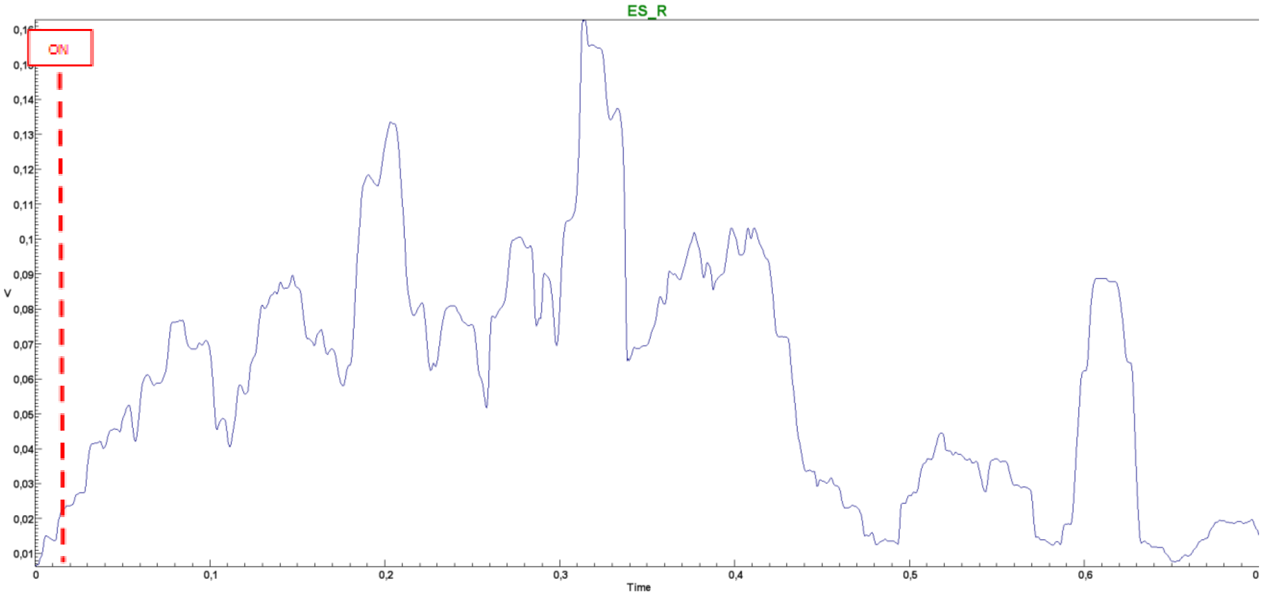
## Trial 1773

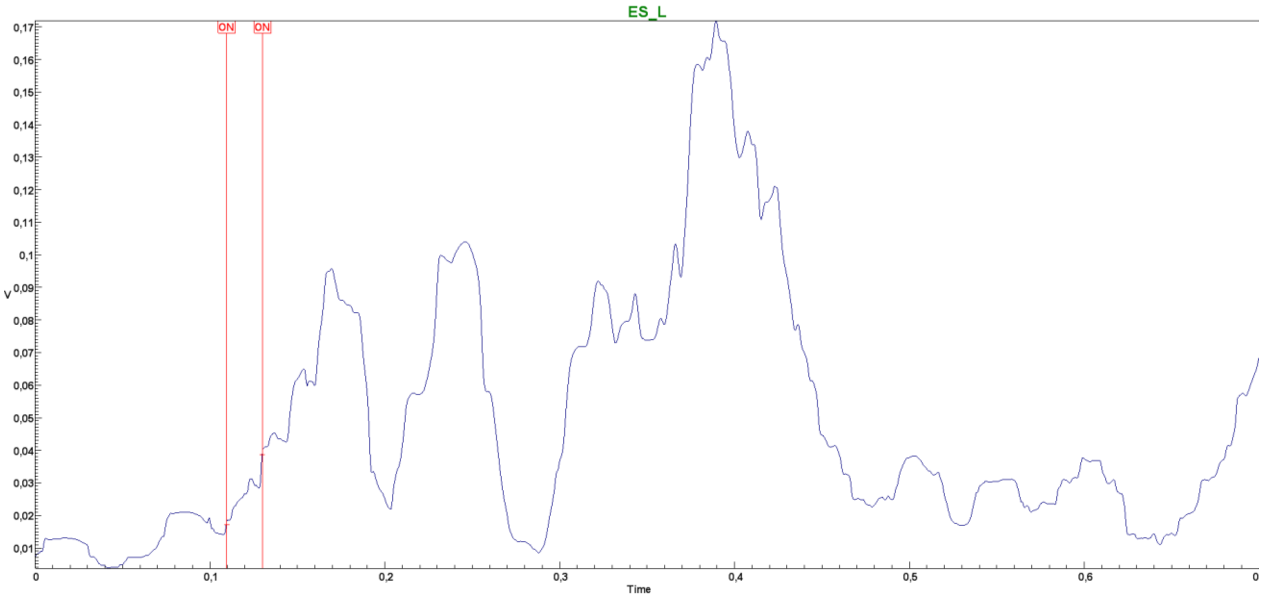

SCM_R
ON
0,5
0,4
0,3
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time
SCM_L
ON
0,5
0,4
0,3
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time
CPVM_R
ON
ON
0,2
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

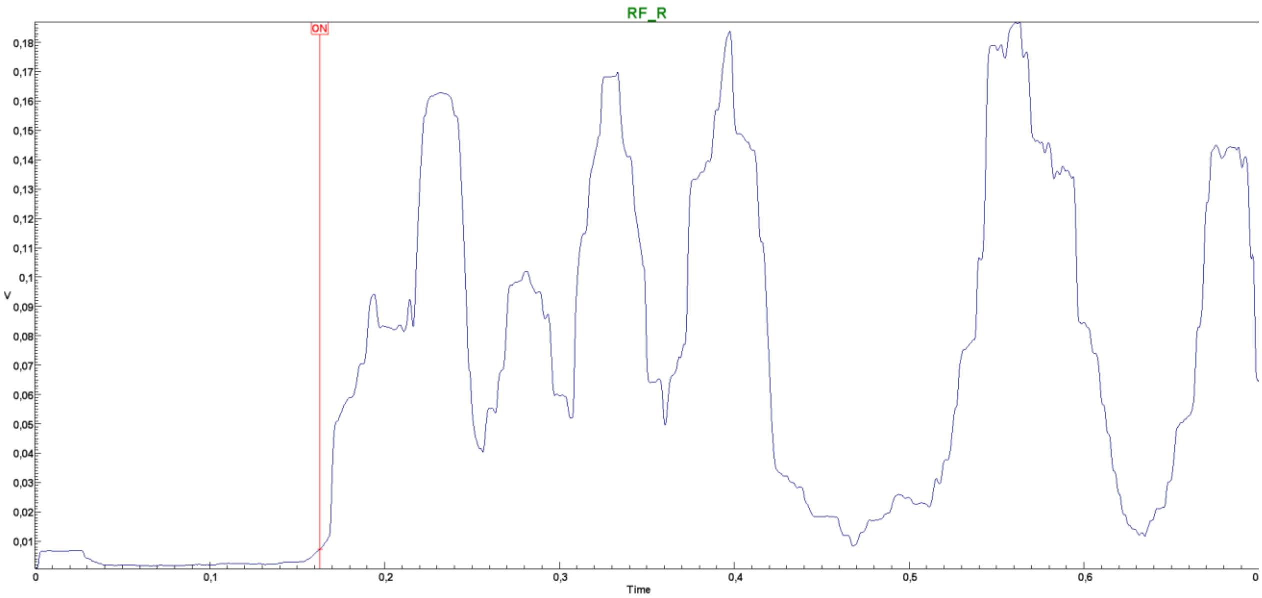

CPVM_L
ON
ON
ON
0,3
0,2
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

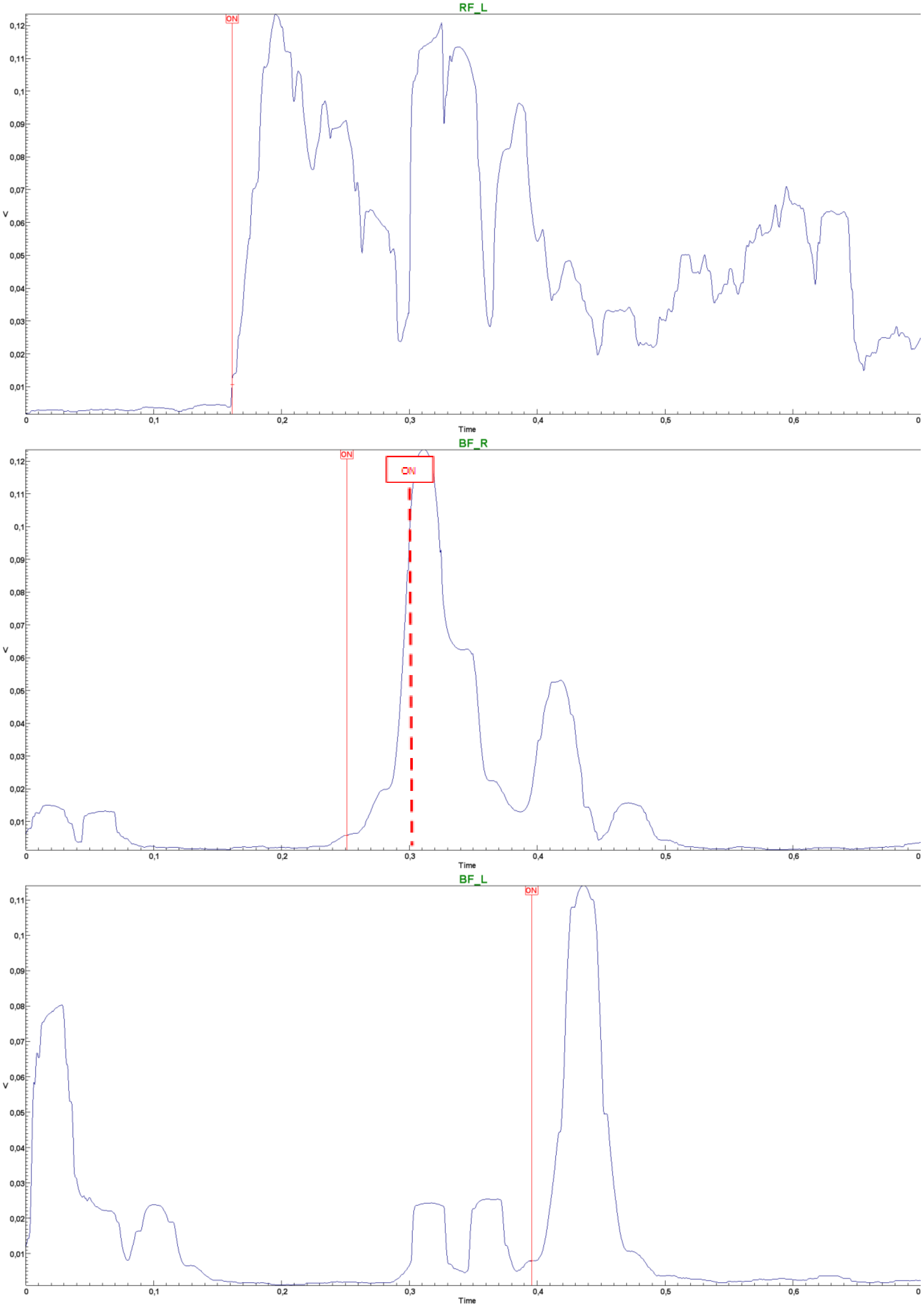

RA_R
ON
0,5
0,4
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

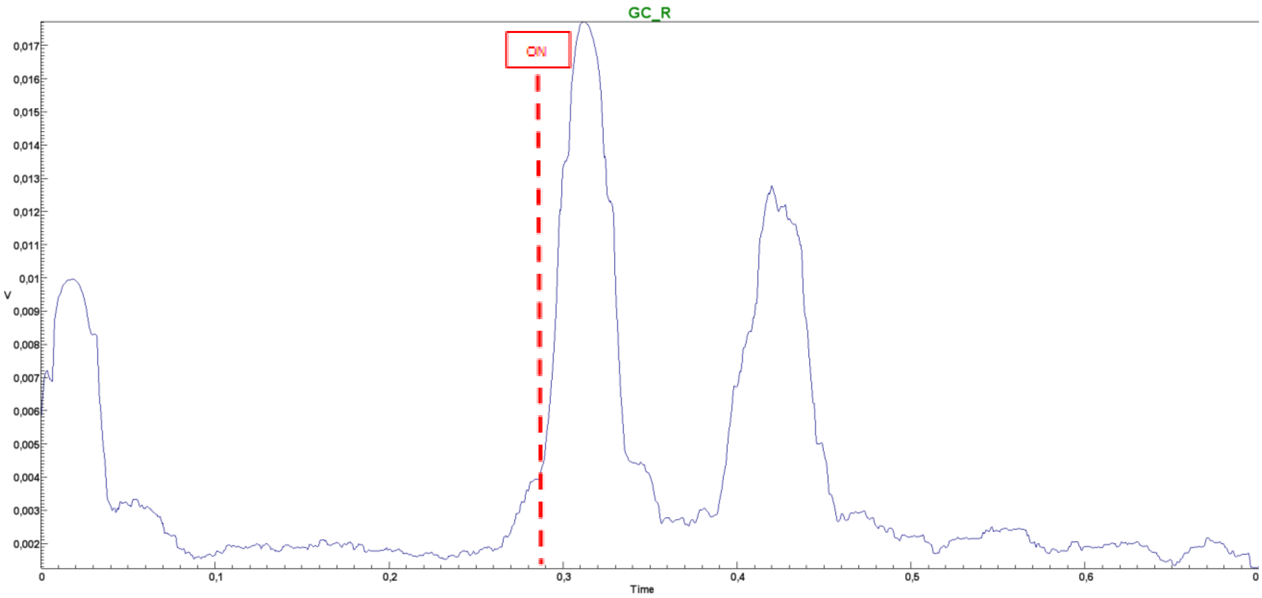

RA_L
ON
ON
0,18
0,17
0,16
0,15
0,14
0,13
0,12
0,11
0,1
V
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


ES_R
ON
V
Time
0
0,1
0,2
0,3
0,4
0,5
0,6


ES_L
ON
ON
V
Time
0
0,1
0,2
0,3
0,4
0,5
0,6


RF_R
ON
V
Time
0
0,1
0,2
0,3
0,4
0,5
0,6


RF_L
ON
V
Time
BF_R
ON
ON
V
Time
BF_L
ON
V
Time


GC_R
ON
V
0,017
0,016
0,015
0,014
0,013
0,012
0,011
0,01
0,009
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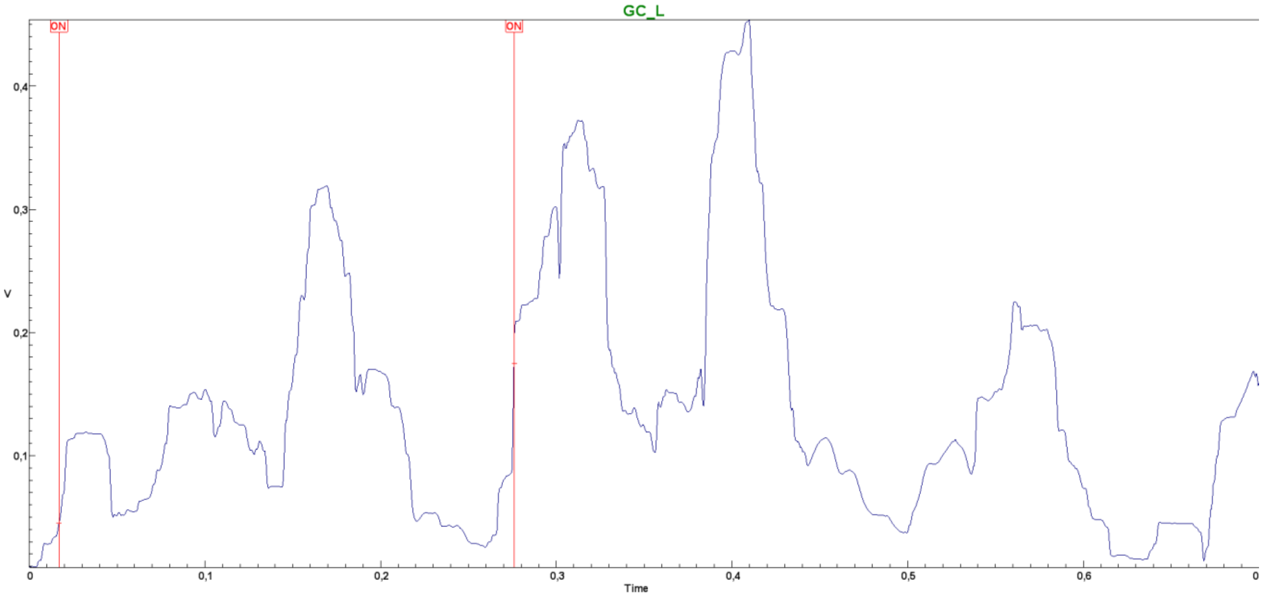
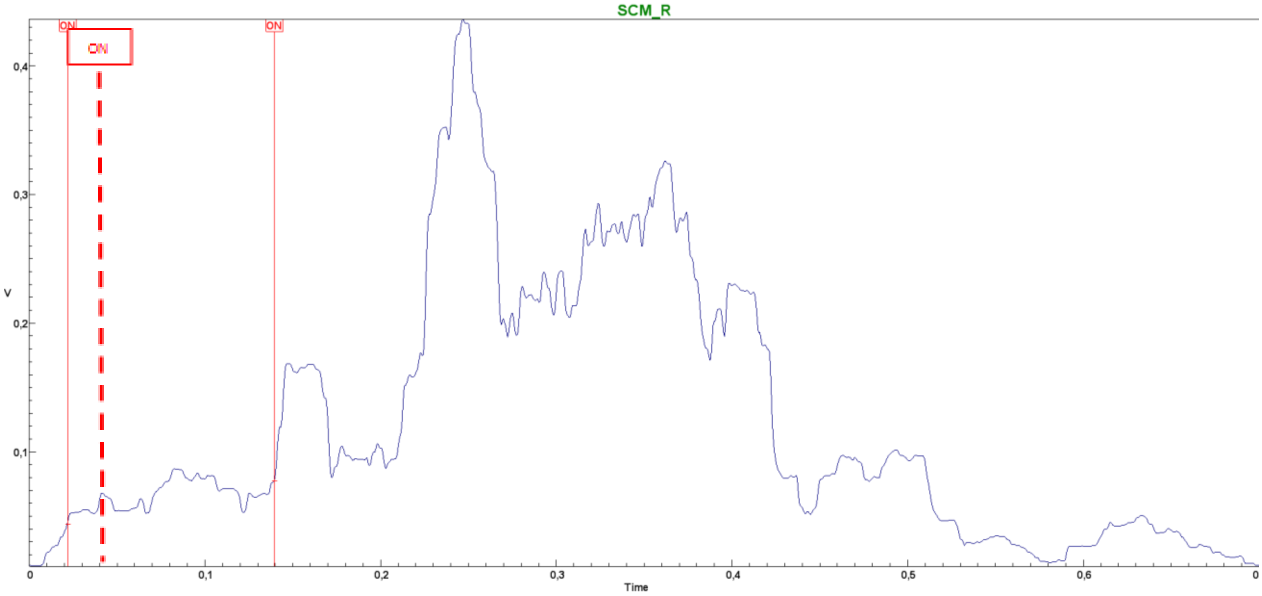
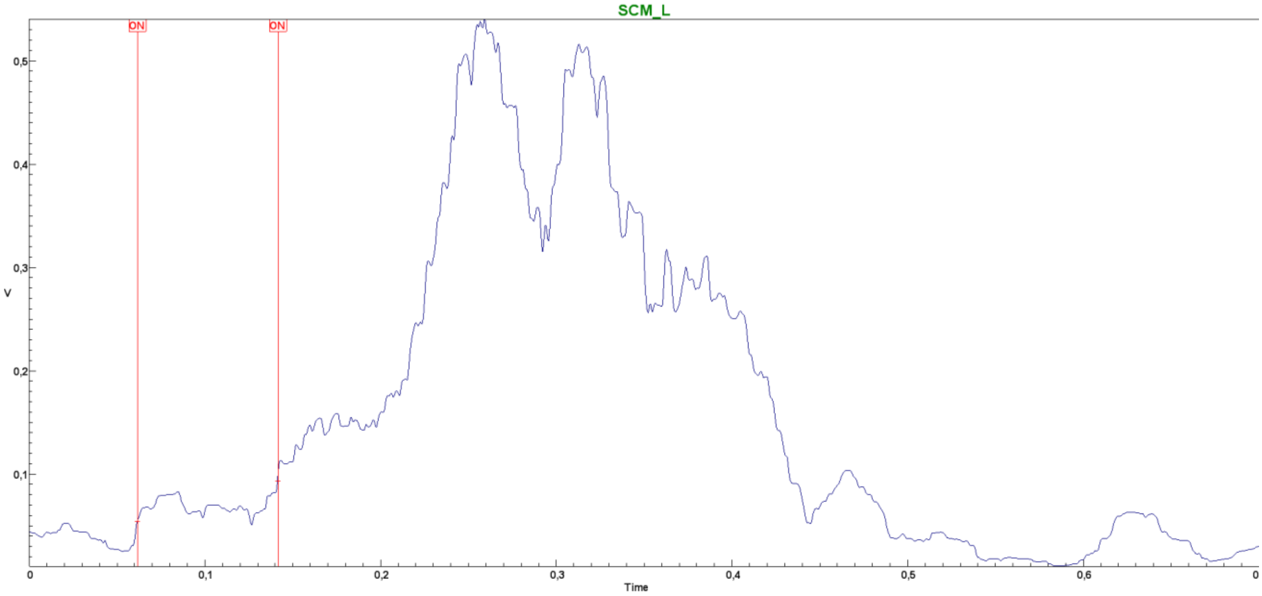
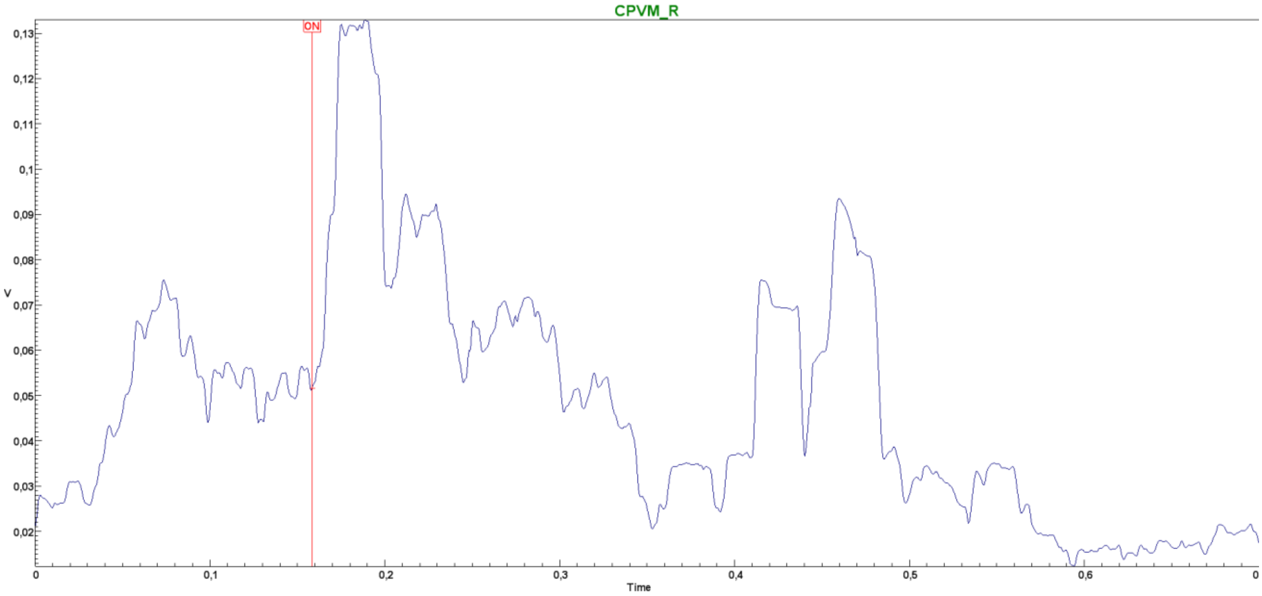
0,007
0,006
0,005
0,004
0,003
0,002
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

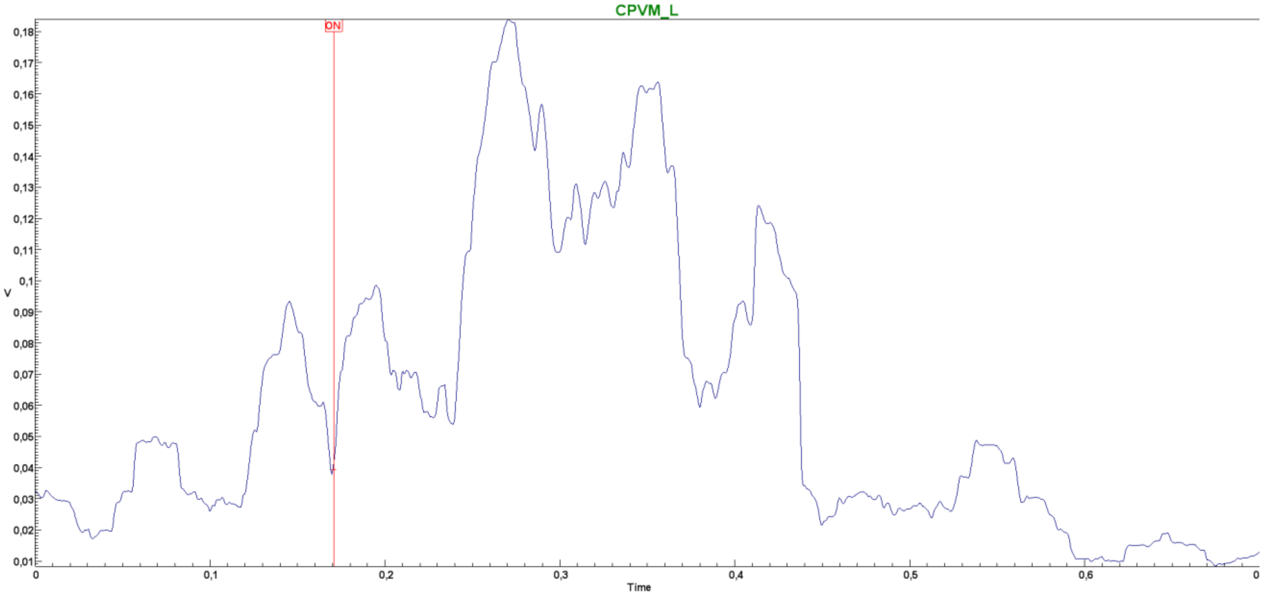

GC_L
ON
ON
V
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

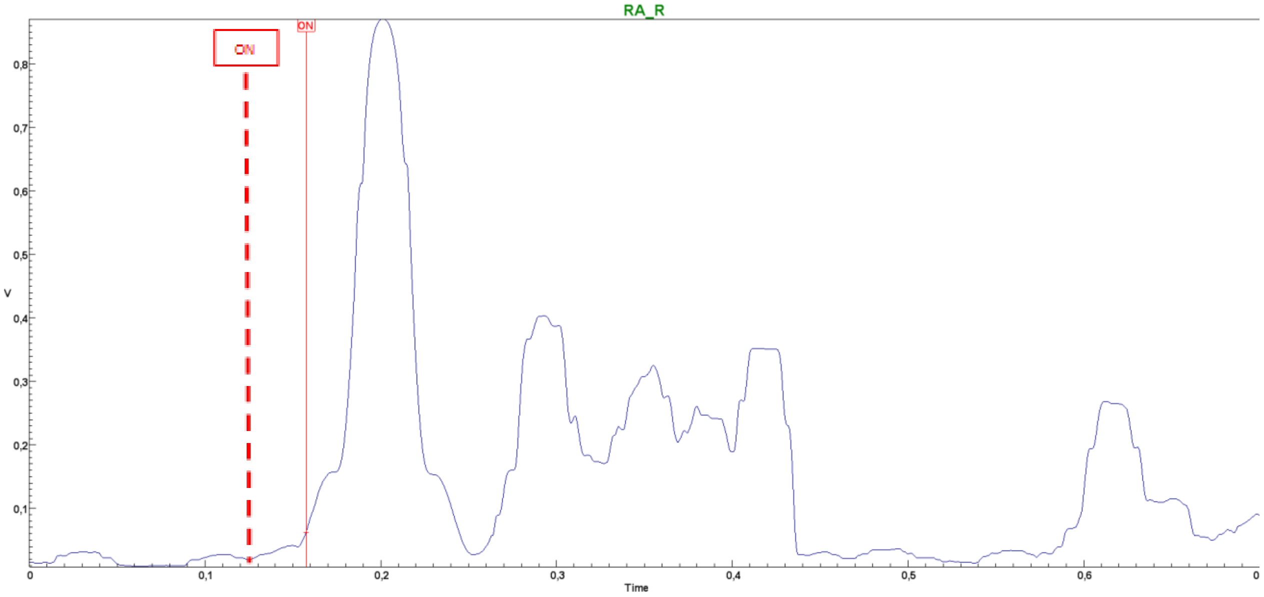
Trial 1774:

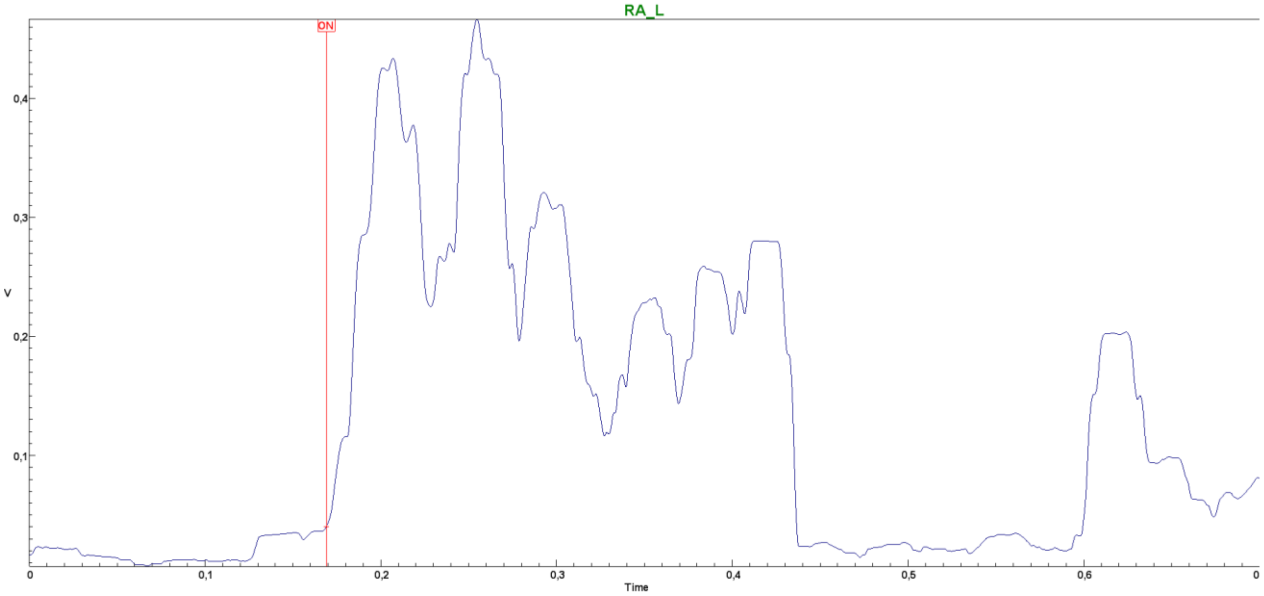


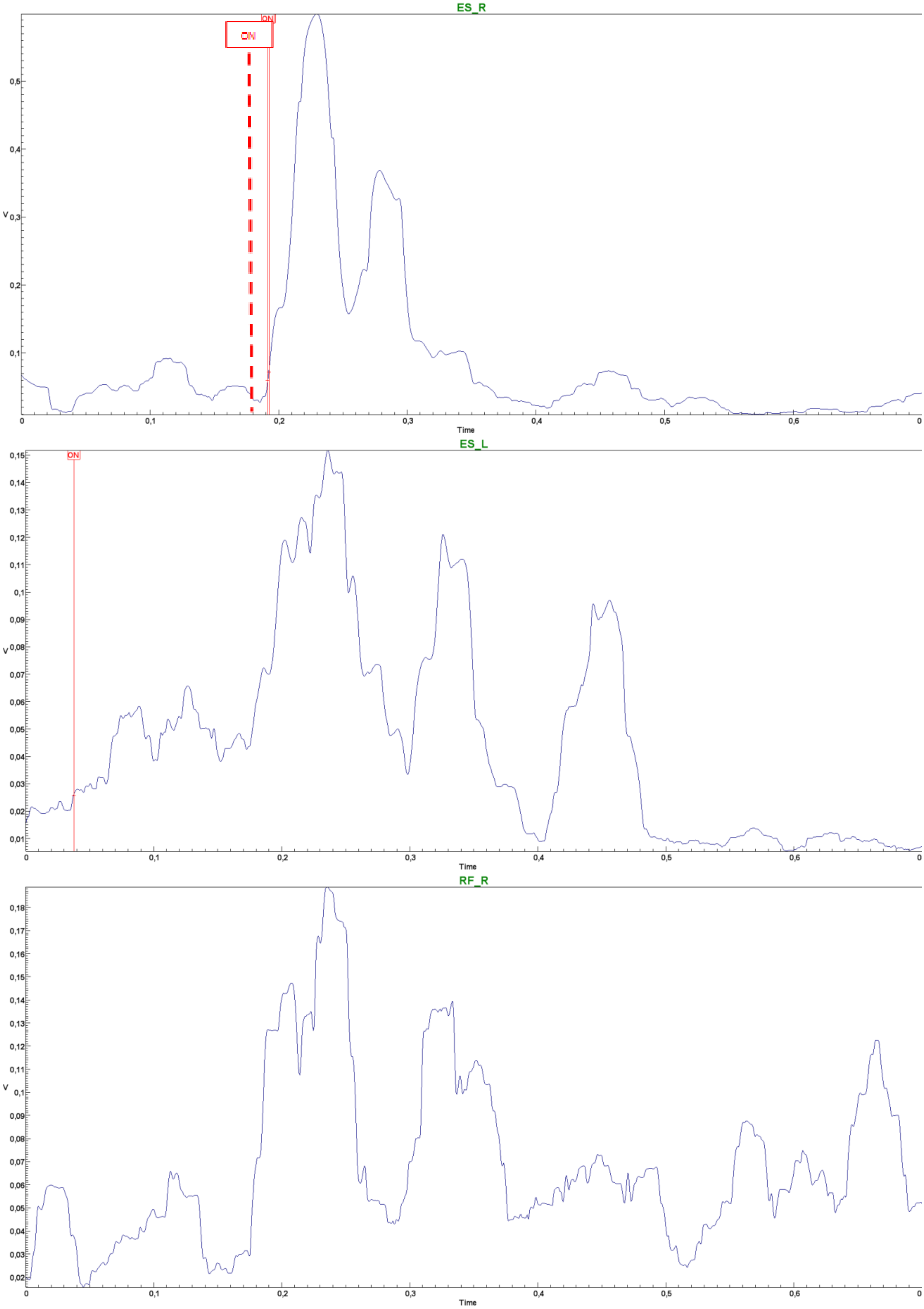



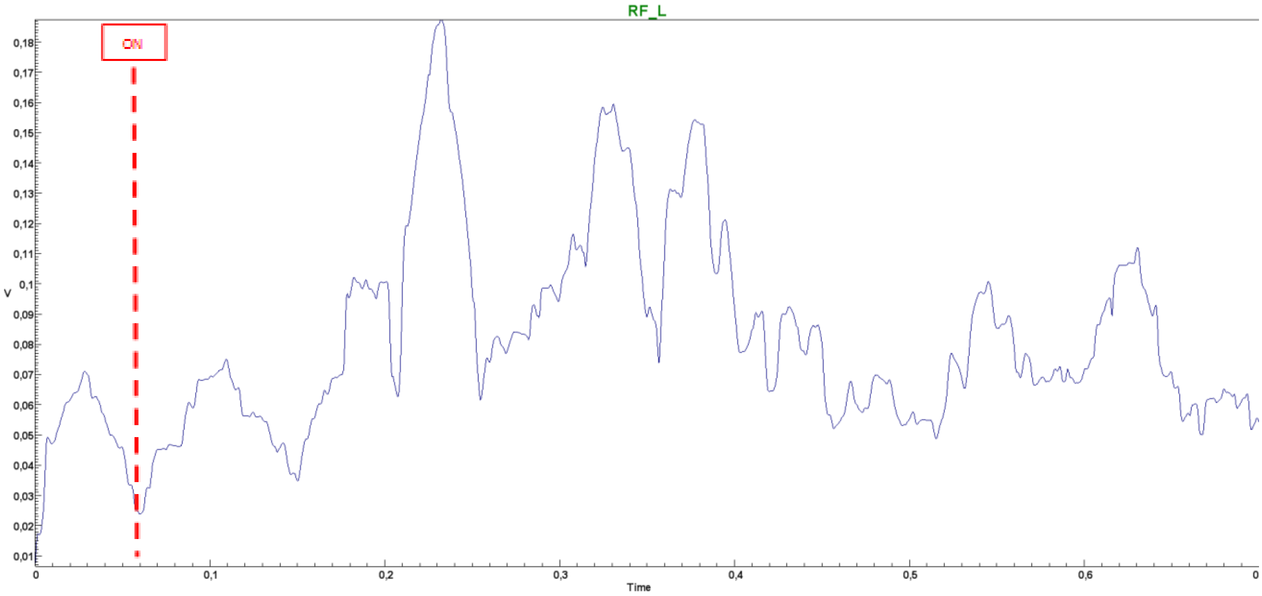



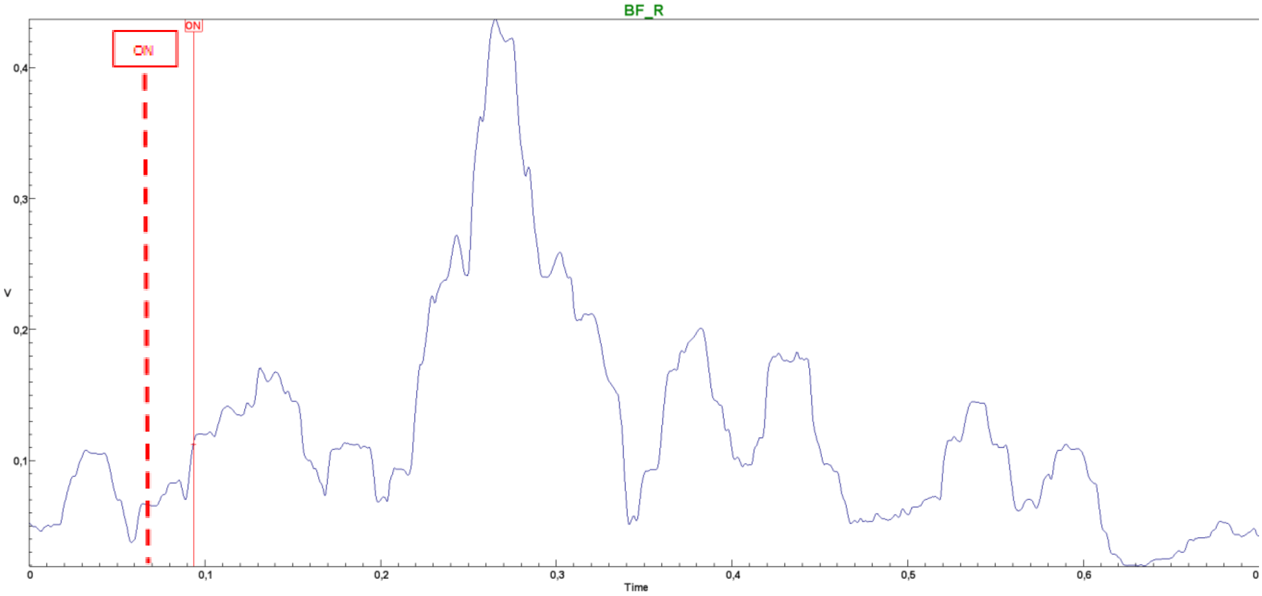

CPVM_L
ON
V
Time

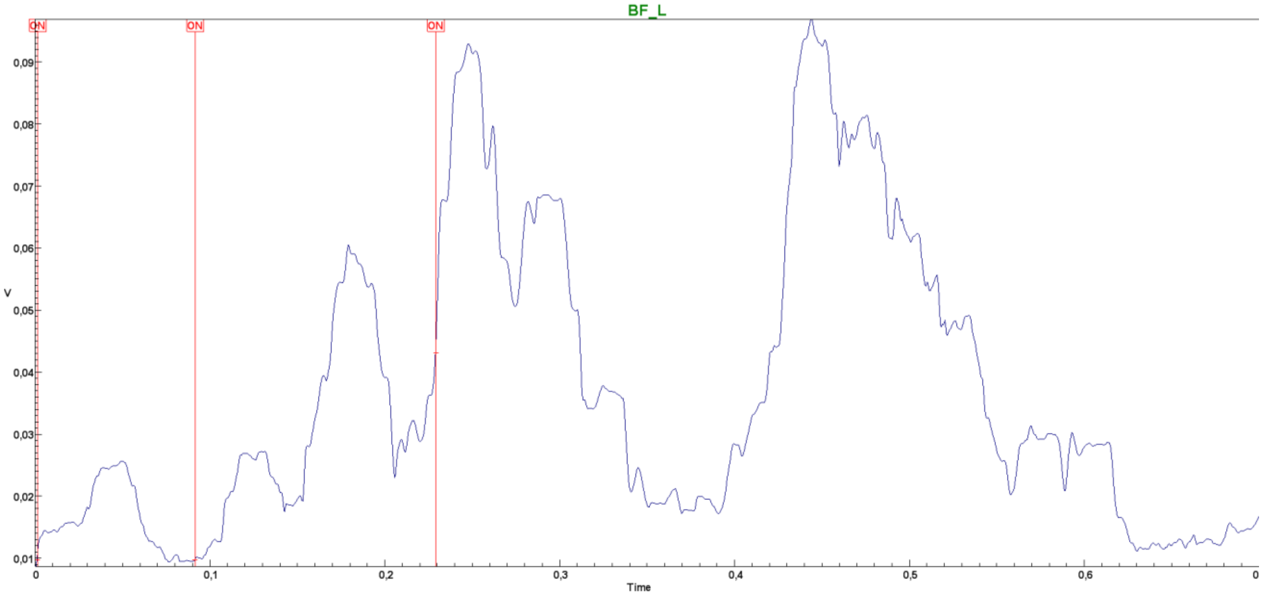

RA_R
ON
ON
V
Time

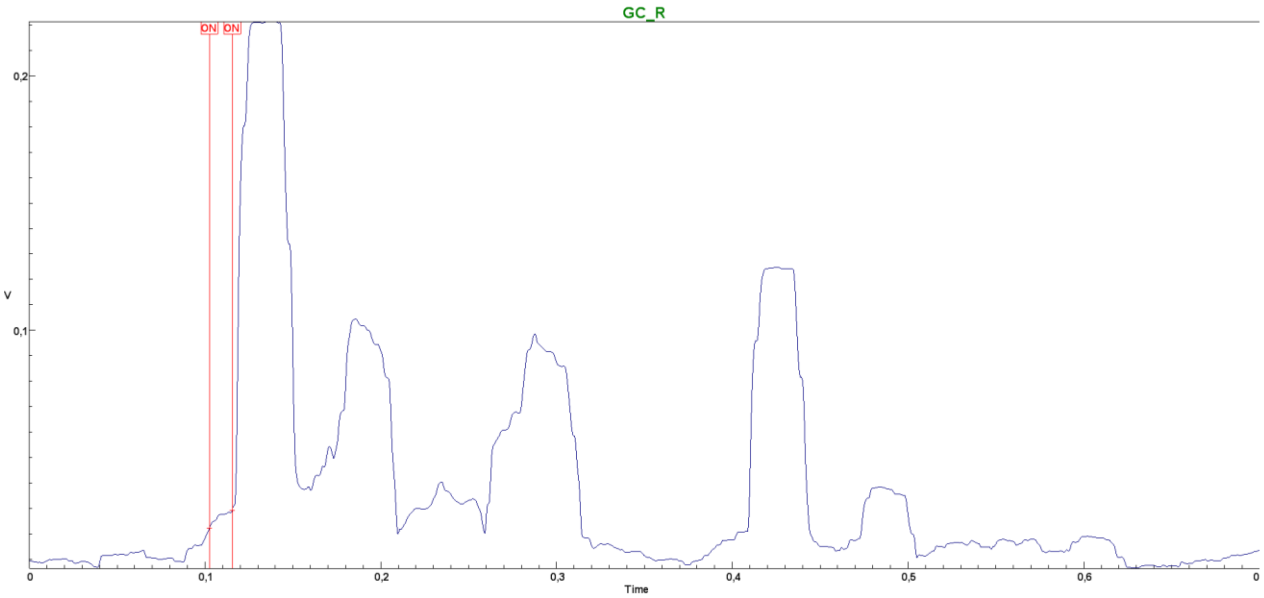

RA_L
ON
V
Time

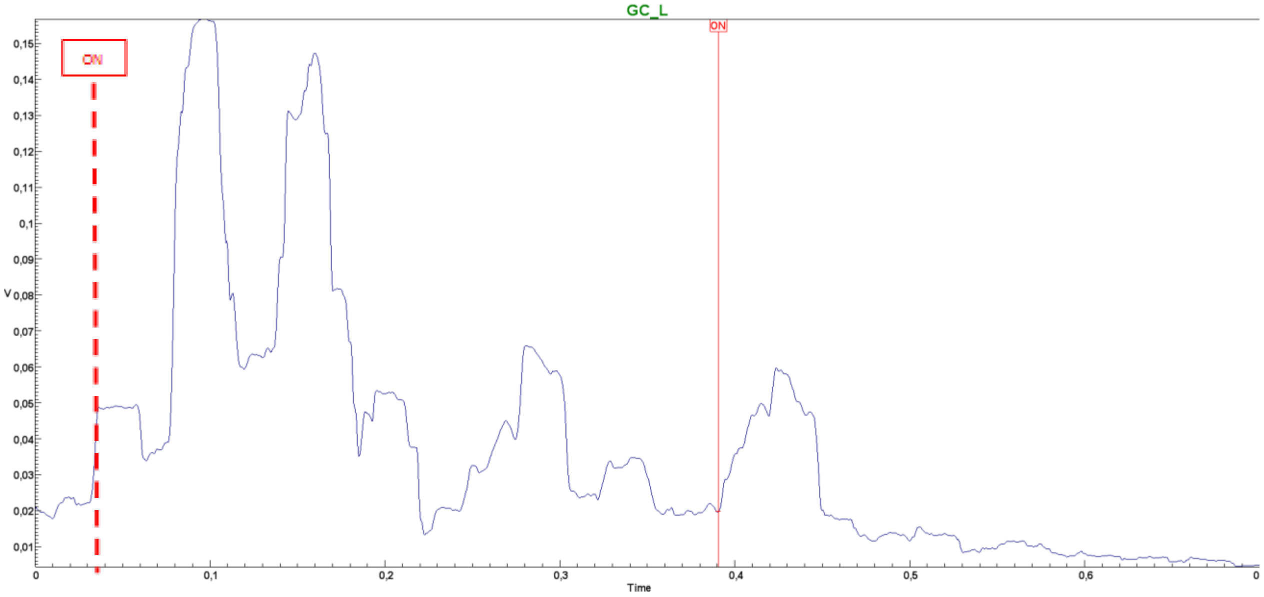

ES_R
ON
V
Time
ES_L
ON
V
Time
RF_R
V
Time


RF_L
ON
V
Time

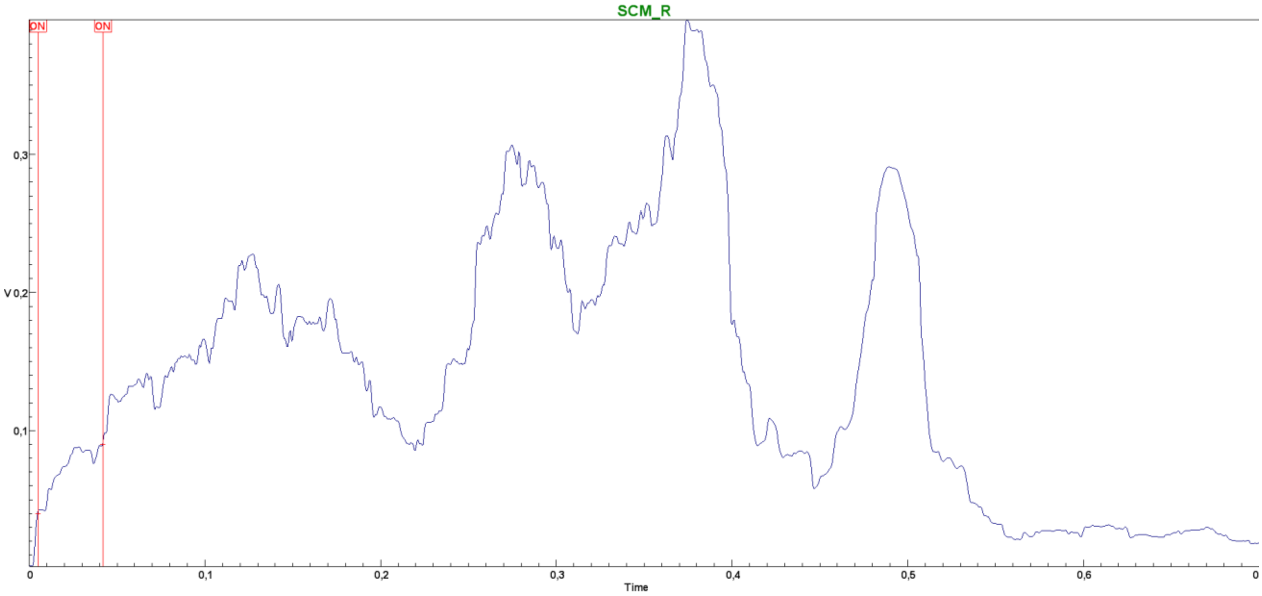

BF_R
ON
ON
V
Time

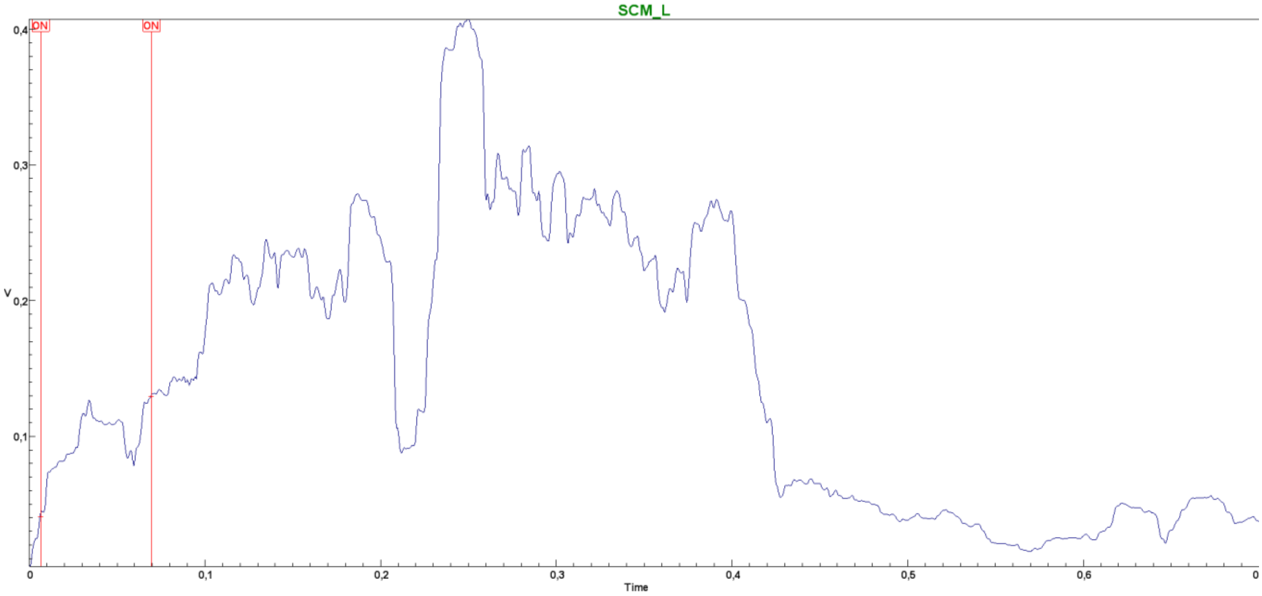

BF_L
ON
ON
ON
V
Time

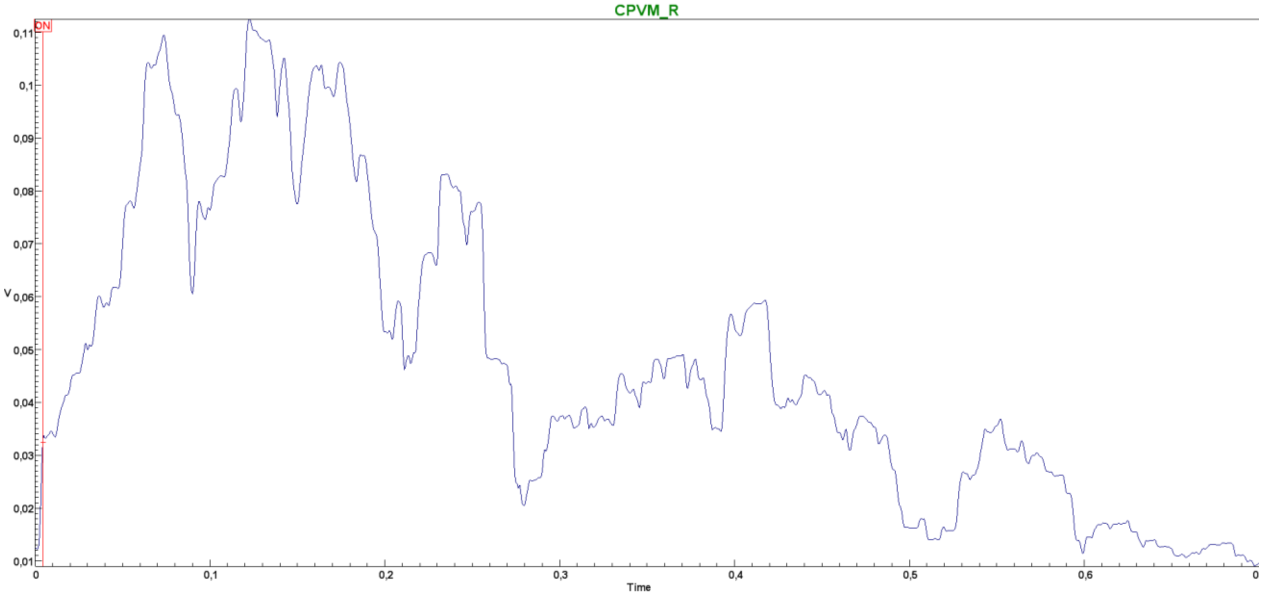

GC_R
ON
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

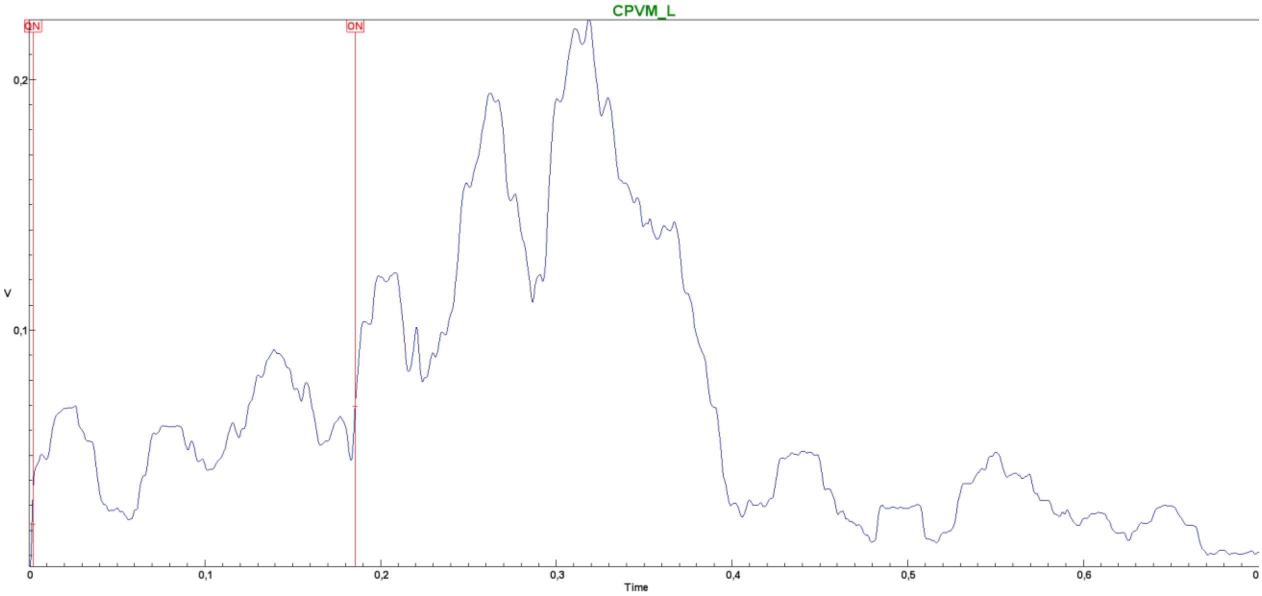

GC_L
ON
ON
V
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

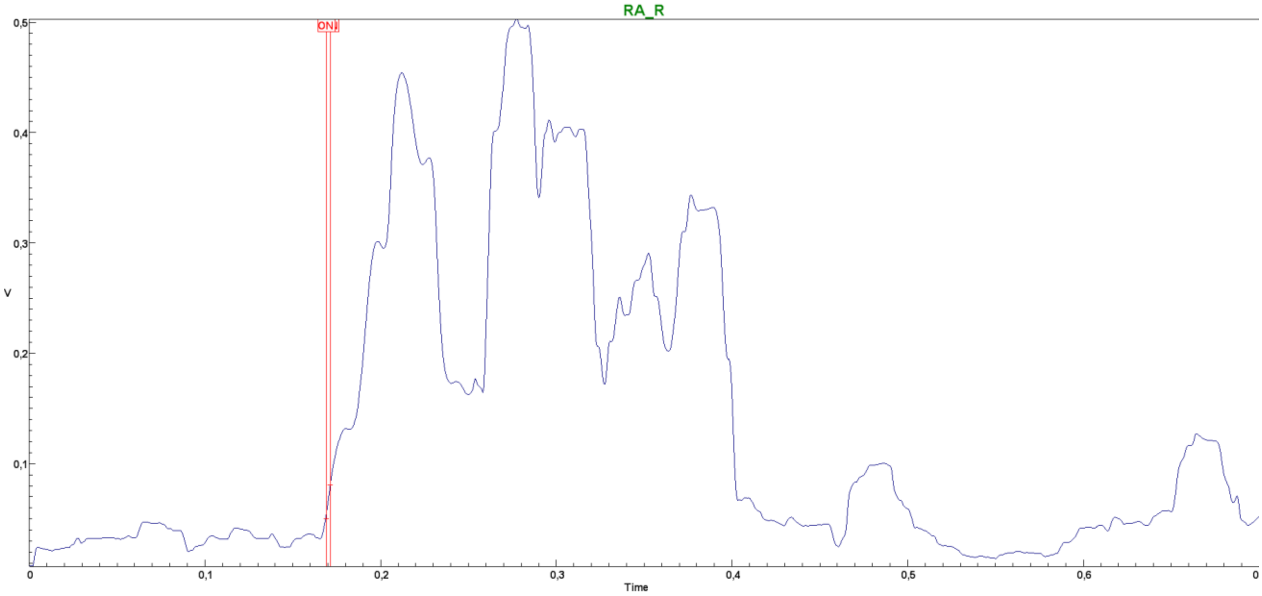
Trial 1775:


SCM_R
ON
ON
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


SCM_L
ON
ON
V
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


CPVM_R
ON
V
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


CPVM_L
ON
ON
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


RA_R
ON
0,5
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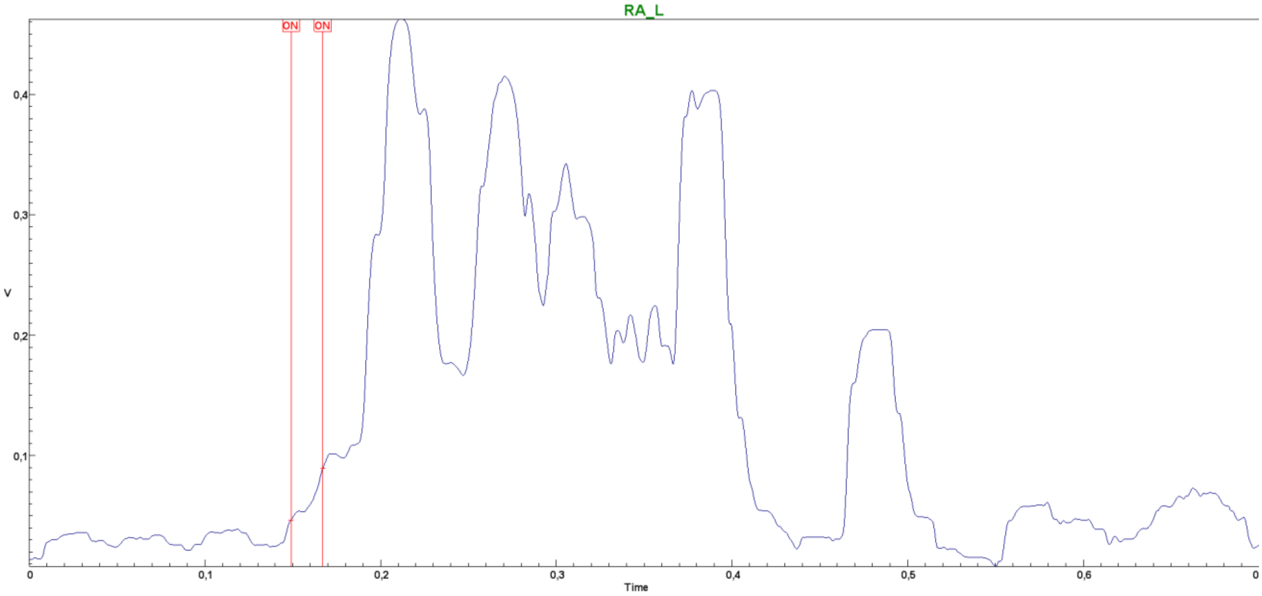
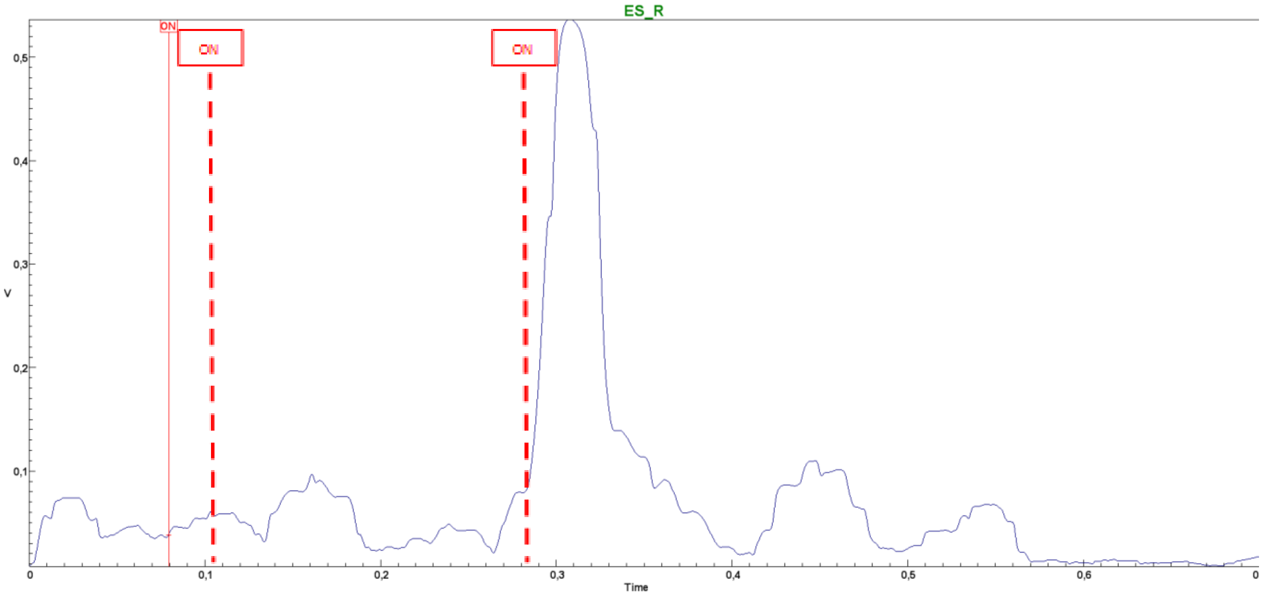
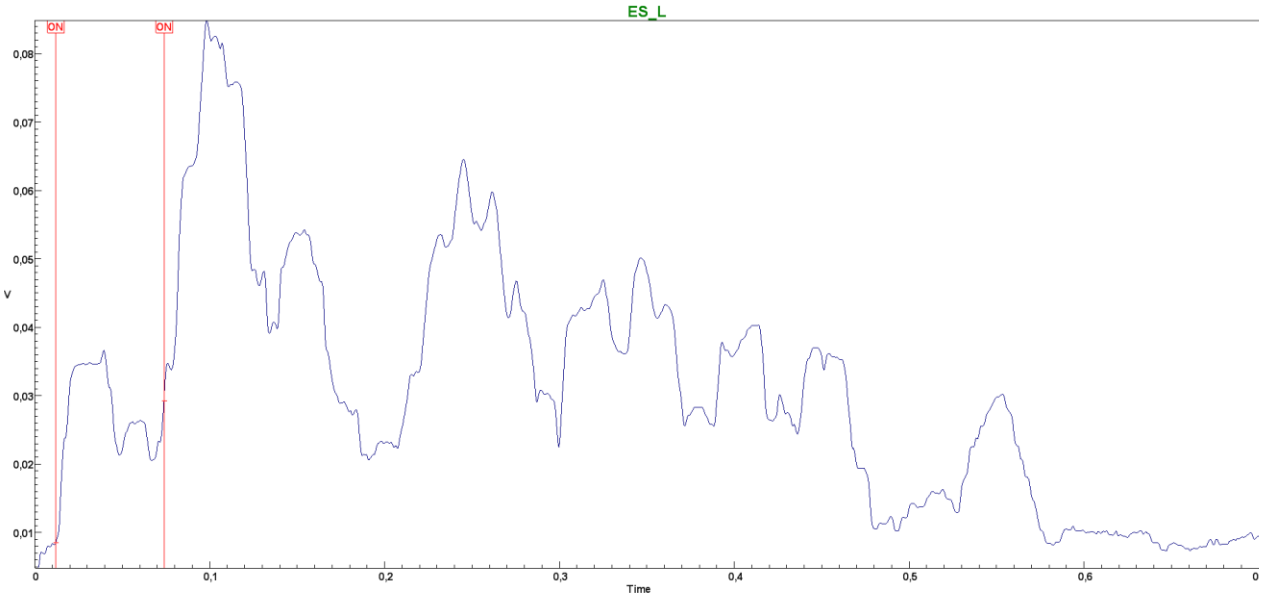
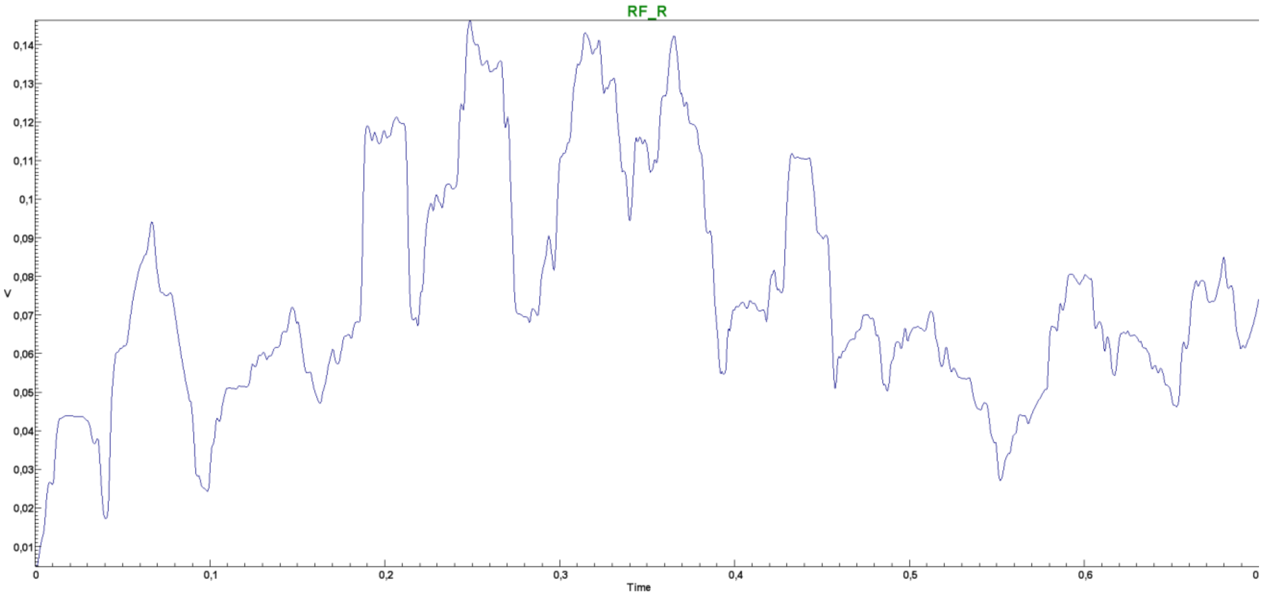
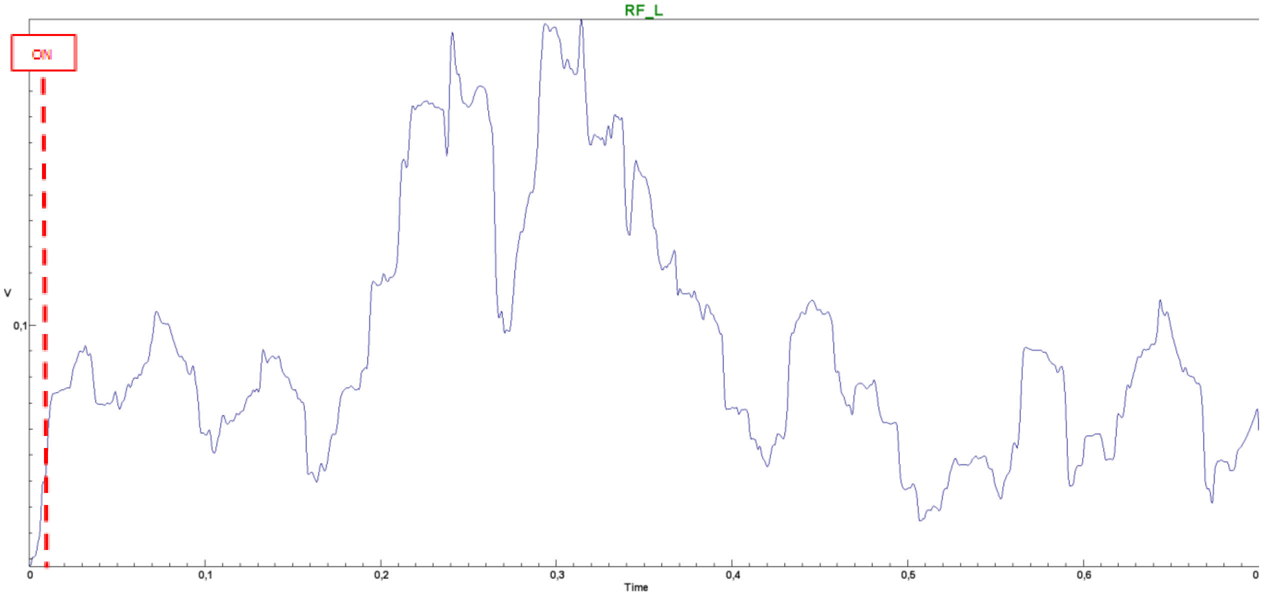
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

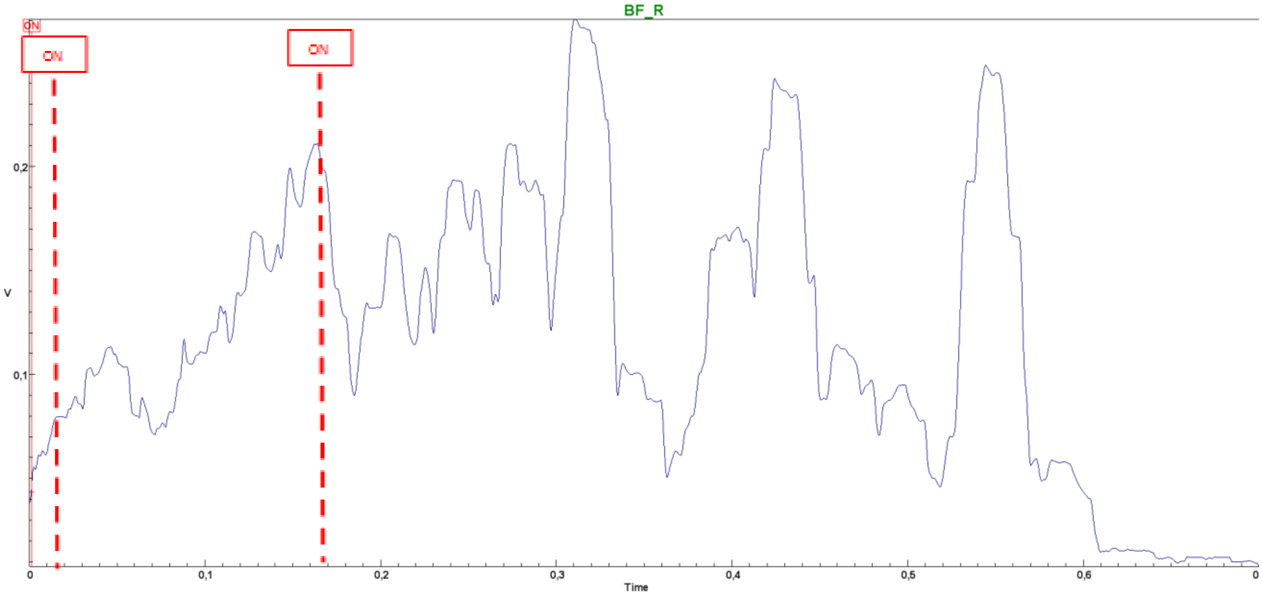

RA_L
ON
ON
0,4
0,3
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

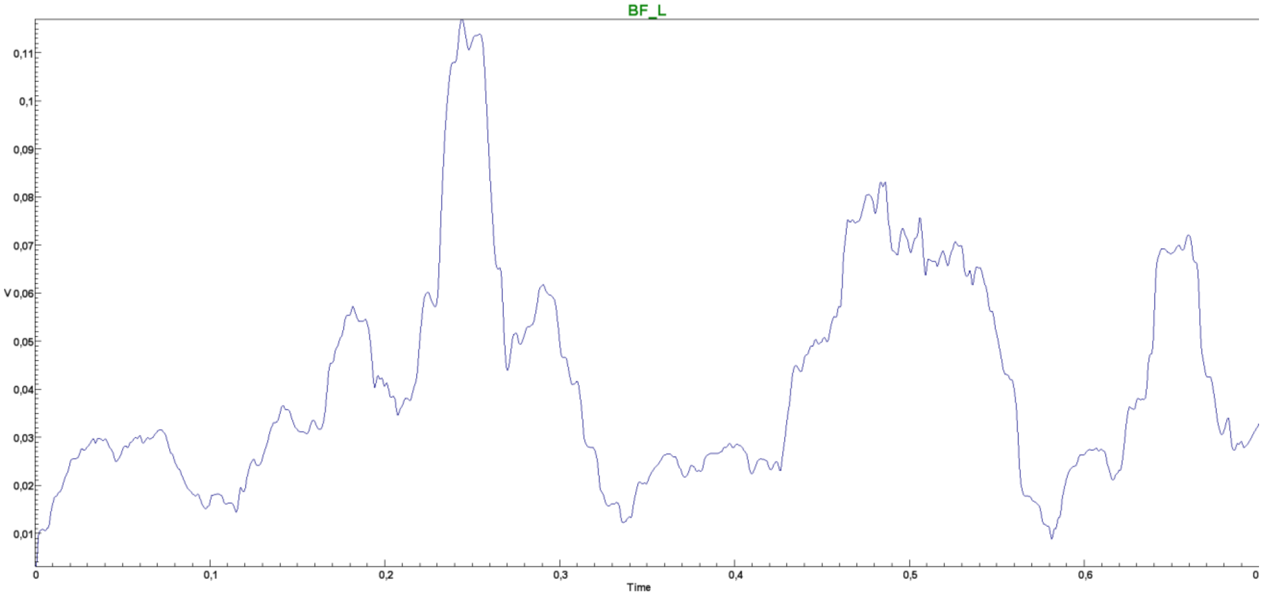

ES_R
ON
ON
ON
V
Time

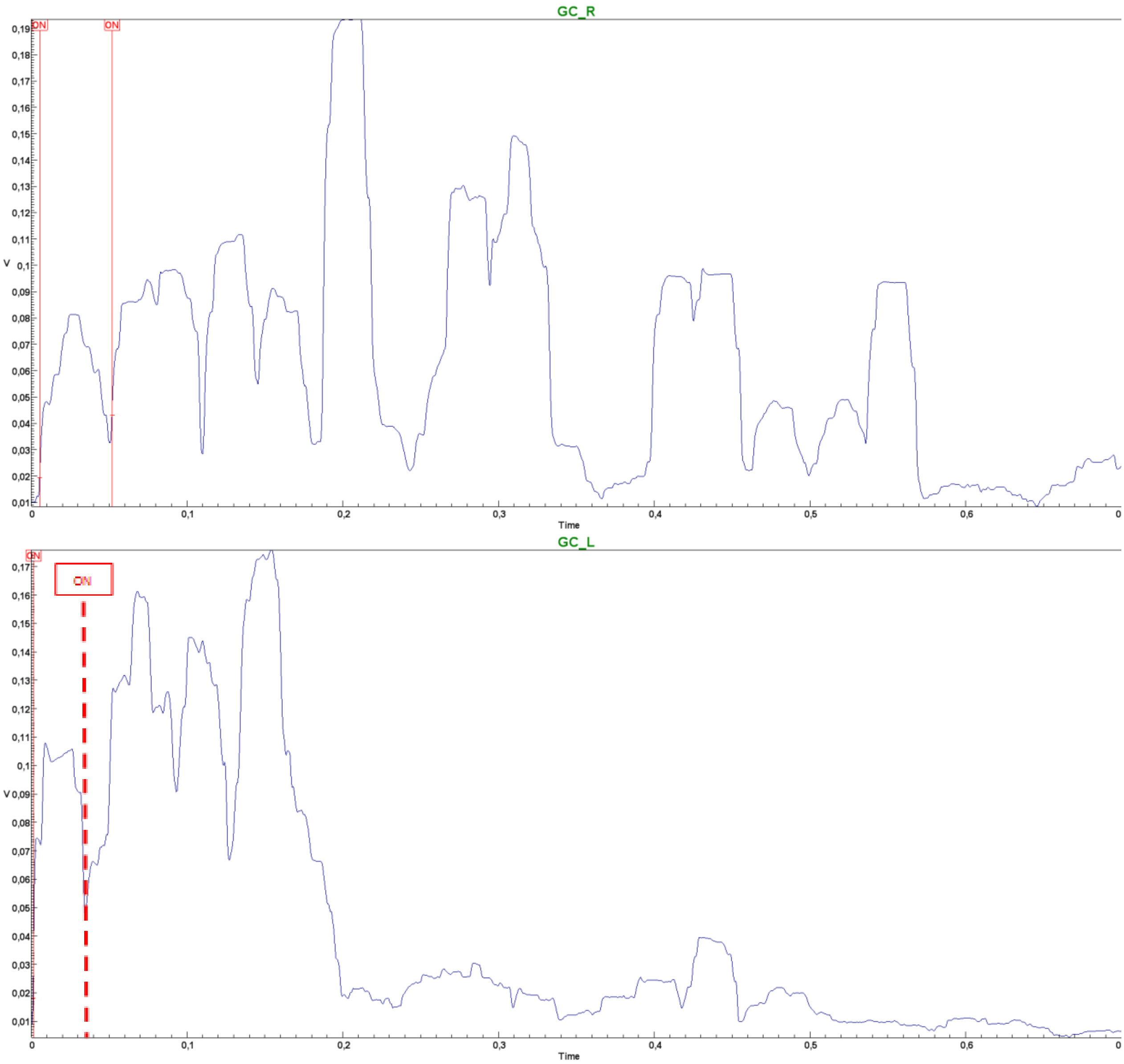

ES_L
ON
ON
V
Time


RF_R
V
Time

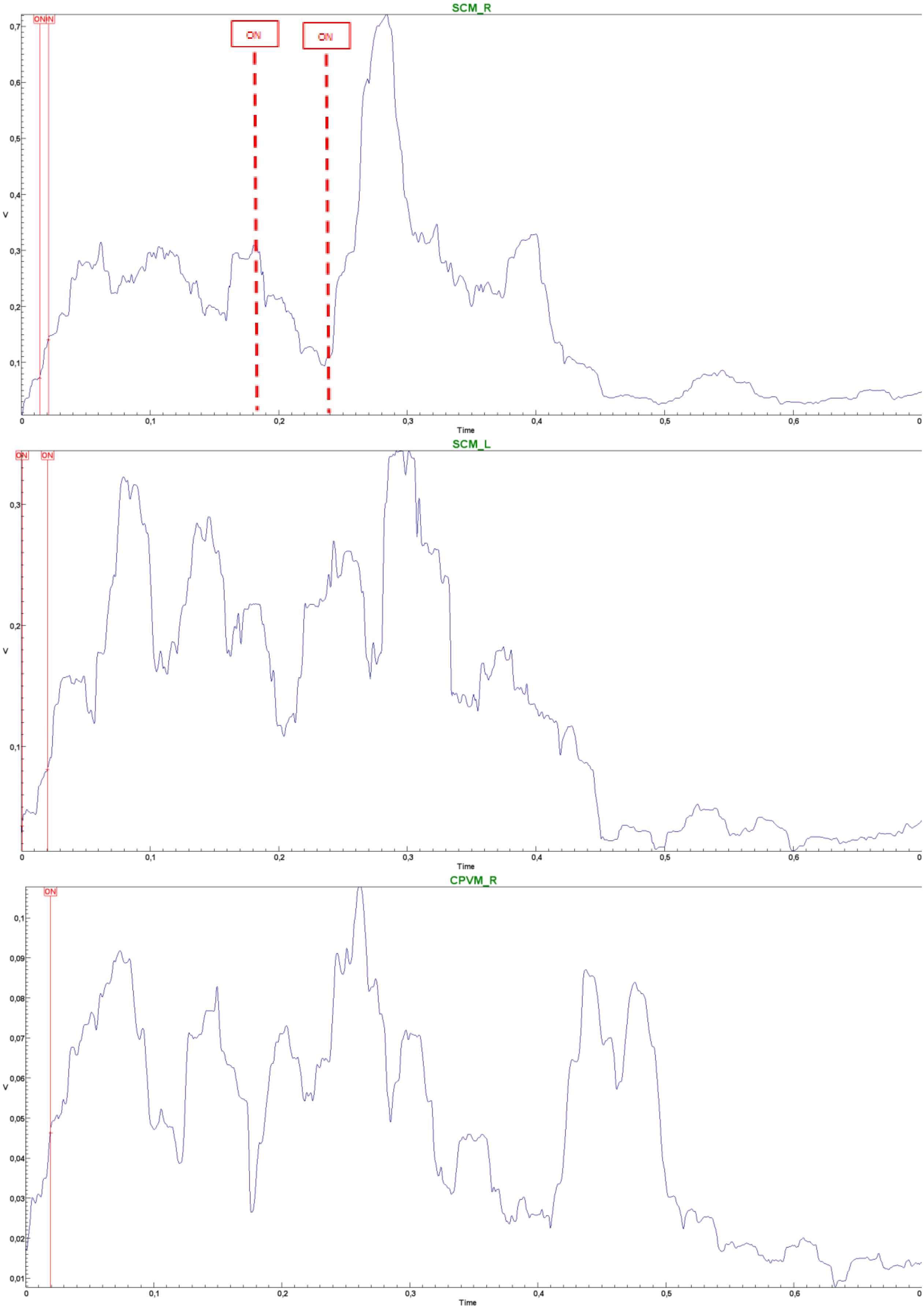

RF_L
ON
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

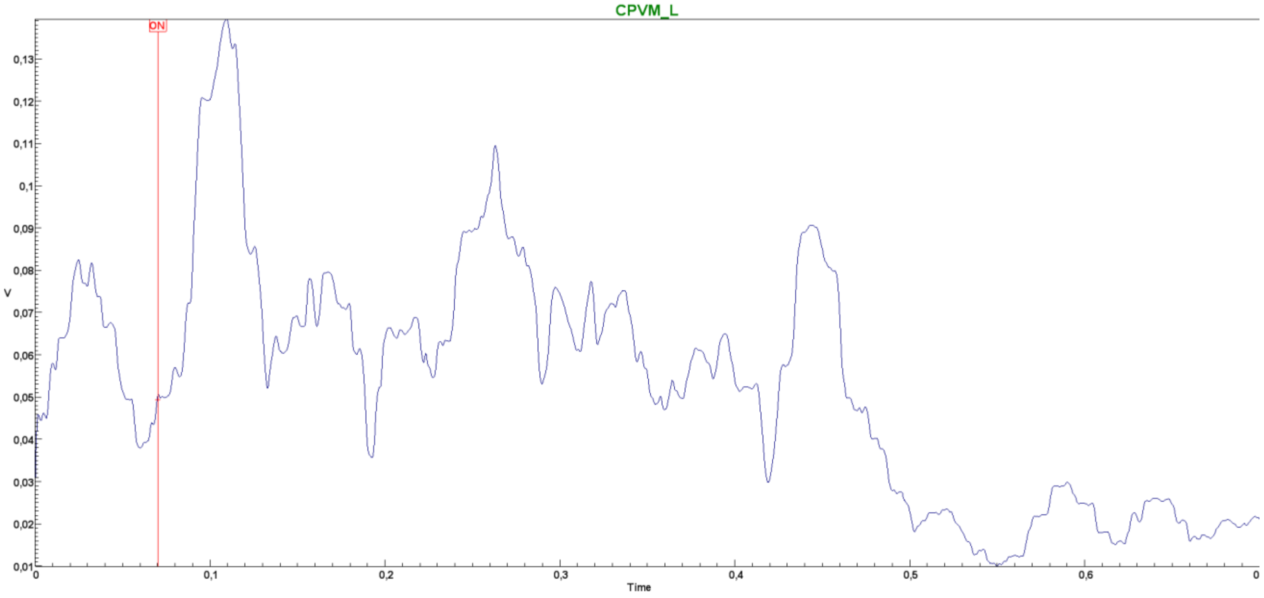

BF_R
ON
ON
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

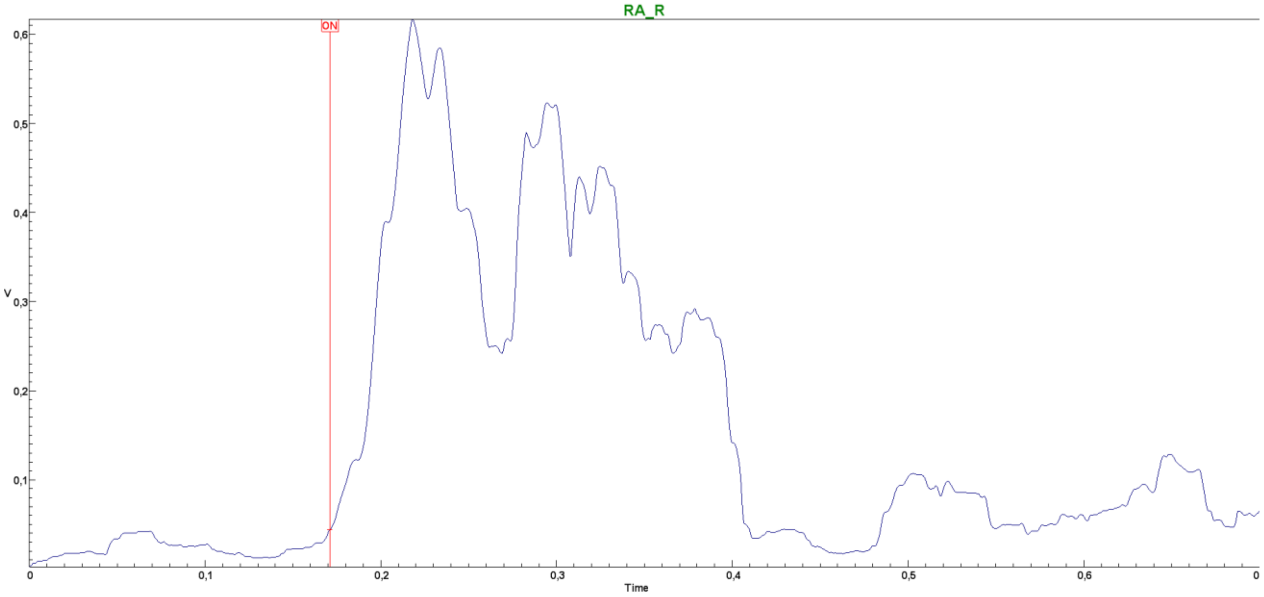

BF_L
0,11
0,1
0,09
0,08
0,07
V 0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

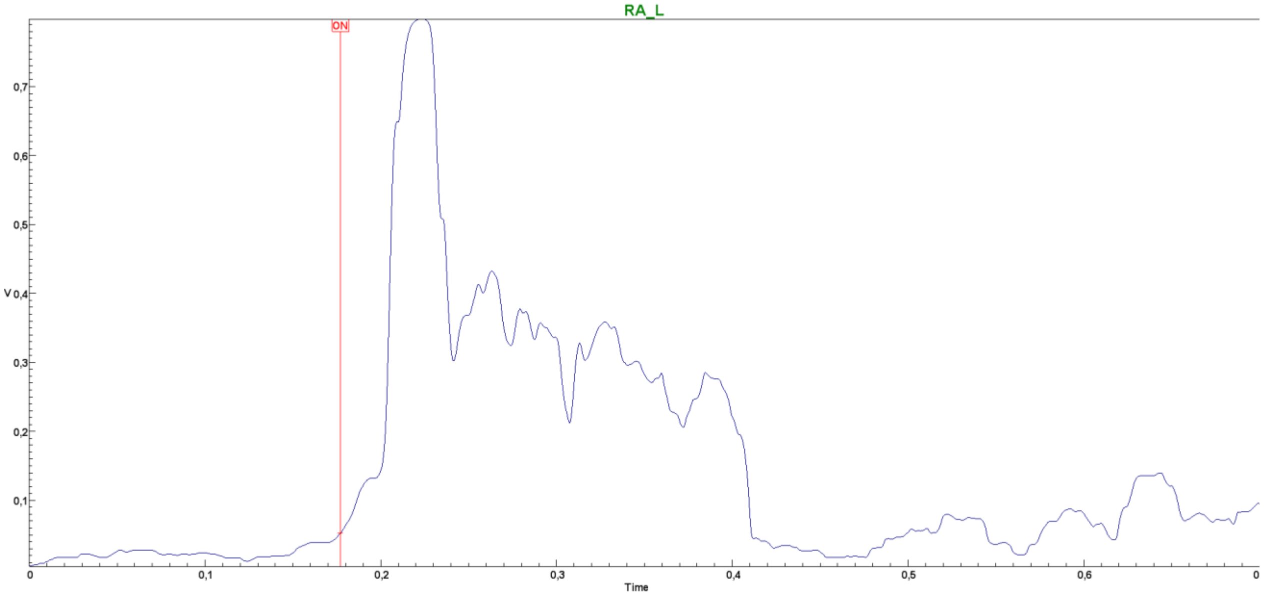

GC_R
ON
ON
V
Time
GC_L
ON
ON
V
Time

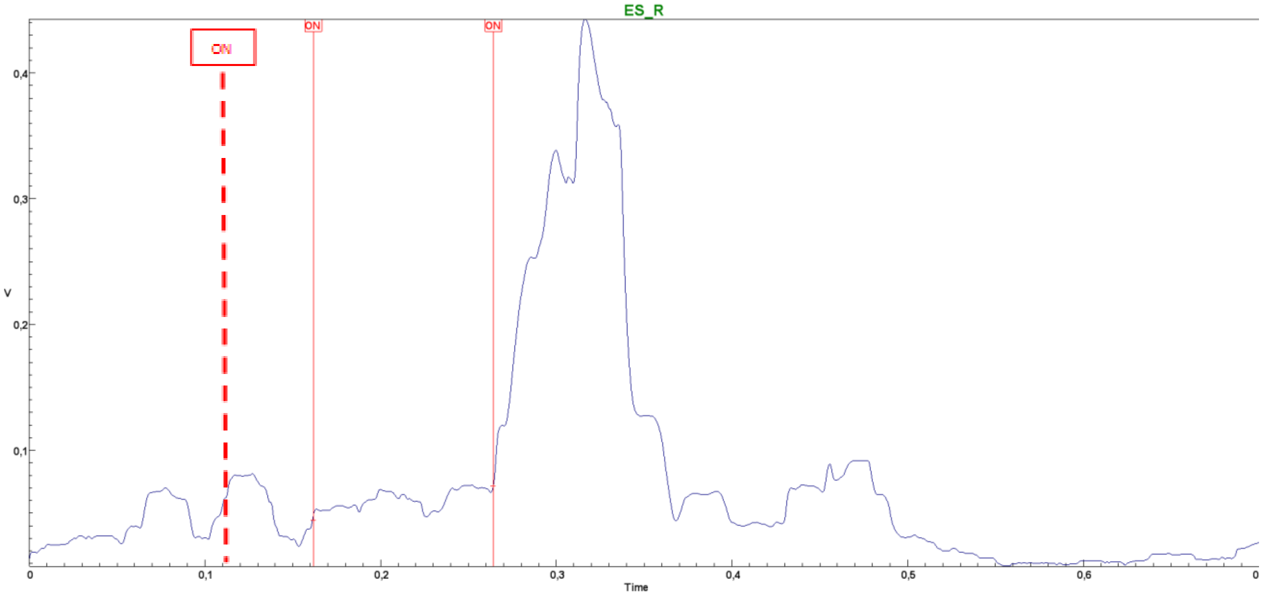
Trial 1776:

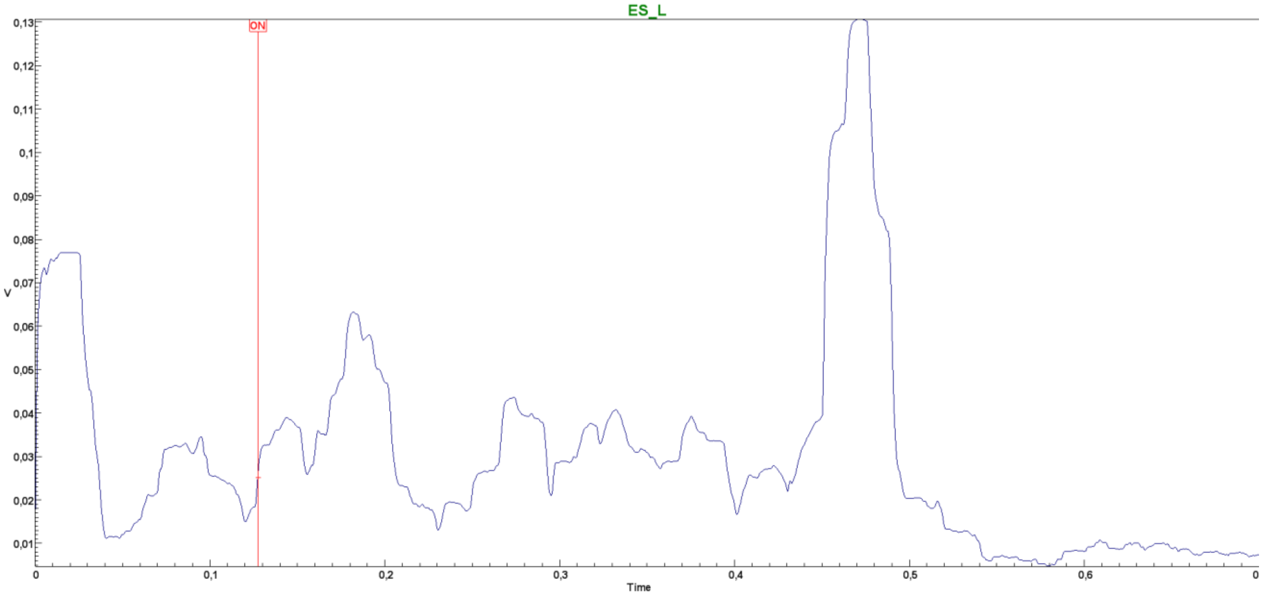



CPVM_L
ON
V
Time


RA_R
ON
V
Time


RA_L
ON
V
Time


ES_R
ON
ON
ON
V
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time


ES_L
ON
V
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
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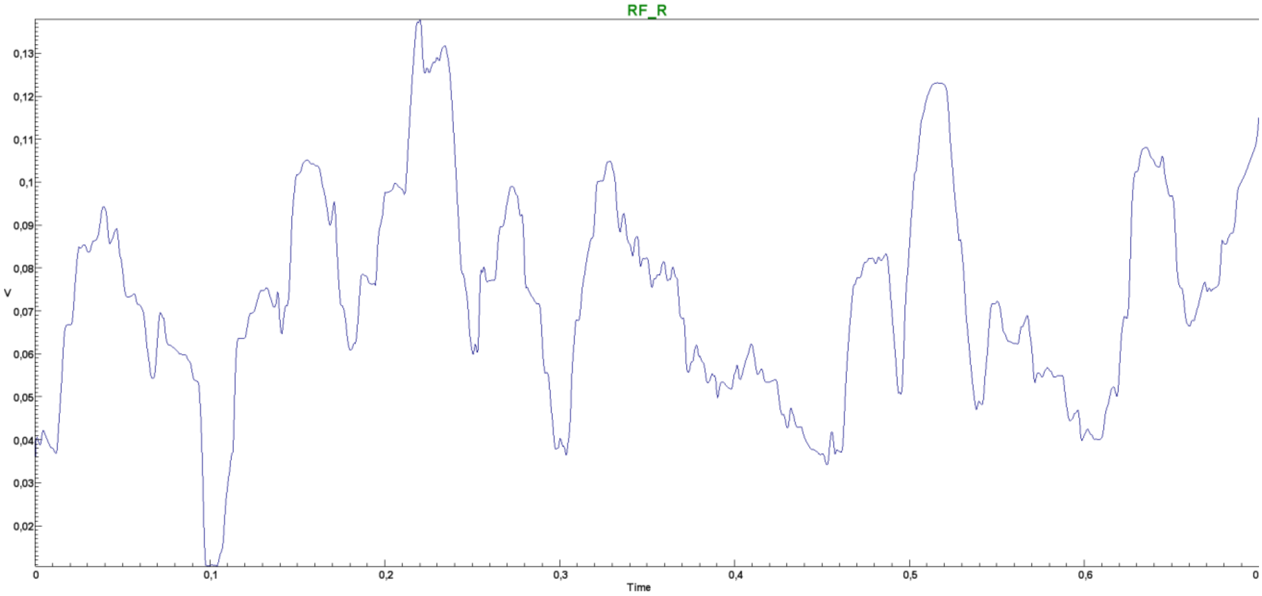
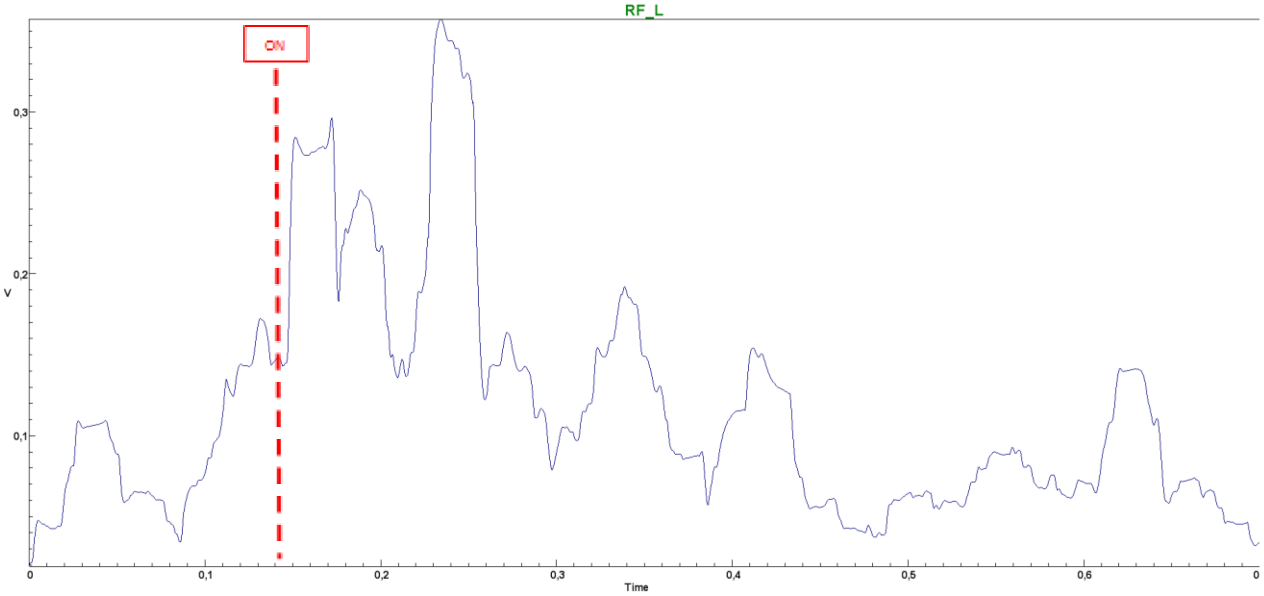
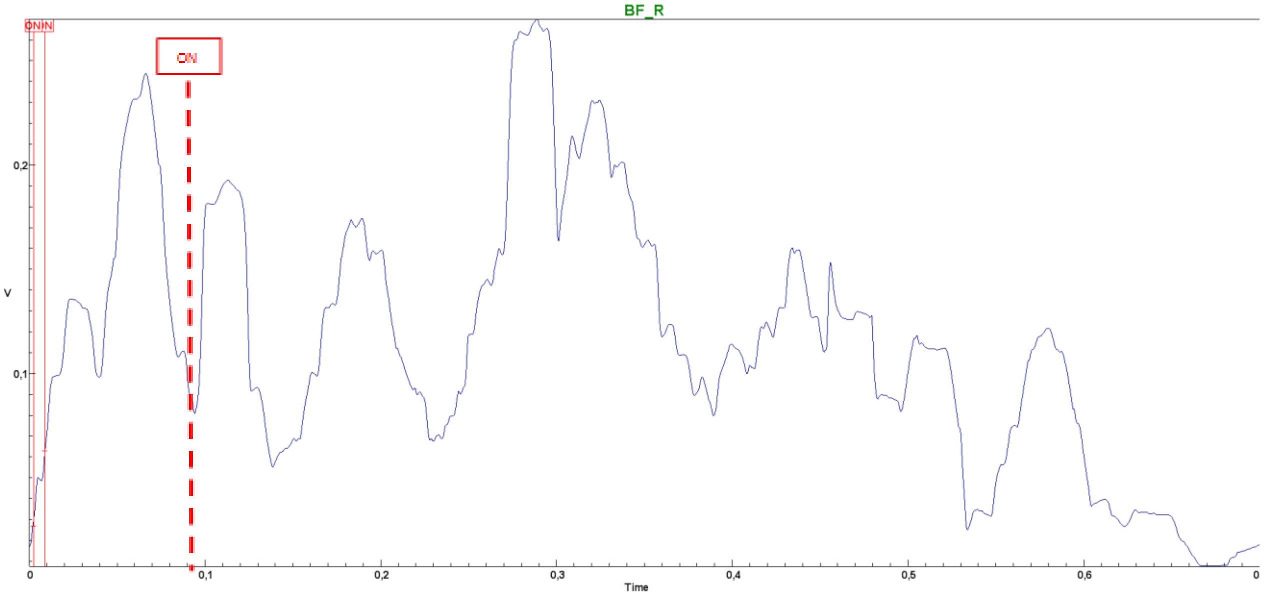
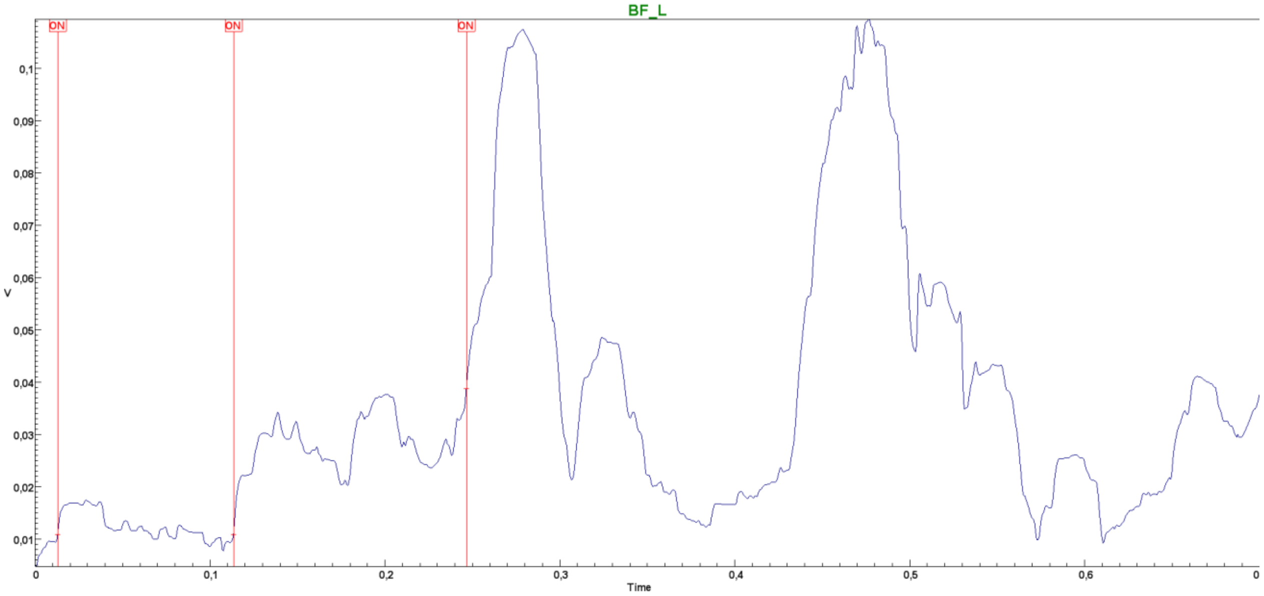
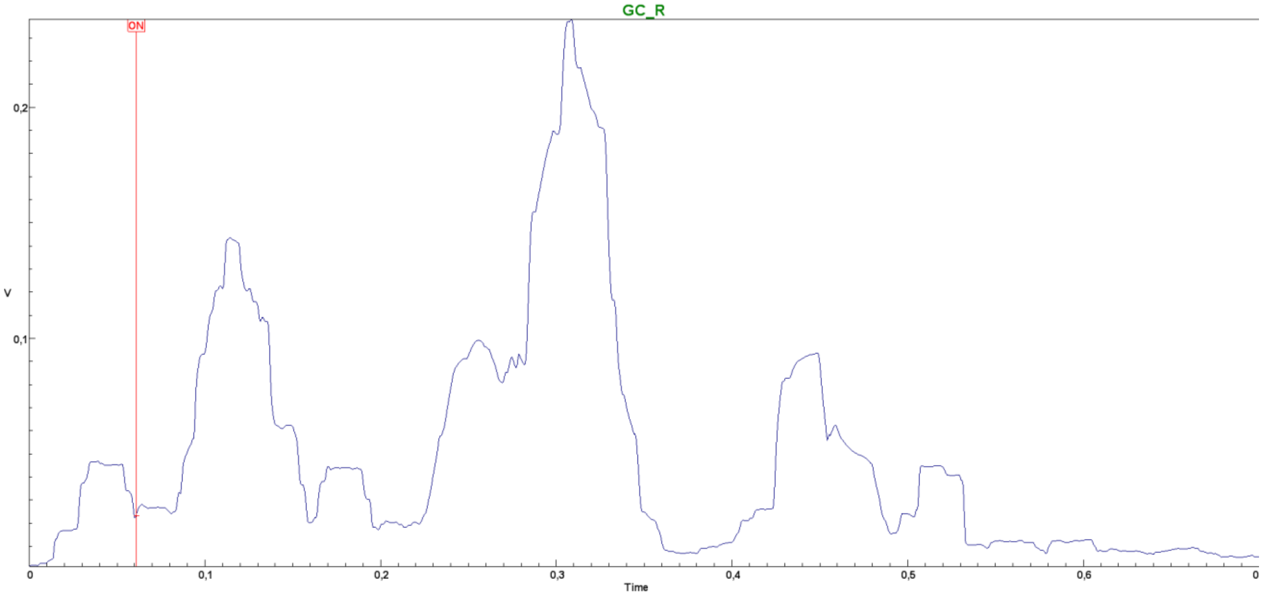
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

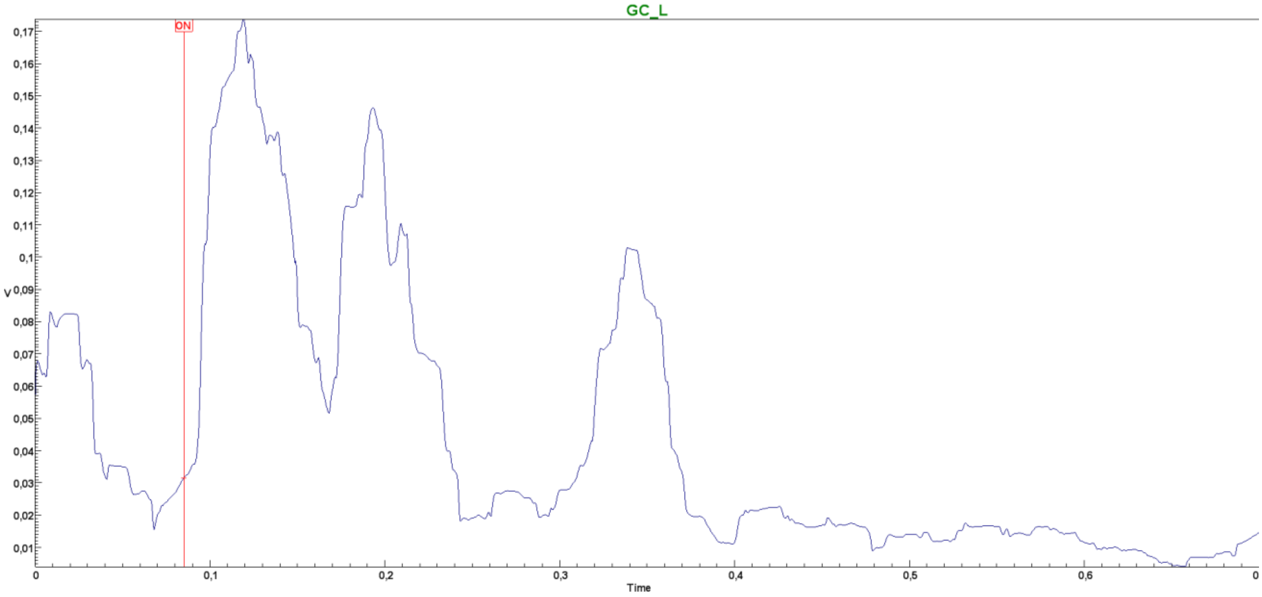

RF_R
V
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0
0,1
0,2
0,3
0,4
0,5
0,6
Time


RF_L
ON
V
Time

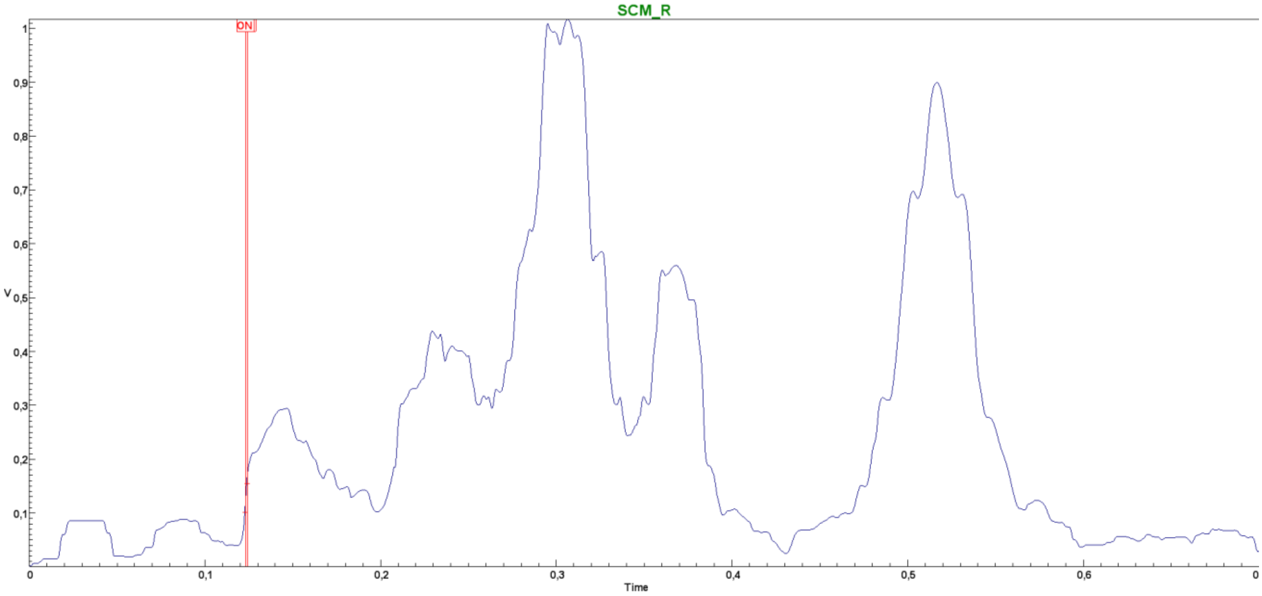

BF_R
ON
V
Time

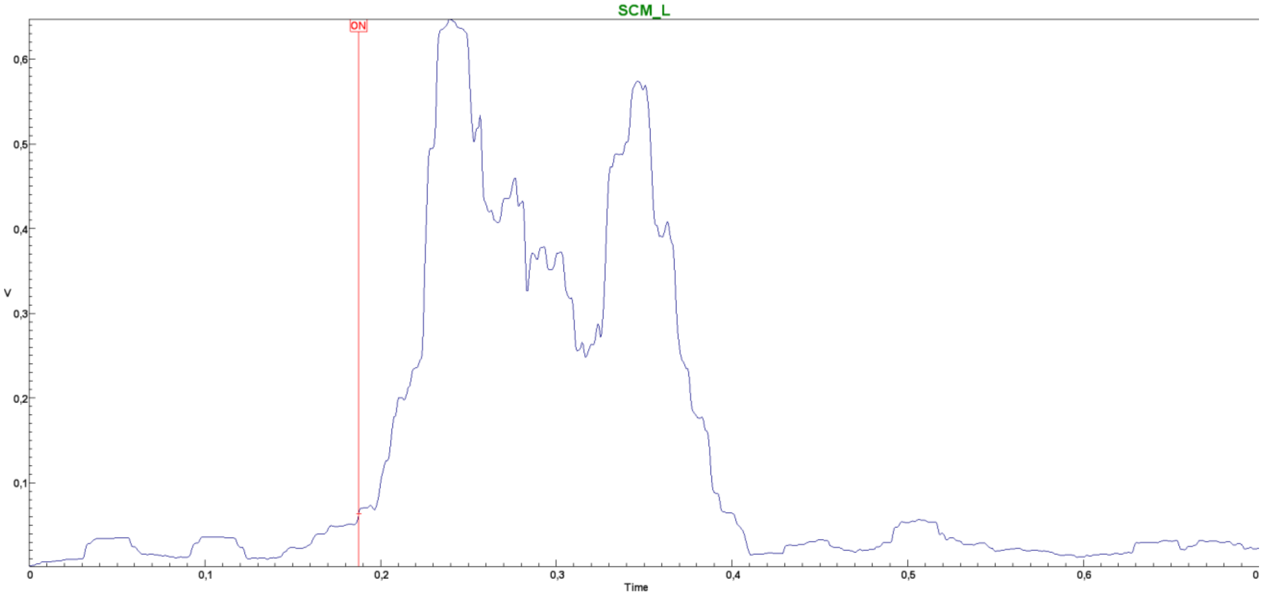

BF_L
ON
ON
ON
V
Time

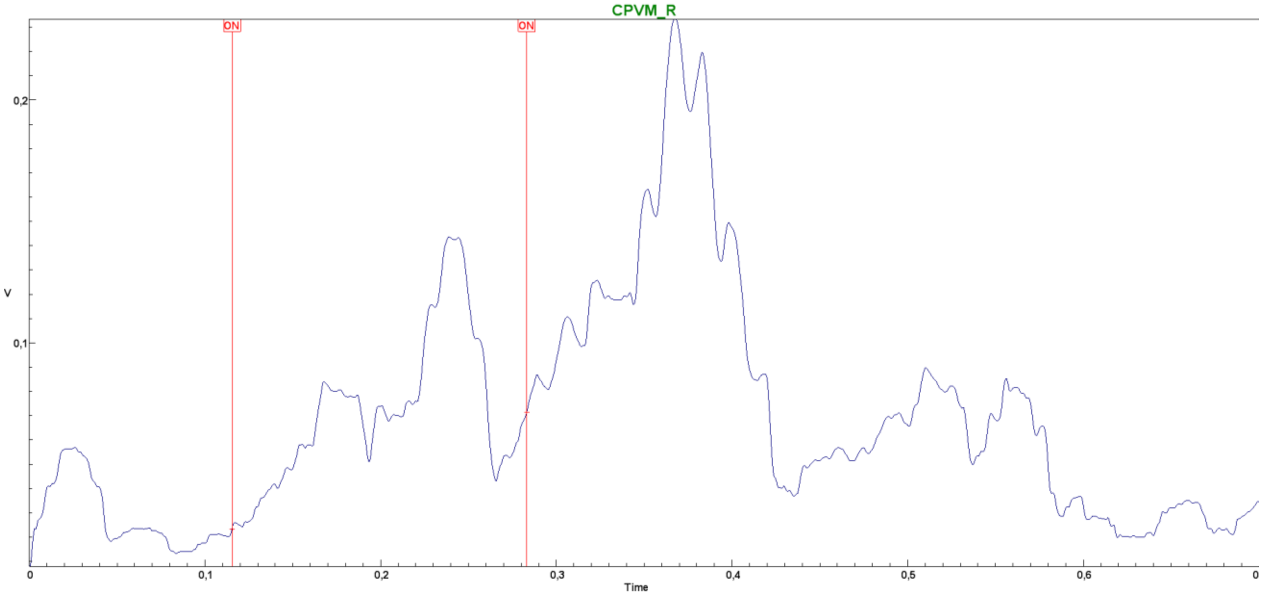

GC_R
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

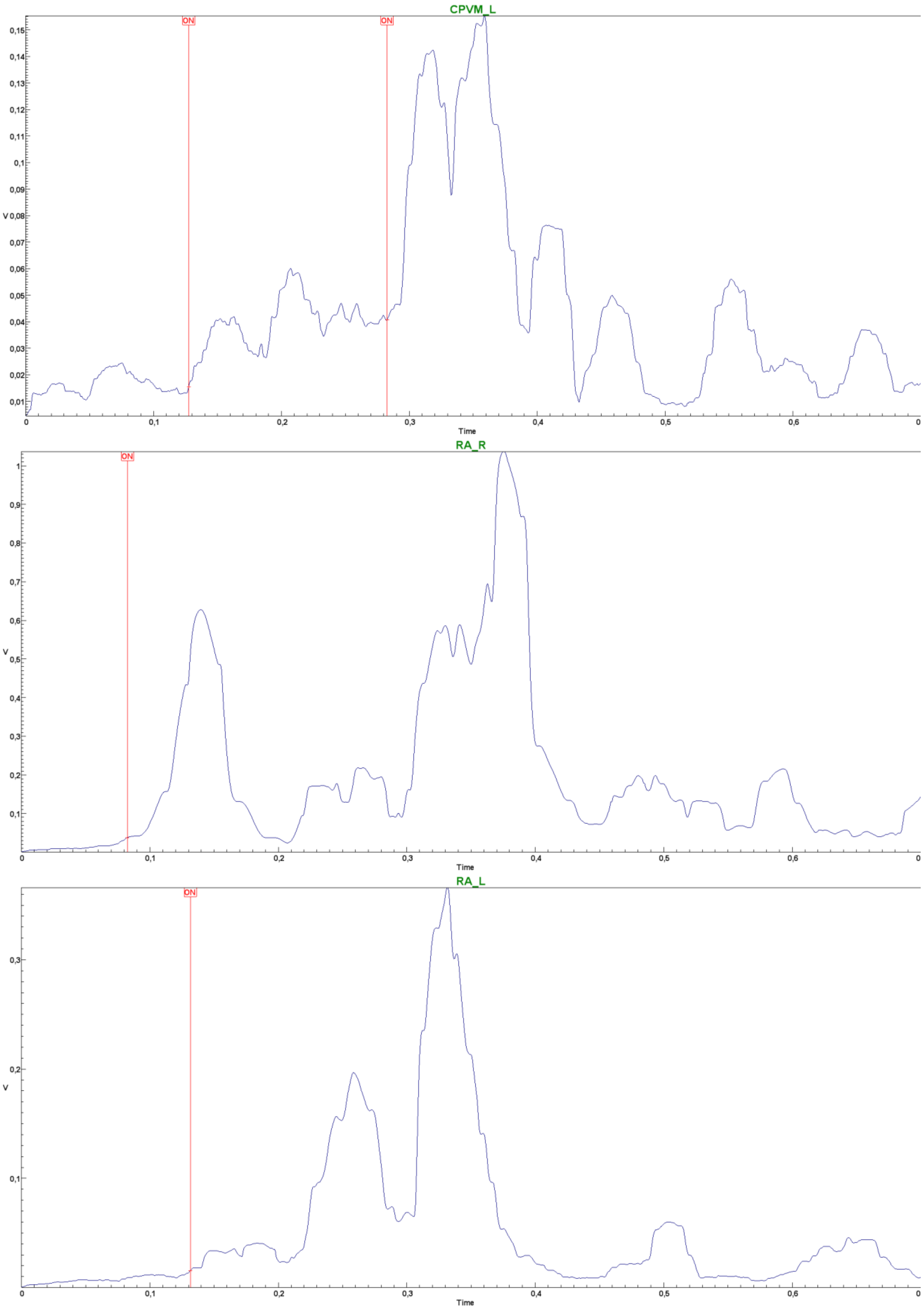

GC_L
ON
V
0,17
0,16
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

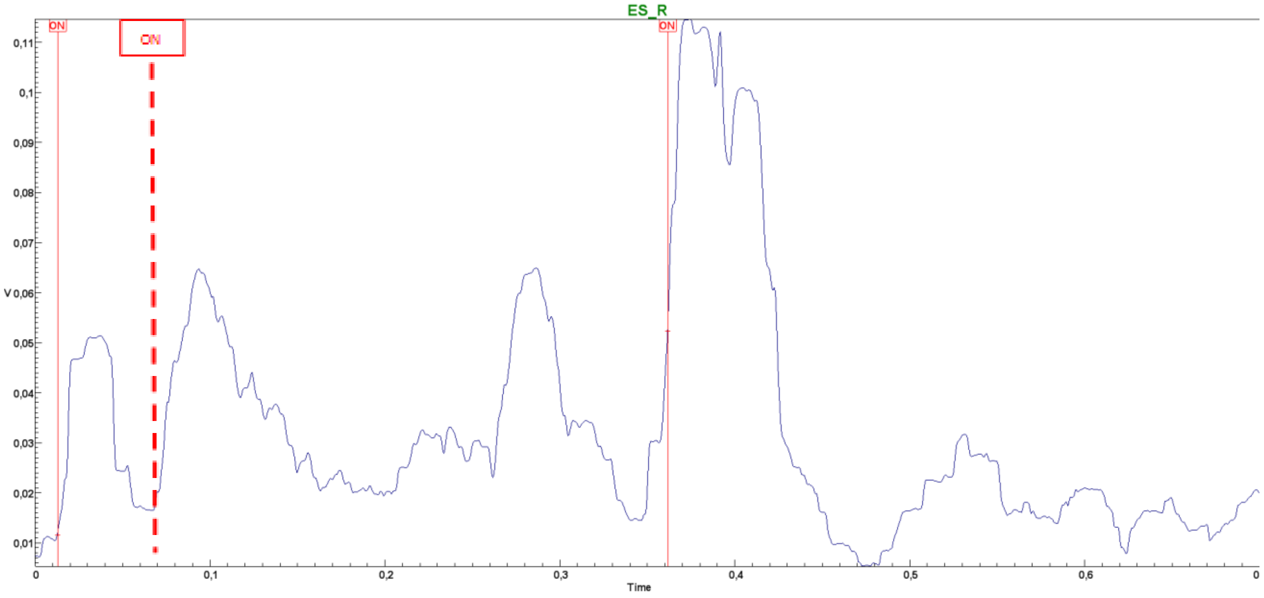
Trial 1778:




CPVM_L
ON
ON
V
Time
RA_R
ON
V
Time
RA_L
ON
V
Time


ES_R
ON
ON
ON
V
Time
0,11
0,1
0,09
0,08
0,07
0,06
0,05
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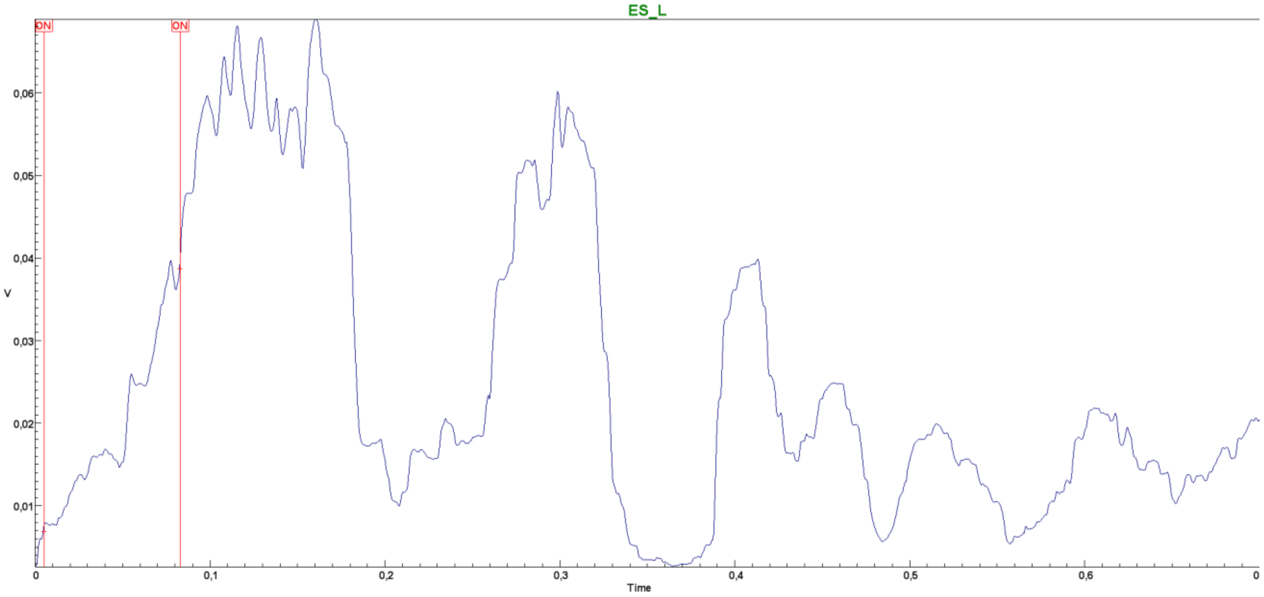
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6


ES_L
ON
ON
V
Time
0,06
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0,03
0,02
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0
0,1
0,2
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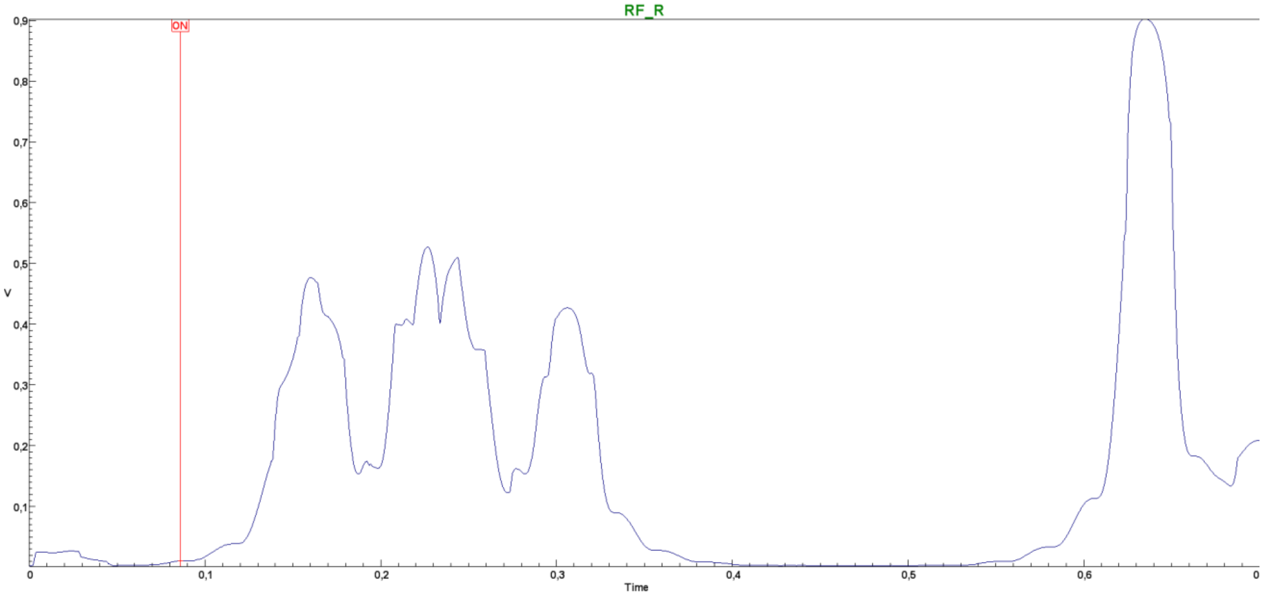
0,4
0,5
0,6


RF_R
ON
V
Time
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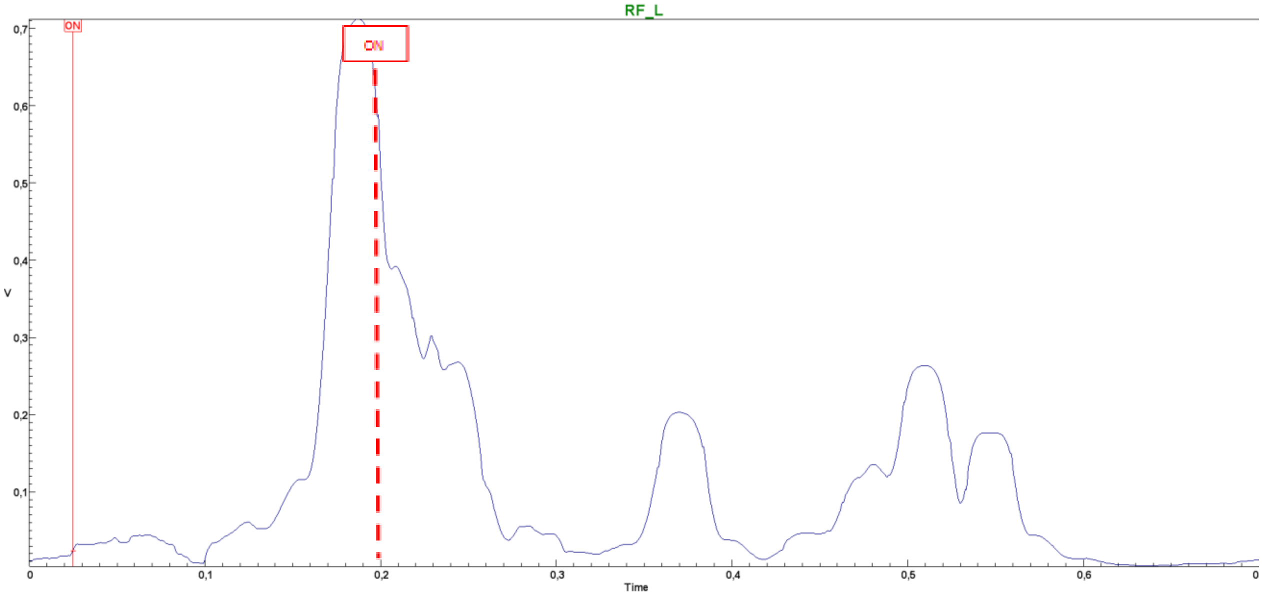
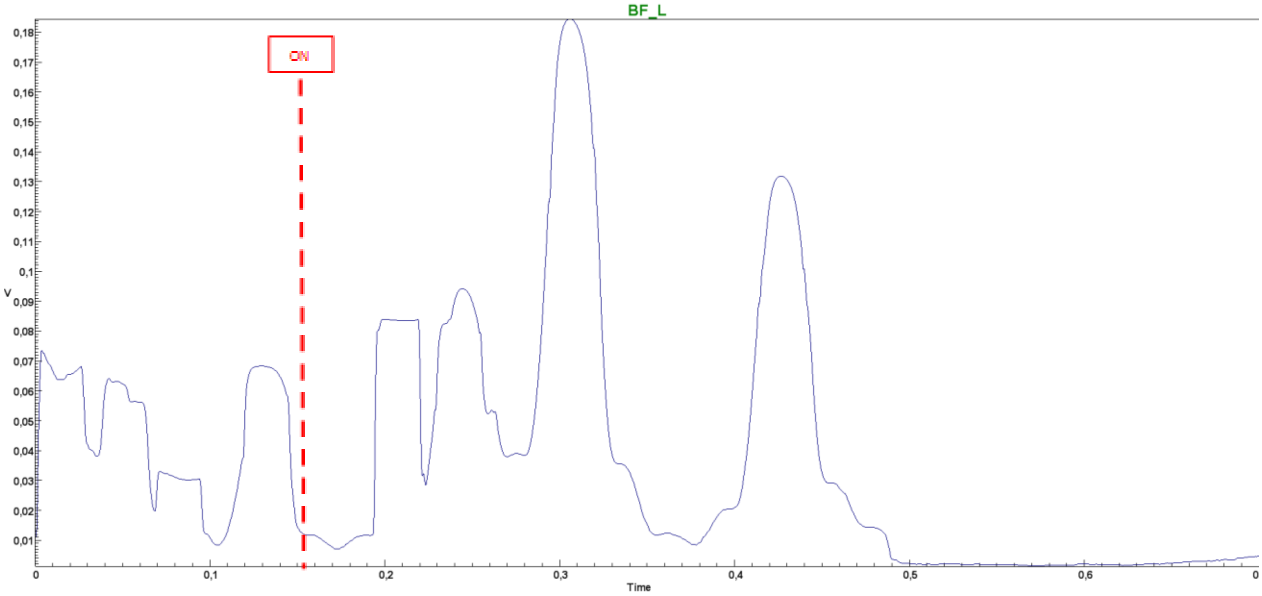
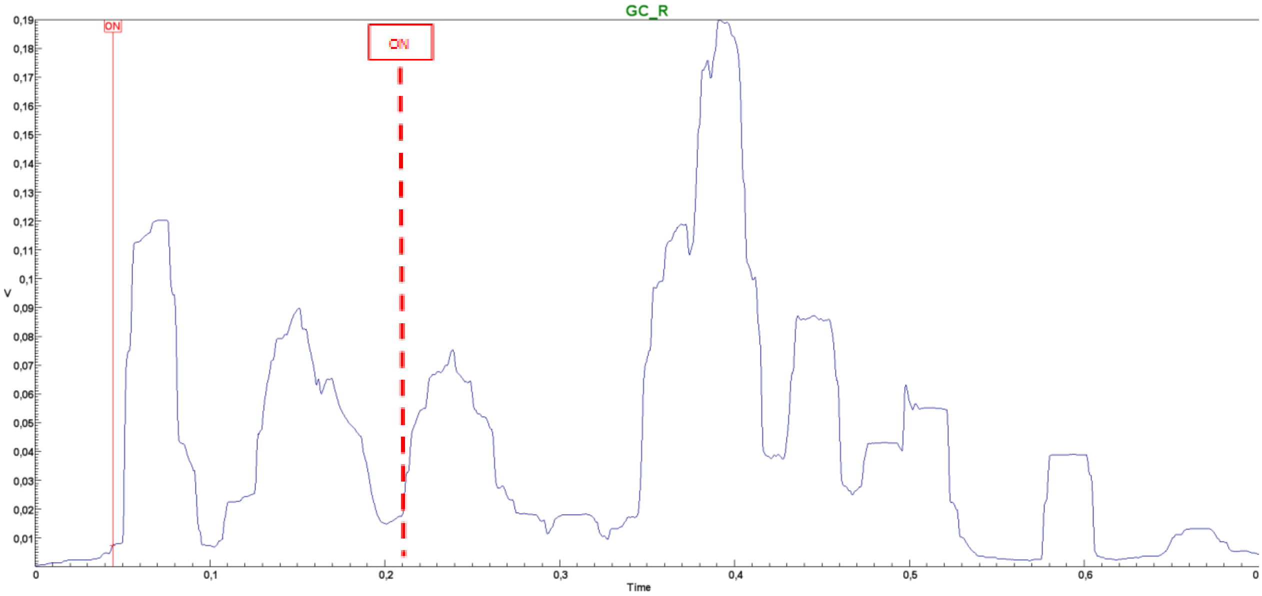
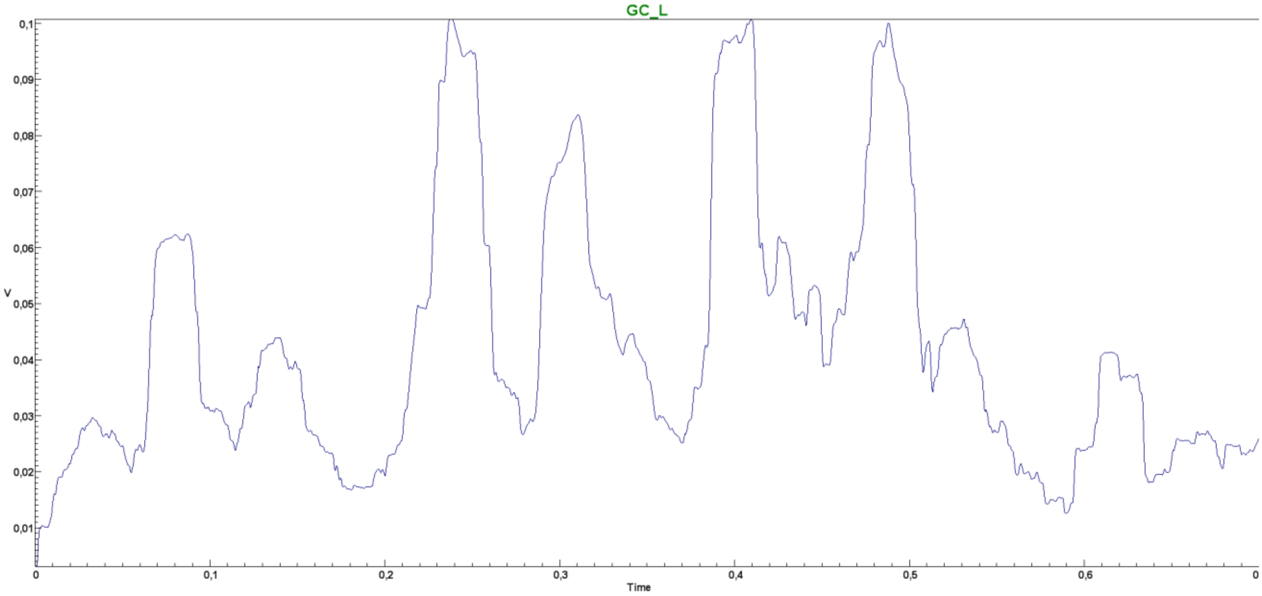
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6

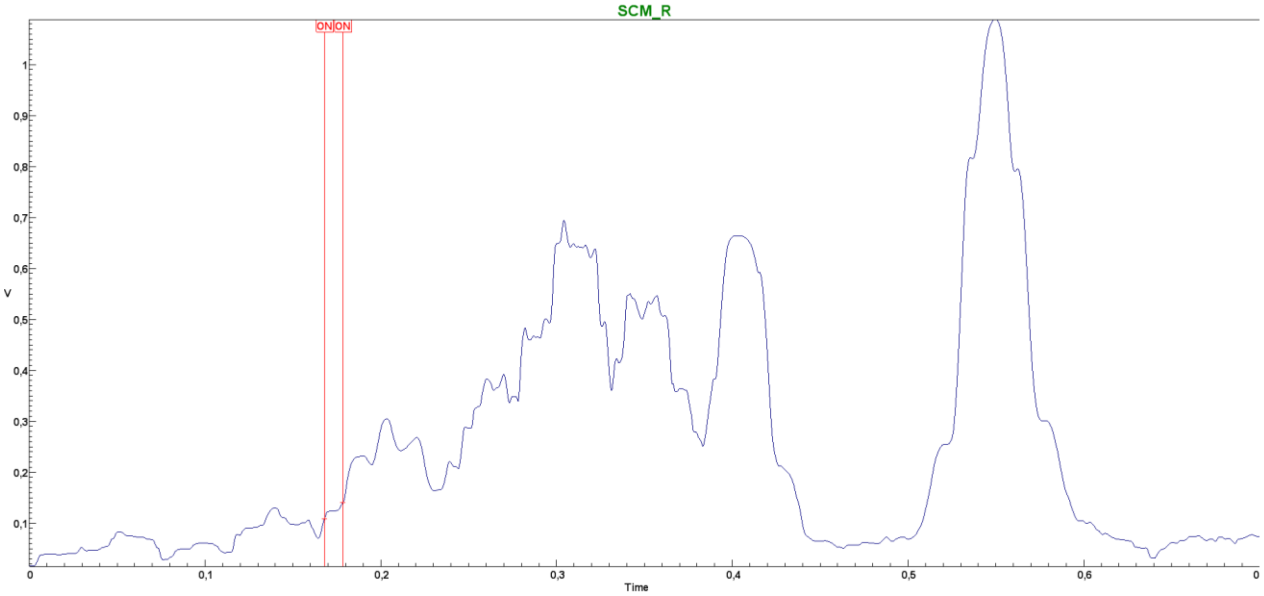

RF_L
ON
ON
V
Time

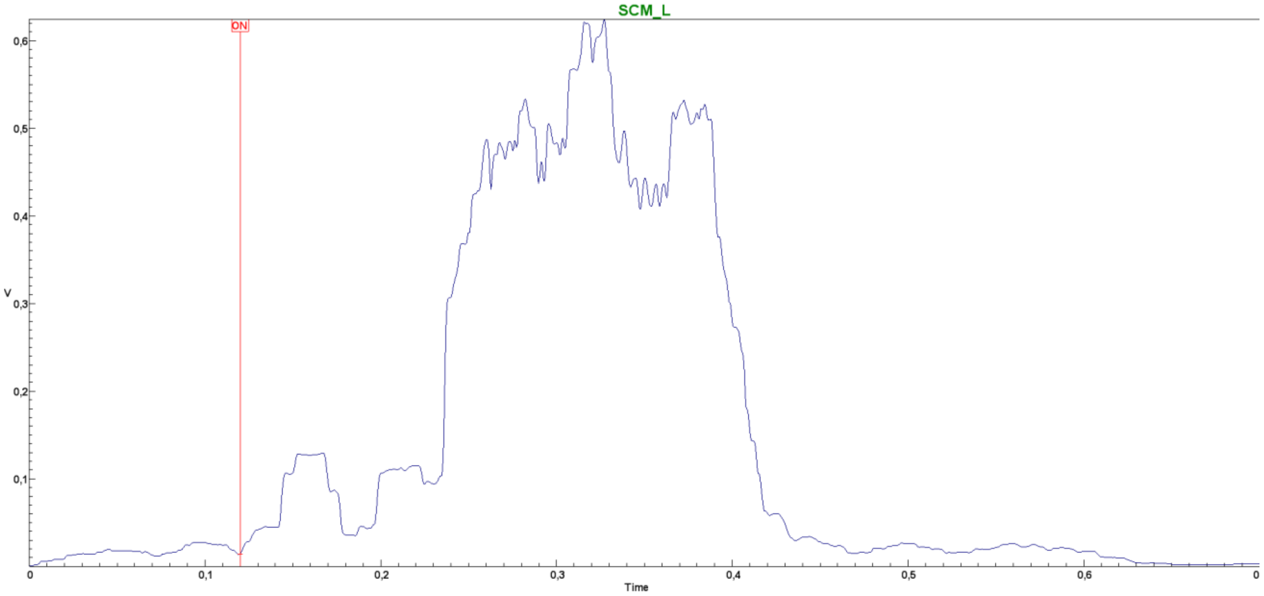

BF_L
ON
V
Time

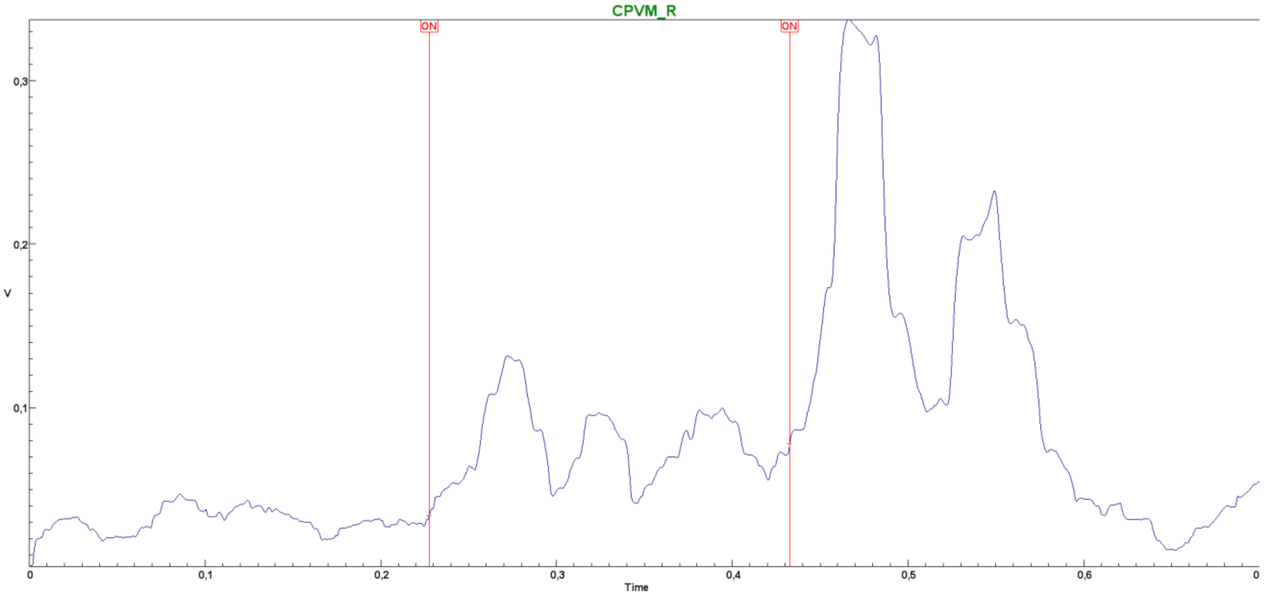

GC_R
ON
ON
V
Time

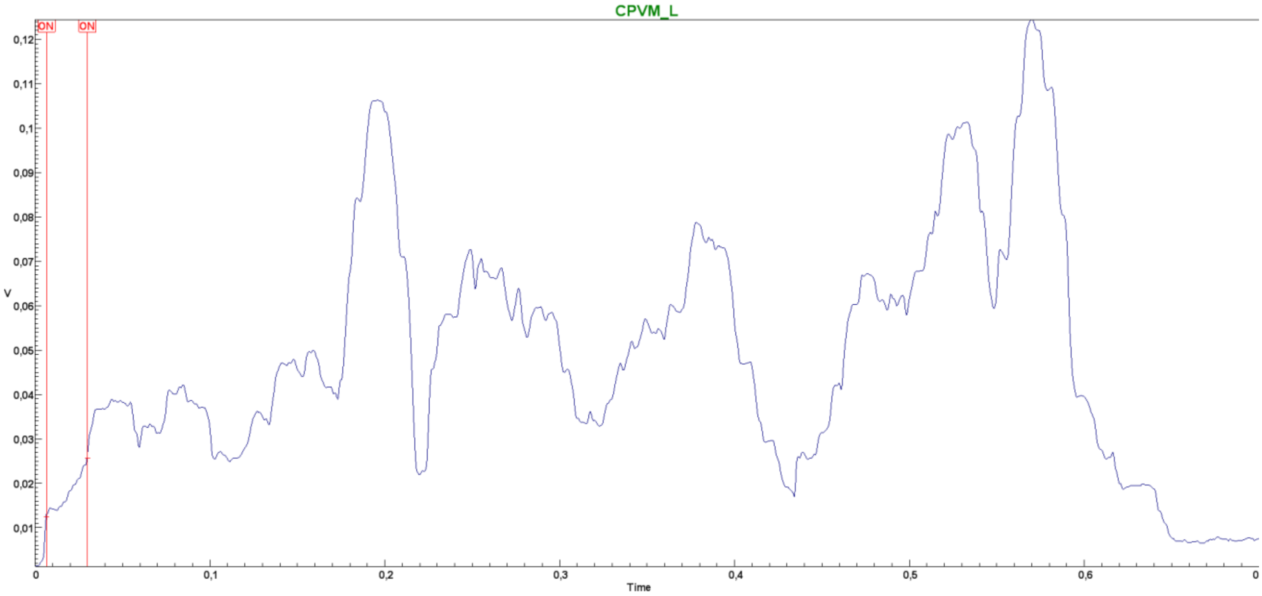

GC_L
V
Time

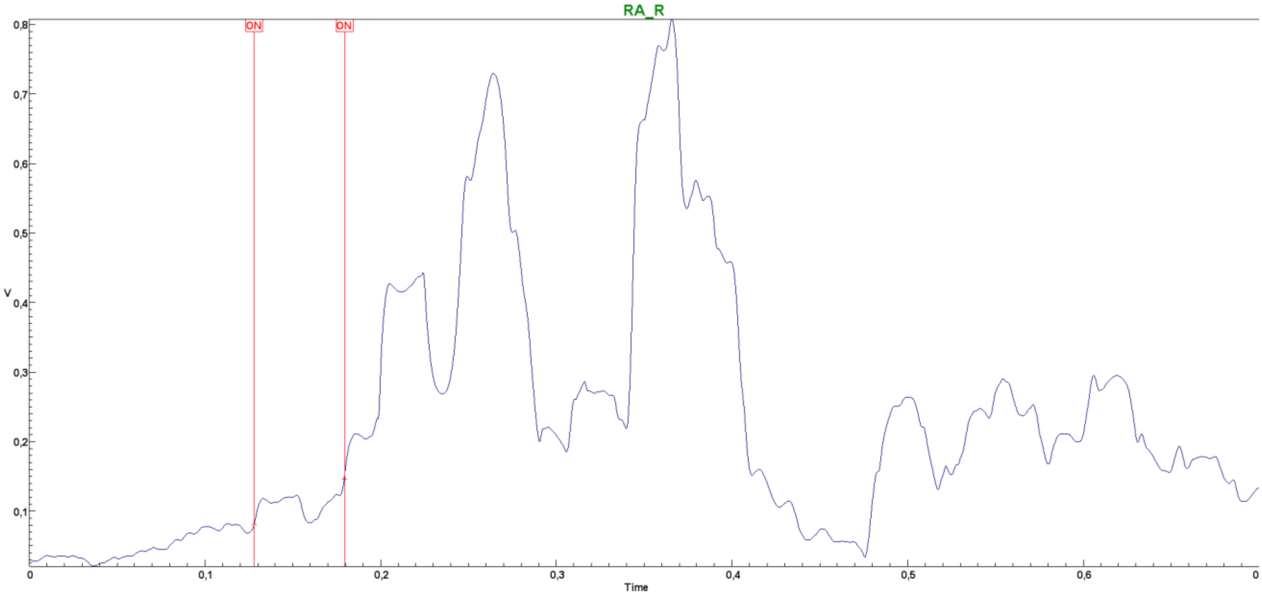
## Trial 1779

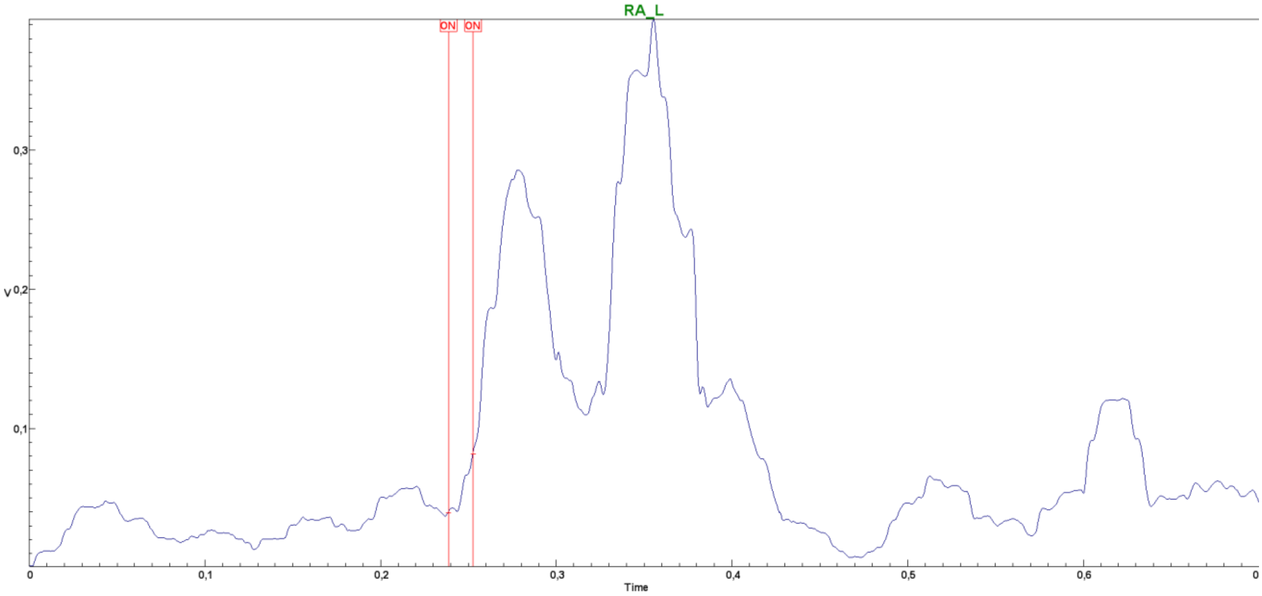


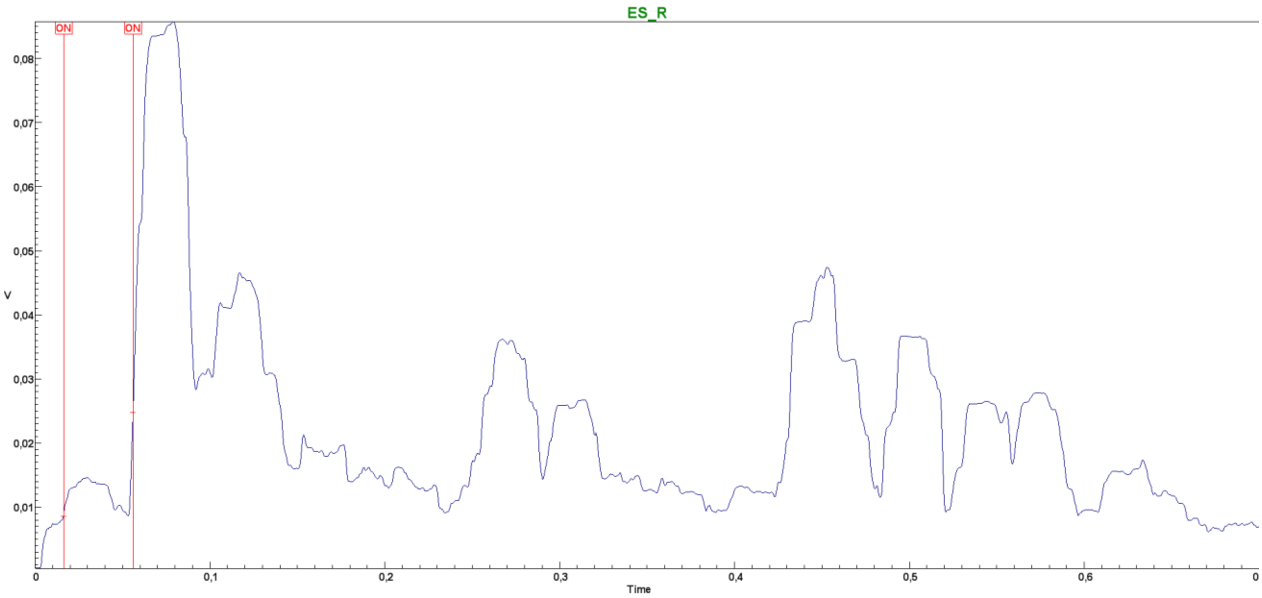



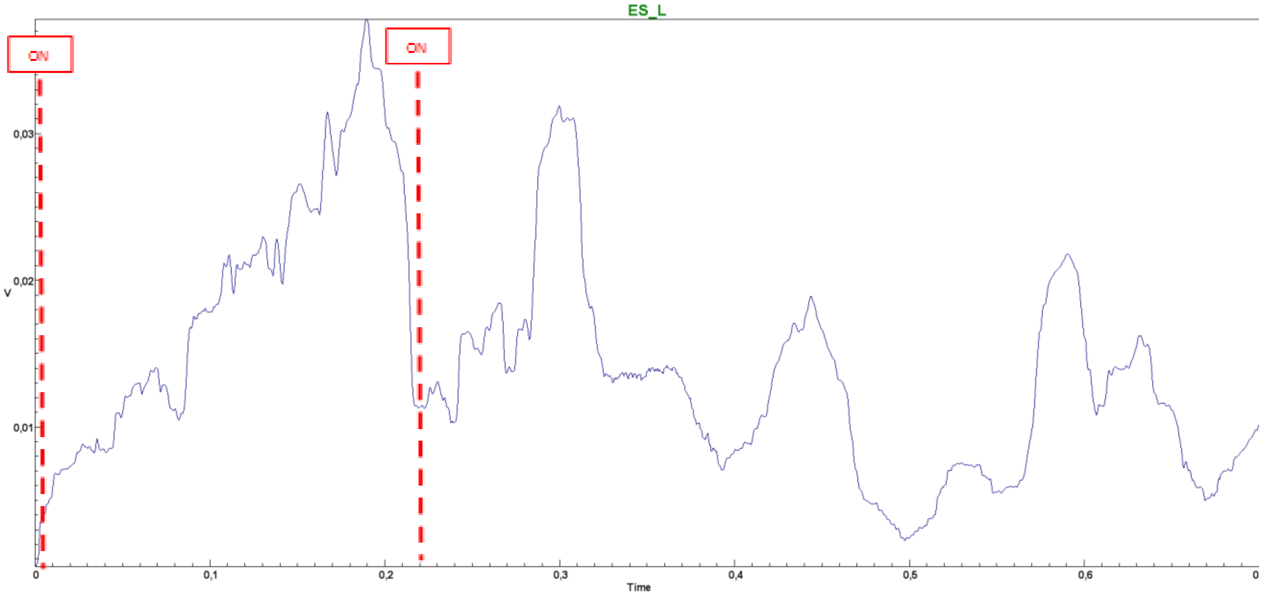



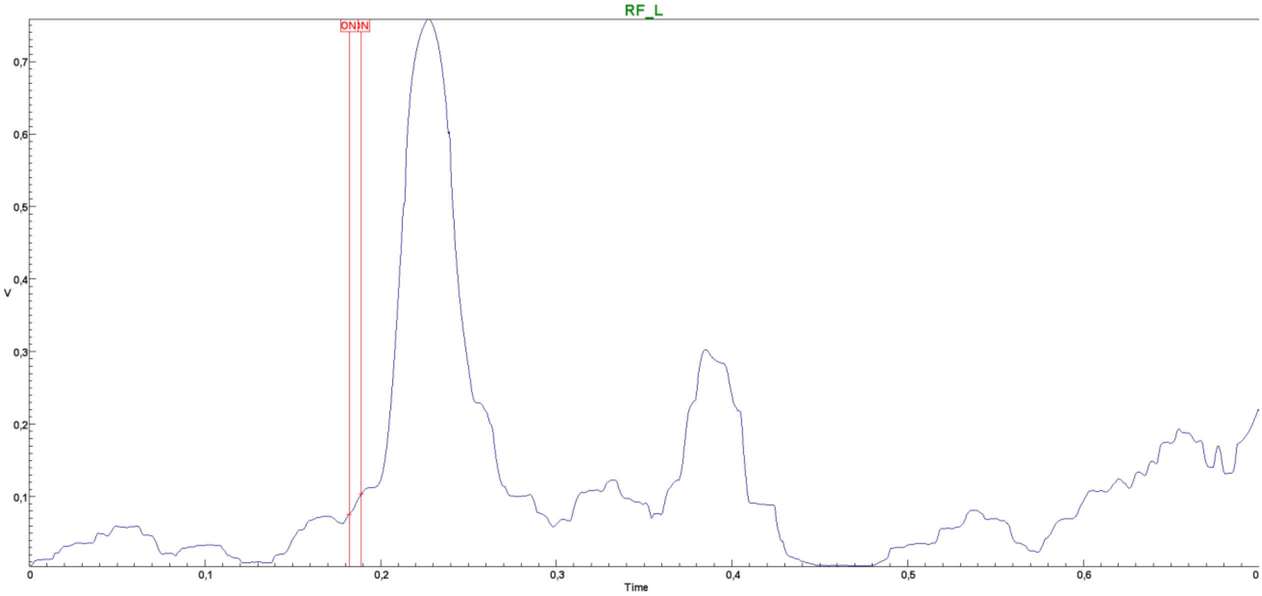

CPVM_L
ON
ON
V
Time
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6

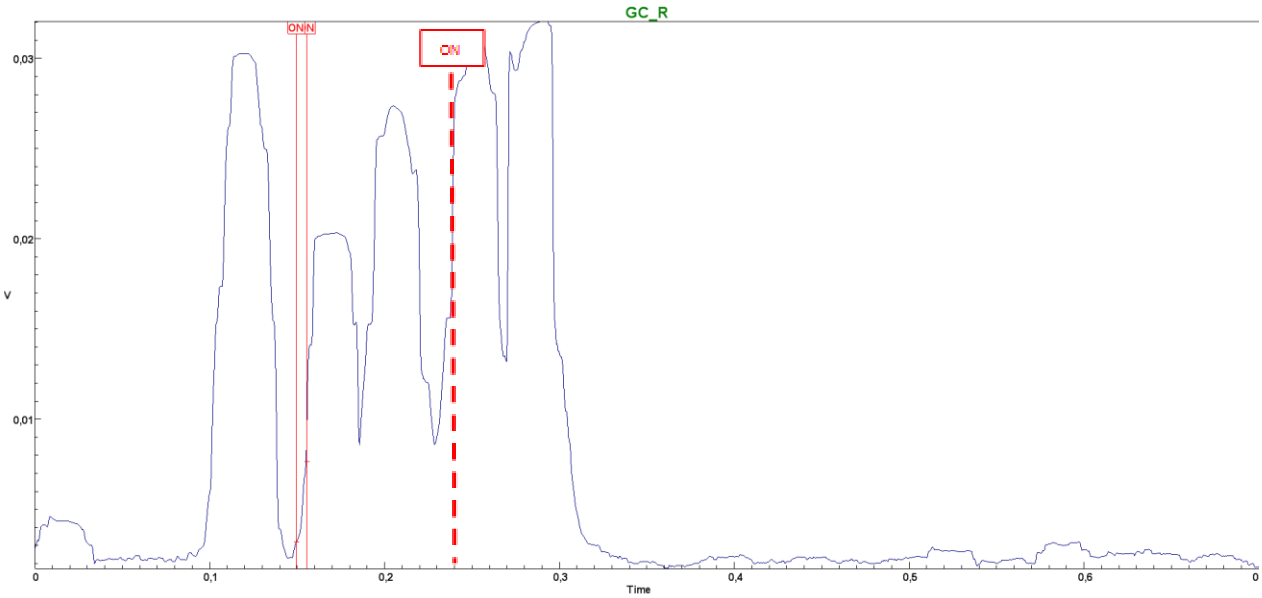

RA_R
ON
ON
V
Time
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6


RA_L
ON
ON
V
Time
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6


ES_R
ON
ON
V
Time


ES_L
ON
ON
V
Time


RF_L
ON
ON
V
Time


GC_R
ON
ON
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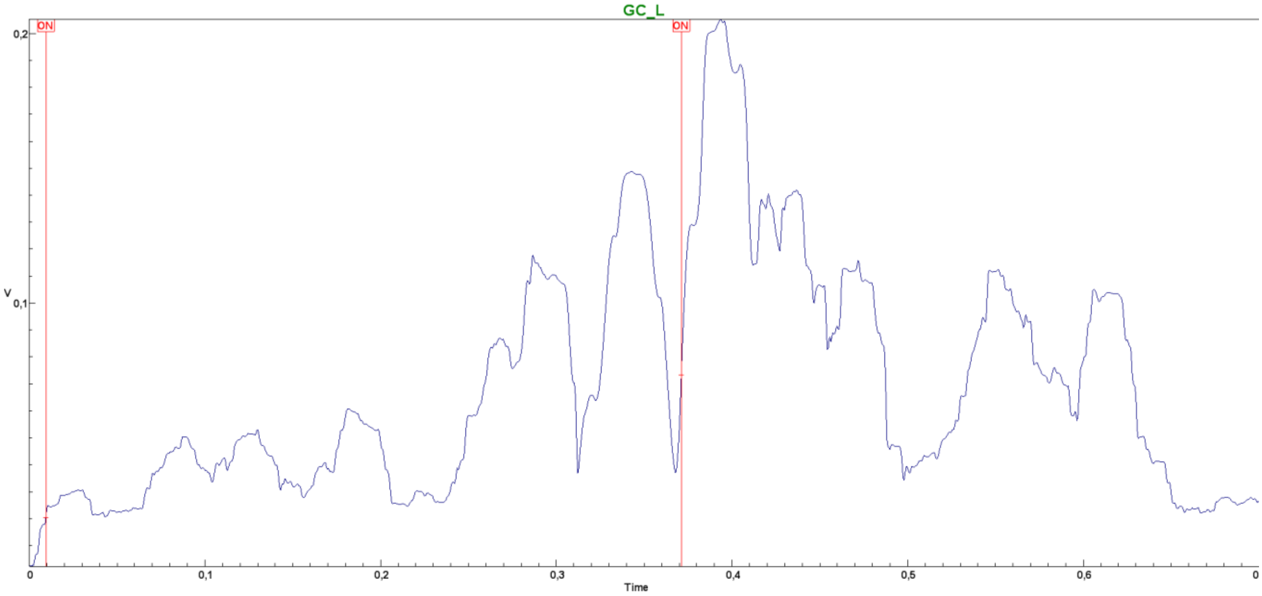
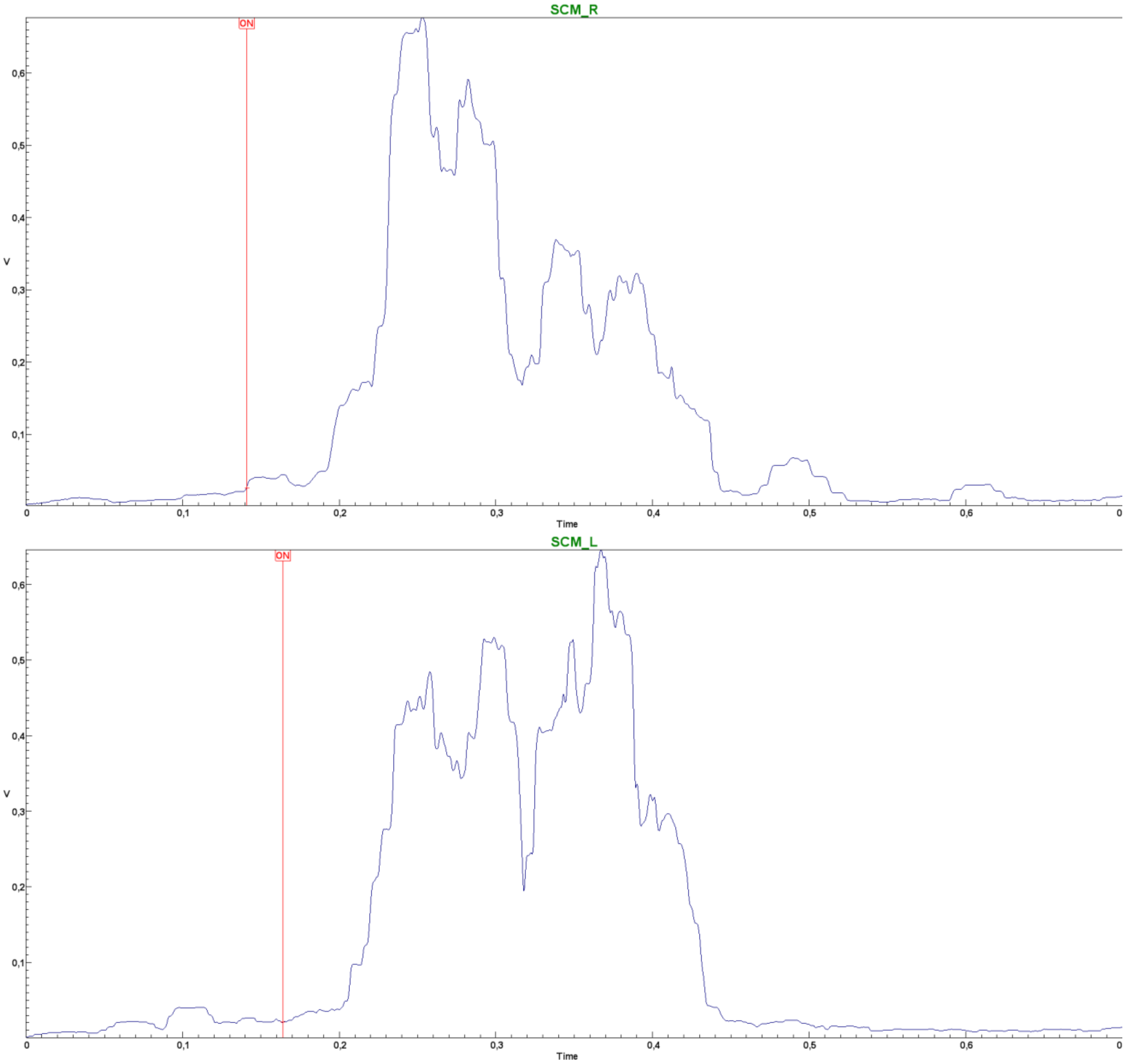
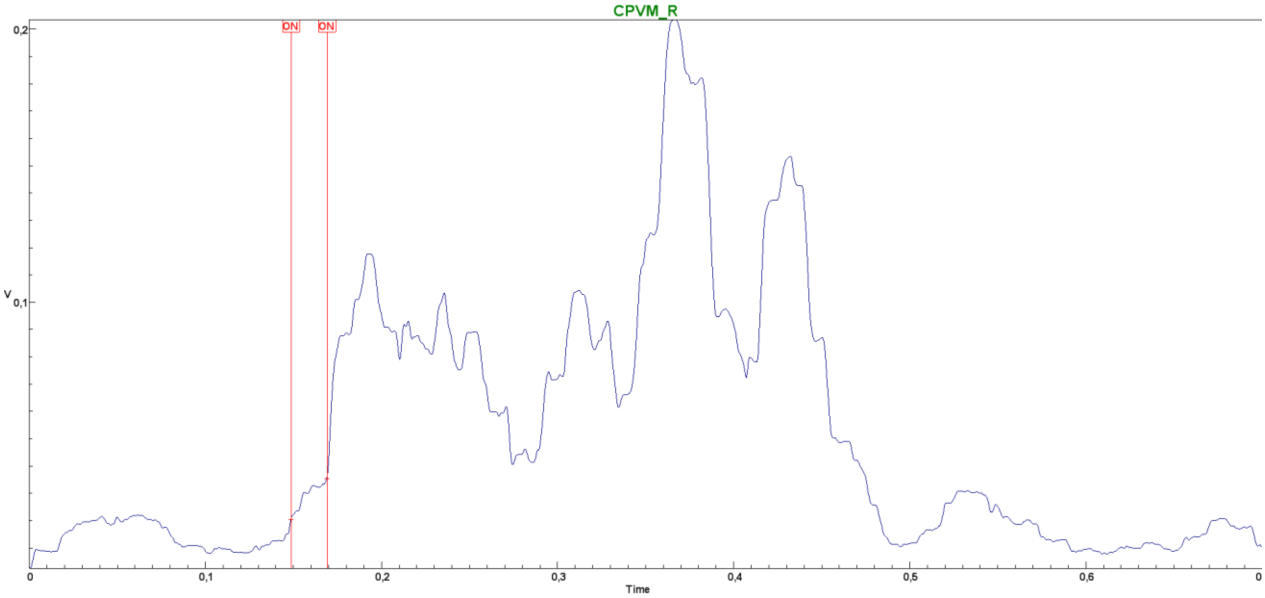
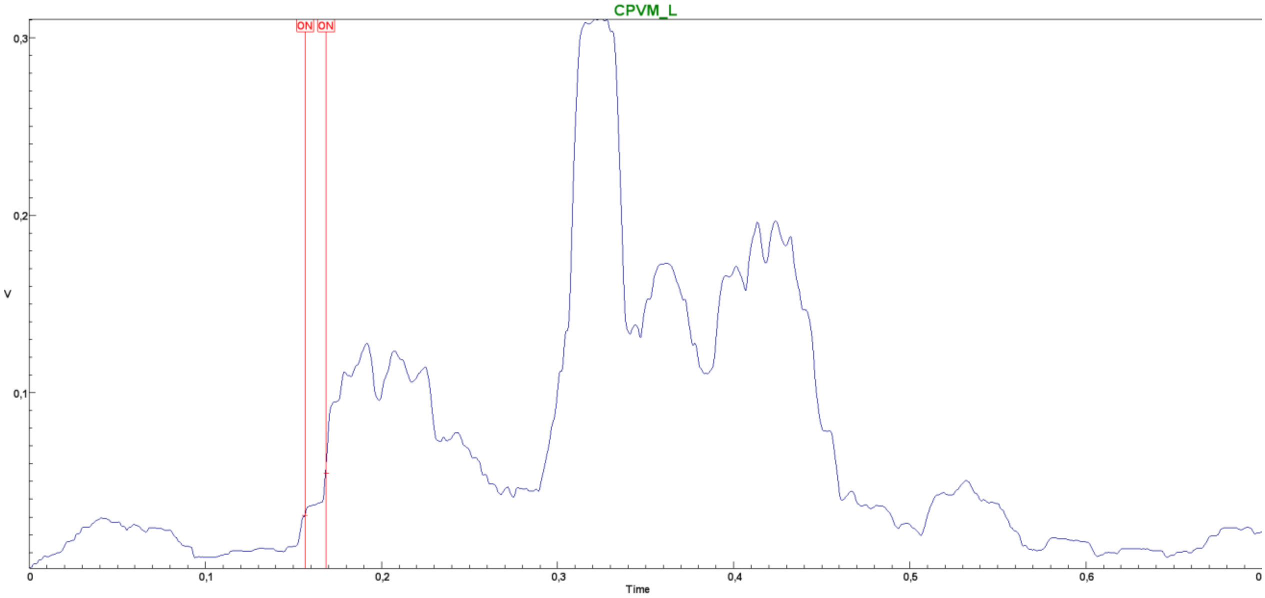
0,02
0,01
V
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

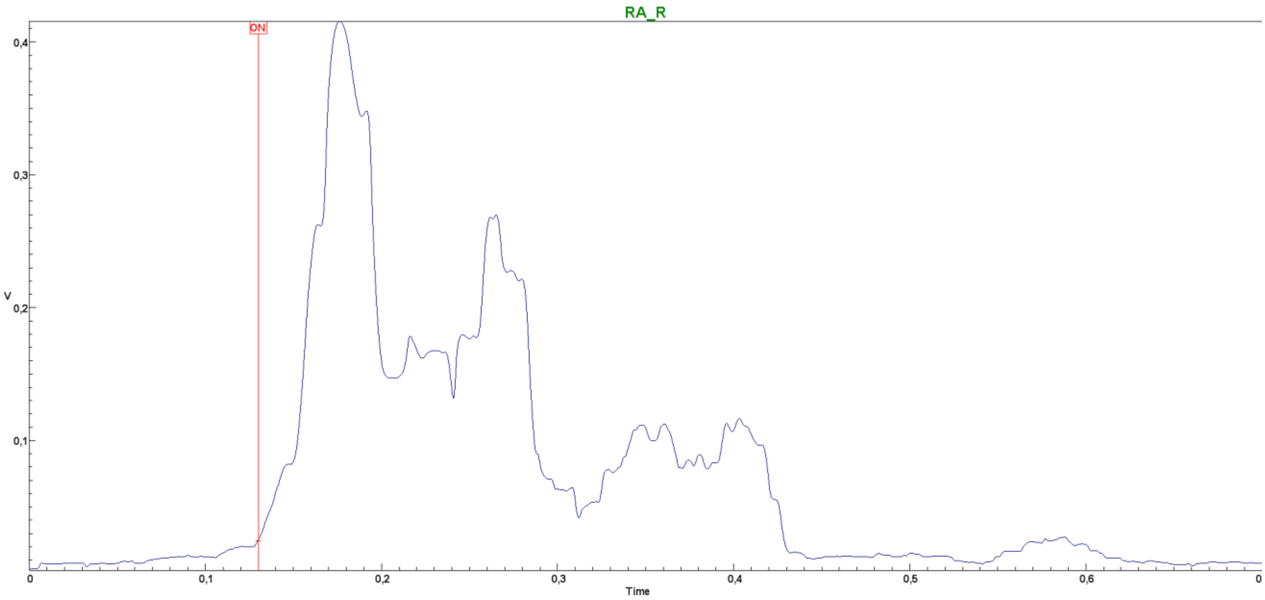

GC_L
ON
ON
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

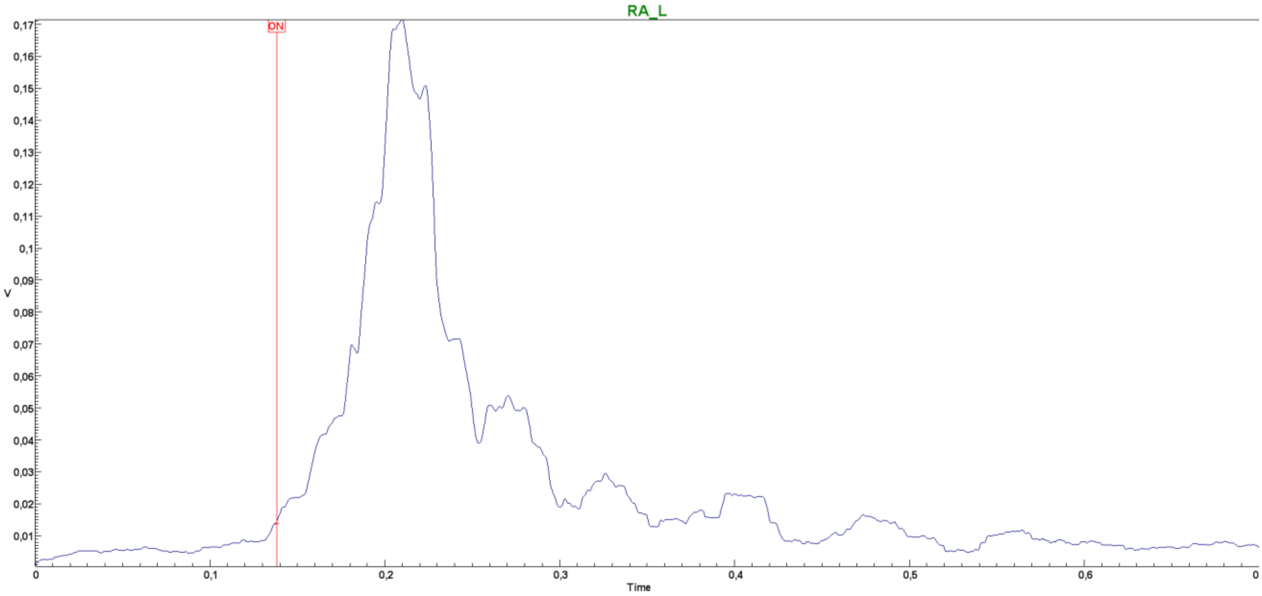
Trial 1780:

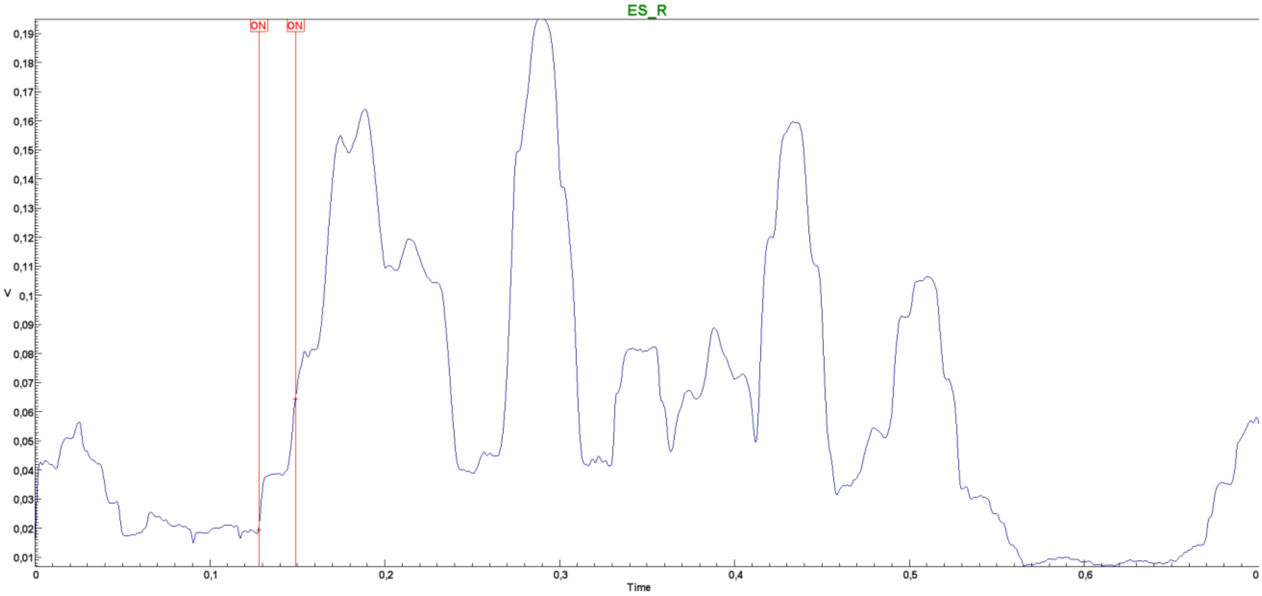

SCM_R
ON
0,6
0,5
0,4
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time
SCM_L
ON
0,6
0,5
0,4
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

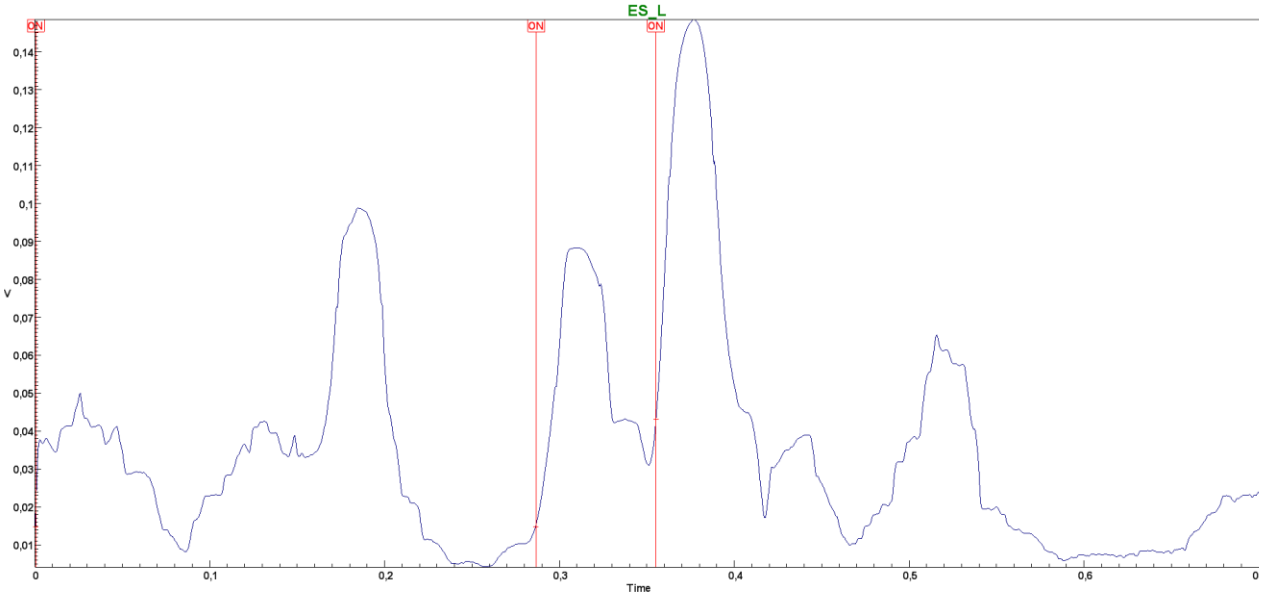

CPVM_R
ON
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time

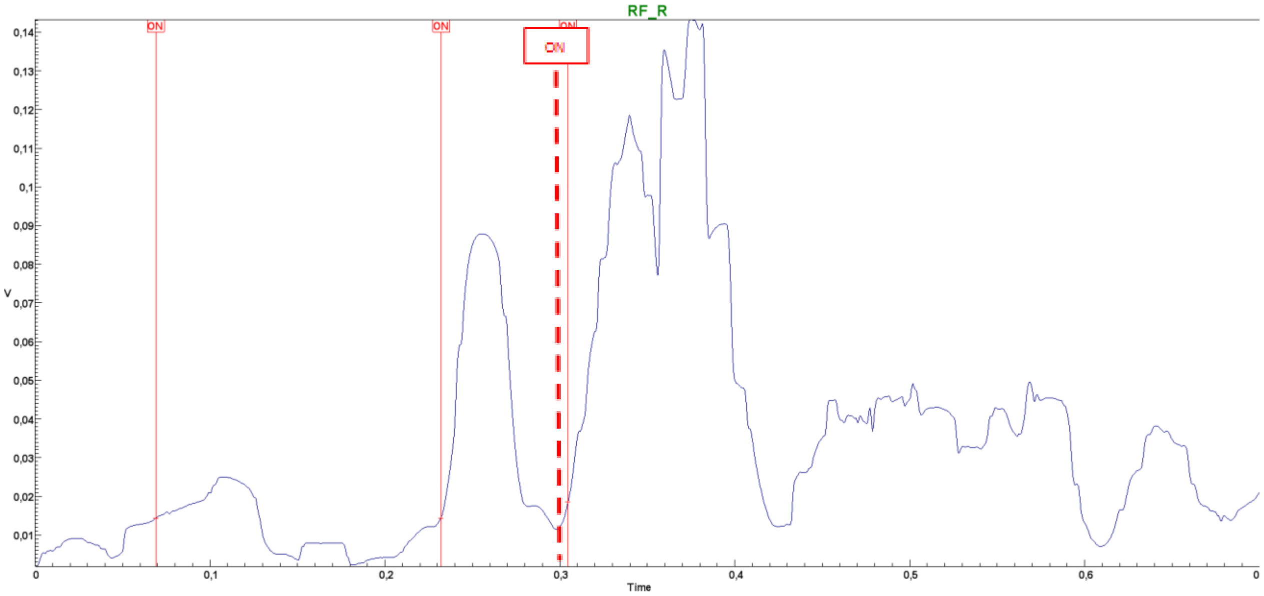

CPVM_L
ON
ON
V
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time


RA_R
ON
V
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time


RA_L
ON
V
Time


ES_R
ON
ON
V
Time


ES_L
ON
ON
ON
V
Time


RF_R
ON
ON
ON
ON
V
Time
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
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0,3
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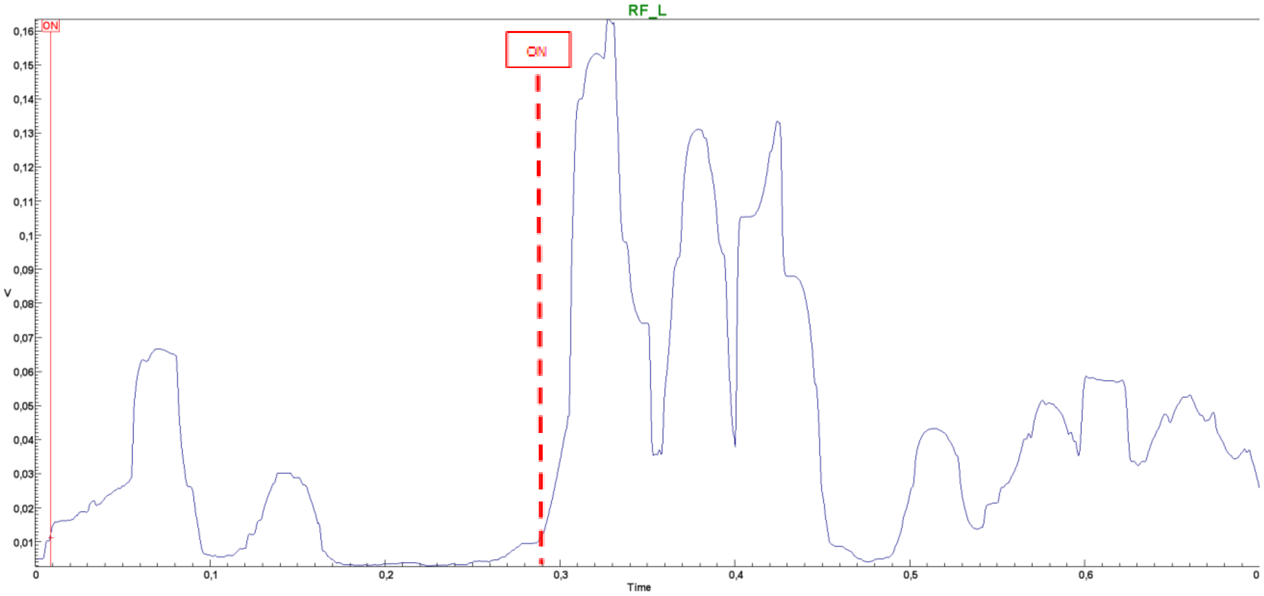
0,5
0,6
0


RF_L
ON
ON
V
Time
0,16
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
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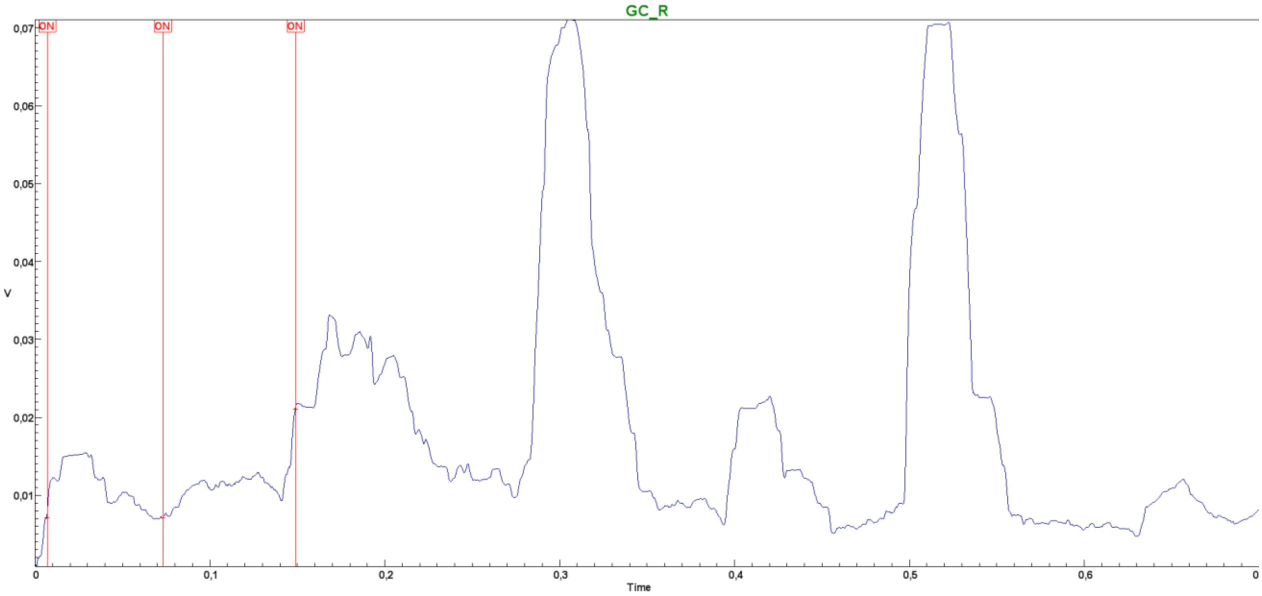
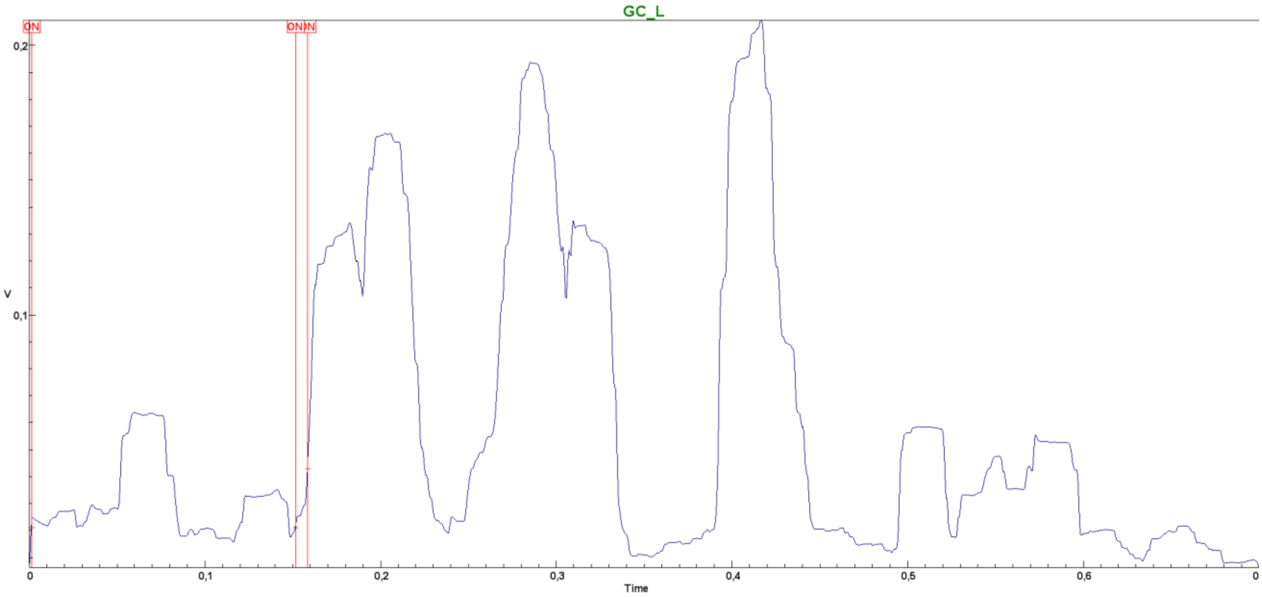
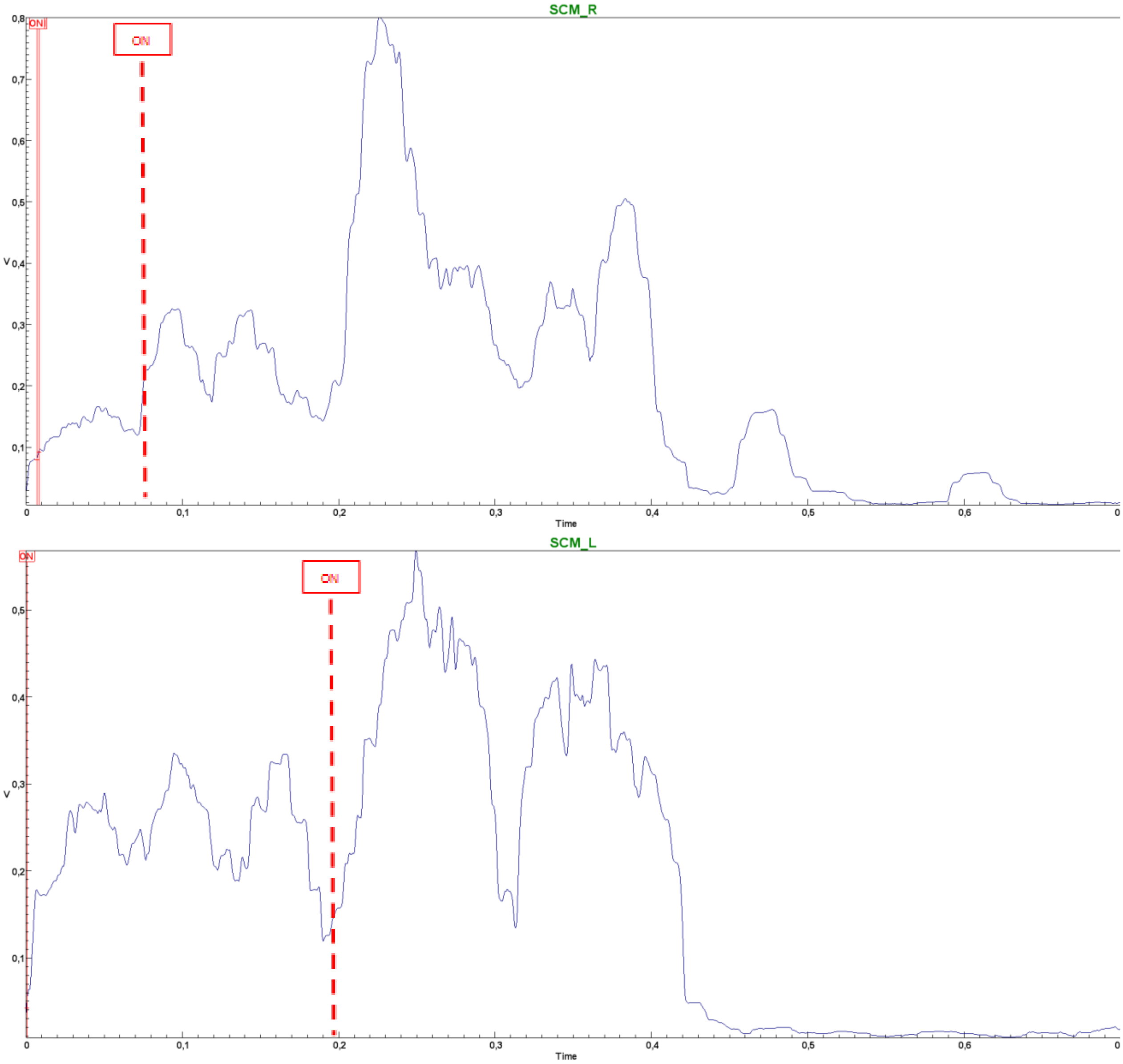
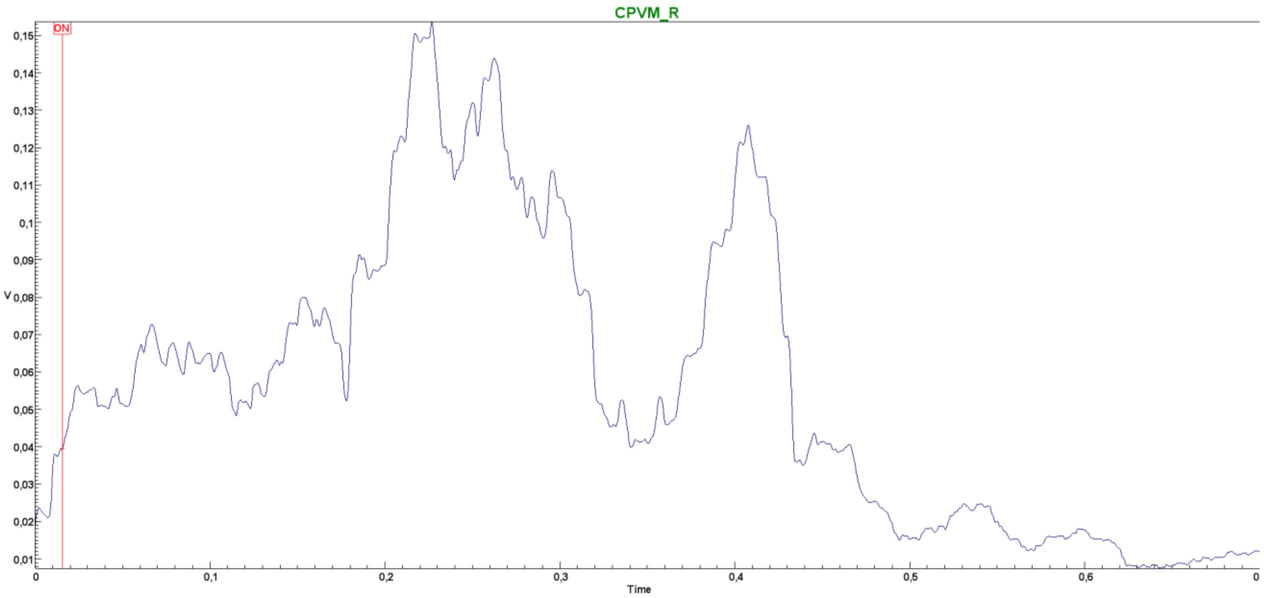
0,5
0,6
0

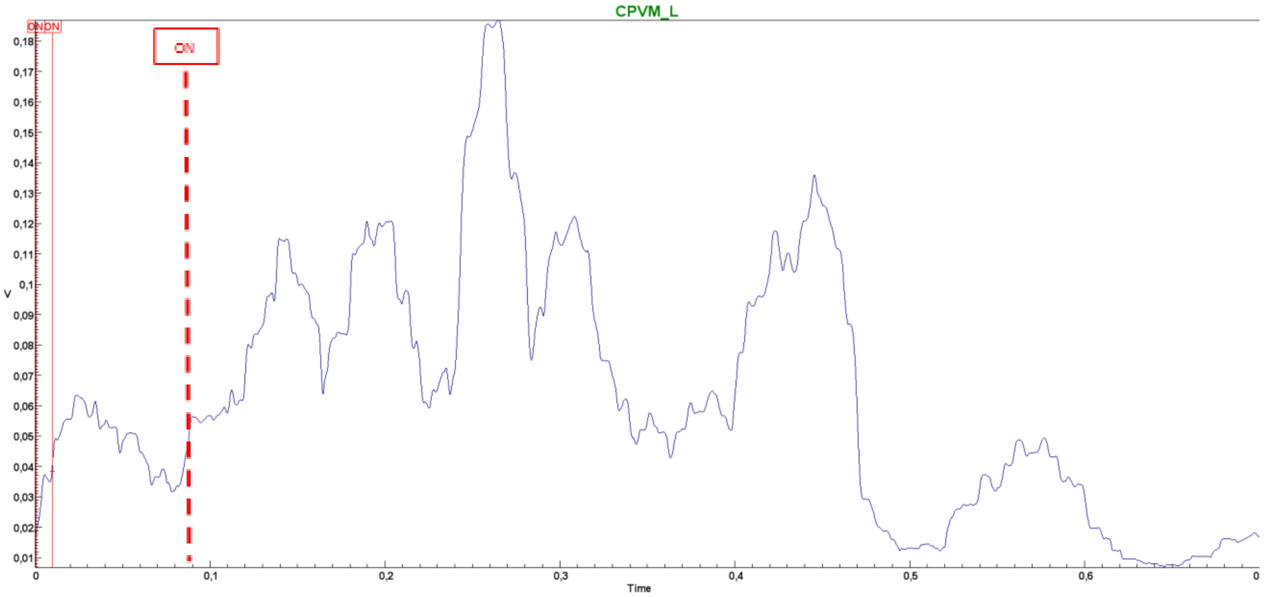

GC_R
ON
ON
ON
0,07
0,06
0,05
0,04
0,03
0,02
0,01
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


GC_L
ON
ON
ON
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

Trial 1781:


SCM_R
ON
ON
V
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time
SCM_L
ON
ON
V
0,5
0,4
0,3
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time


CPVM_R
ON
V
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
Time


CPVM_L
ON
ON
V
0,18
0,17
0,16
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
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0,02
0,01
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0,1
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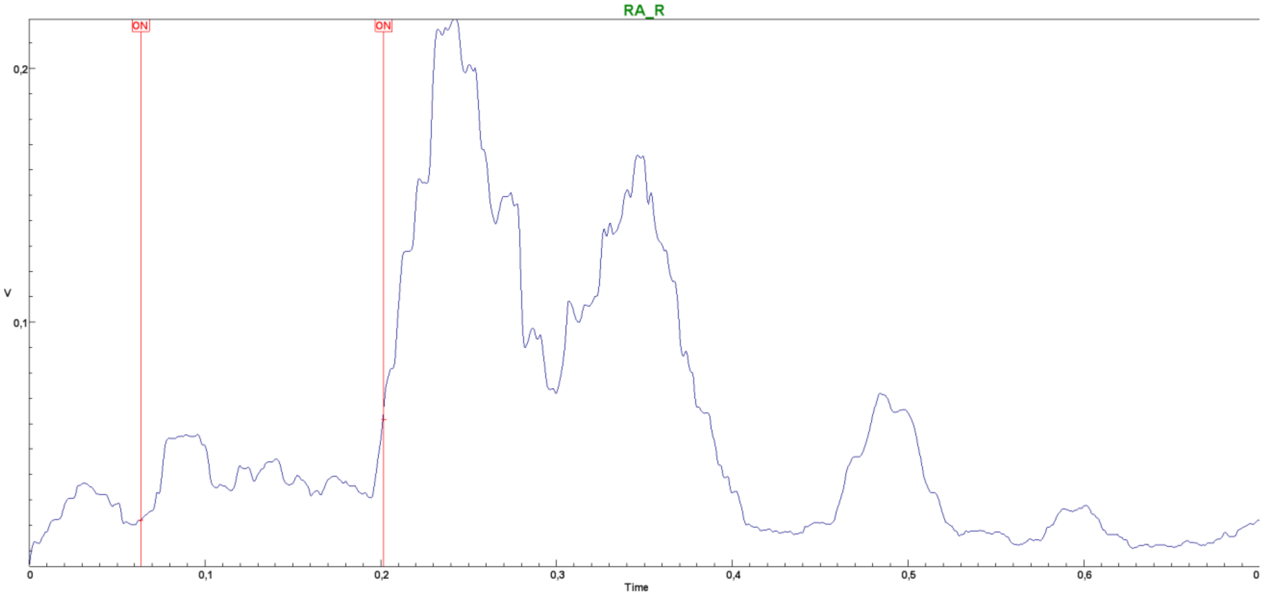
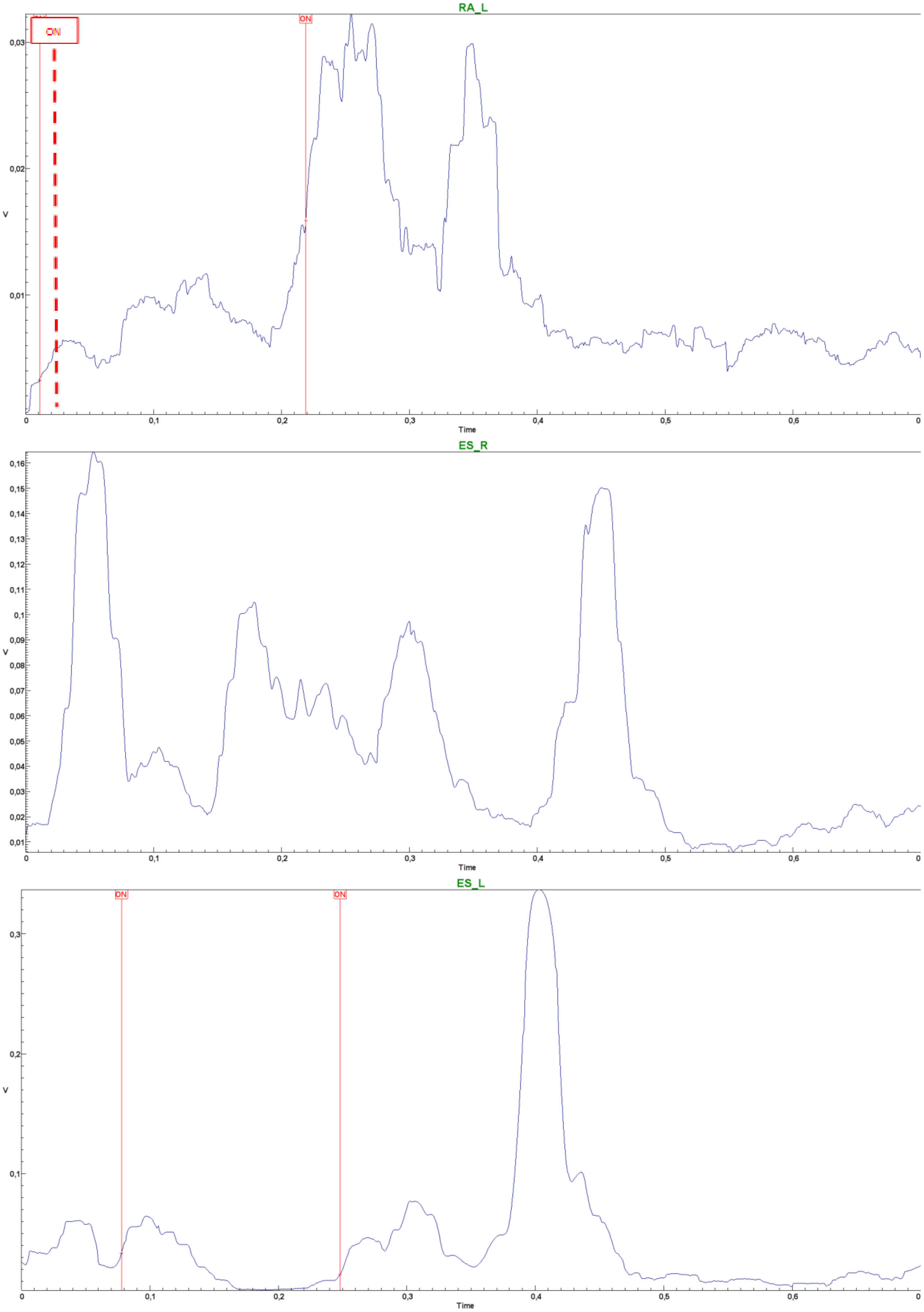
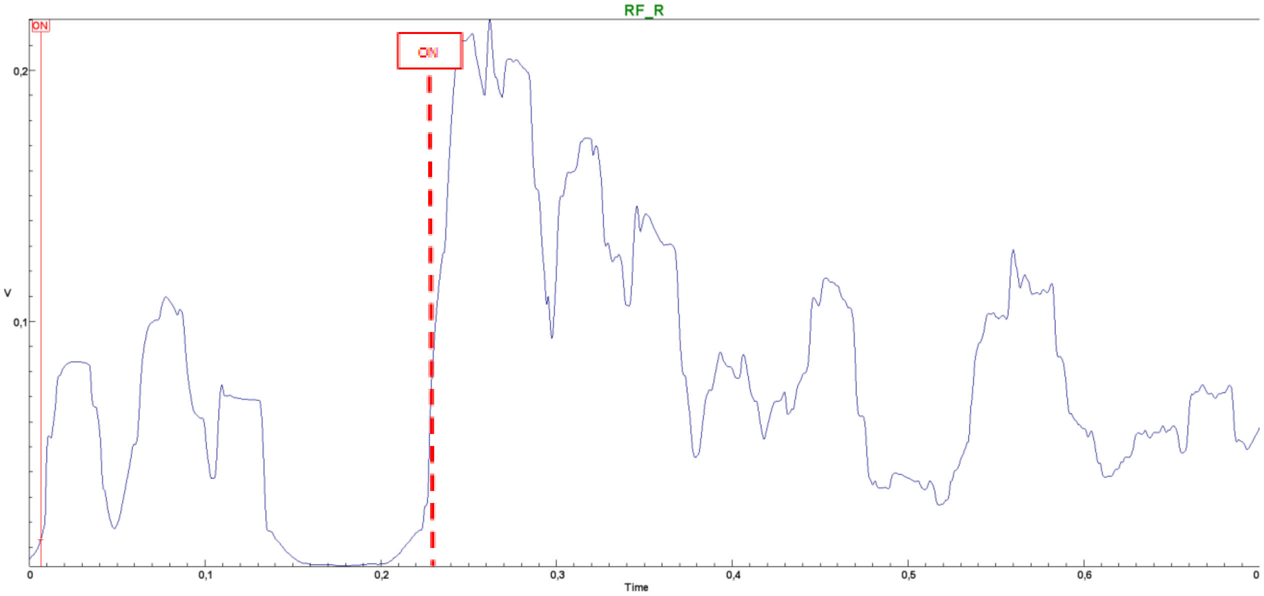
0,3
0,4
0,5
0,6
Time


RA_R
ON
ON
V
0,2
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
Time



RA_L
ON
ON
V
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
Time
ES_R
V
0,16
0,15
0,14
0,13
0,12
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
Time
ES_L
ON
ON
V
0,3
0,2
0,1
Time


RF_R
ON
ON
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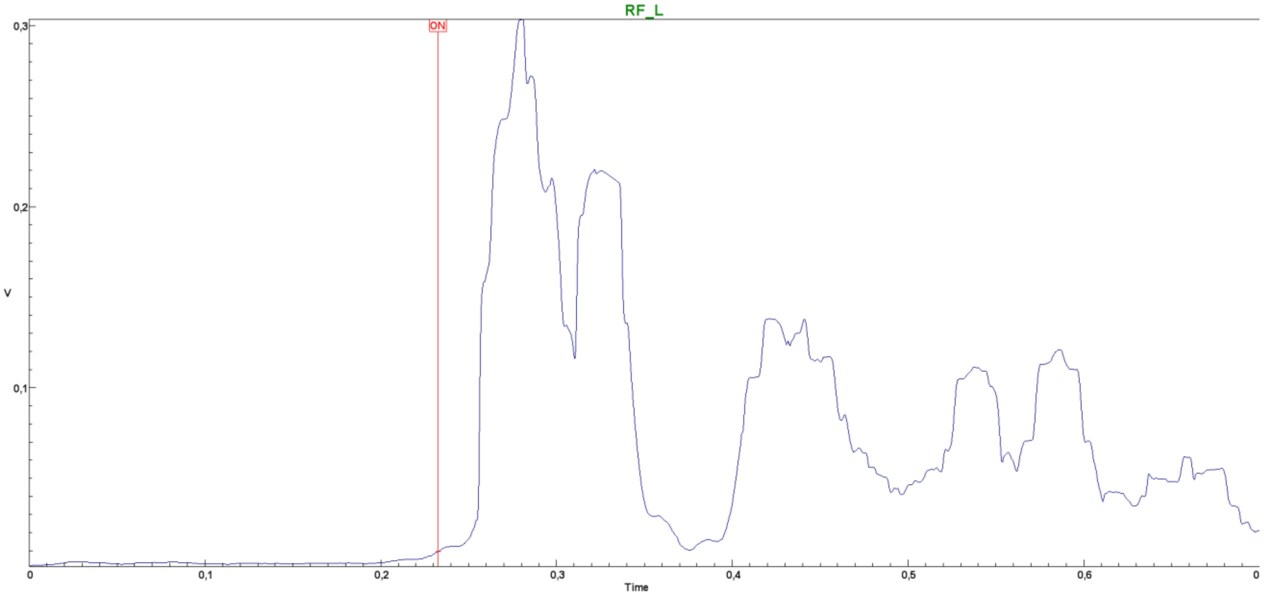
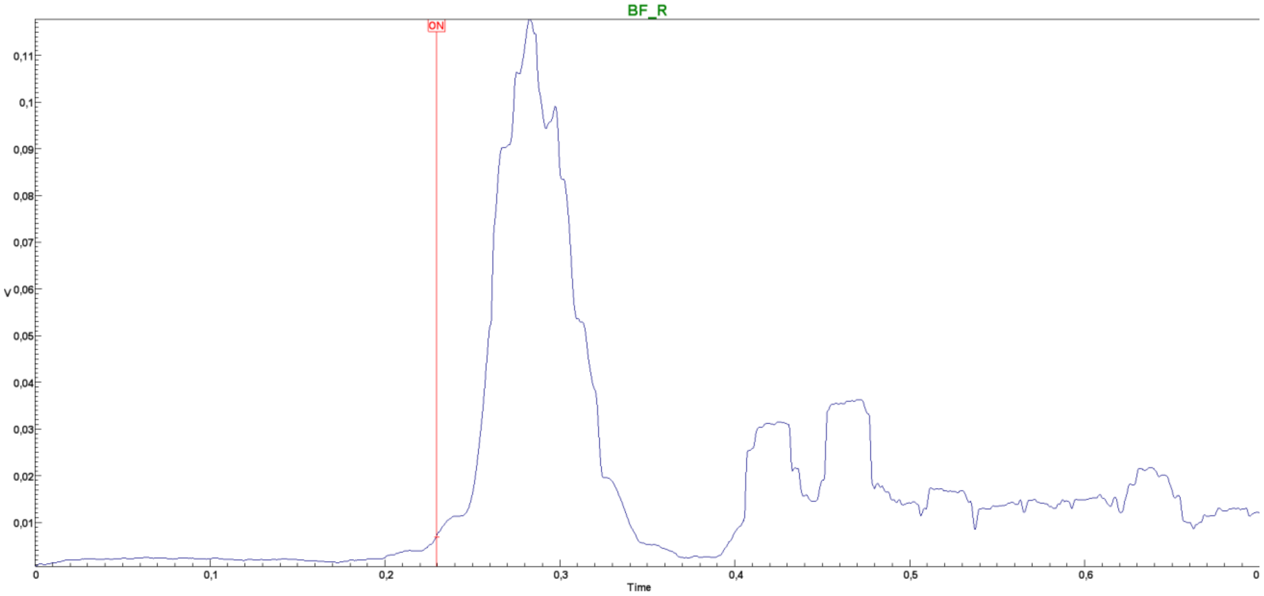
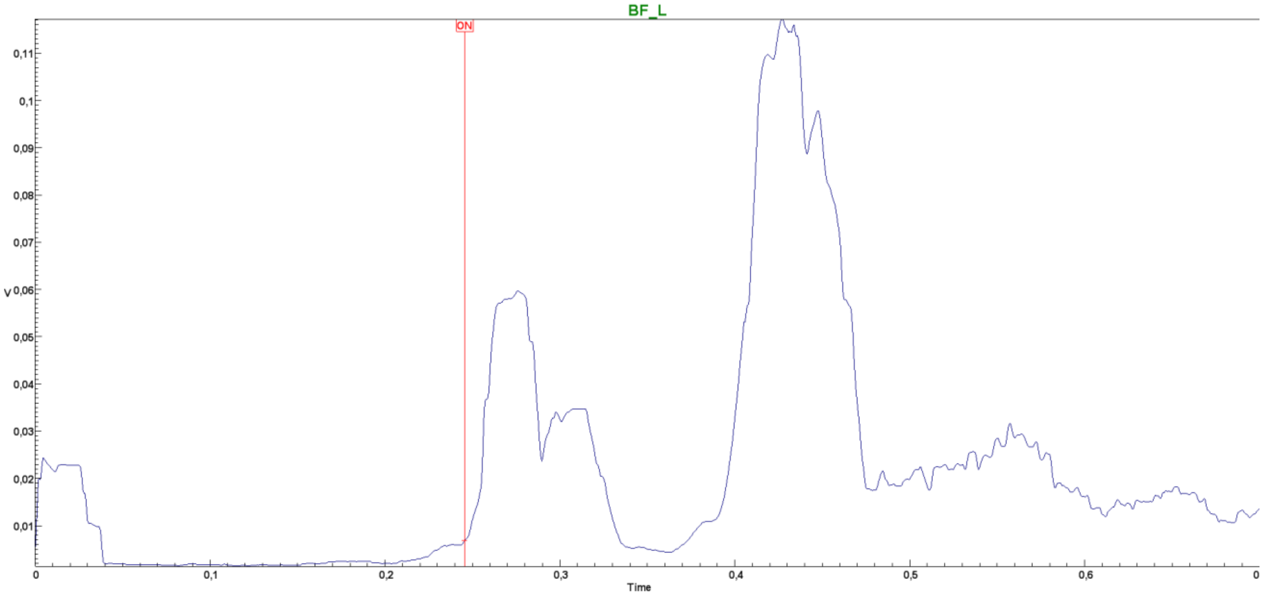
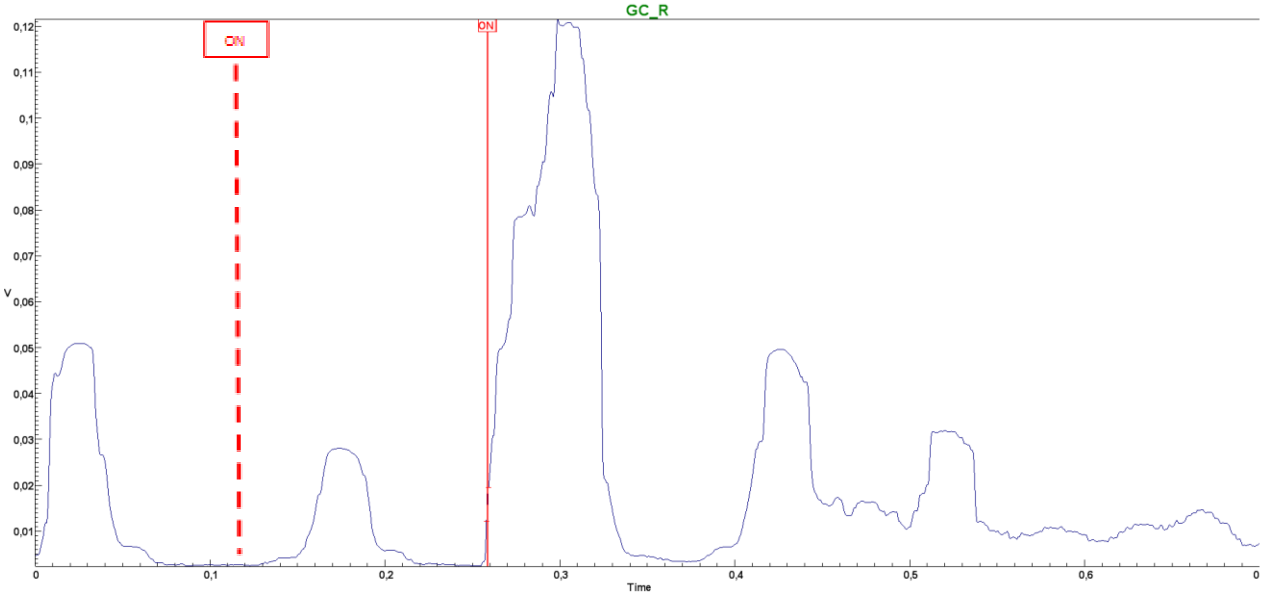
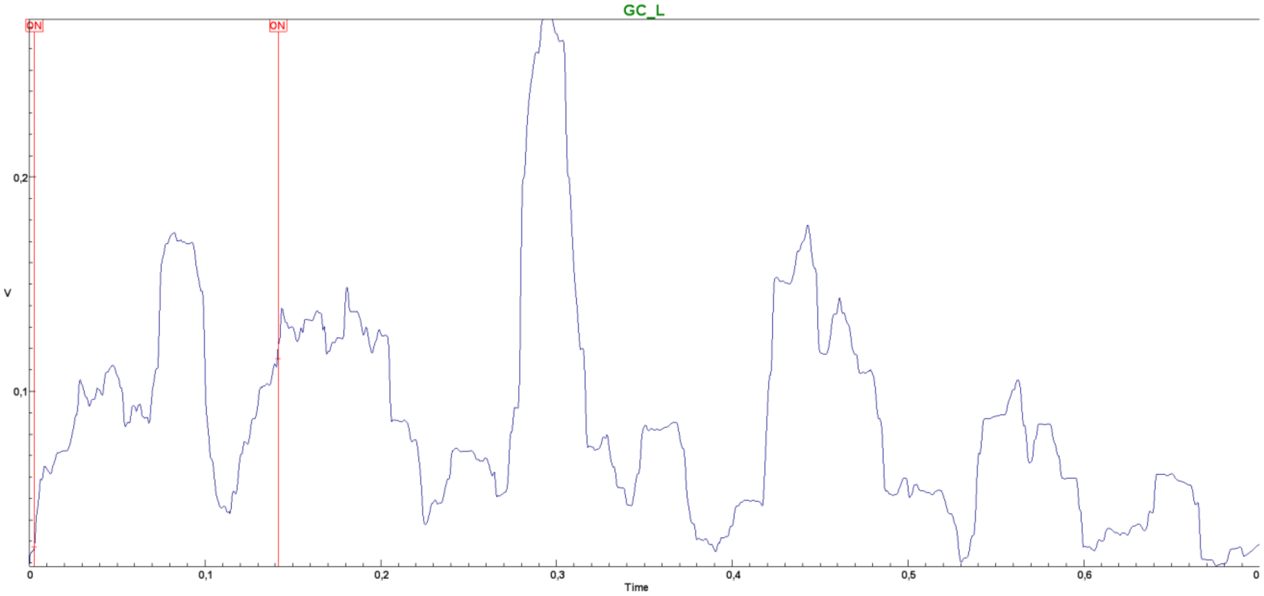
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


RF_L
ON
0,3
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time

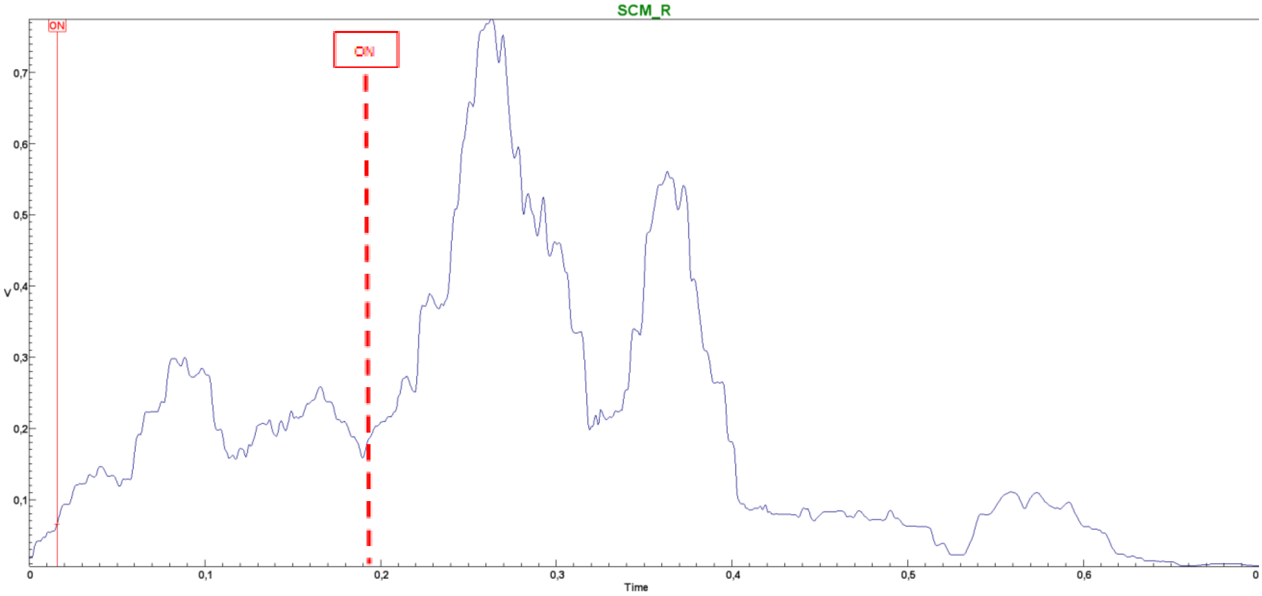

BF_R
ON
0,11
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


BF_L
ON
V
Time


GC_R
ON
ON
V
Time


GC_L
ON
ON
V
Time

Trial 1782


SCM_R
ON
ON
0,7
0,6
0,5
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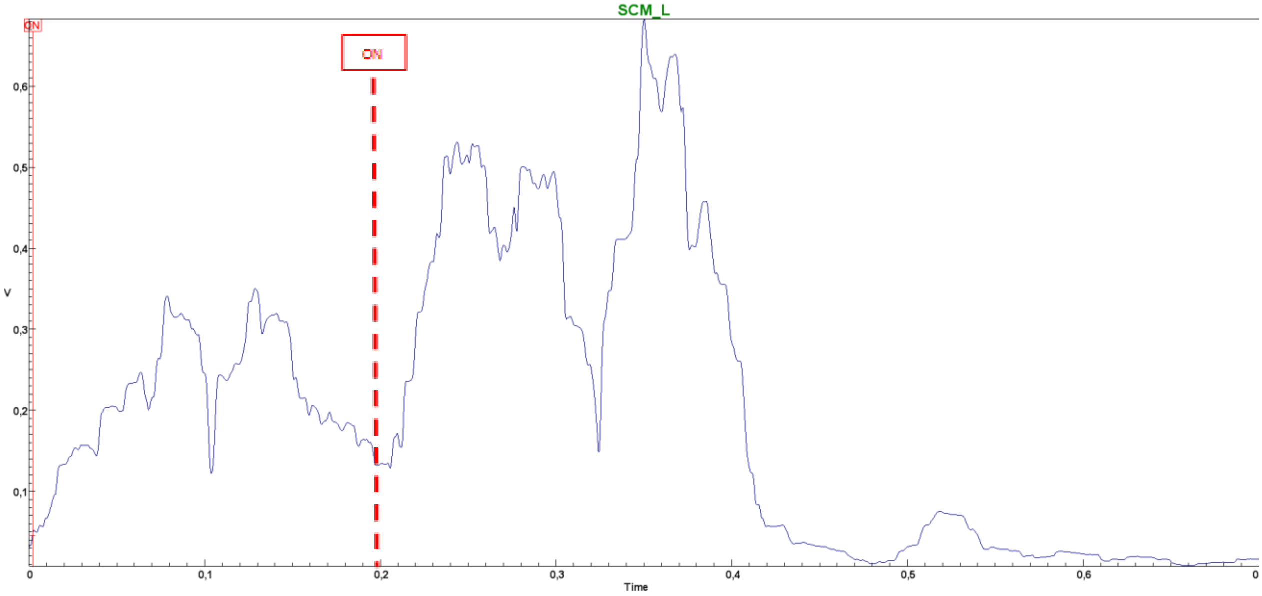
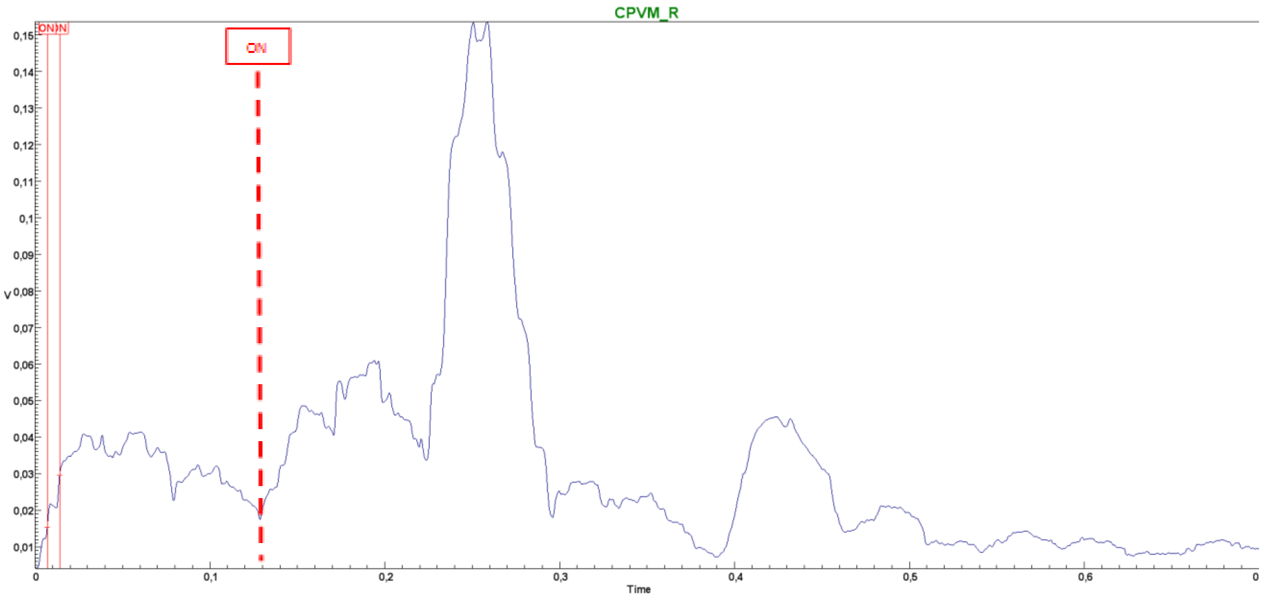
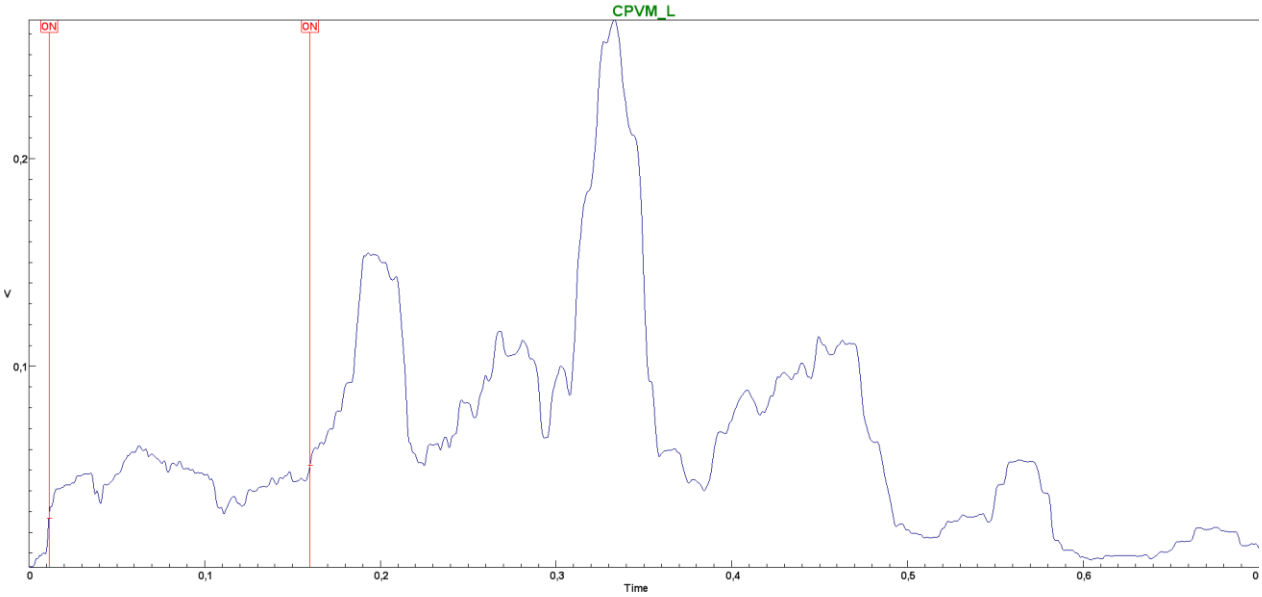
0,3
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


SCM_L
ON
ON
0,6
0,5
0,4
0,3
0,2
0,1
V
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


CPVM_R
ON
ON
ON
0,15
0,14
0,13
0,12
0,11
0,1
0,09
V 0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


CPVM_L
ON
ON
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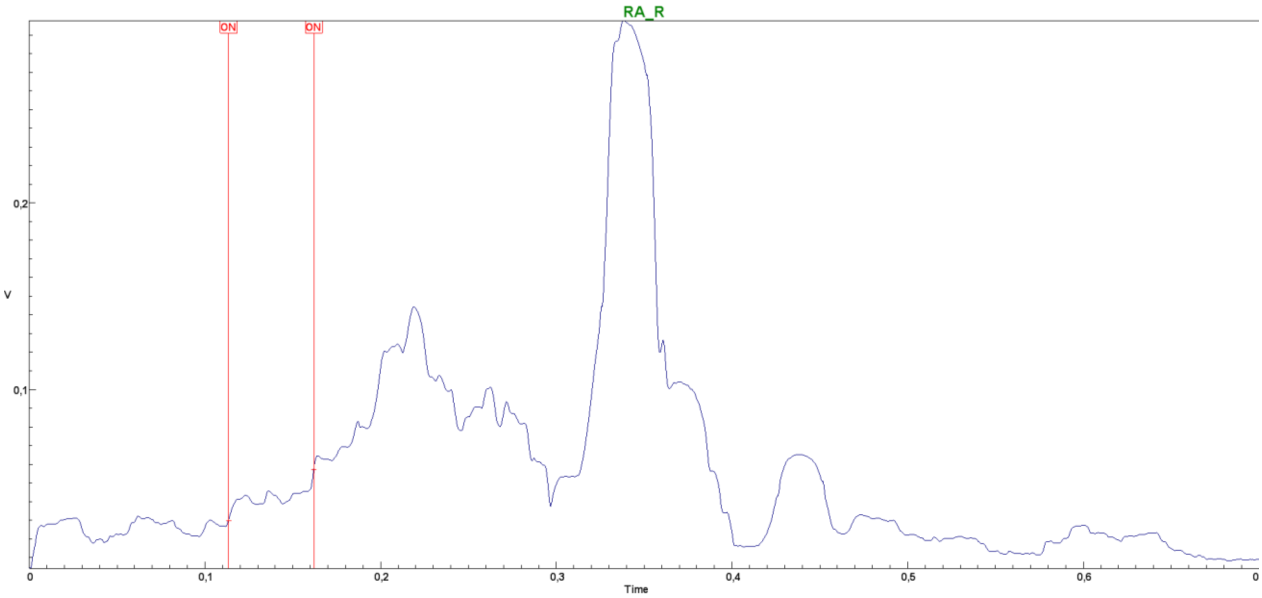
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


RA_R
ON
ON
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V
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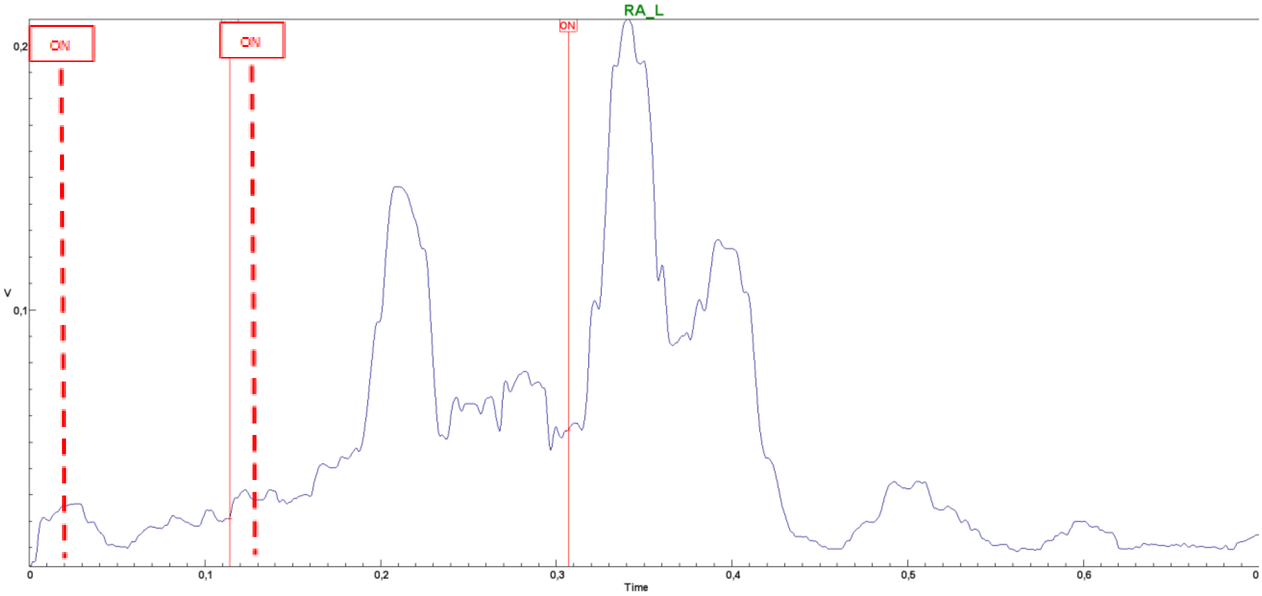
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


RA_L
ON
ON
ON
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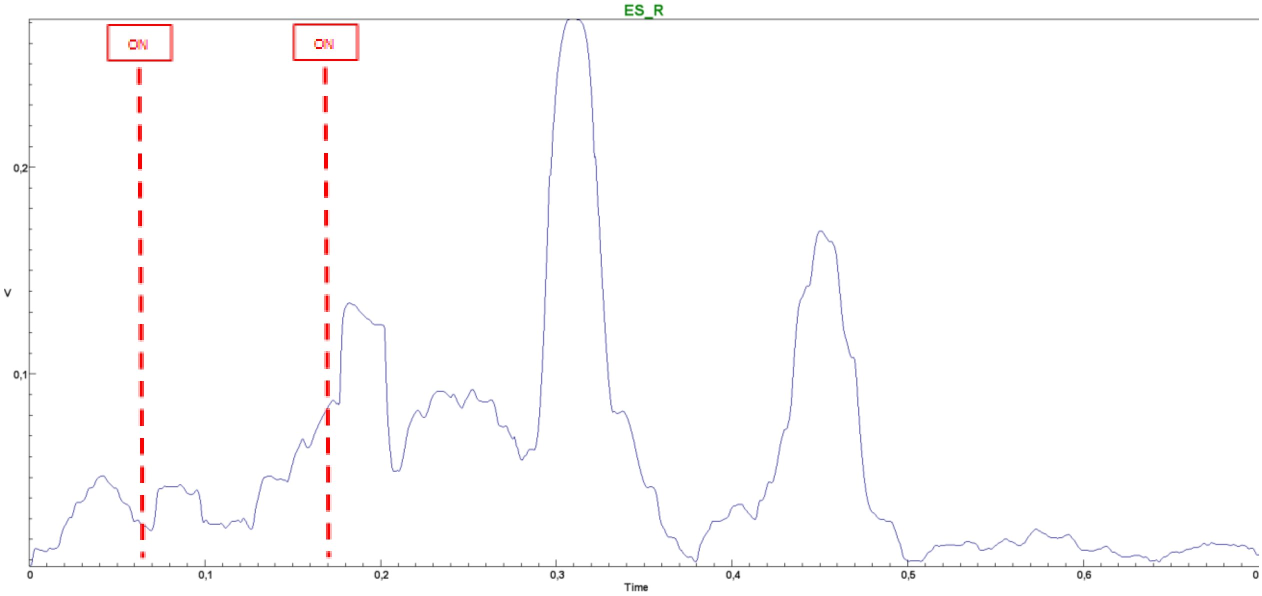
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


ES_R
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ON
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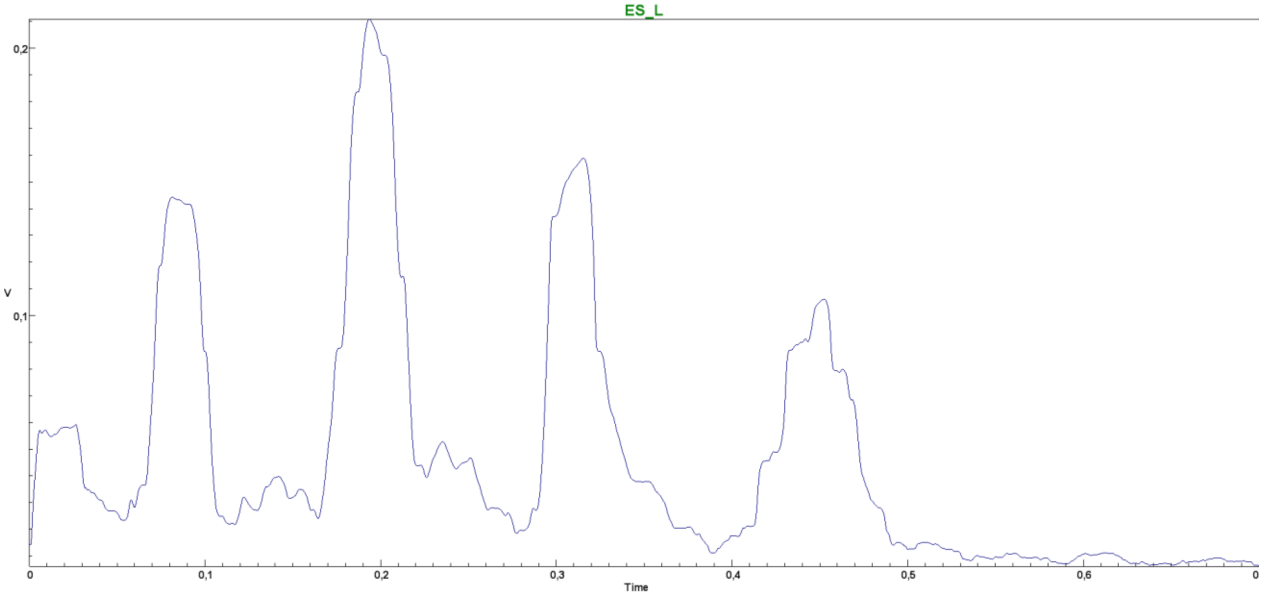
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


ES_L
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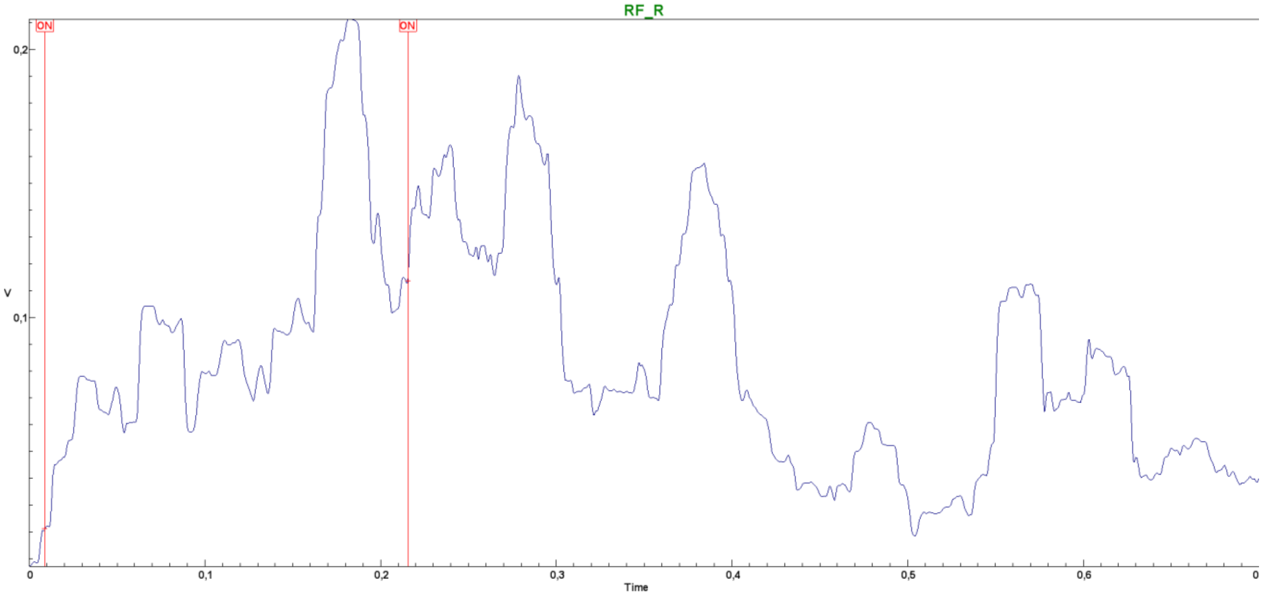
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


RF_R
ON
ON
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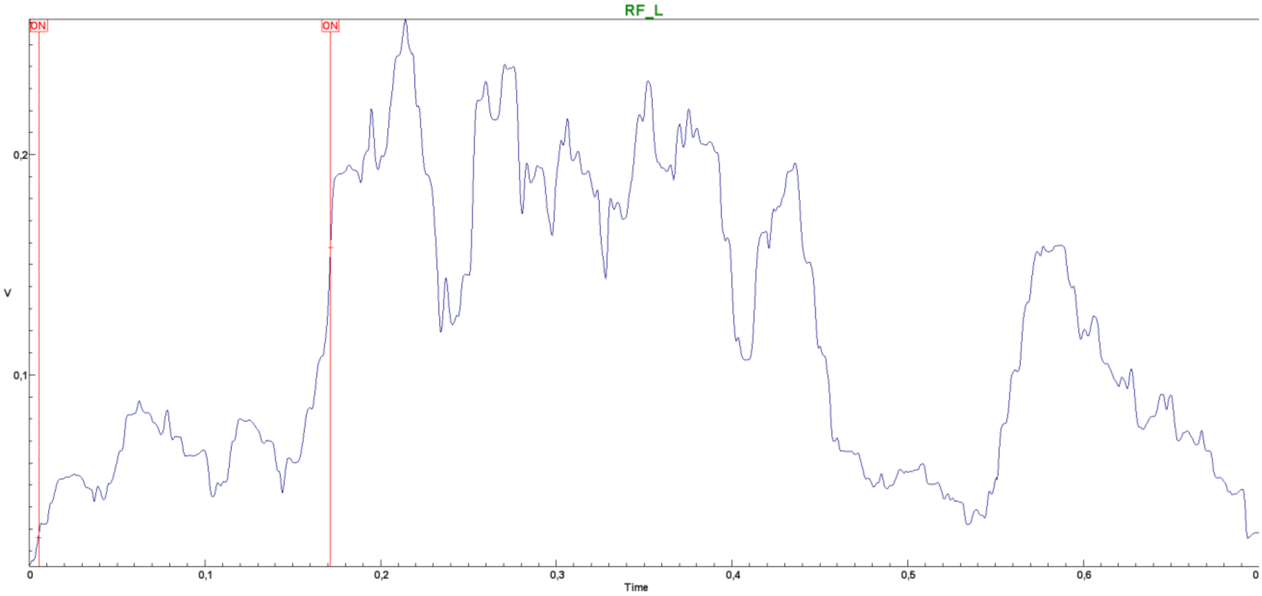
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


RF_L
ON
ON
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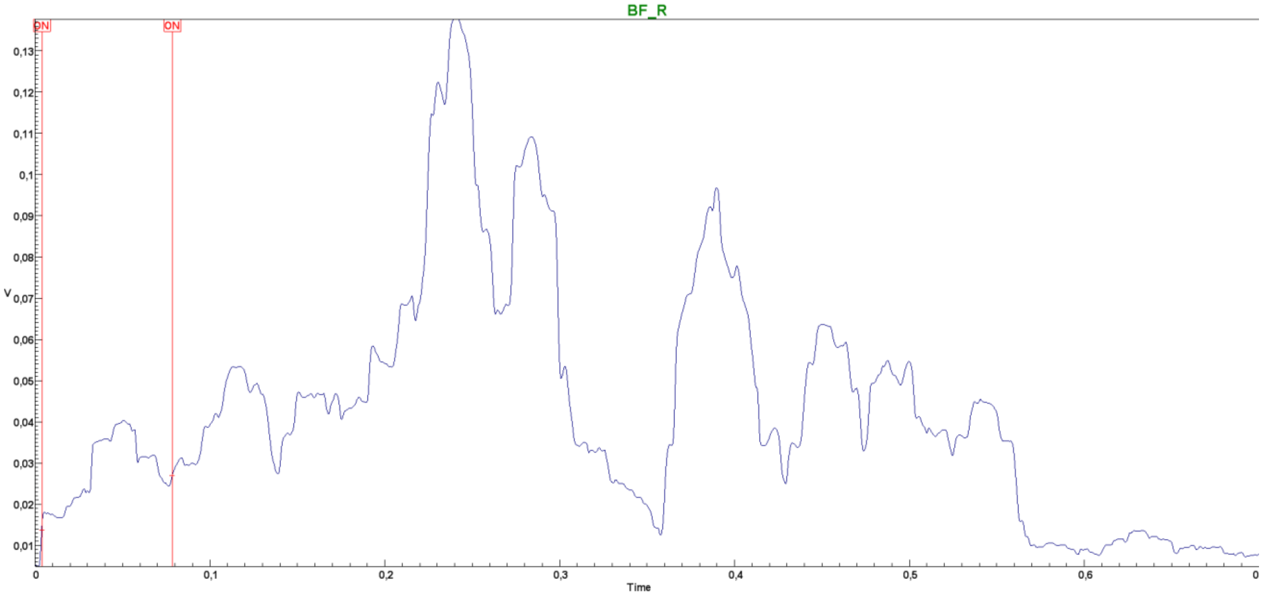
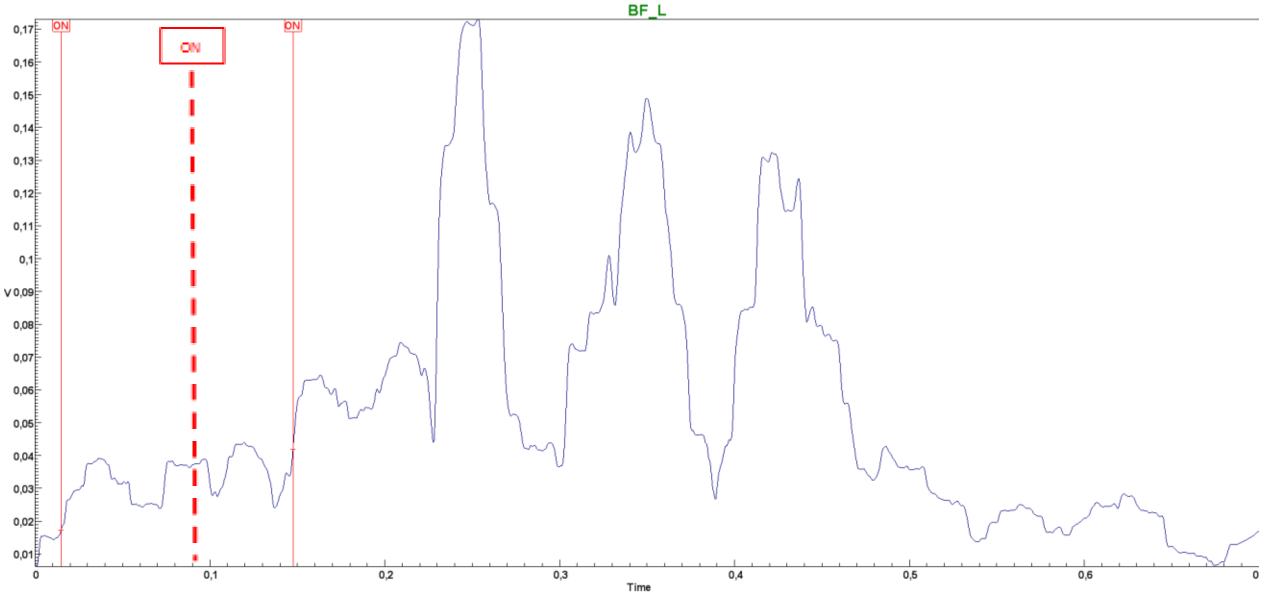
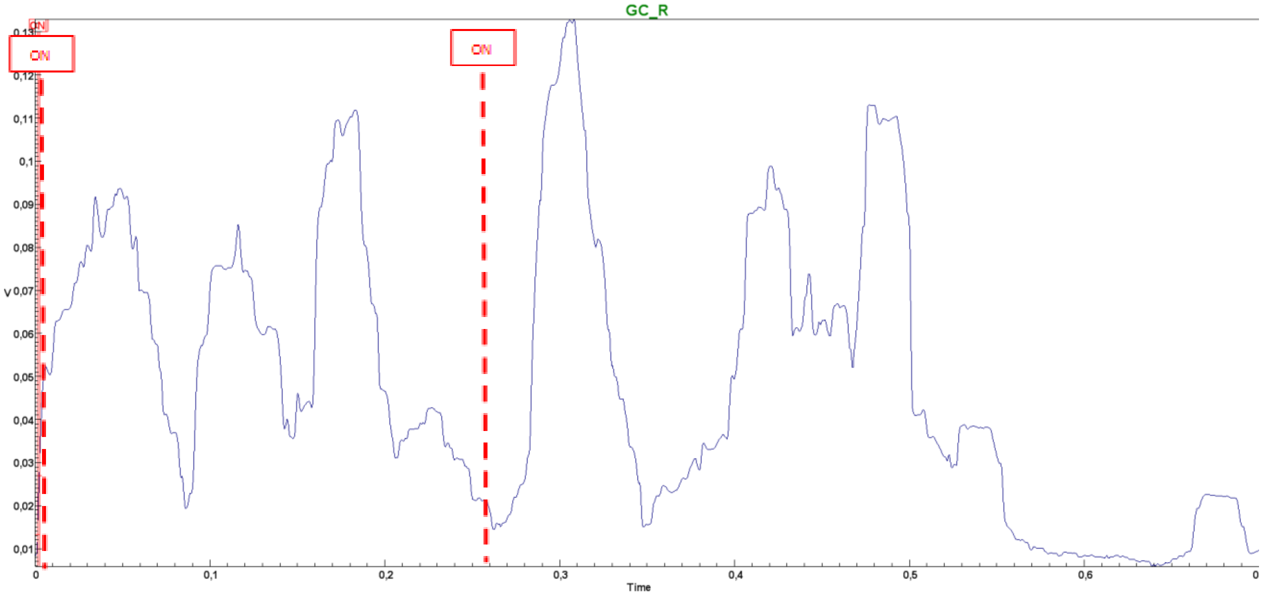
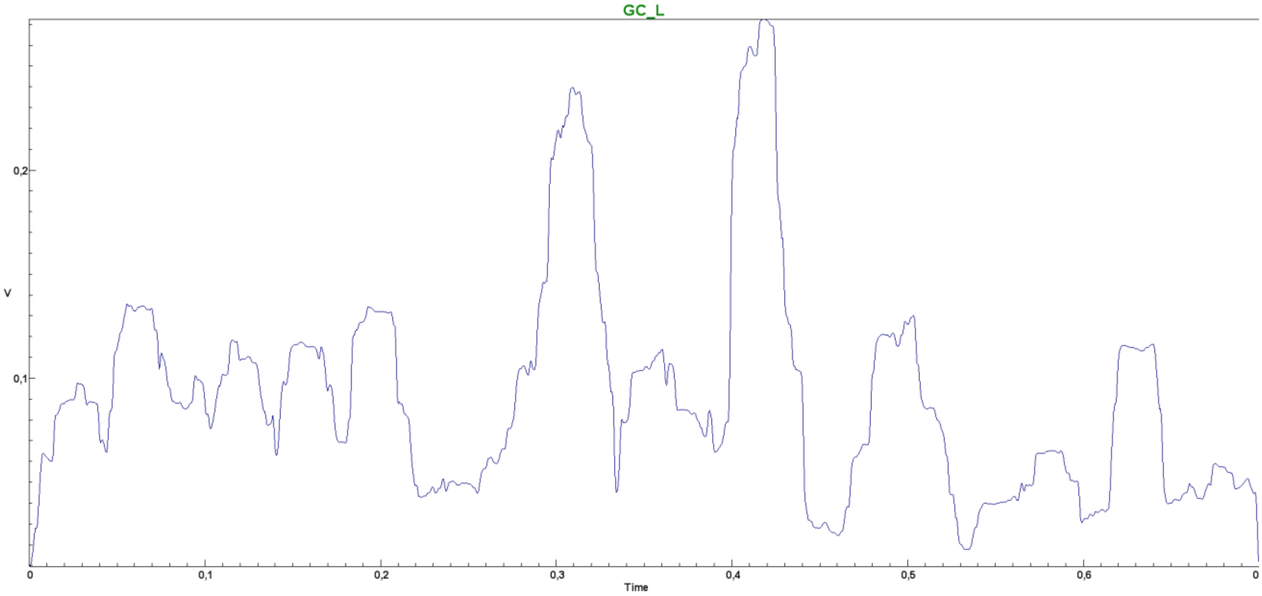
V
0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


BF_R
ON
ON
0,13
0,12
0,11
0,1
0,09
0,08
V
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
0,1
0,2
0,3
0,4
0,5
0,6
0
Time


BF_L
ON
ON
ON
V
Time


GC_R
ON
ON
ON
V
Time


GC_L
V
Time

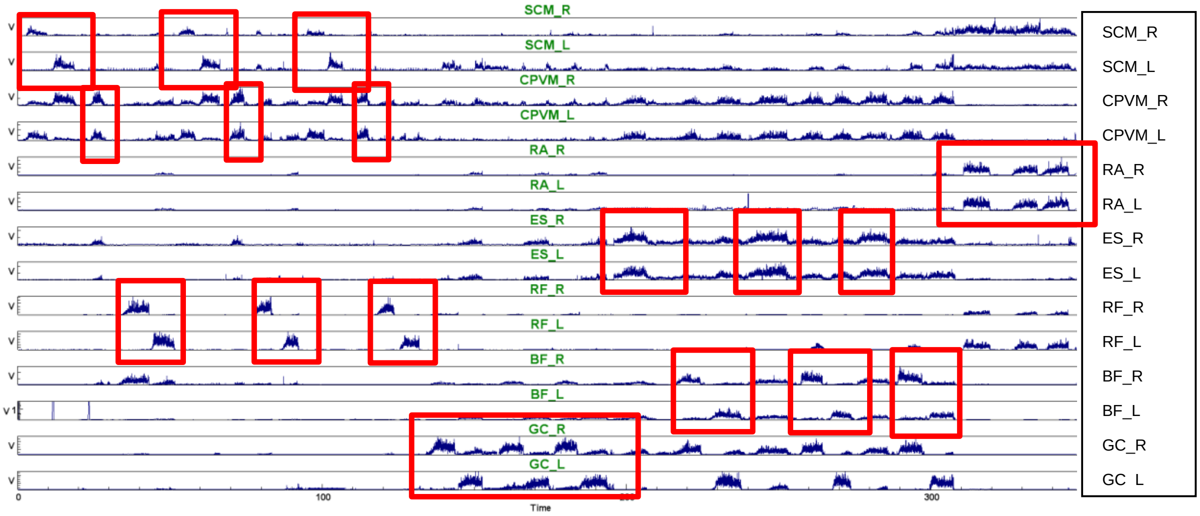
## 6.3 Tabular Overview of Muscle Onset Times

The following table lists onset times of muscular activity for each trial and muscle in (s). Onset definition is marked as “c” for criteria and “m” for manually found onsets by visual inspection

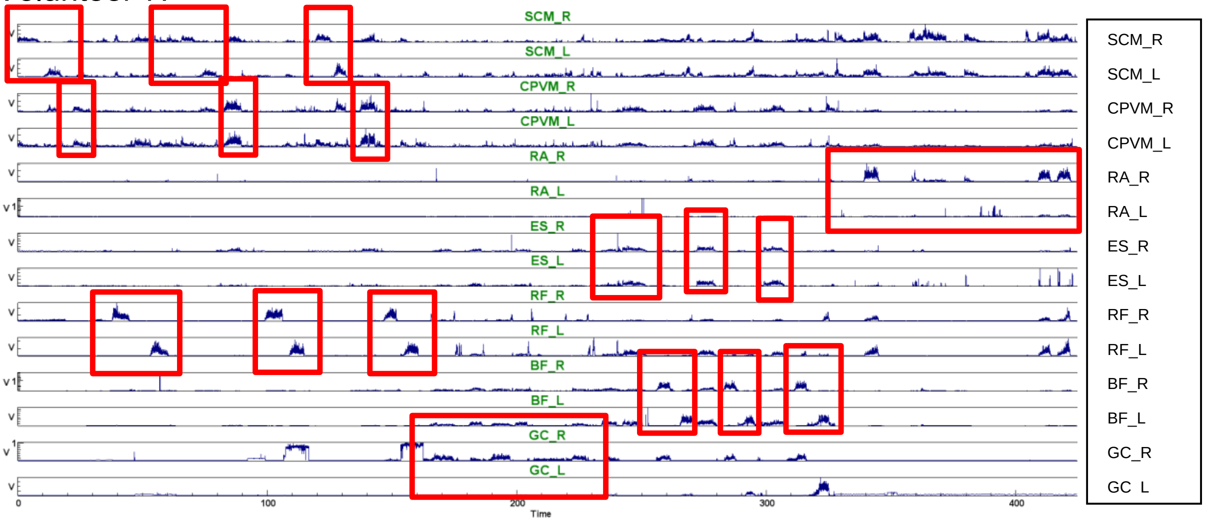
| volunteer | trial | onset definition | SCM_R | SCM_L | CPVM_R | CPVM_L | RA_R | RA_L | ES_R | ES_L | RF_R | RF_L | BF_R | BF_L | GC_R | GC_L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1767 | c | 0,144 | 0,218 | 0,162 | 0,139 | 0,187 | 0,177 | 0,175 | 0,008 | 0,089 | 0,180 | 0,229 | 0,083 | 0,174 | 0,219 |
| | | | | | | 0,175 | 0,188 | | | 0,267 | | 0,209 | | | | 0,240 |
| | | m | | | | | | | | | 0,039 | | | 0,277 | | |
| | 1768 | c | 0,174 | 0,241 | 0,190 | 0,191 | 0,206 | 0,190 | 0,201 | 0,171 | N/A | 0,154 | N/A | N/A | 0,076 | 0,055 |
| | | | | 0,255 | 0,192 | 0,198 | 0,209 | 0,217 | | 0,174 | | | | | 0,000 | 0,185 |
| | | | | | | | | | | | | | | | 0,000 | 0,262 |
| | | m | | | | | | | | | | | | | 0,188 | |
| | 1769 | c | 0,214 | 0,087 | 0,171 | 0,205 | 0,189 | 0,183 | 0,193 | 0,006 | 0,124 | 0,022 | 0,105 | | 0,191 | 0,133 |
| | | | | | 0,211 | 0,218 | | | 0,215 | 0,008 | 0,135 | 0,207 | 0,232 | | 0,266 | 0,268 |
| | | m | | | | | | | | 0,162 | | | | 0,032 | | |
| | 1771 | c | 0,144 | 0,184 | 0,118 | 0,144 | 0,135 | 0,129 | 0,277 | 0,053 | 0,130 | 0,132 | N/A | | N/A | 0,161 |
| | | | | | 0,167 | | 0,136 | | | | | | | | | |
| | | m | | | | | | | 0,154 | 0,178 | | | | 0,172 | | 0,240 |
| 6 | 1772 | c | 0,193 | 0,233 | 0,181 | 0,180 | 0,164 | 0,045 | | | | 0,025 | 0,008 | | 0,053 | |
| | | | 0,198 | 0,236 | | | 0,184 | 0,212 | | | | 0,180 | 0,191 | | | |
| | | m | | | | 0,077 | | | 0,088 | 0,125 | 0,180 | | | 0,012 | | 0,025 |
| | | | | | | | | | | | | | | 0,312 | | 0,252 |
| | 1773 | c | 0,171 | 0,223 | 0,008 | 0,051 | 0,172 | 0,004 | | 0,110 | 0,163 | 0,162 | 0,251 | 0,396 | | 0,017 |
| | | | | 0,226 | 0,178 | 0,183 | | 0,217 | | 0,130 | | | | | | 0,276 |
| | | | | | | 0,205 | | | | | | | | | | |
| | | m | | | | | | | 0,015 | | | | | 0,301 | 0,289 | |
| 7 | 1774 | c | 0,022 | 0,062 | 0,159 | 0,171 | 0,158 | 0,169 | 0,192 | 0,038 | | | 0,094 | 0,002 | 0,103 | 0,391 |
| | | | 0,140 | 0,142 | | | | | 0,193 | | | | | 0,092 | 0,116 | |
| | | | | | | | | | | | | | | 0,229 | | |
| | | m | | | 0,039 | 0,121 | | | | | 0,177 | 0,066 | 0,062 | | | 0,037 |
| | | | | | | | | | | | | | | | | |
| | 1775 | c | 0,005 | 0,007 | 0,005 | 0,002 | 0,169 | 0,149 | 0,080 | 0,012 | | | 0,002 | | 0,006 | 0,002 |
| | | | 0,042 | 0,070 | | 0,186 | 0,172 | 0,167 | | 0,074 | | | | | 0,052 | |
| | | m | | | | | | | 0,283 | | 0,102 | 0,168 | 0,010 | 0,012 | | 0,036 |
| | 1776 | c | 0,015 | 0,001 | 0,020 | 0,070 | 0,171 | 0,177 | 0,162 | 0,128 | | | 0,003 | 0,013 | 0,061 | 0,085 |
| | | | 0,021 | 0,021 | | | | | 0,264 | | | | 0,009 | 0,114 | | |
| | | | | | | | | | | | | | | 0,247 | | |
| | | m | 0,239 | | 0,180 | | | | | | 0,109 | 0,092 | 0,141 | | | |
| 8 | 1778 | c | 0,123 | 0,188 | 0,116 | 0,128 | 0,083 | 0,132 | 0,013 | 0,005 | 0,086 | 0,025 | N/A | | 0,045 | |
| | | | 0,124 | | 0,283 | 0,283 | | | 0,362 | 0,083 | | | | | | |
| | | m | | | | | | | 0,069 | | | 0,157 | | 0,197 | | 0,211 |
| | 1779 | c | 0,168 | 0,120 | 0,228 | 0,007 | 0,128 | 0,239 | 0,017 | | N/A | N/A | N/A | N/A | 0,150 | 0,010 |
| | | | 0,179 | | 0,433 | 0,030 | 0,180 | 0,253 | 0,056 | | | | | | 0,156 | 0,371 |
| | | m | | | | | | | | 0,005 | | | | | | |
| | | | | | | | | | | 0,221 | | | | | | 0,243 |
| 9 | 1780 | c | 0,141 | 0,164 | 0,149 | 0,157 | 0,013 | 0,138 | 0,128 | 0,001 | 0,069 | 0,009 | N/A | N/A | 0,007 | 0,002 |
| | | | | | 0,169 | 0,169 | | | 0,149 | 0,287 | 0,232 | | | | 0,073 | 0,152 |
| | | | | | | | | | | 0,355 | 0,305 | | | | 0,149 | 0,159 |
| | | m | | | | | | | | | 0,300 | 0,280 | | | | |
| | 1781 | c | 0,007 | 0,001 | 0,016 | 0,001 | 0,064 | 0,011 | 0,078 | | 0,007 | 0,233 | 0,230 | 0,246 | 0,258 | 0,003 |
| | | | 0,009 | | | 0,010 | 0,202 | 0,219 | 0,248 | | | | | | 0,259 | 0,142 |
| | | m | 0,076 | 0,198 | | 0,088 | | | 0,025 | | 0,230 | | | | | 0,120 |
| | 1782 | c | 0,016 | 0,002 | 0,007 | 0,012 | 0,114 | 0,114 | | 0,000 | 0,009 | 0,006 | 0,004 | 0,015 | 0,015 | |
| | | | | | 0,014 | 0,160 | 0,162 | 0,307 | | 0,000 | 0,216 | 0,172 | 0,079 | 0,148 | 0,003 | |
| | | m | 0,194 | 0,199 | 0,129 | | | | 0,020 | 0,064 | | | | | 0,091 | 0,010 |
| | | | | | | | | | 0,129 | 0,170 | | | | | | 0,260 |

## 6.4 Overview MVC Activity

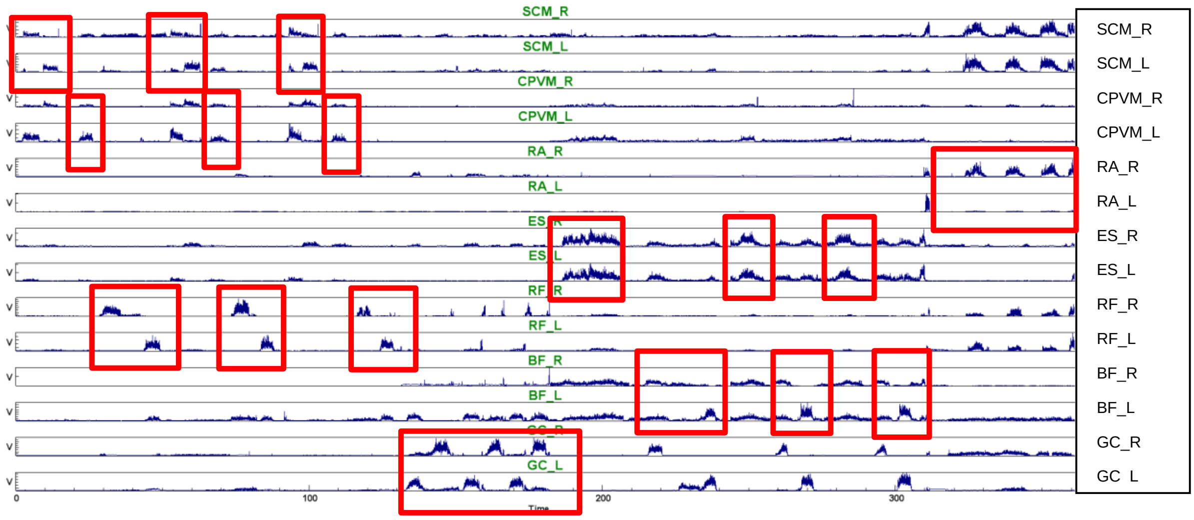
Volunteer 6:



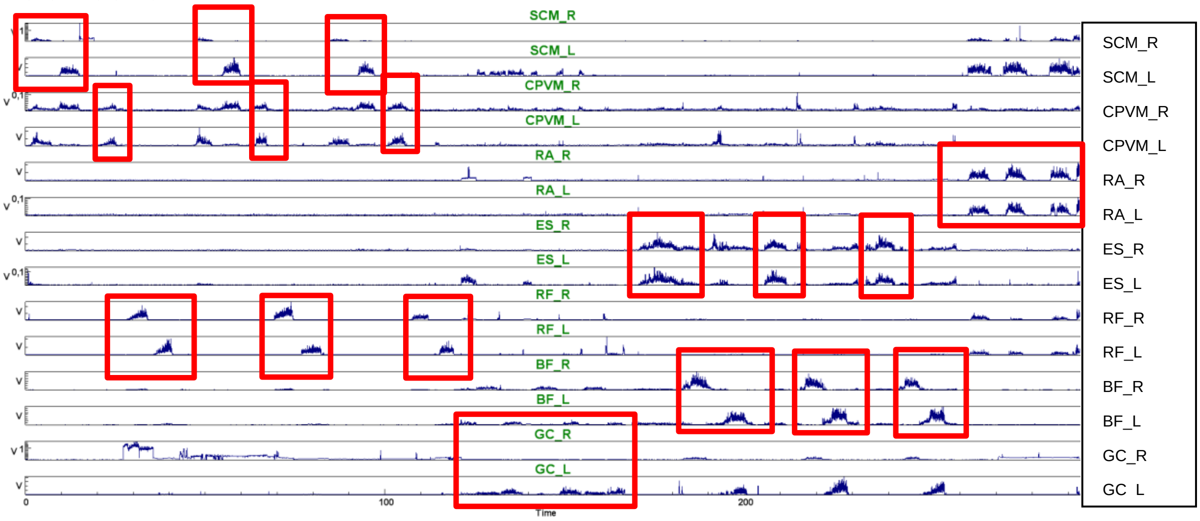

Volunteer 7:



Volunteer 8:



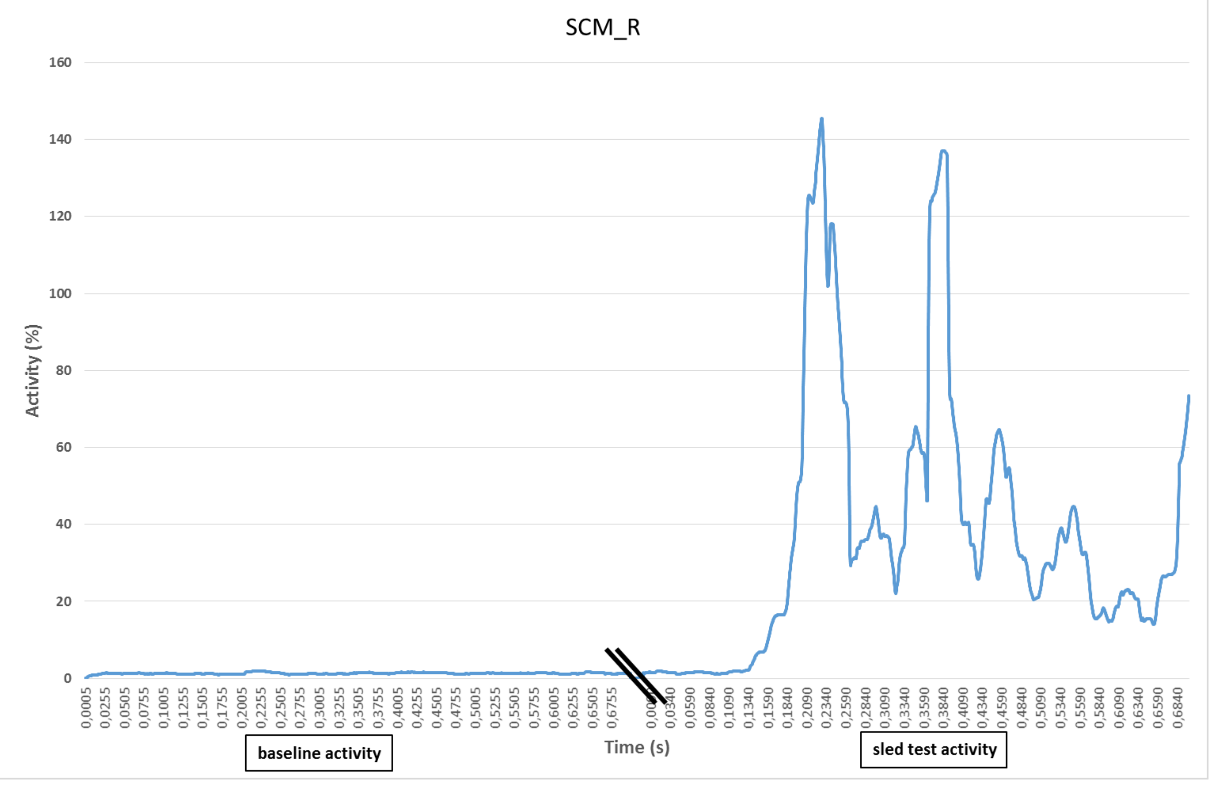

Volunteer 9:

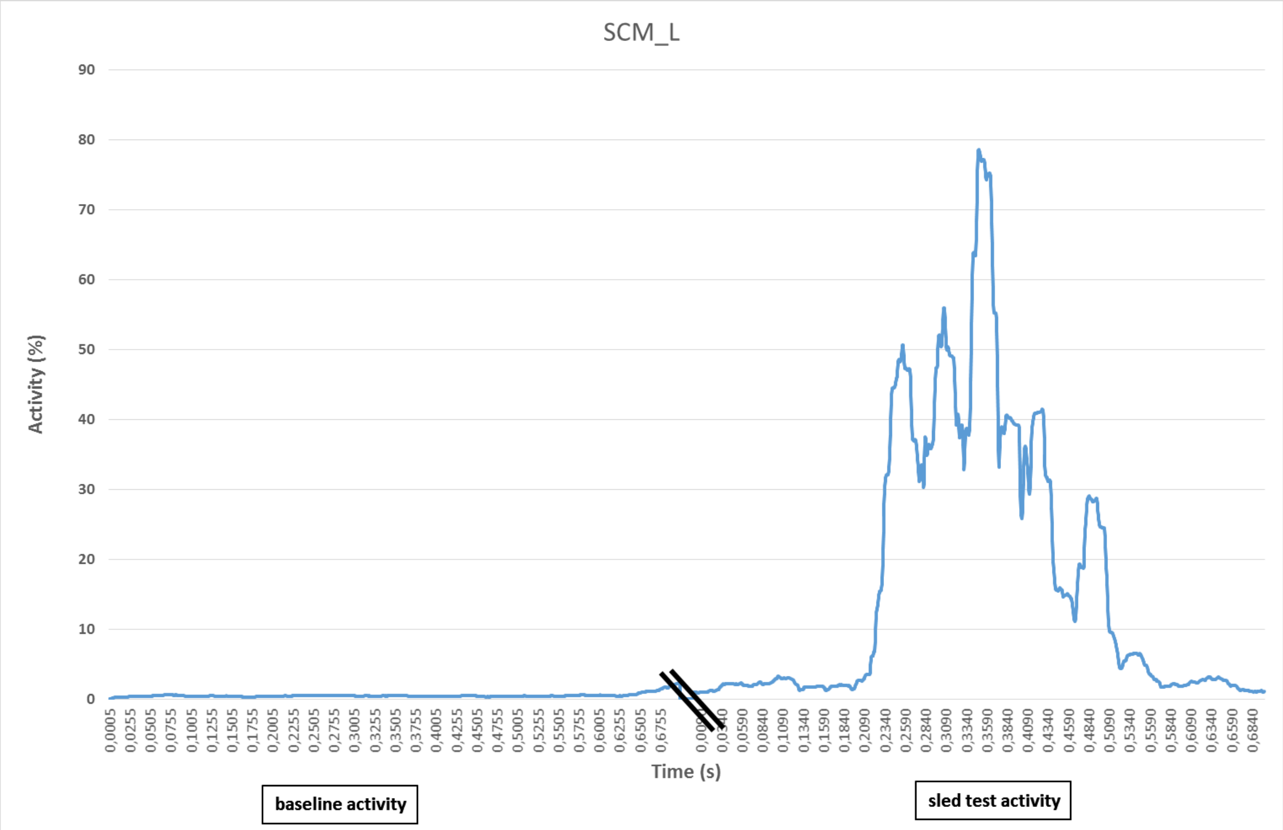


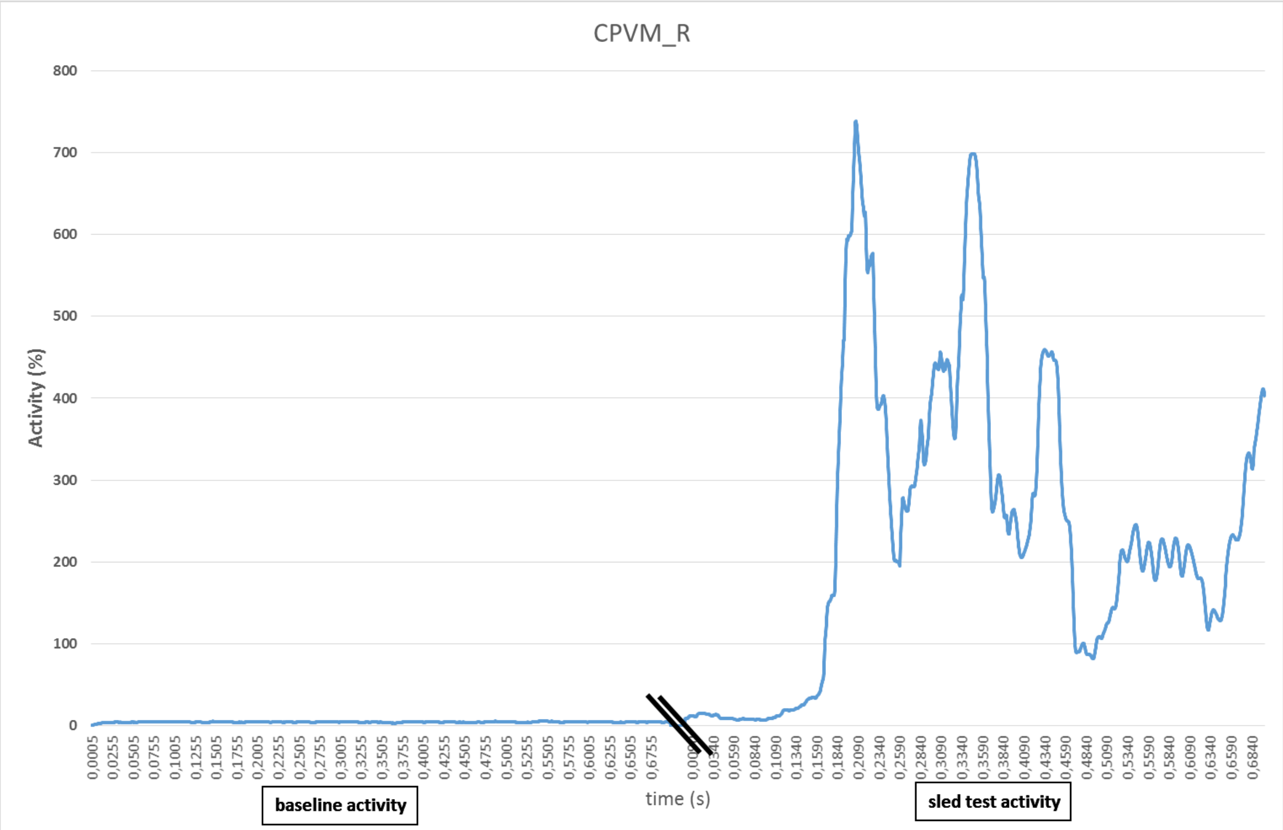
## 6.5 STATIC AND DYNAMIC NORMALIZED DATA

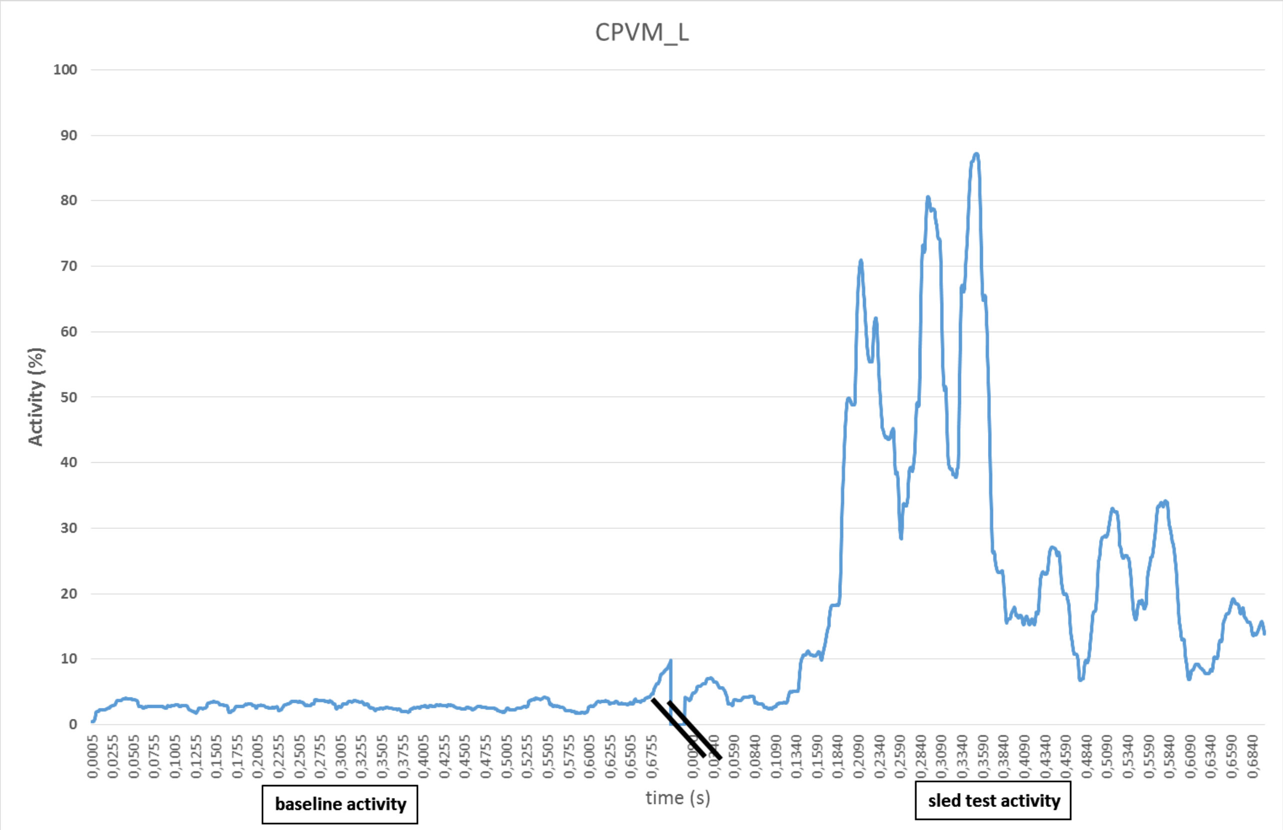
The following figures show normalized muscular activity in relation to MVC after processing for each trial and every muscle in (%) over time (s). The left half of the graph depicts baseline activity while the right half shows sled test activity. The two black bars indicate interrupted time scale. Impact occurs at time t=0 (black bars)

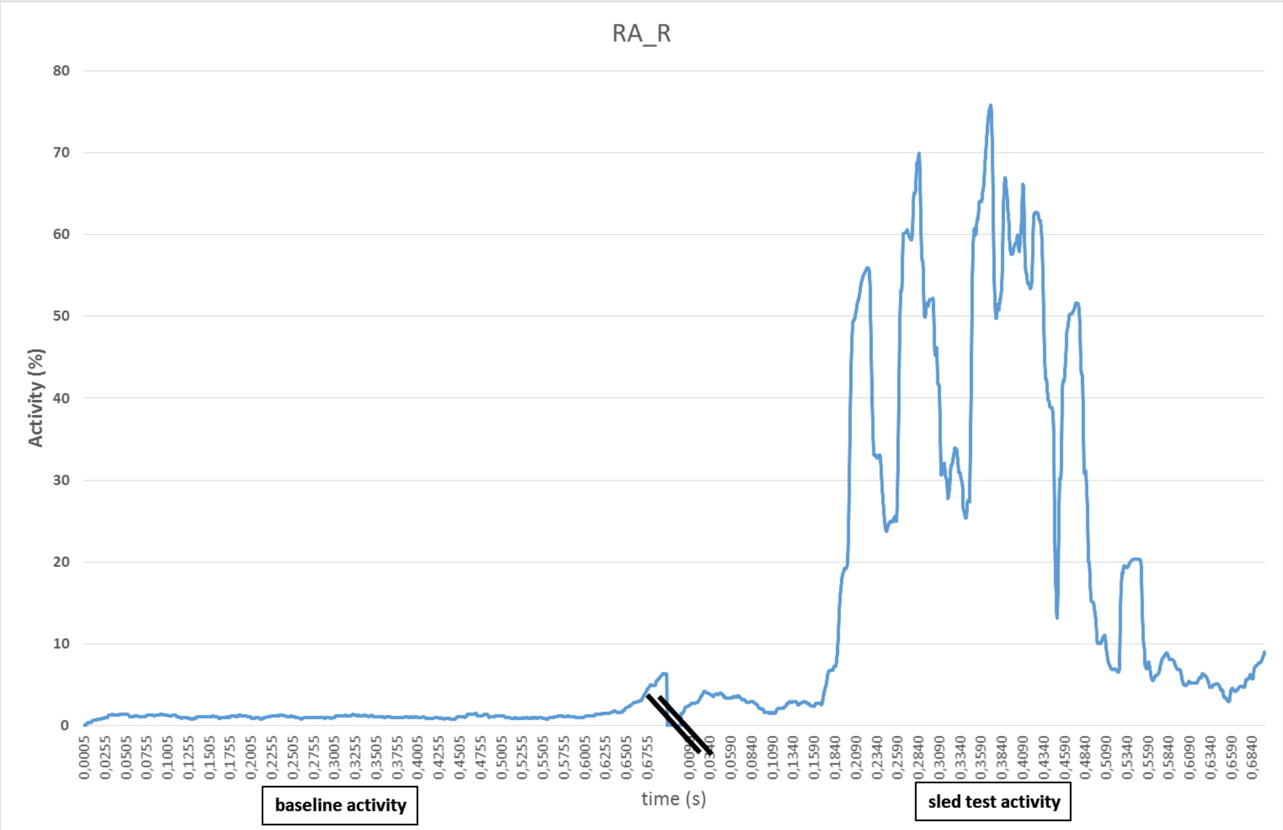
Trial 1767:

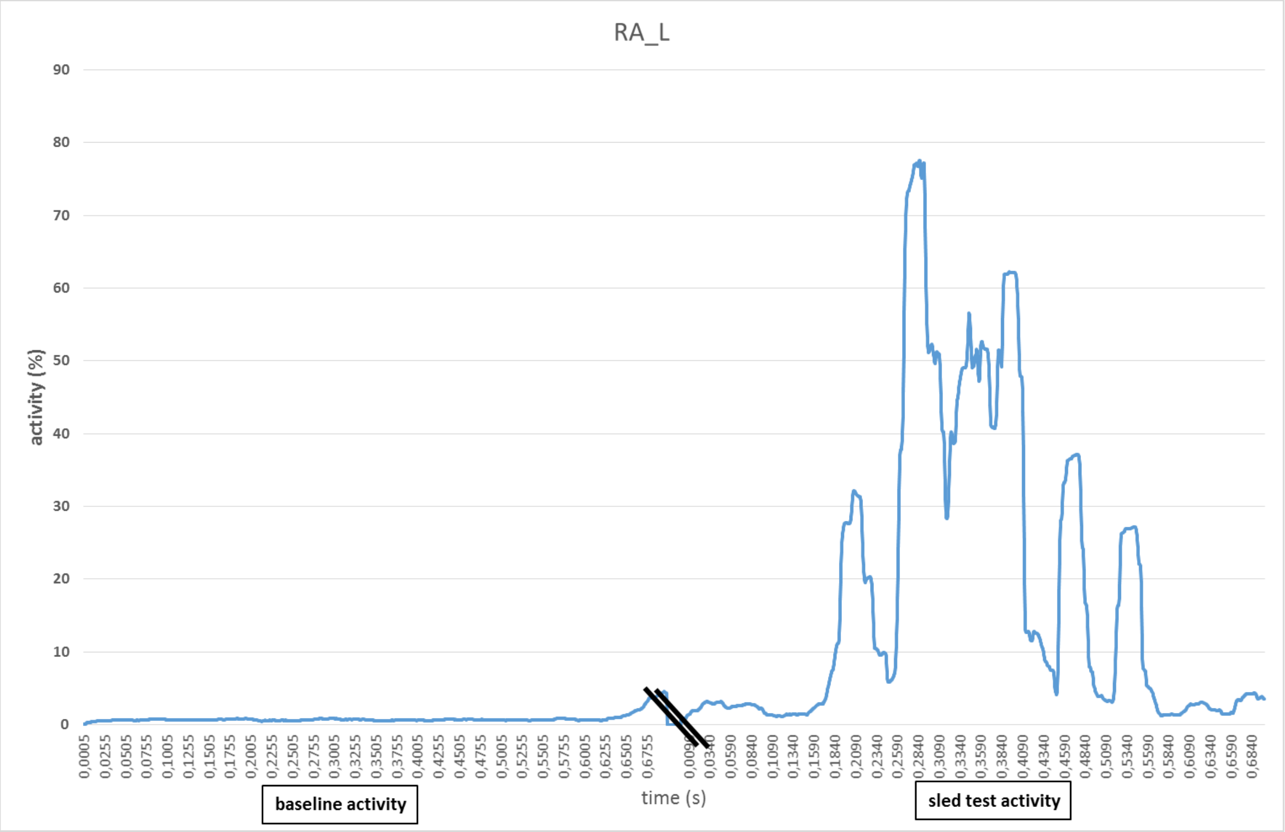


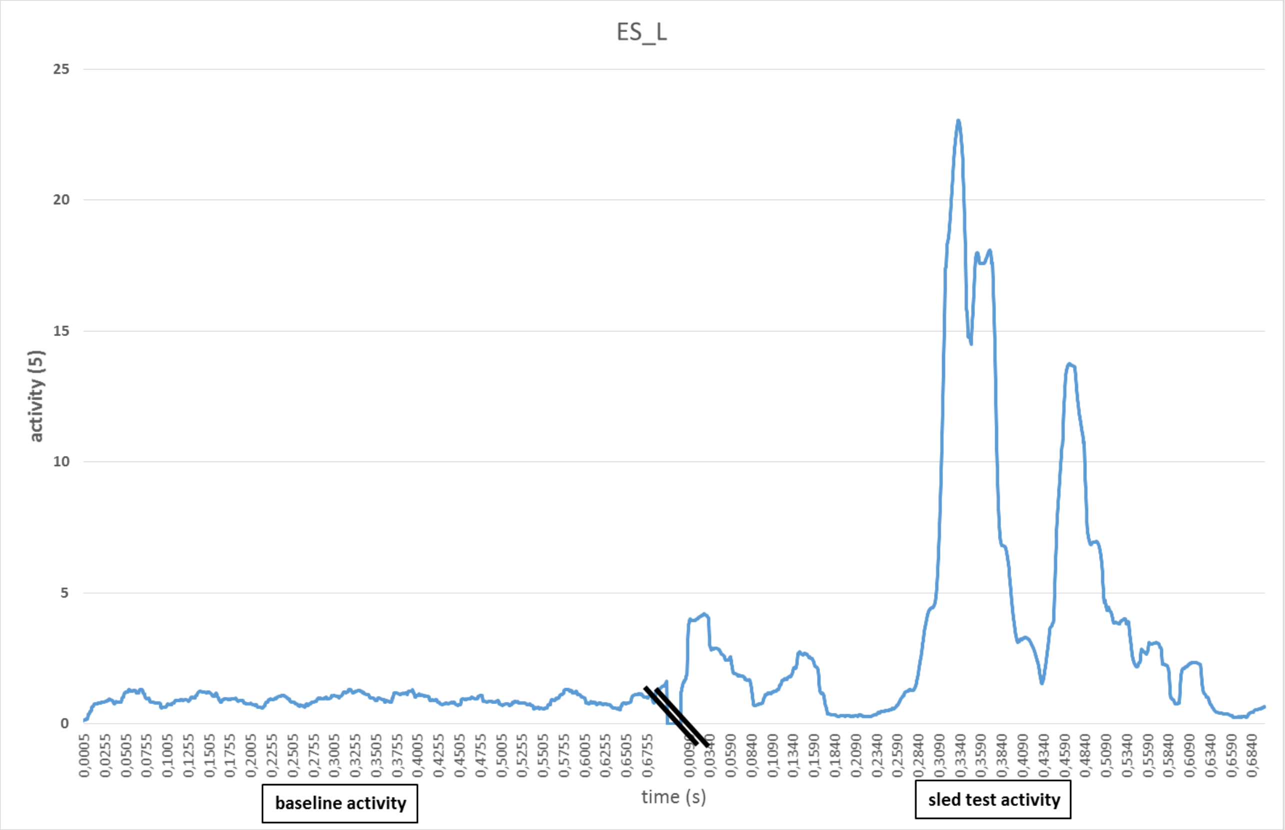

SCM_L
Activity (%)
Time (s)
baseline activity
sled test activity

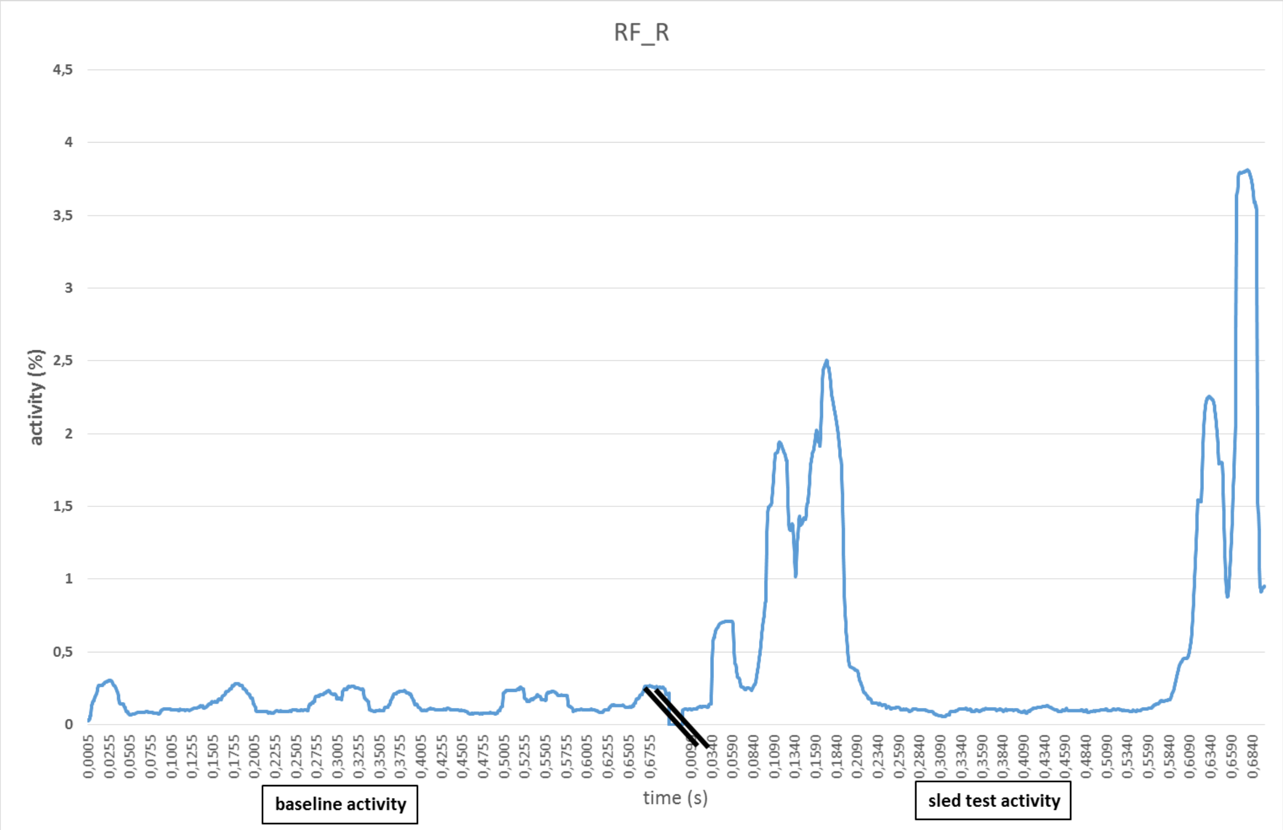

CPVM_R
Activity (%)
time (s)
baseline activity
sled test activity

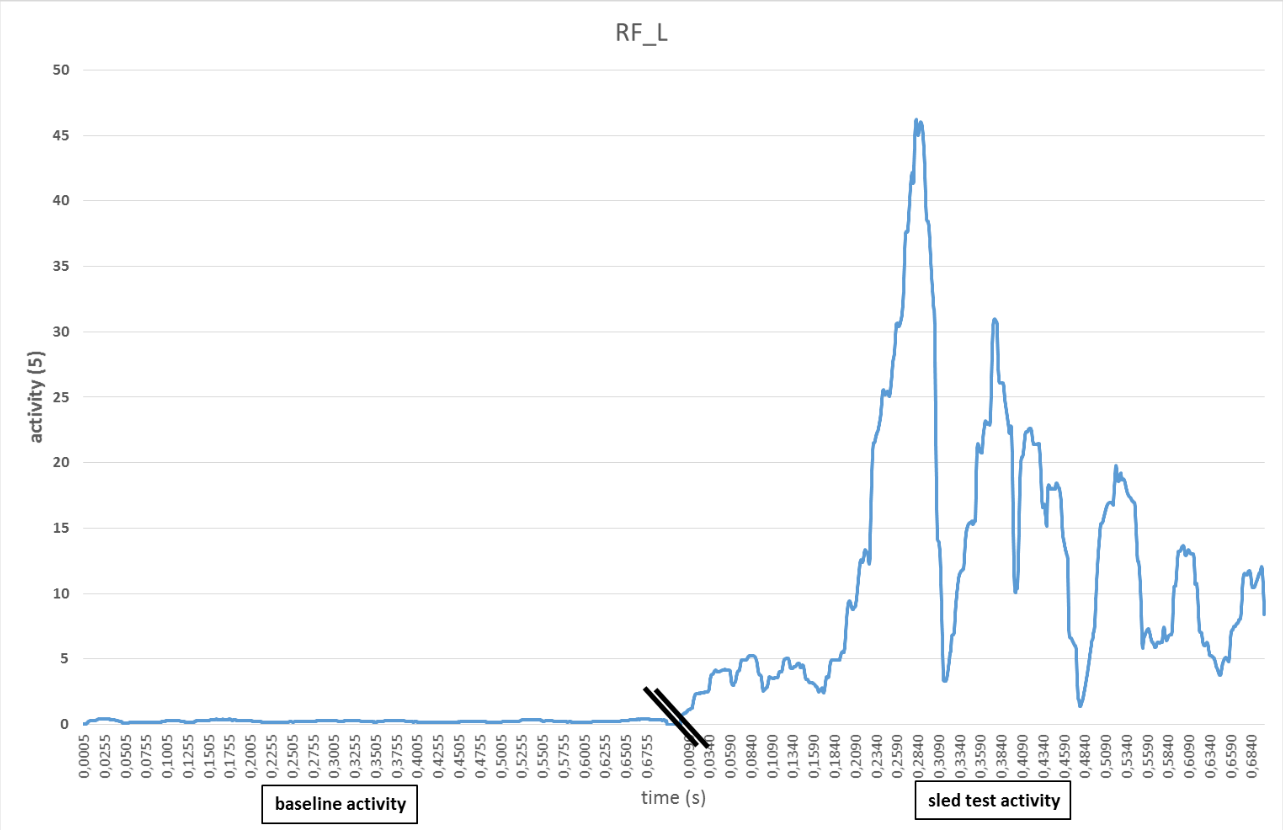

CPVM_L
Activity (%)
time (s)
baseline activity
sled test activity

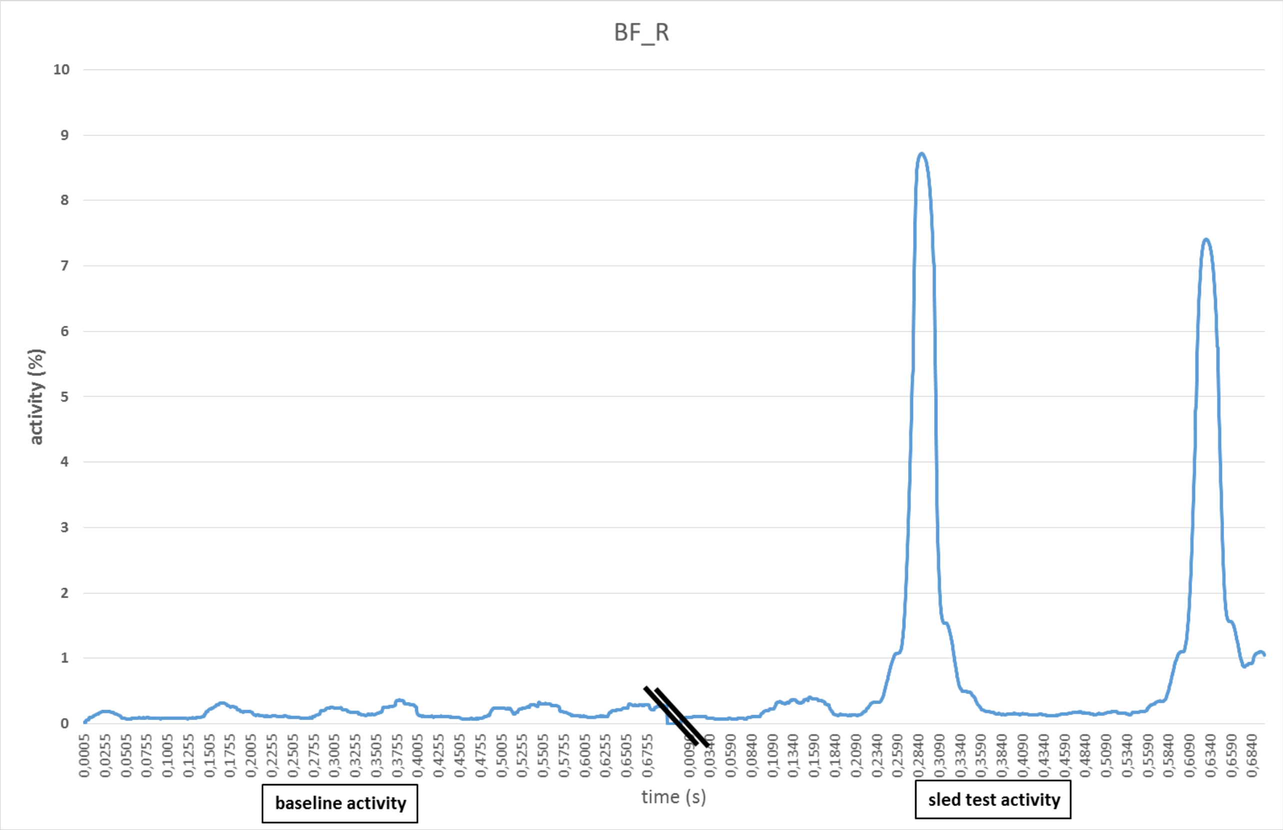

RA_R
Activity (%)
time (s)
baseline activity
sled test activity

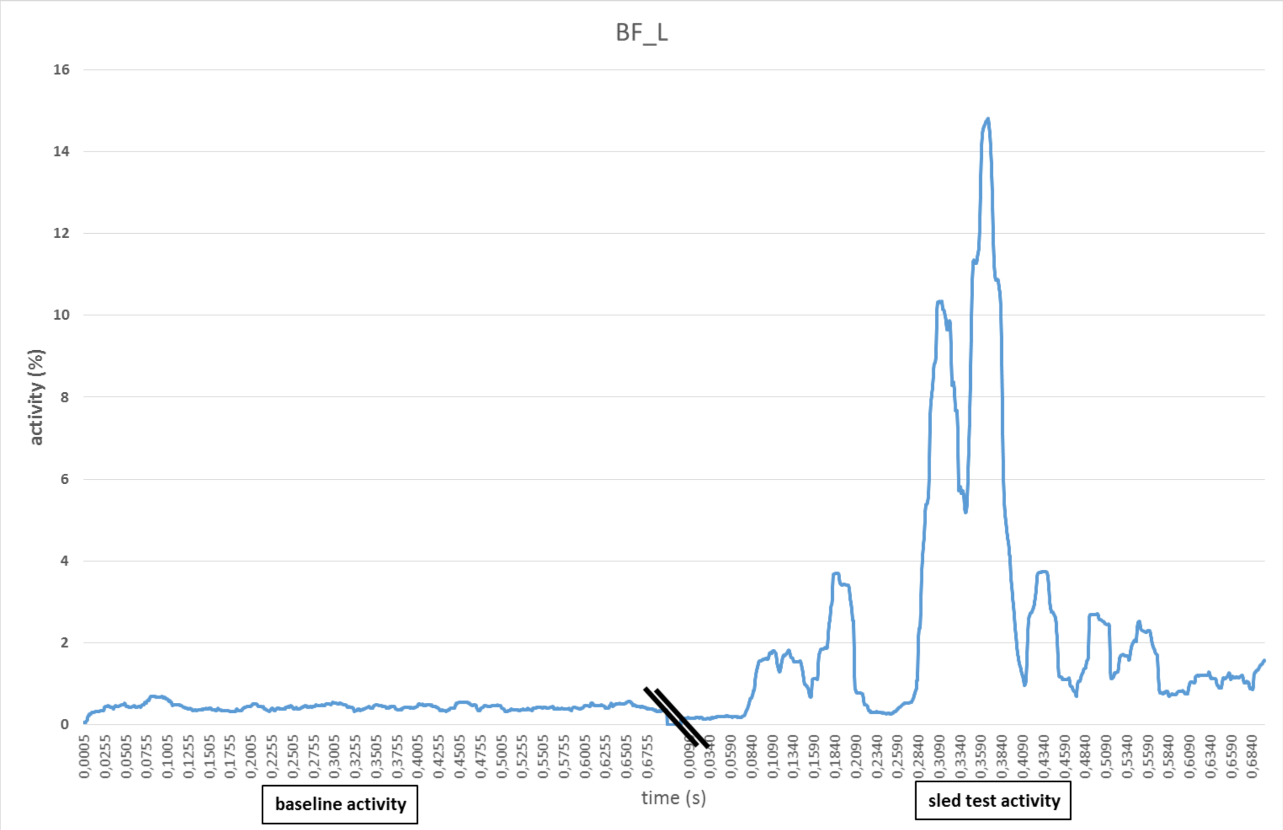

RA_L
activity (%)
time (s)
baseline activity
sled test activity

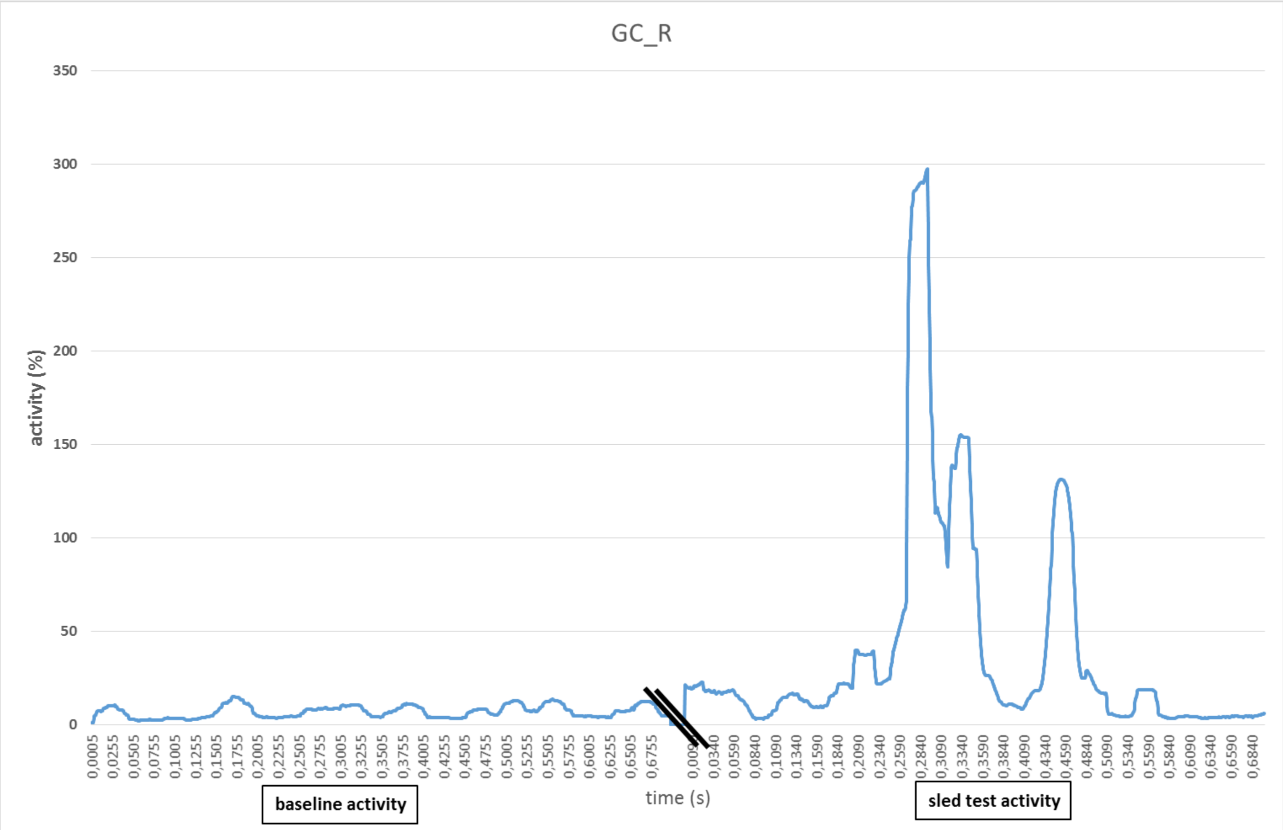

ES_L
activity (5)
time (s)
baseline activity
sled test activity


RF_R
activity (%)
time (s)
baseline activity
sled test activity

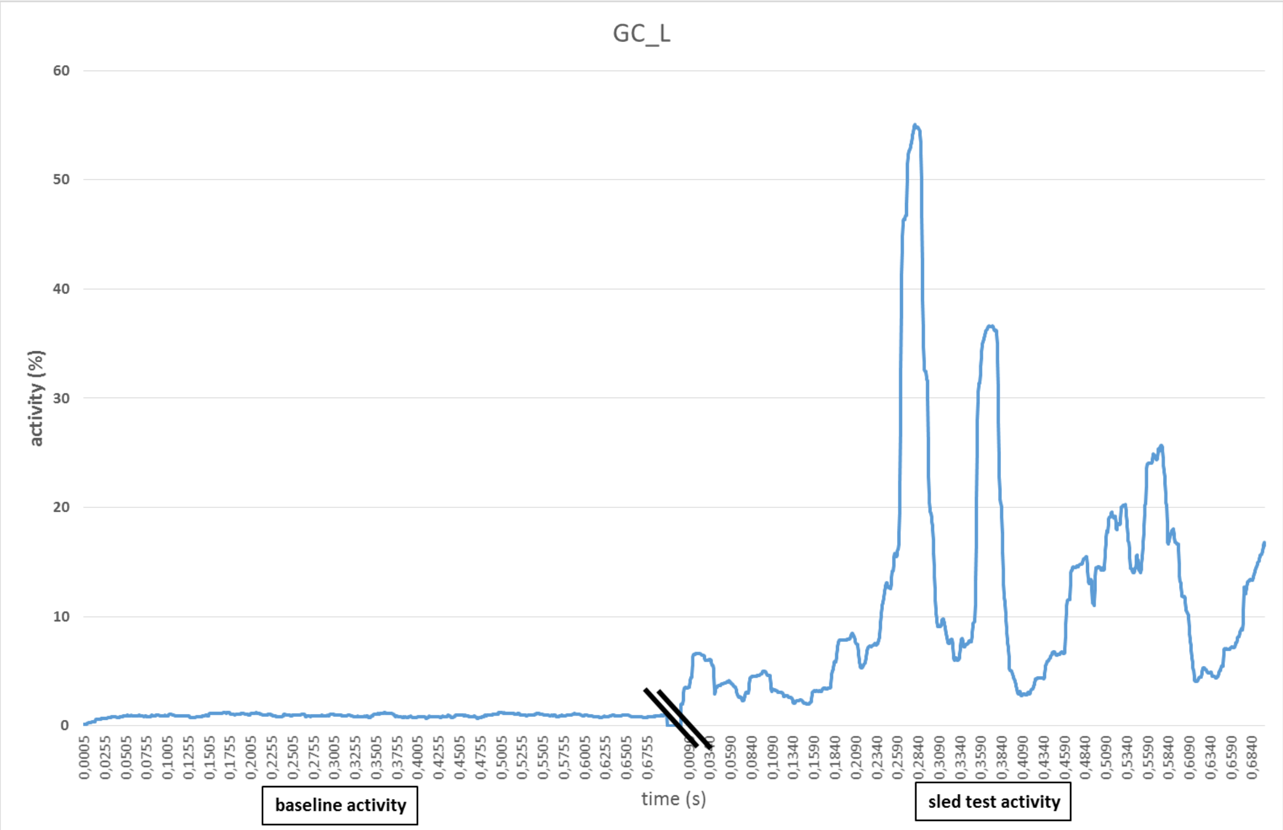

RF_L
activity (5)
time (s)
baseline activity
sled test activity


BF_R
activity (%)
time (s)
baseline activity
sled test activity


BF_L
activity (%)
time (s)
baseline activity
sled test activity

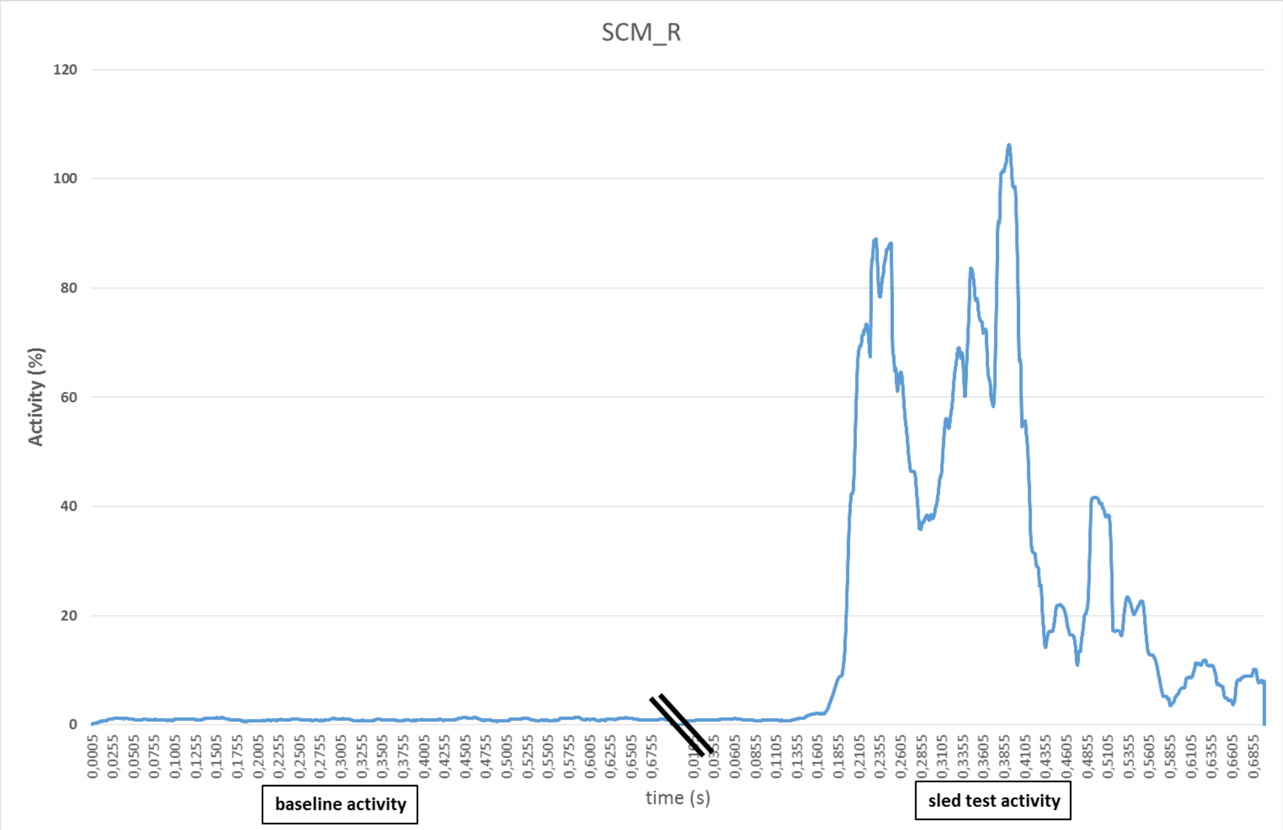


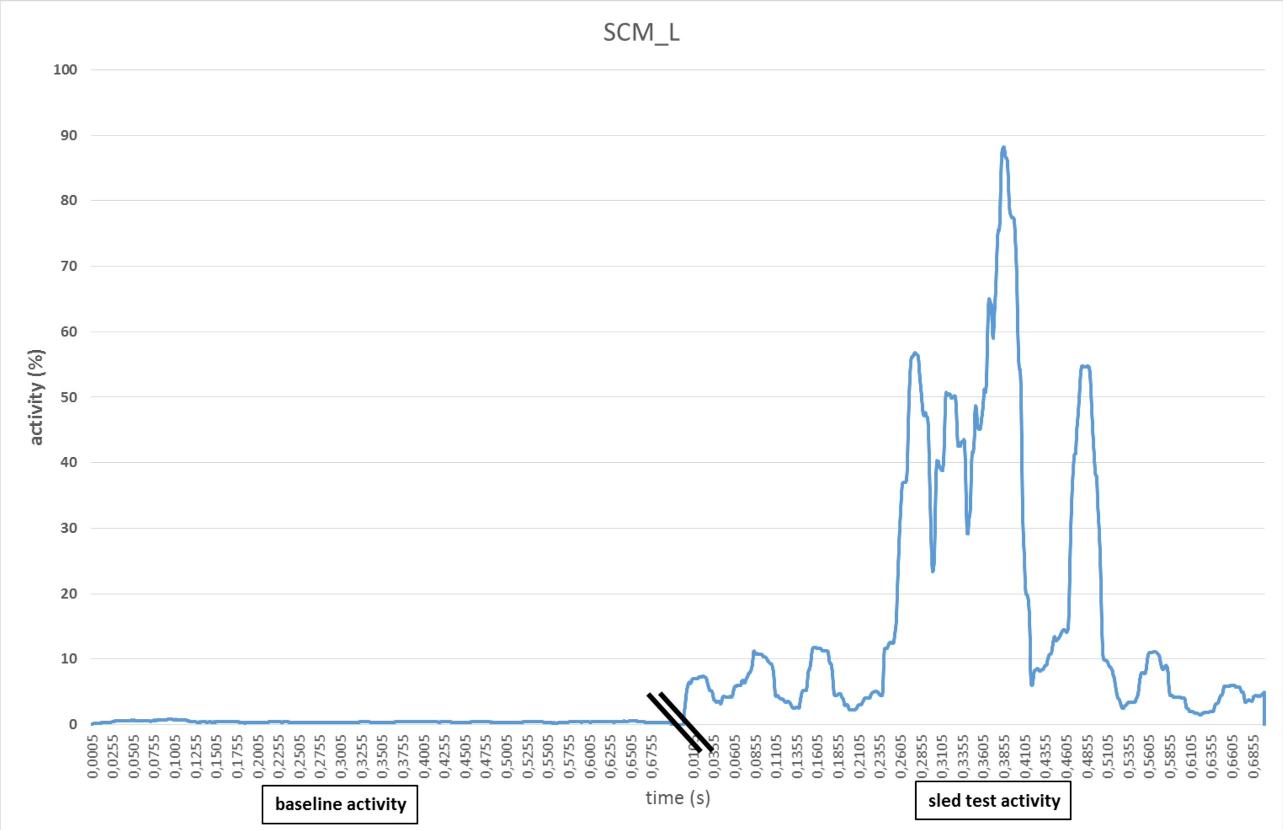
GC_R
activity (%)
time (s)
baseline activity
sled test activity

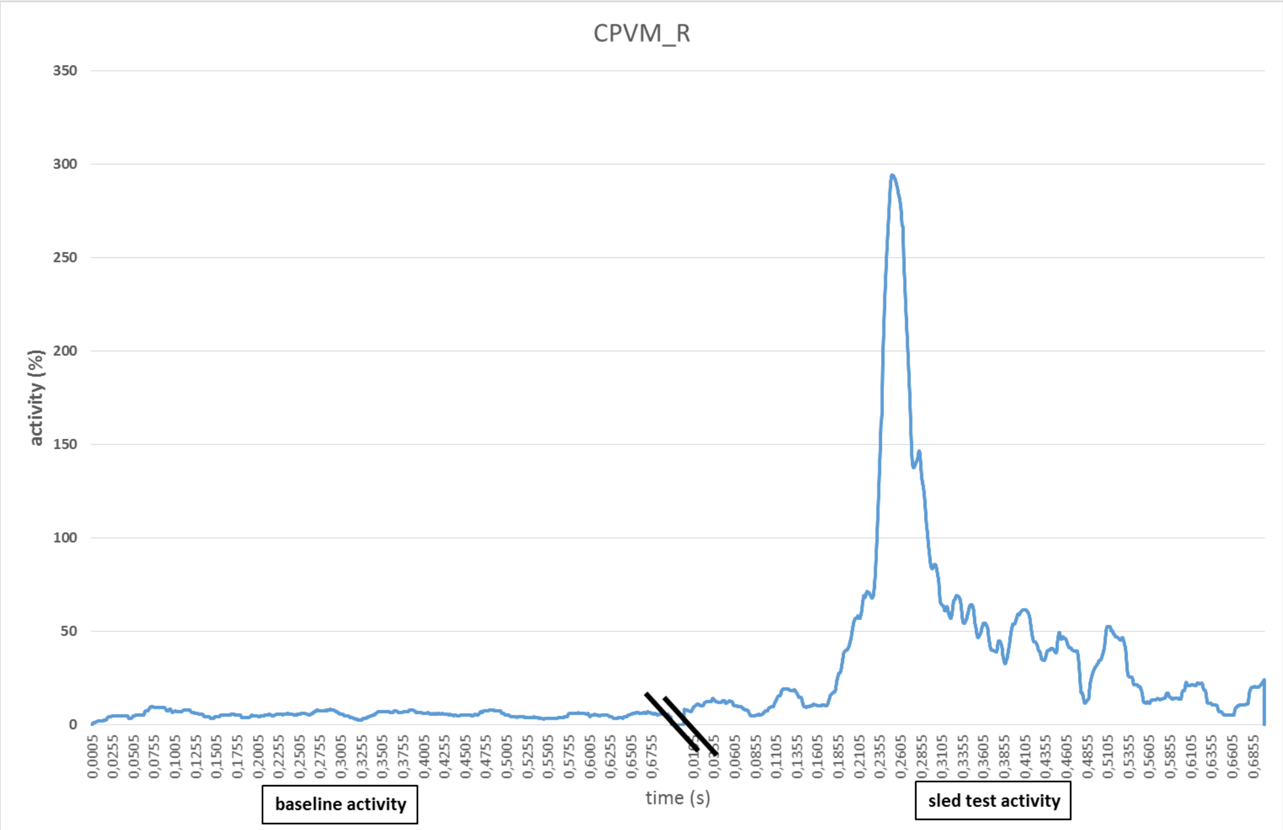



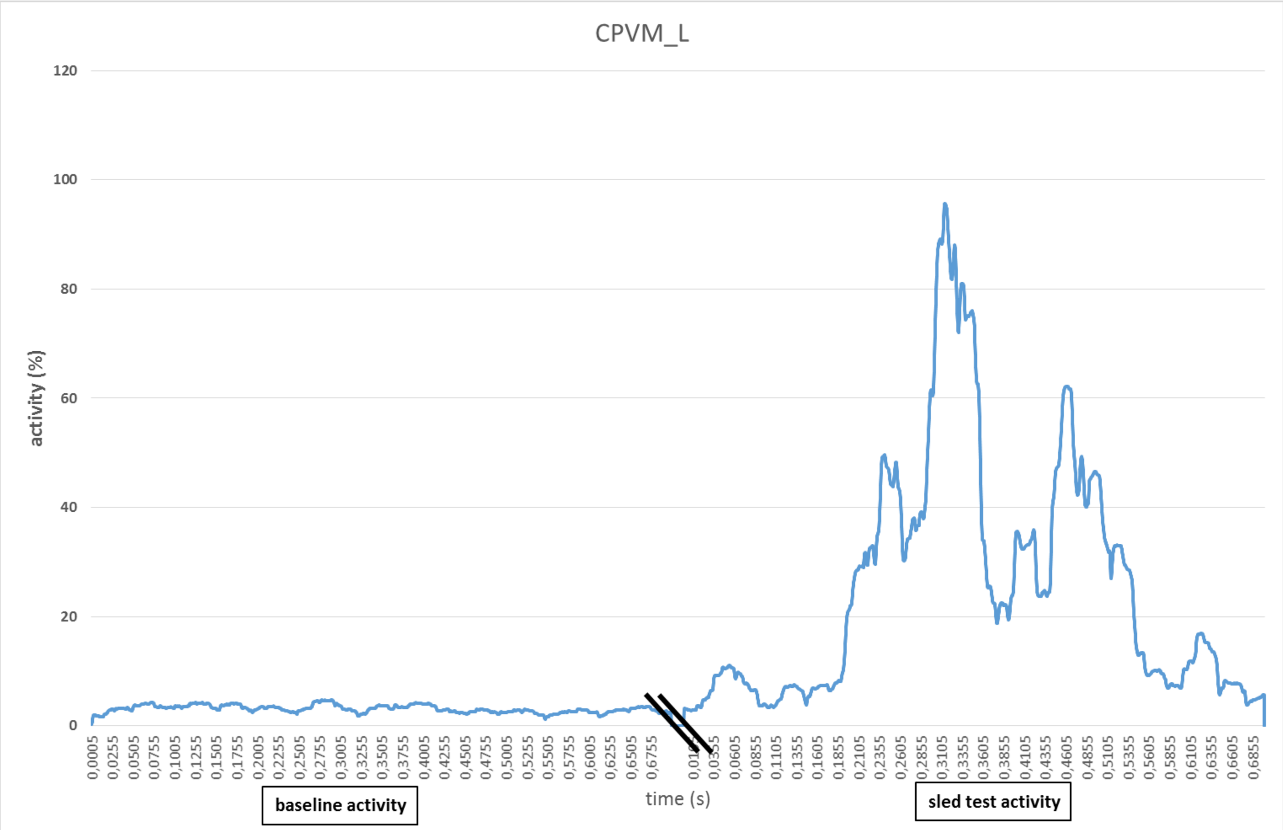
GC_L
activity (%)
time (s)
baseline activity
sled test activity


Trial 1768

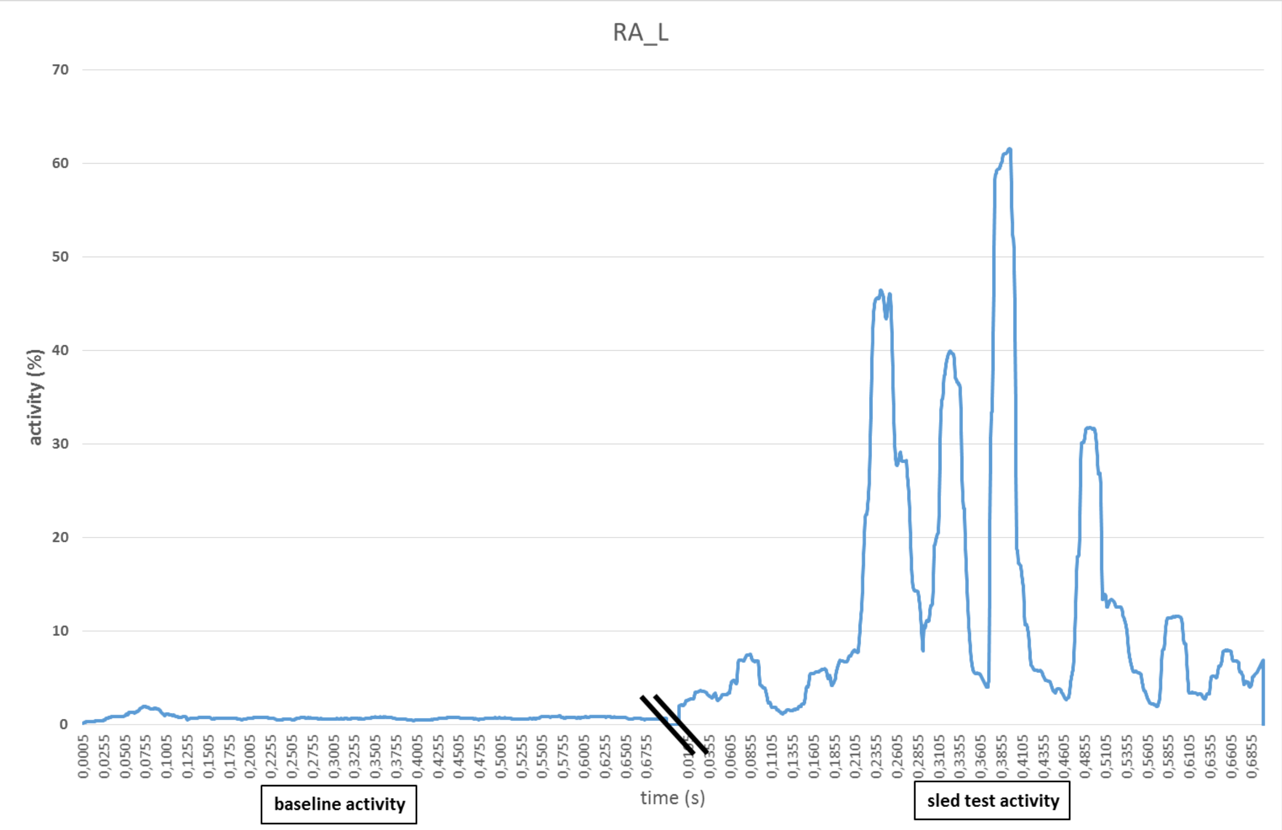

SCM_R
Activity (%)
time (s)
baseline activity
sled test activity

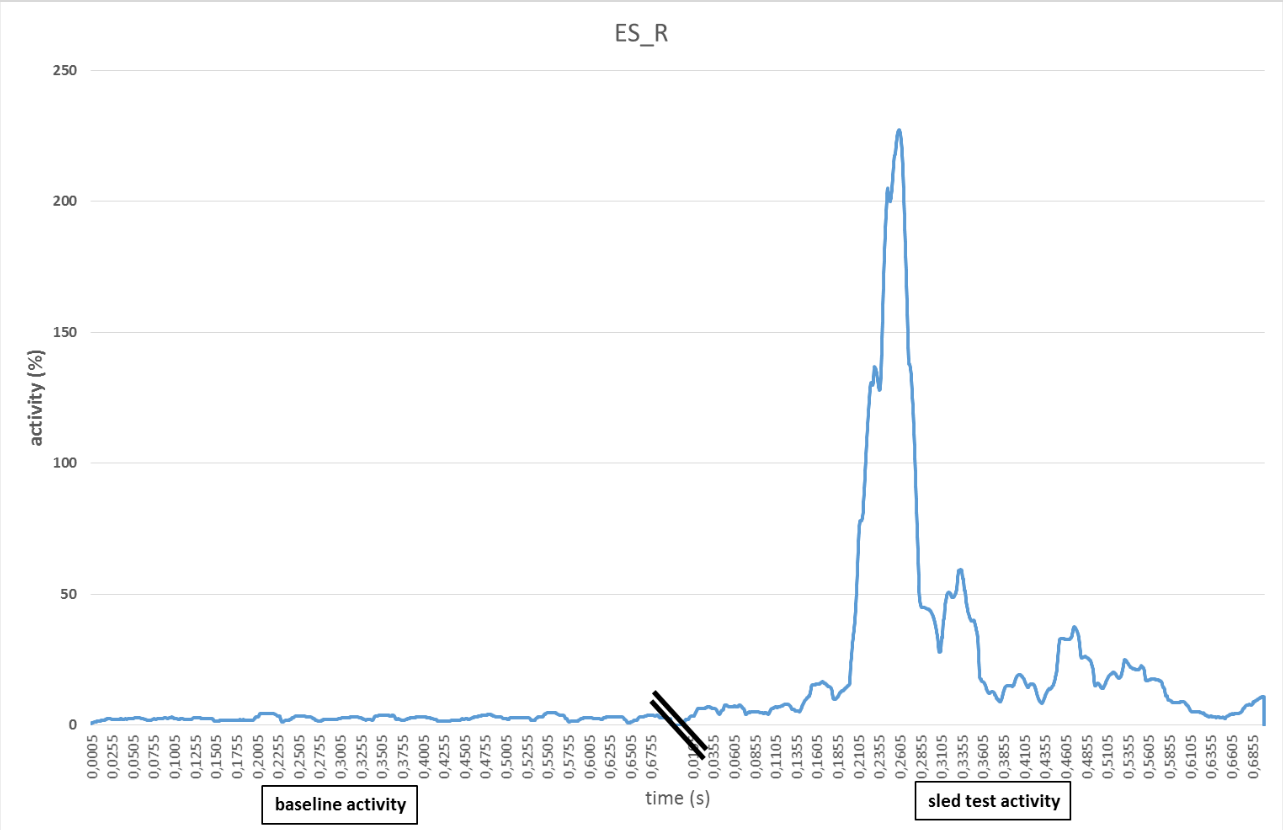

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

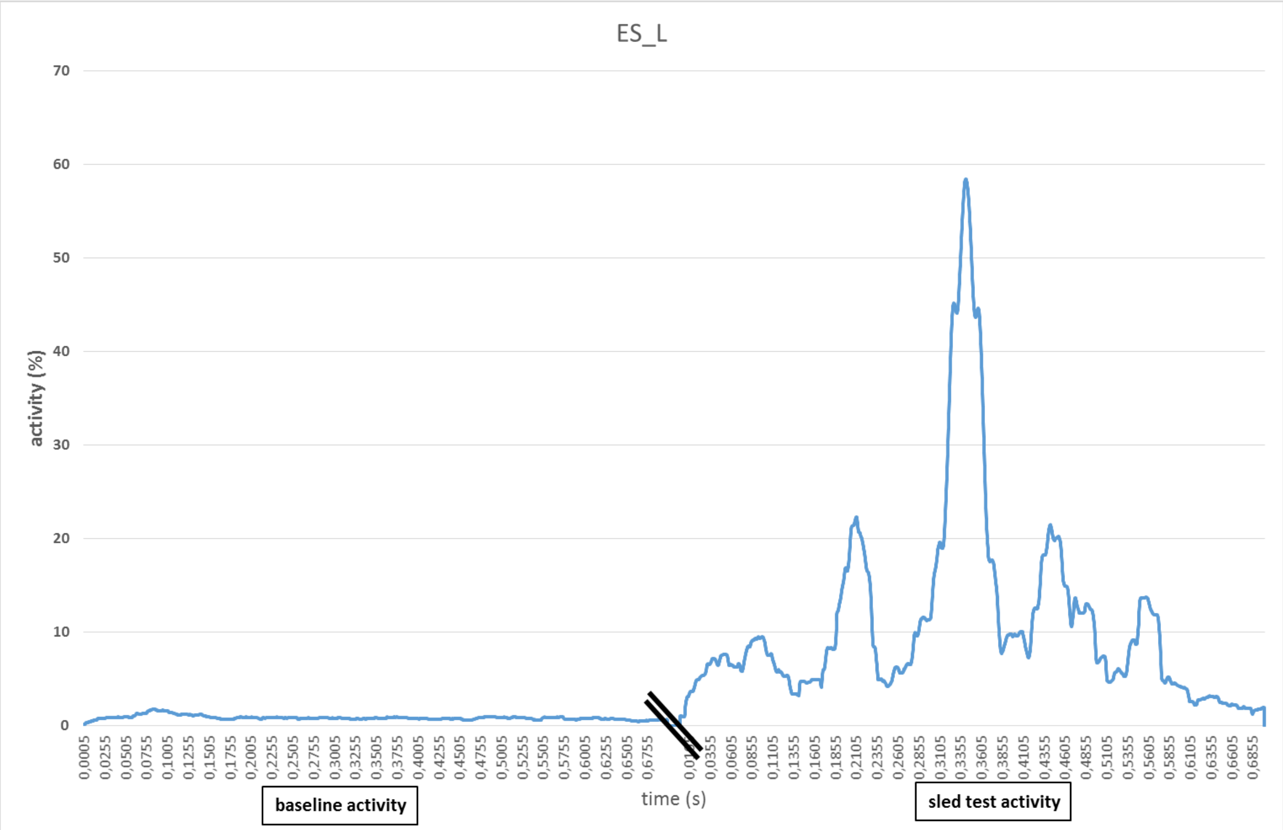

CPVM_R
activity (%)
time (s)
baseline activity
sled test activity

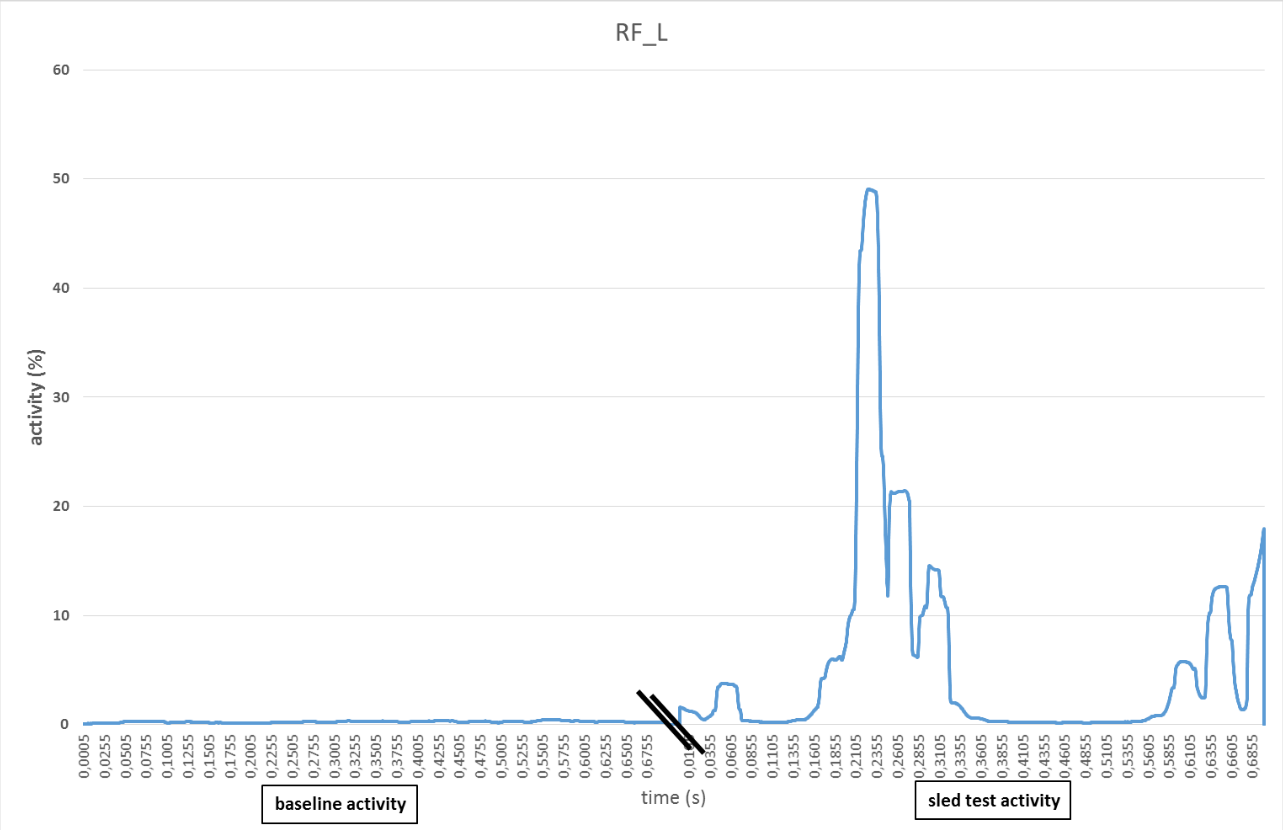

CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

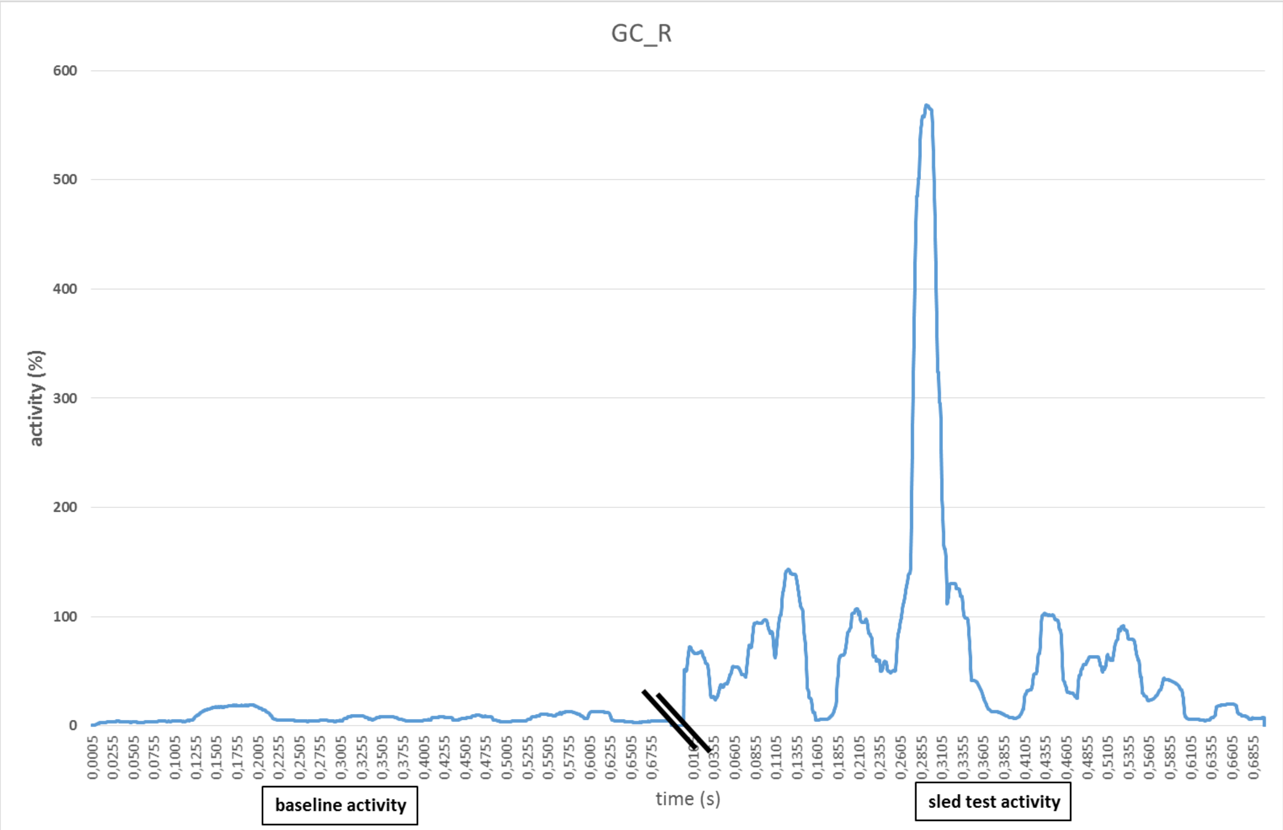

RA_R
activity (%)
time (s)
baseline activity
sled test activity

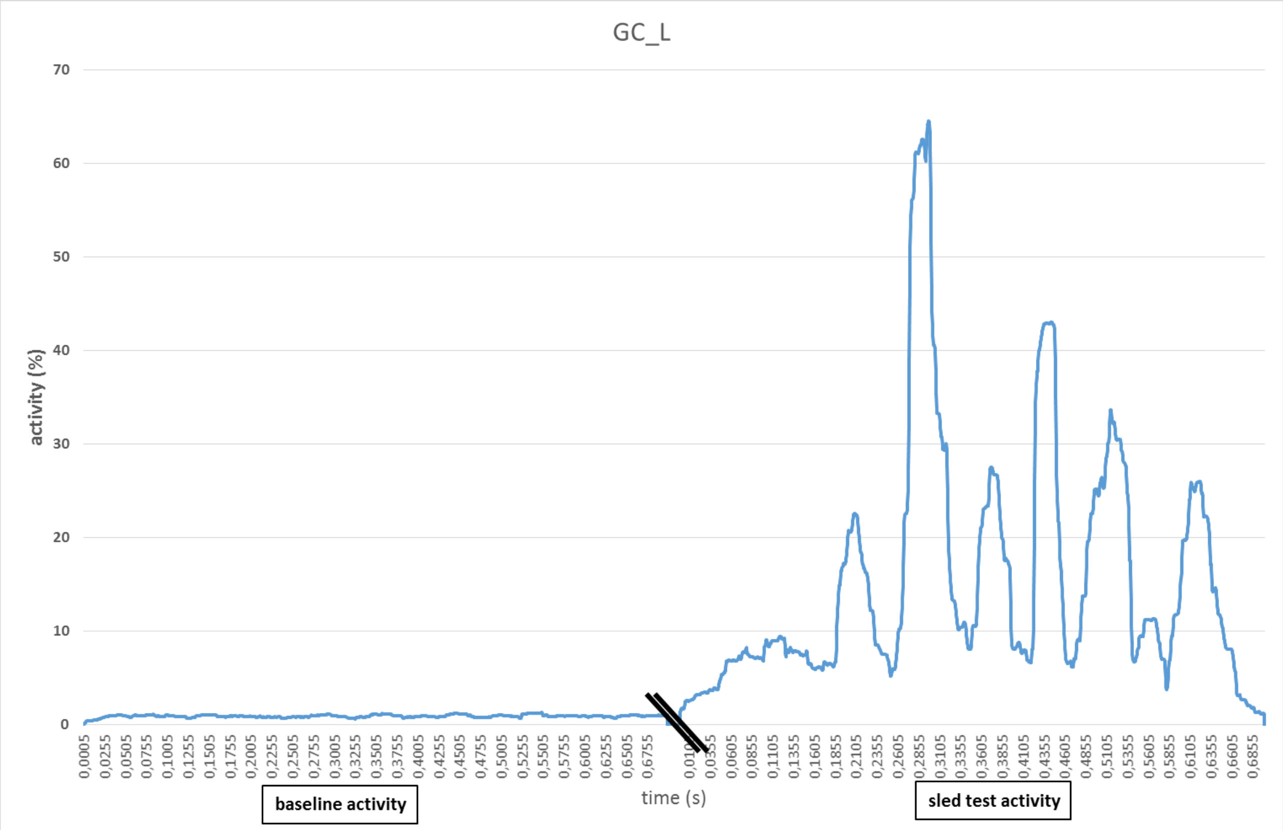

RA_L
activity (%)
time (s)
baseline activity
sled test activity


ES_R
activity (%)
time (s)
baseline activity
sled test activity

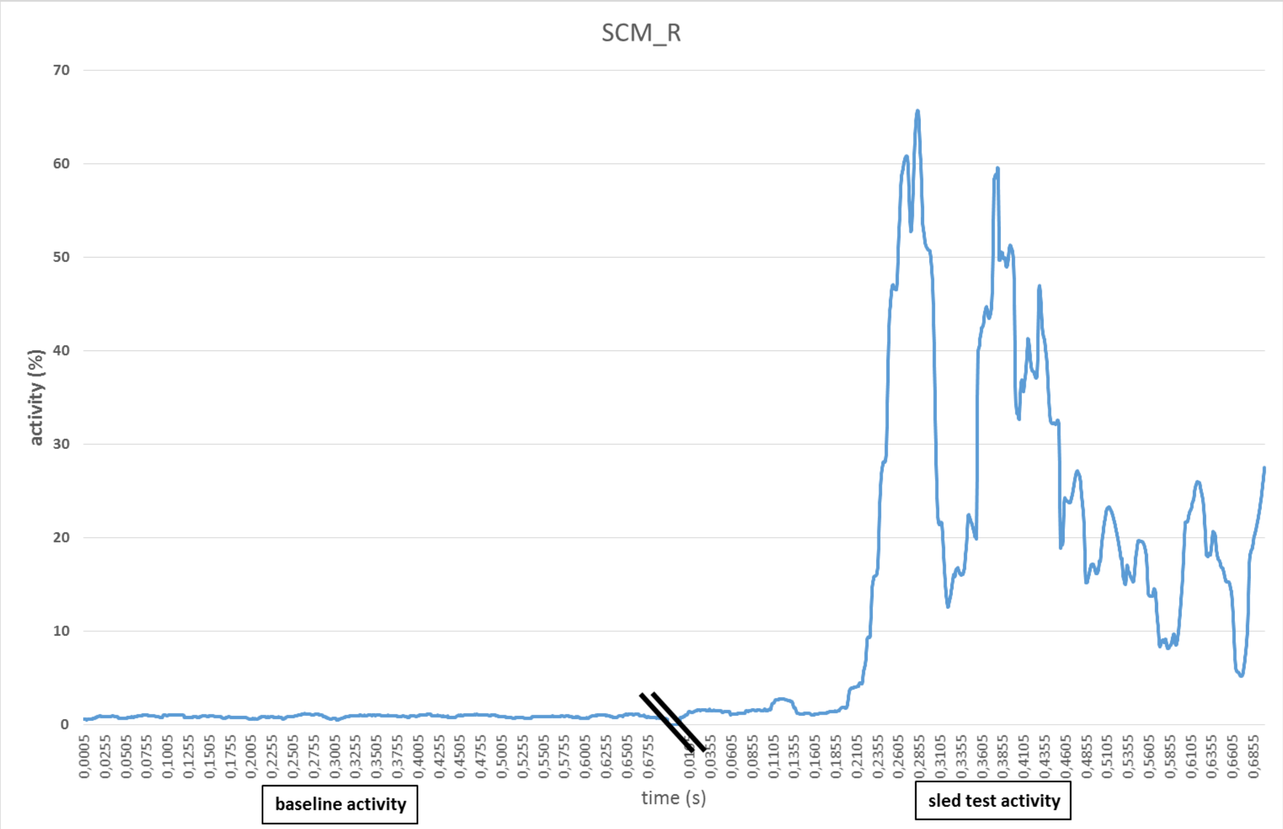

ES_L
activity (%)
time (s)
baseline activity
sled test activity

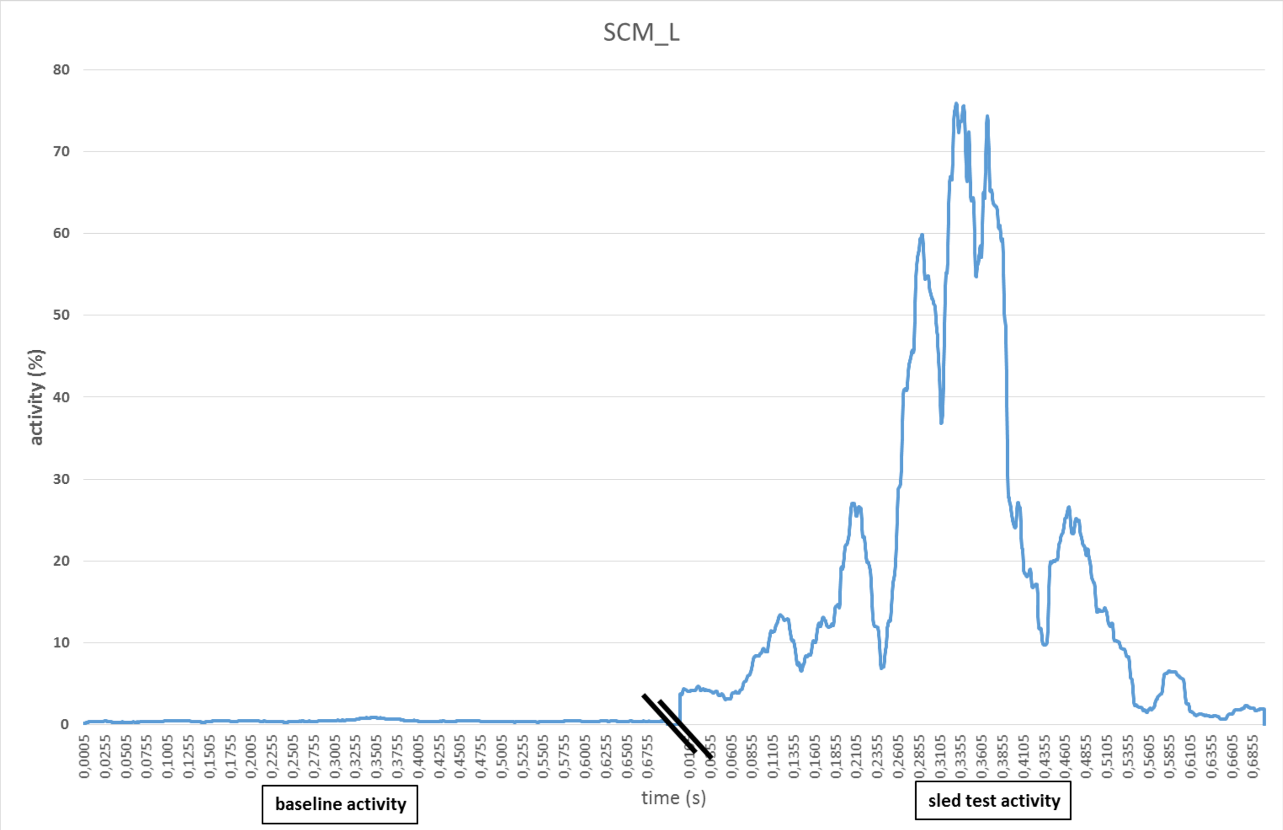

RF_L
activity (%)
time (s)
baseline activity
sled test activity

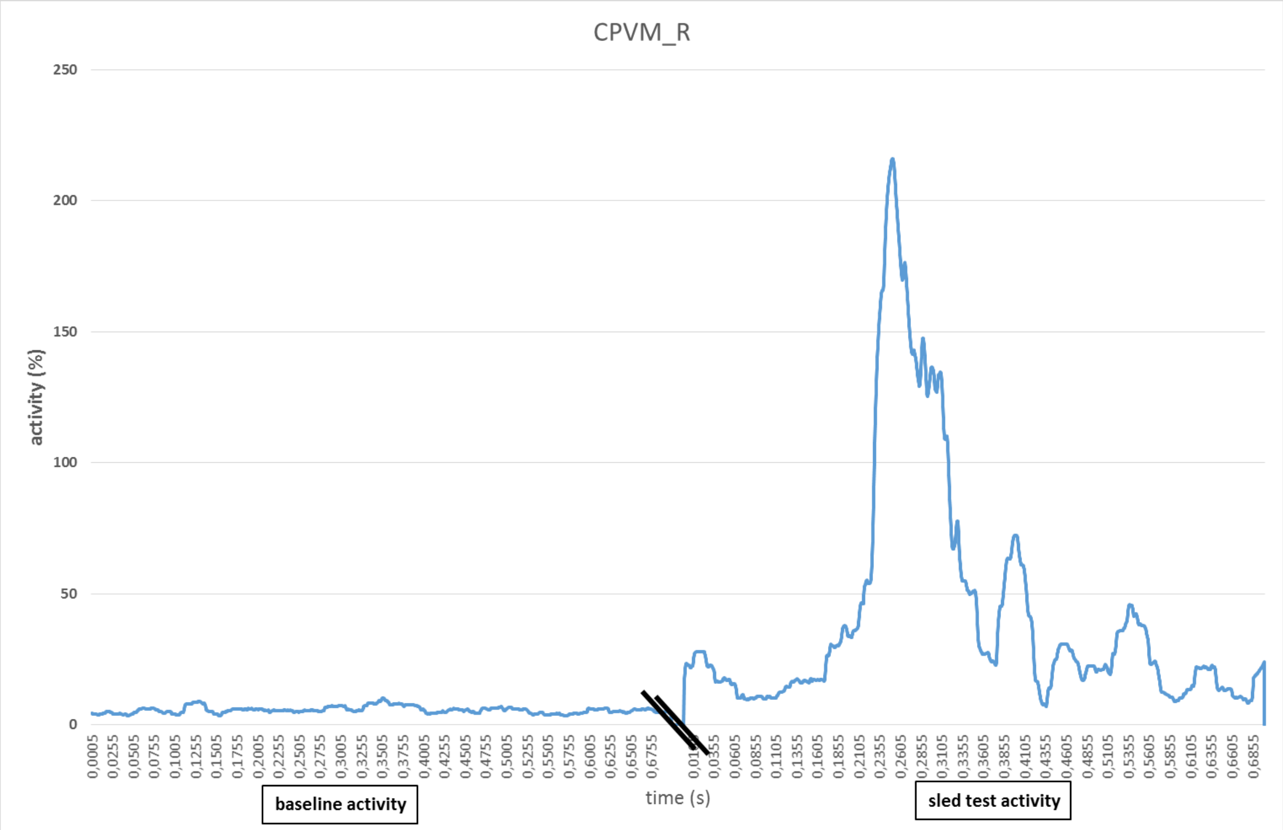

GC_R
activity (%)
time (s)
baseline activity
sled test activity

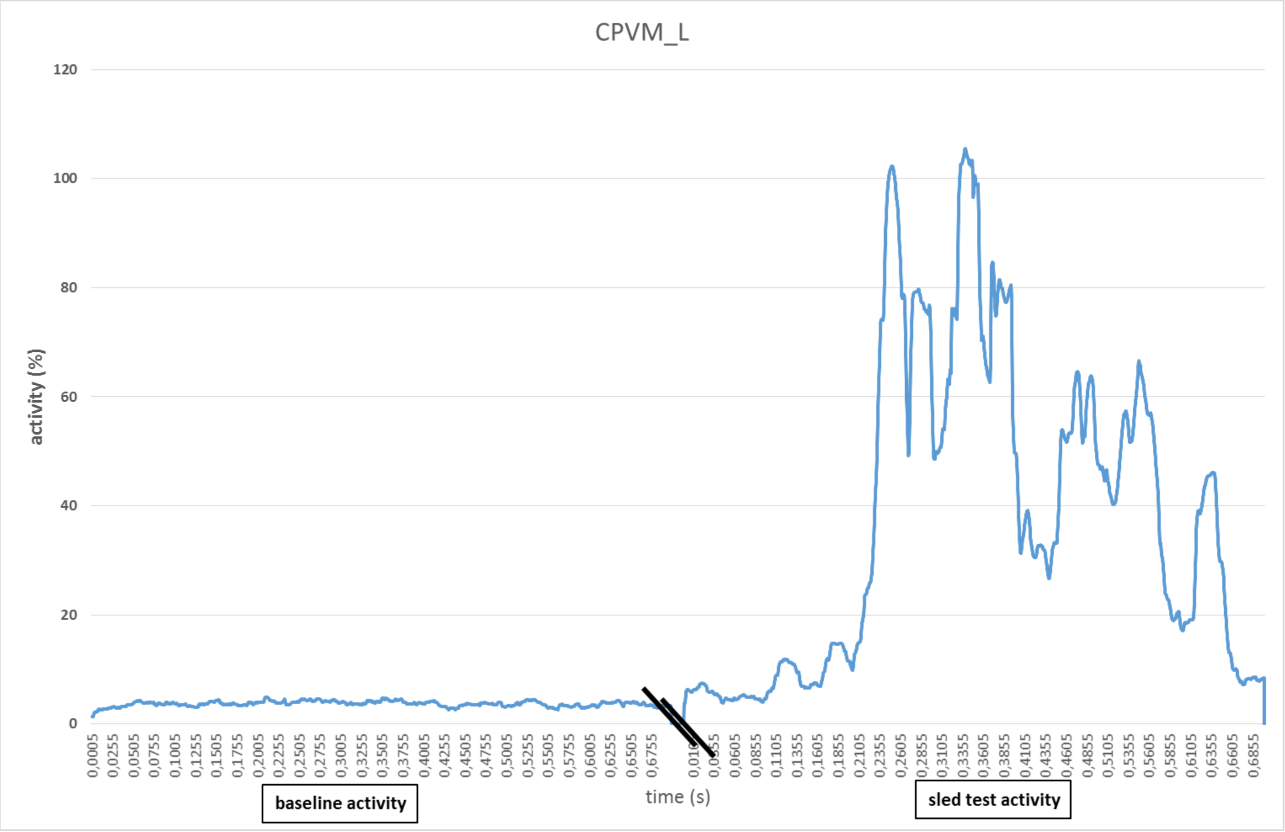

GC_L
activity (%)
time (s)
baseline activity
sled test activity

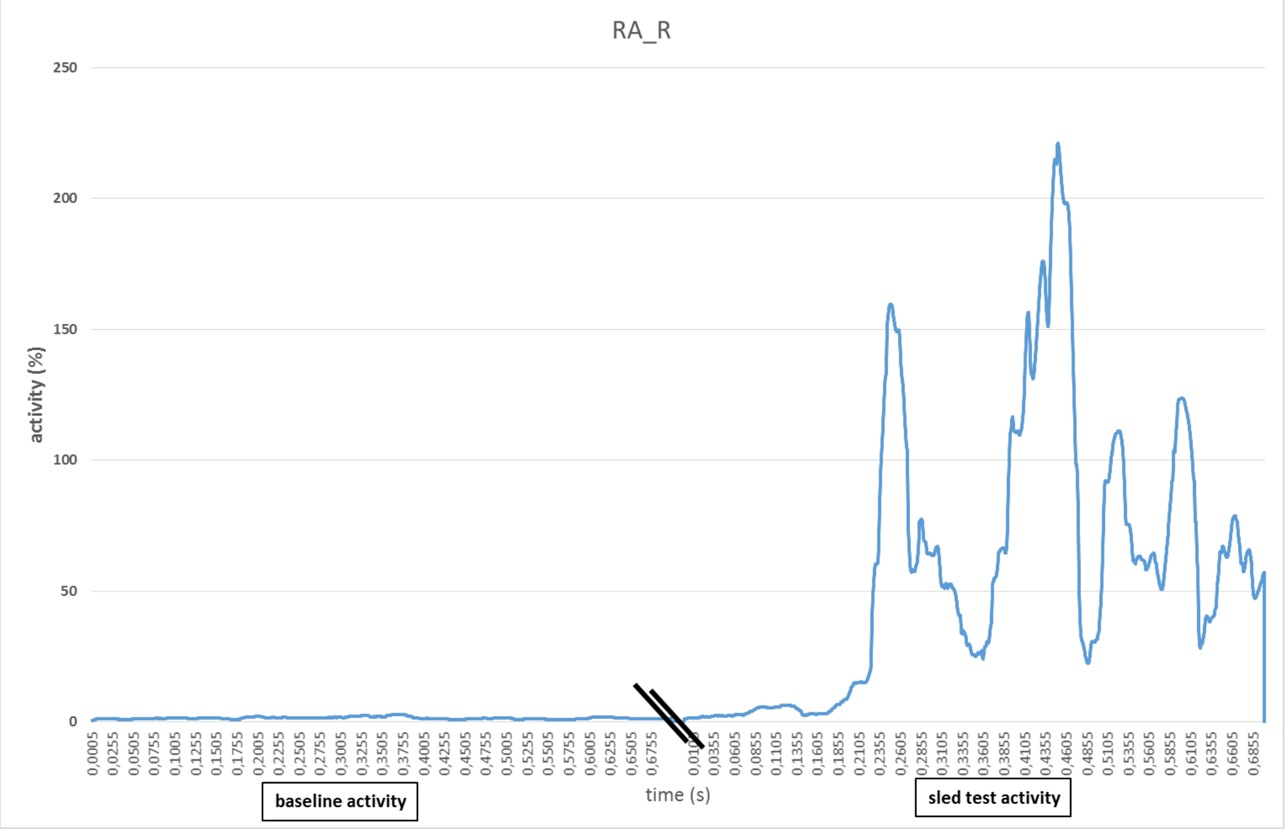
Trial 1769

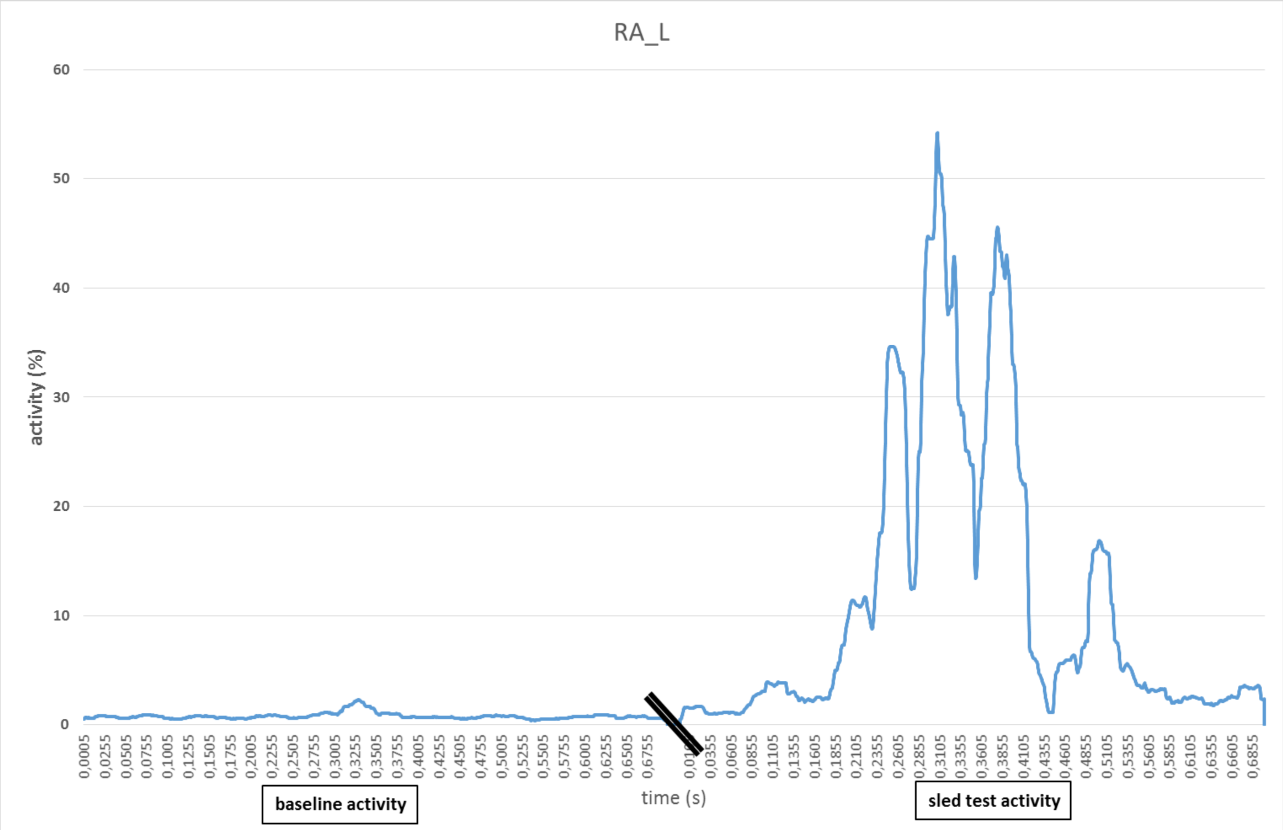

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

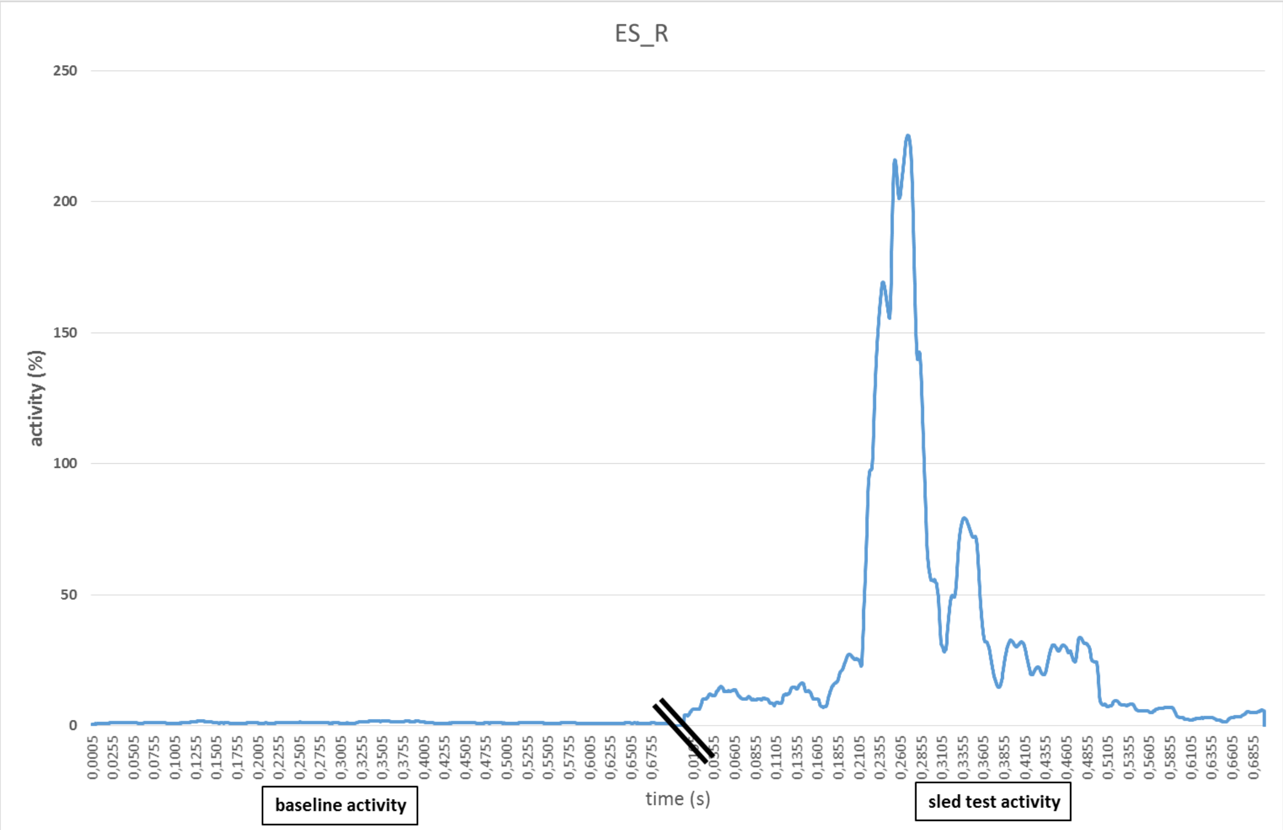

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

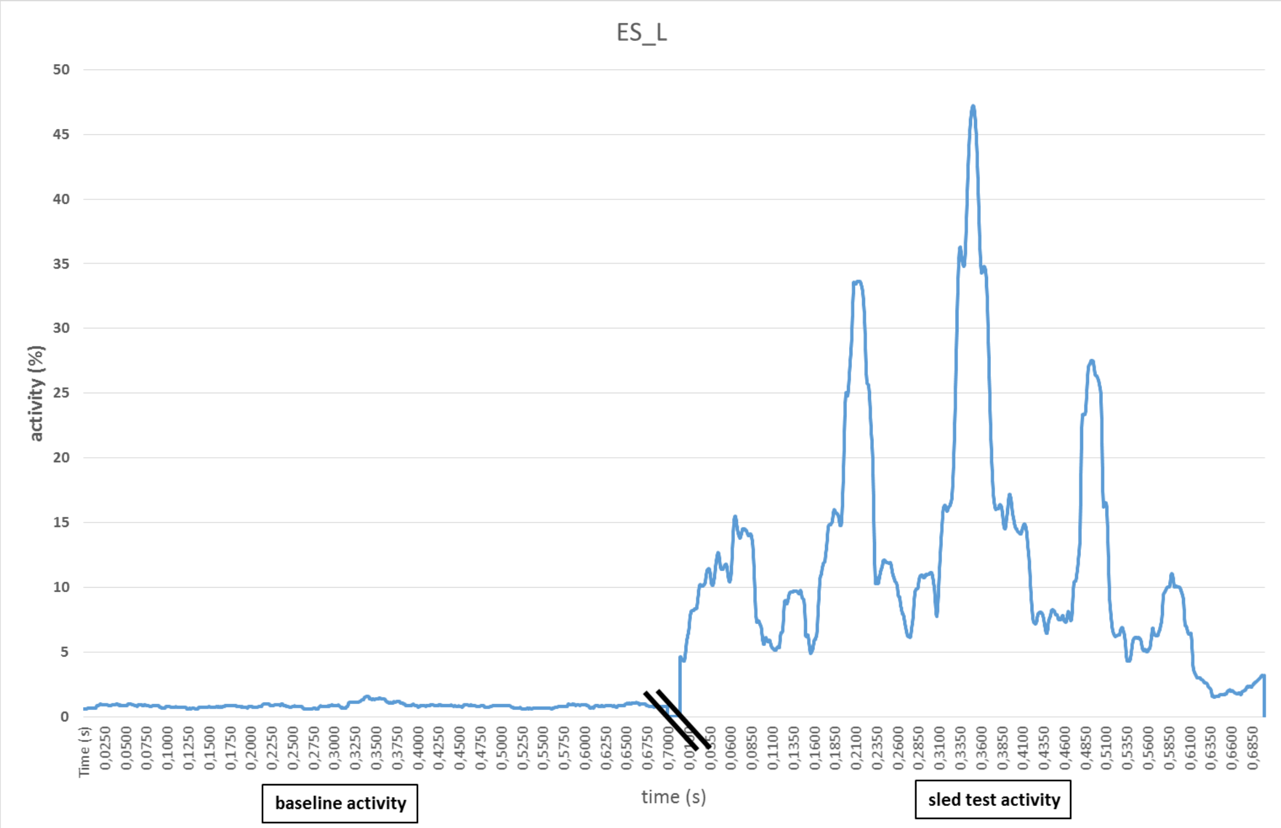

CPVM_R
activity (%)
time (s)
baseline activity
sled test activity


CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

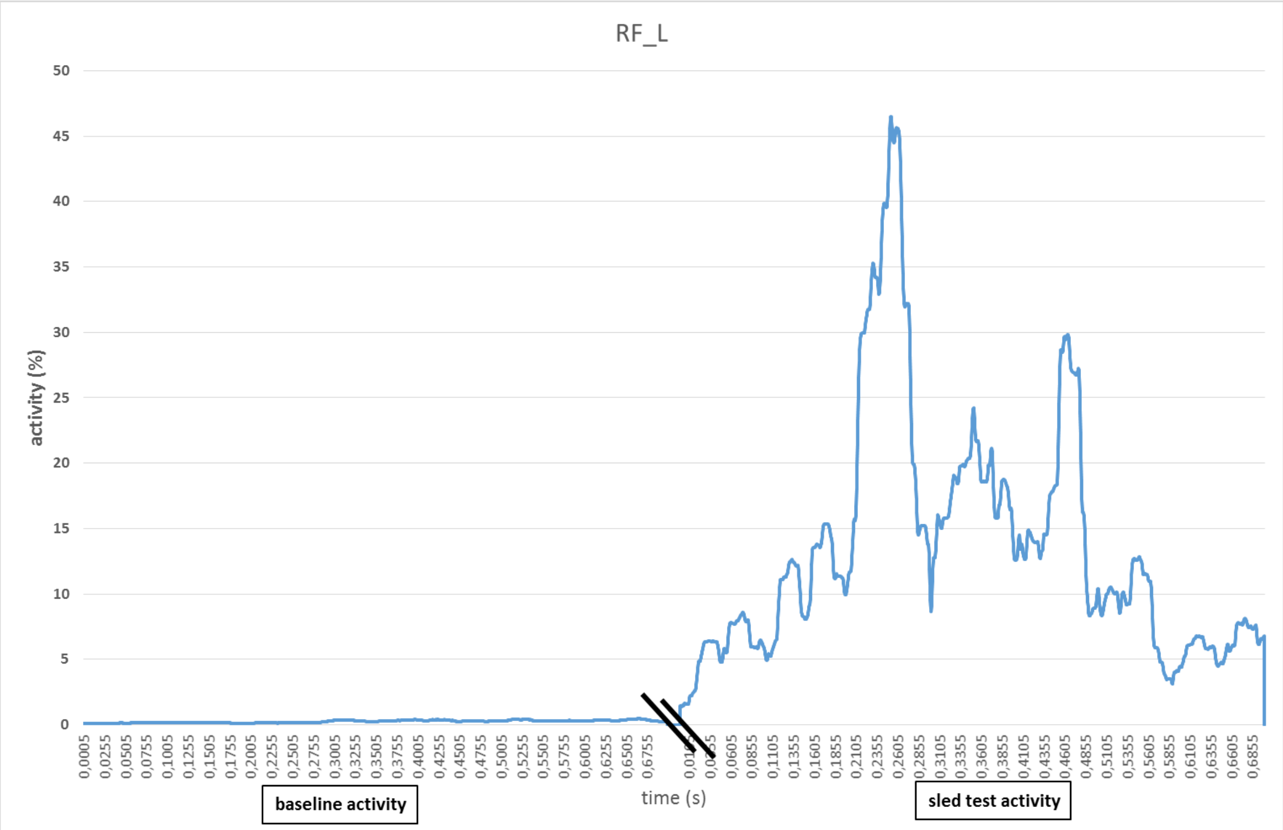

RA_R
activity (%)
time (s)
baseline activity
sled test activity

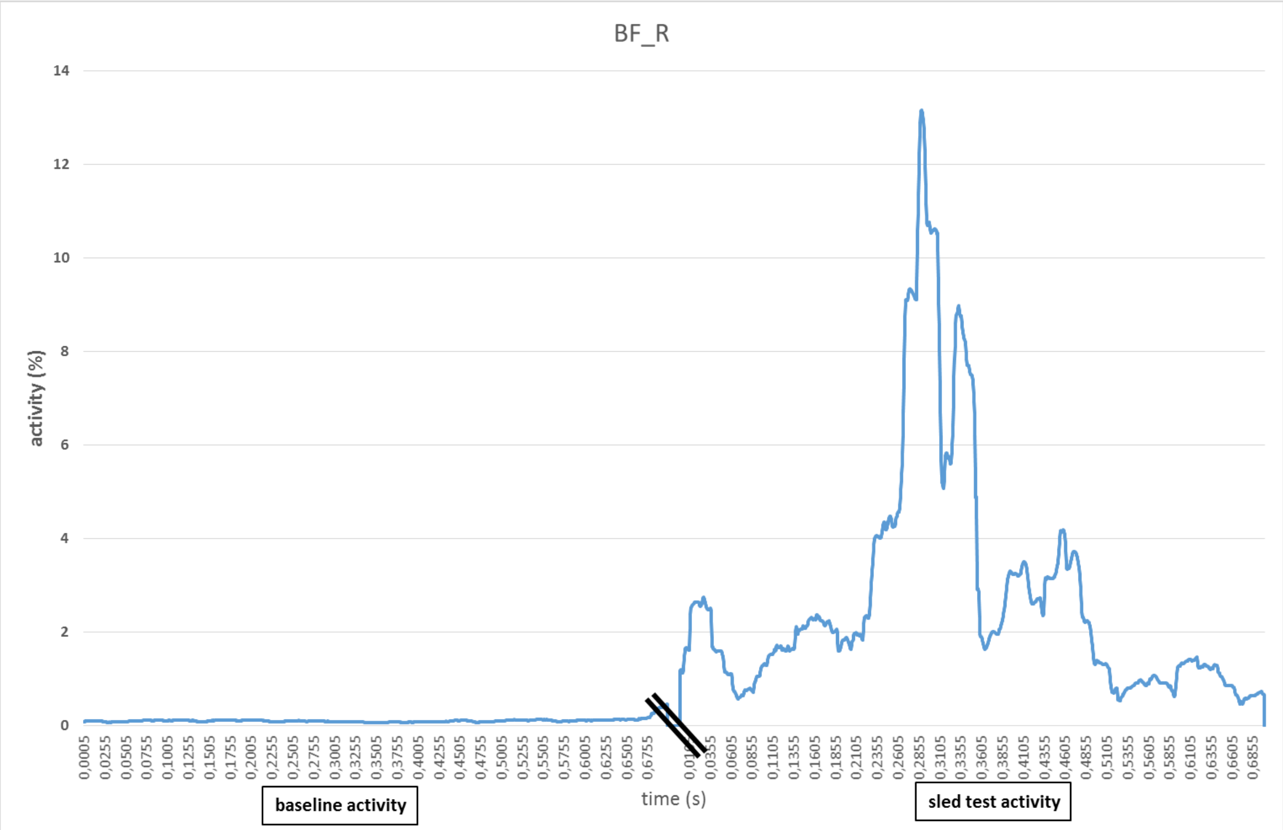

RA_L
60
50
40
30
20
10
0
activity (%)
time (s)
baseline activity
sled test activity

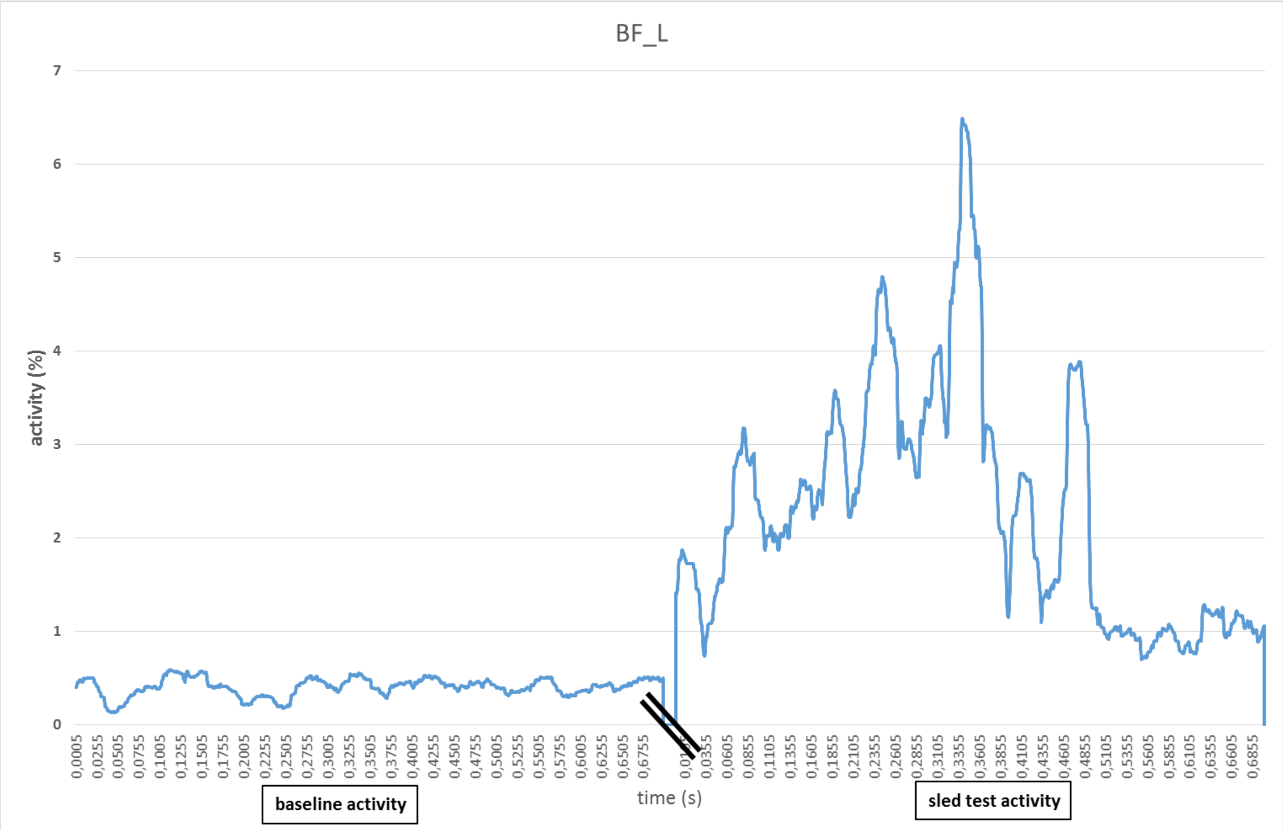

ES_R
250
200
150
100
50
0
activity (%)
time (s)
baseline activity
sled test activity

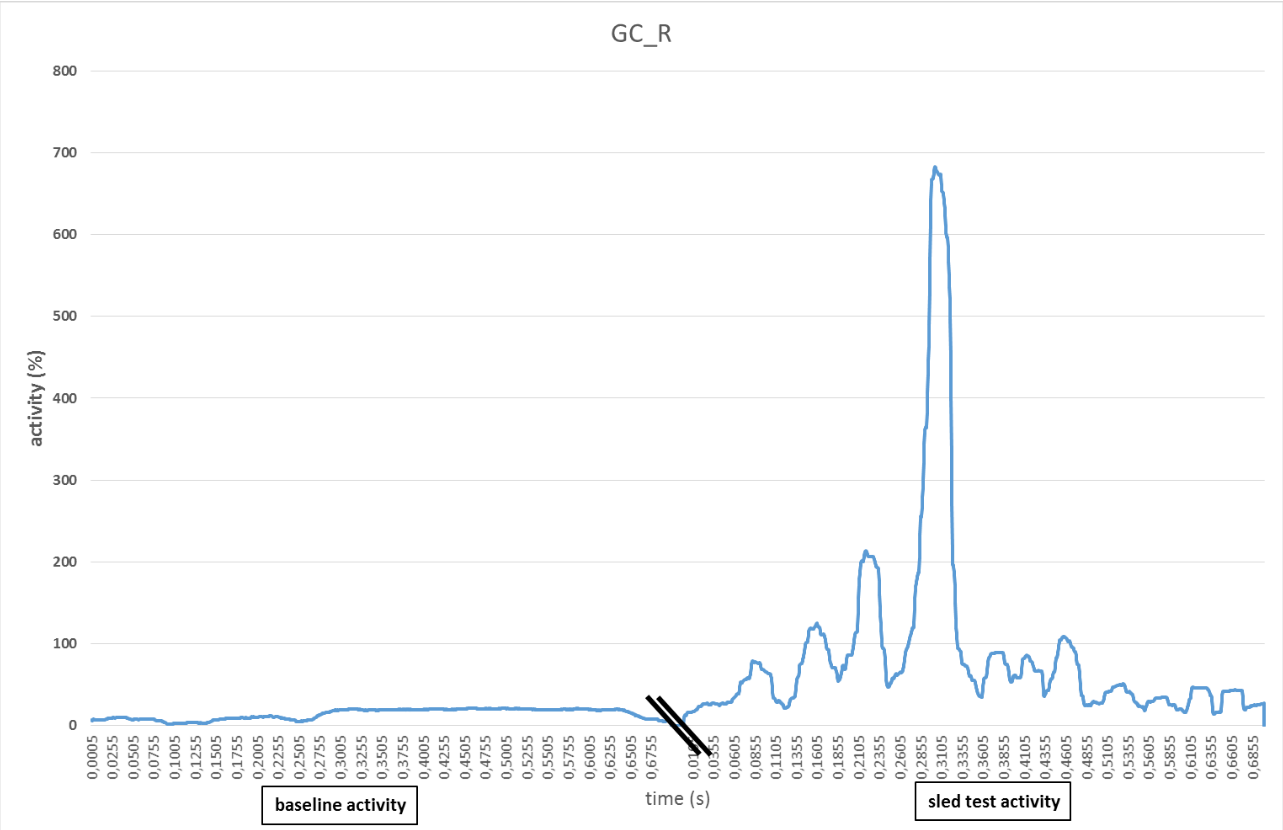

ES_L
activity (%)
50
45
40
35
30
25
20
15
10
5
0
Time (s)
time (s)
baseline activity
sled test activity

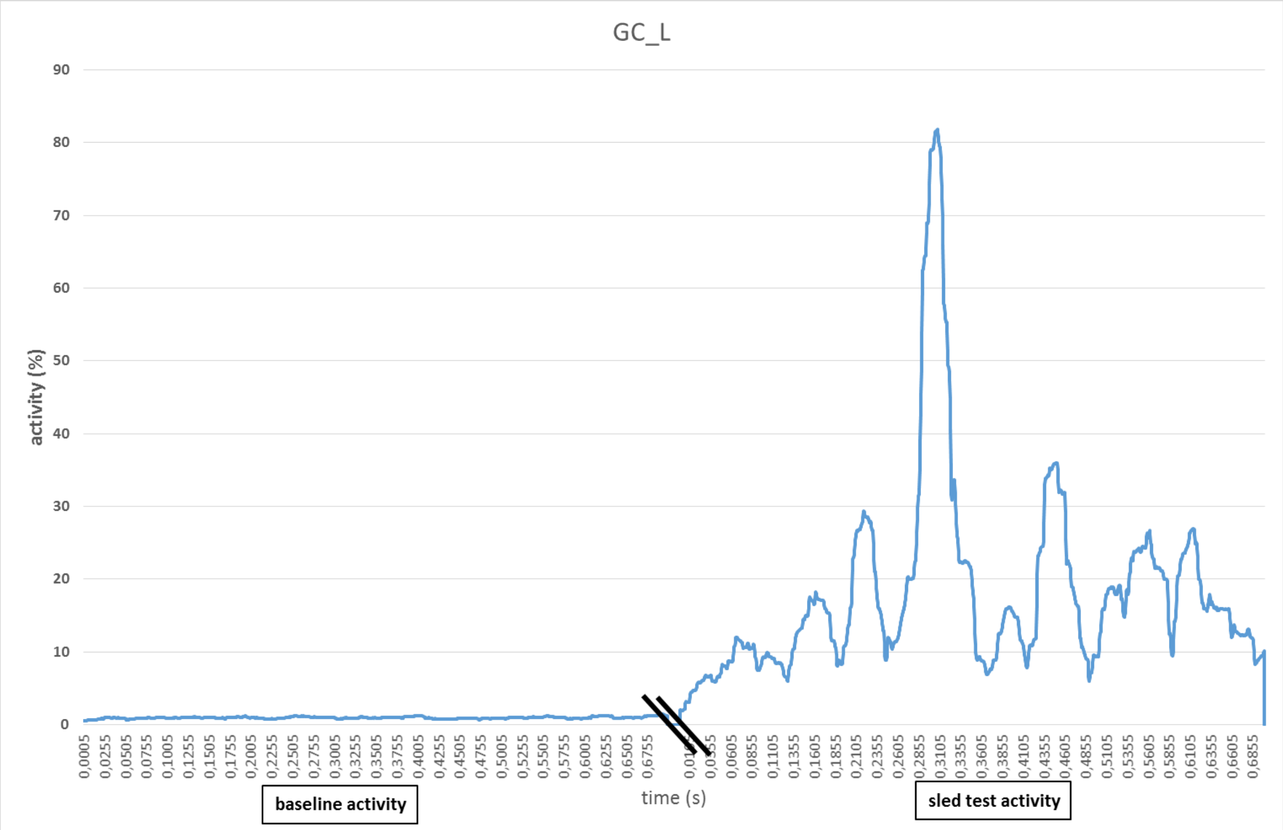

RF_R
activity (%)
45
40
35
30
25
20
15
10
5
0
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity

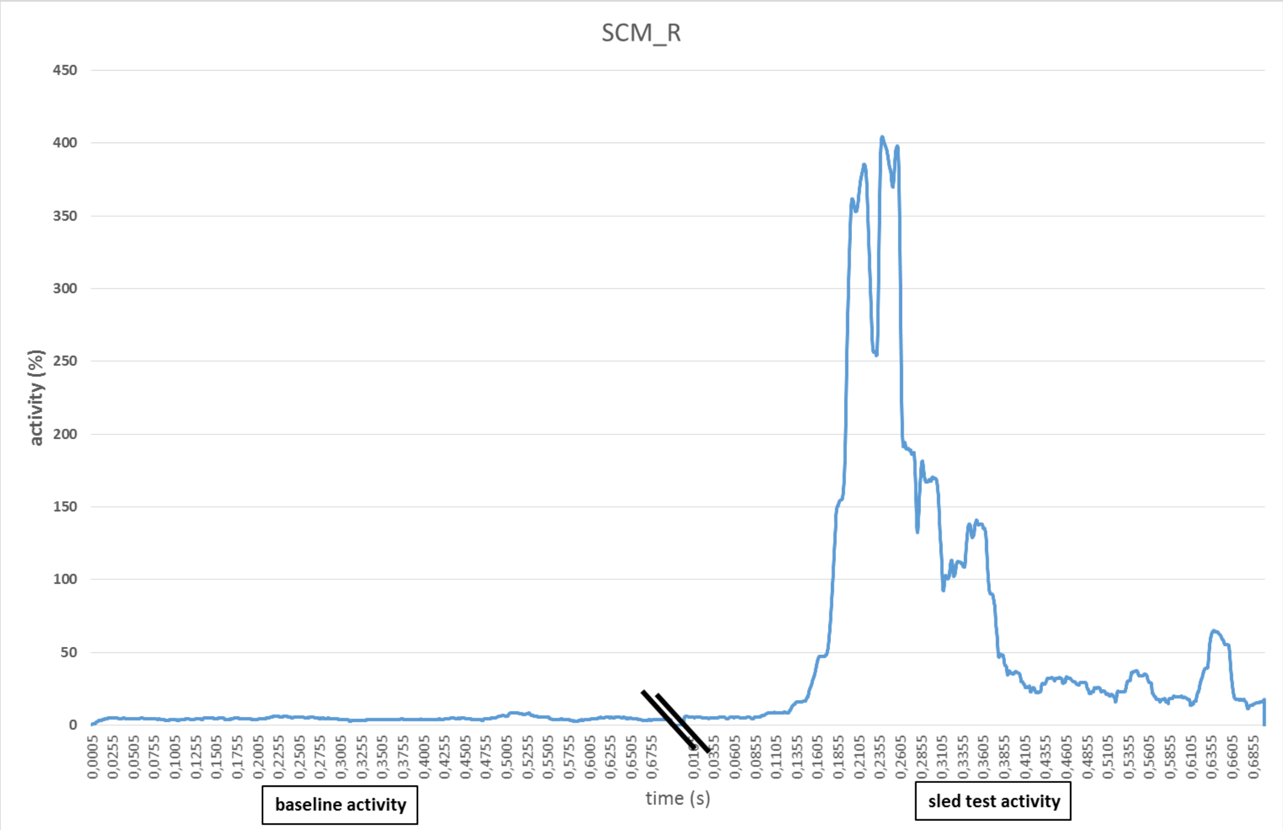

BF_R
activity (%)
time (s)
baseline activity
sled test activity


BF_L
activity (%)
time (s)
baseline activity
sled test activity

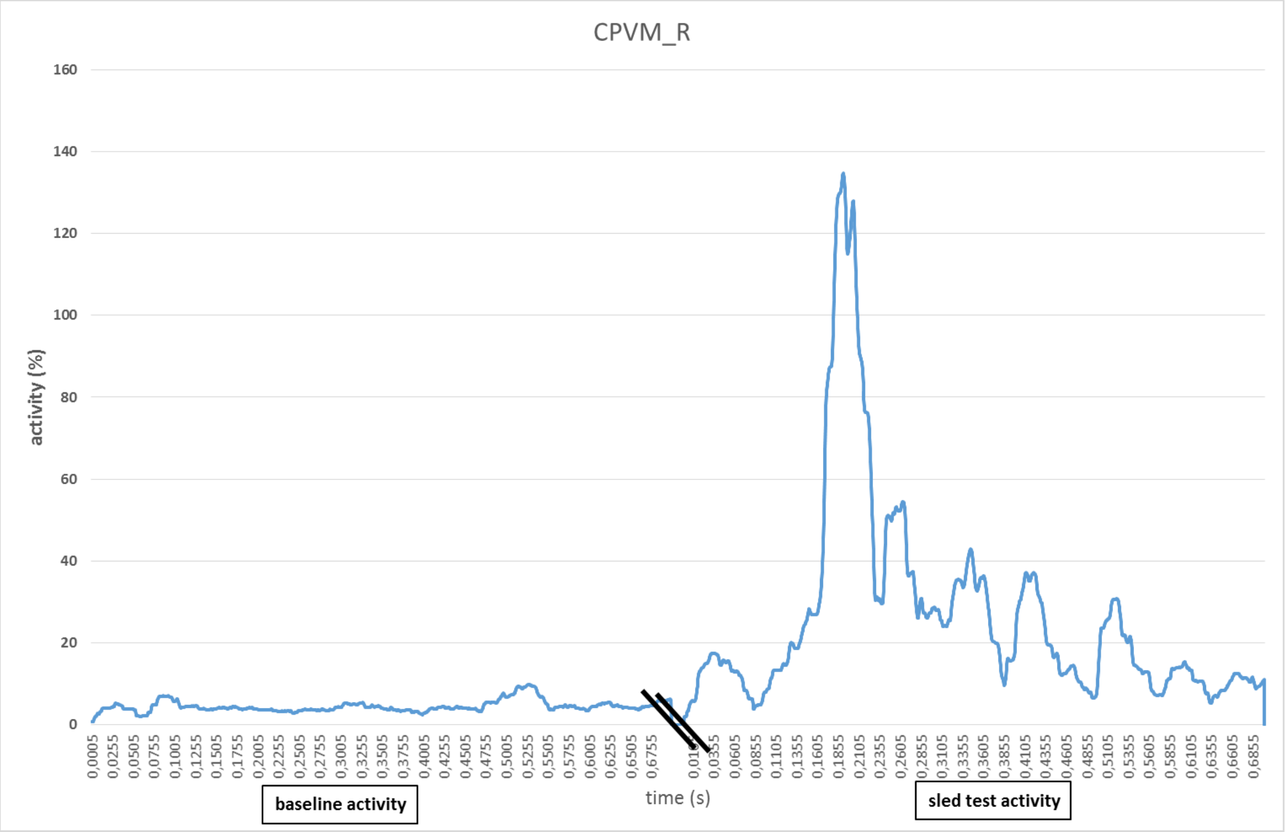

GC_R
activity (%)
time (s)
baseline activity
sled test activity

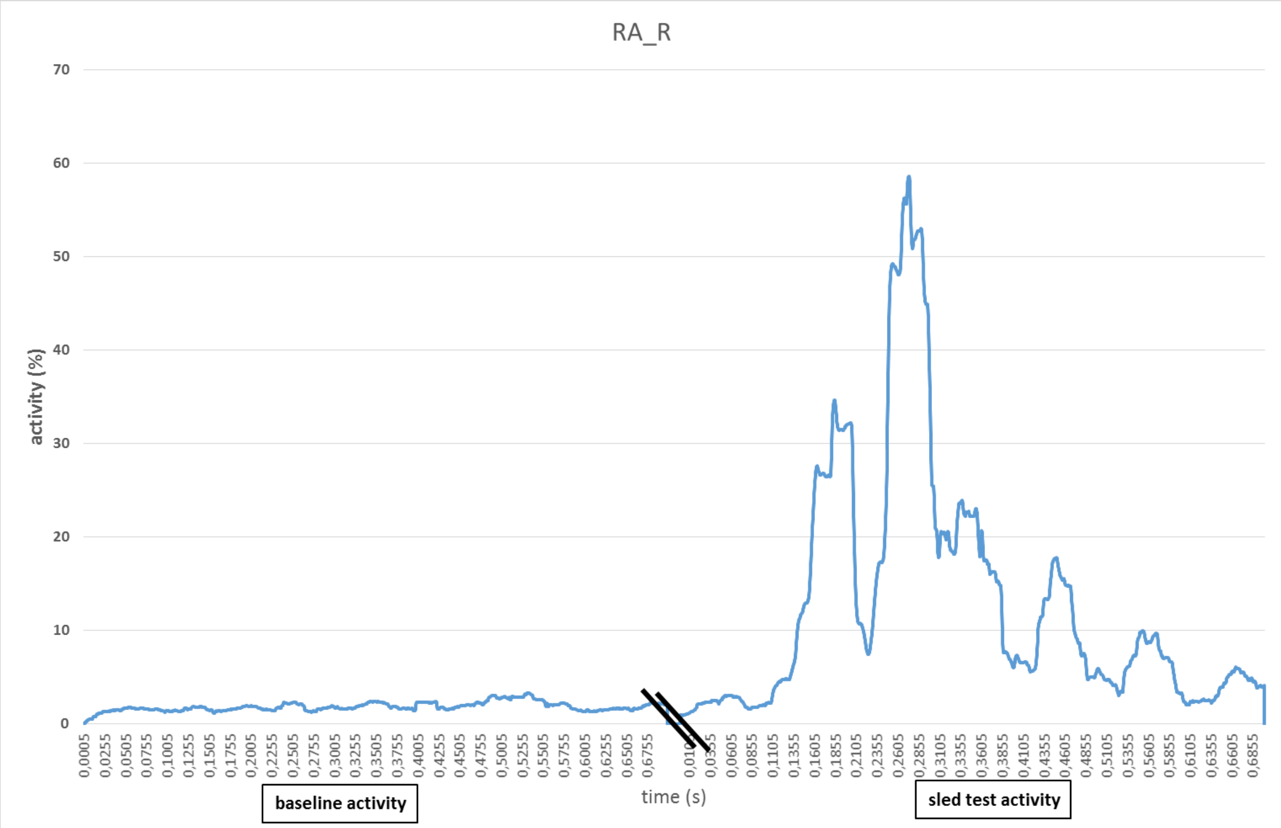

GC_L
activity (%)
time (s)
baseline activity
sled test activity

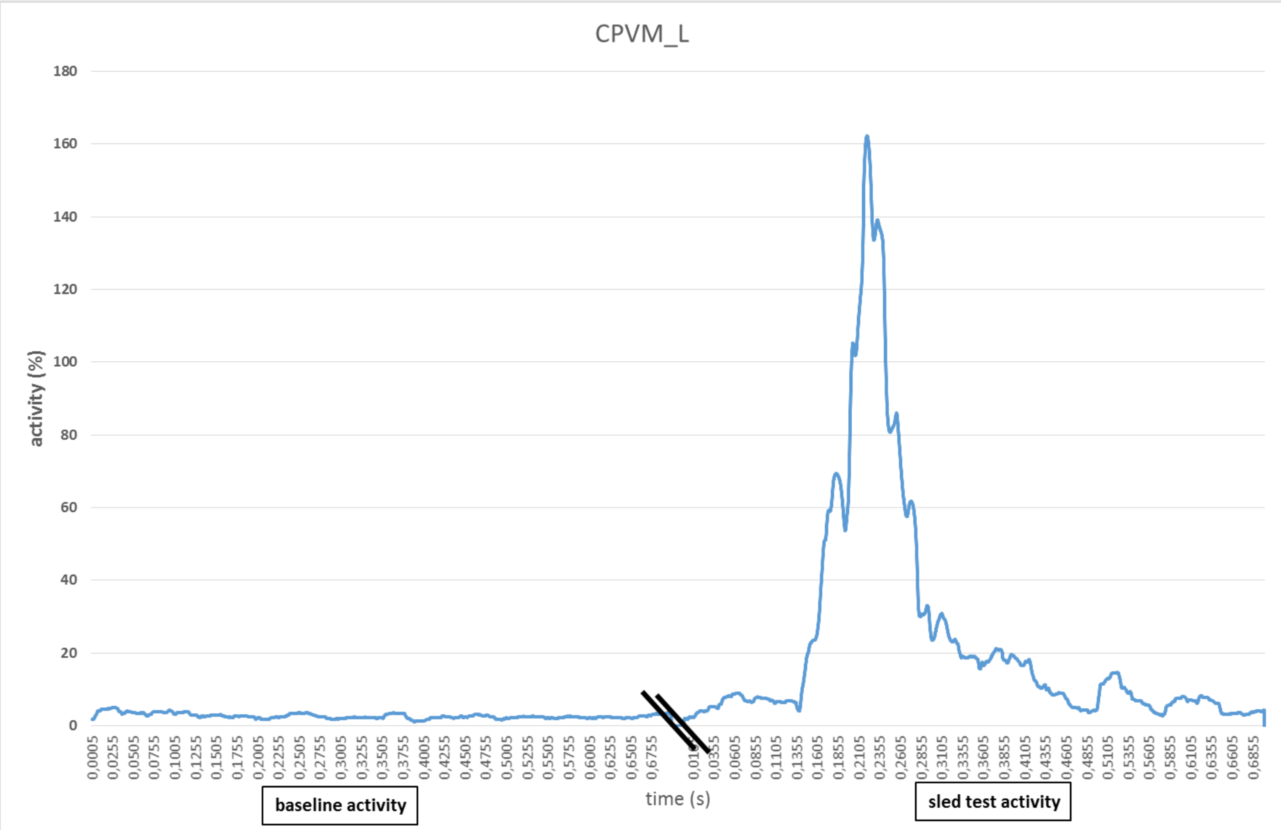
Trial 1771

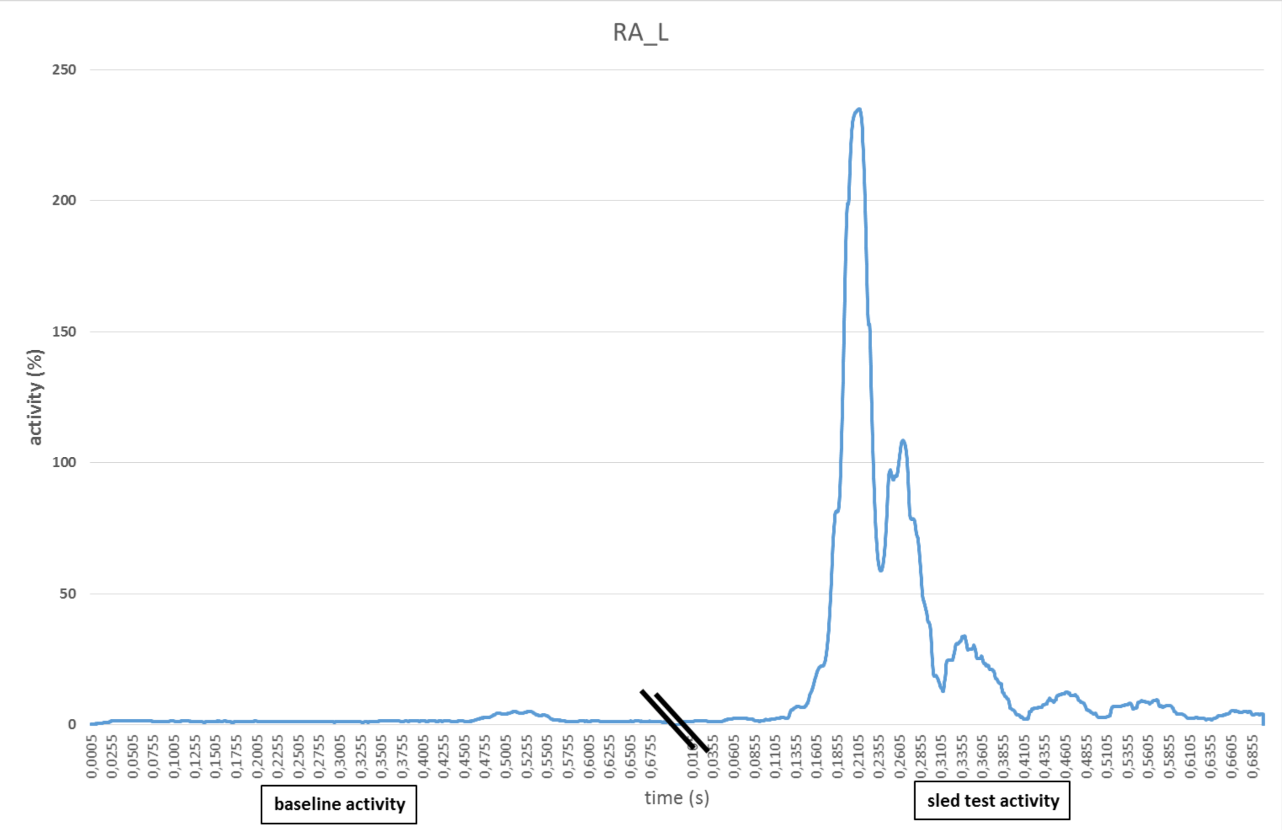

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

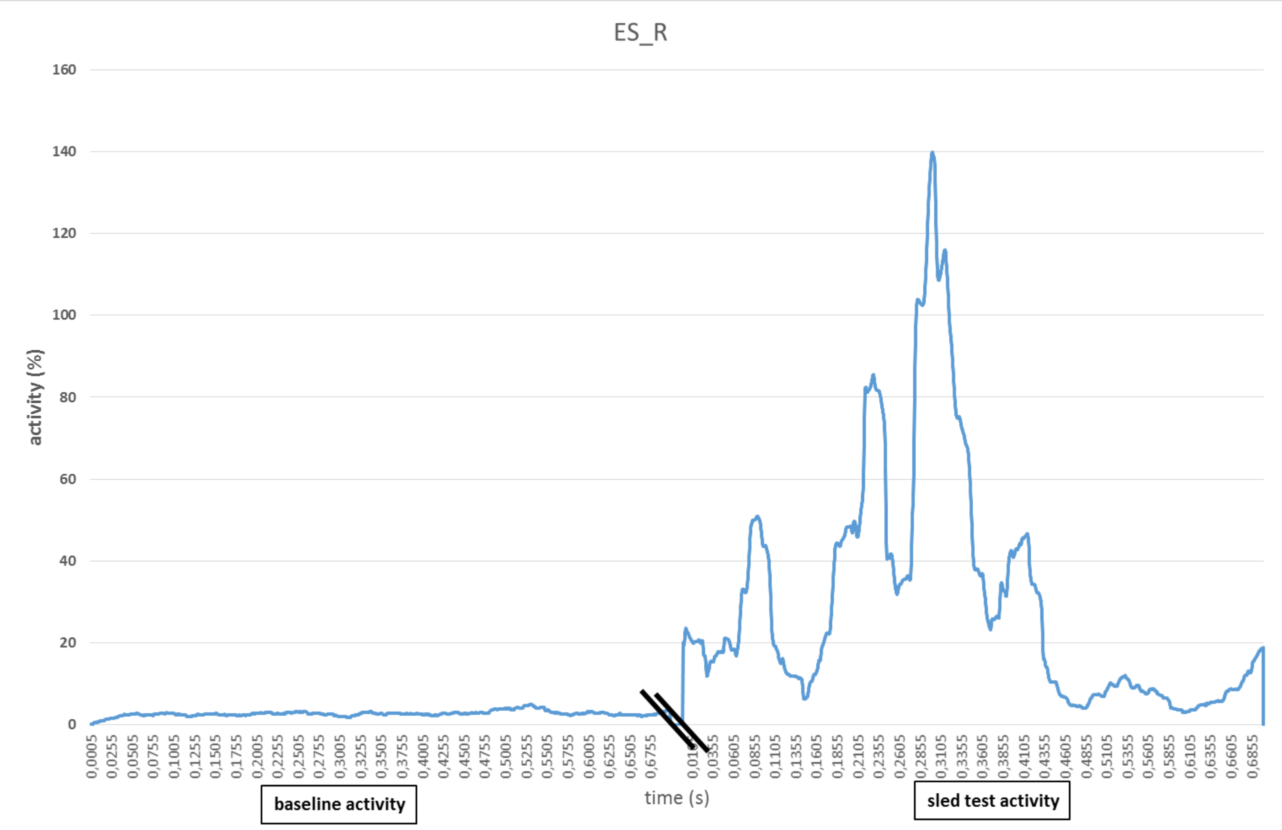

SCM_L
activity (%)
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

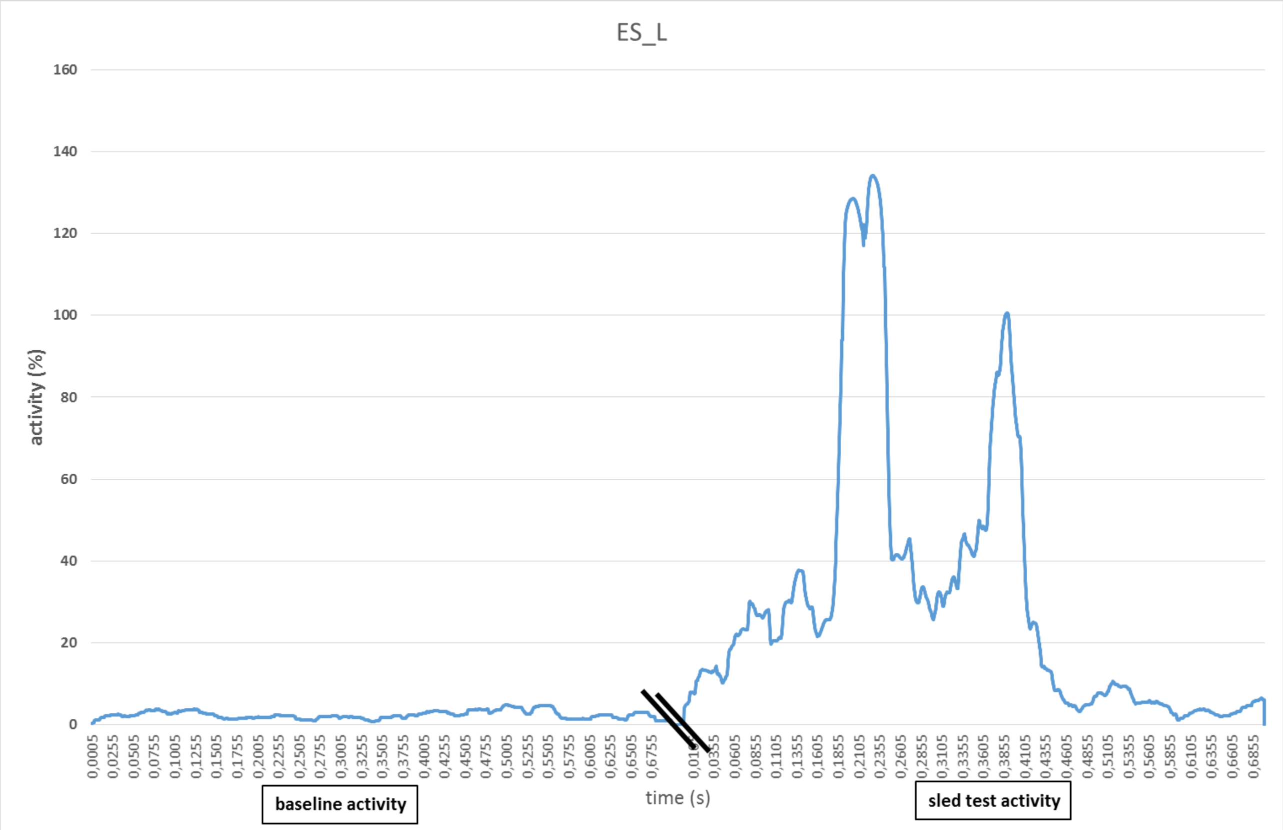

CPVM_R
activity (%)
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

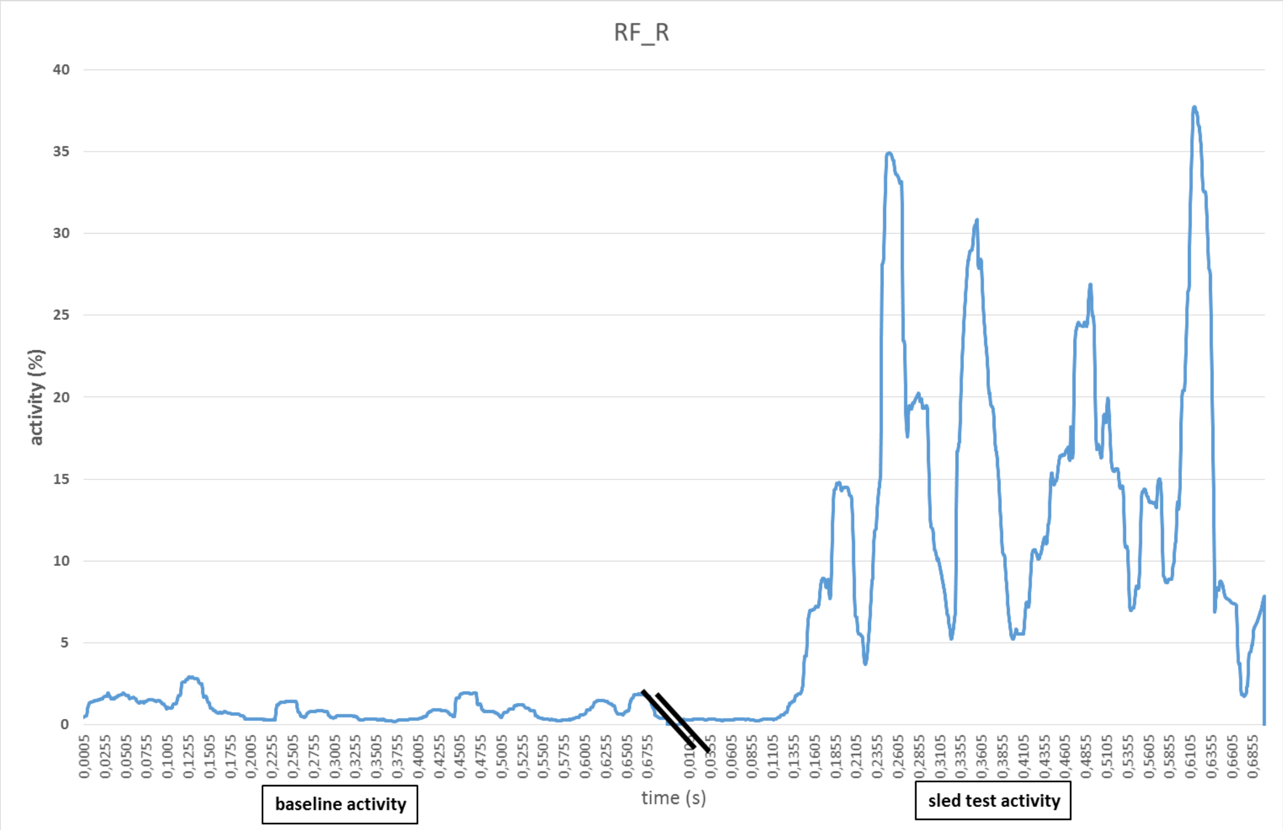

RA_R
activity (%)
70
60
50
40
30
20
10
0
time (s)
baseline activity
sled test activity

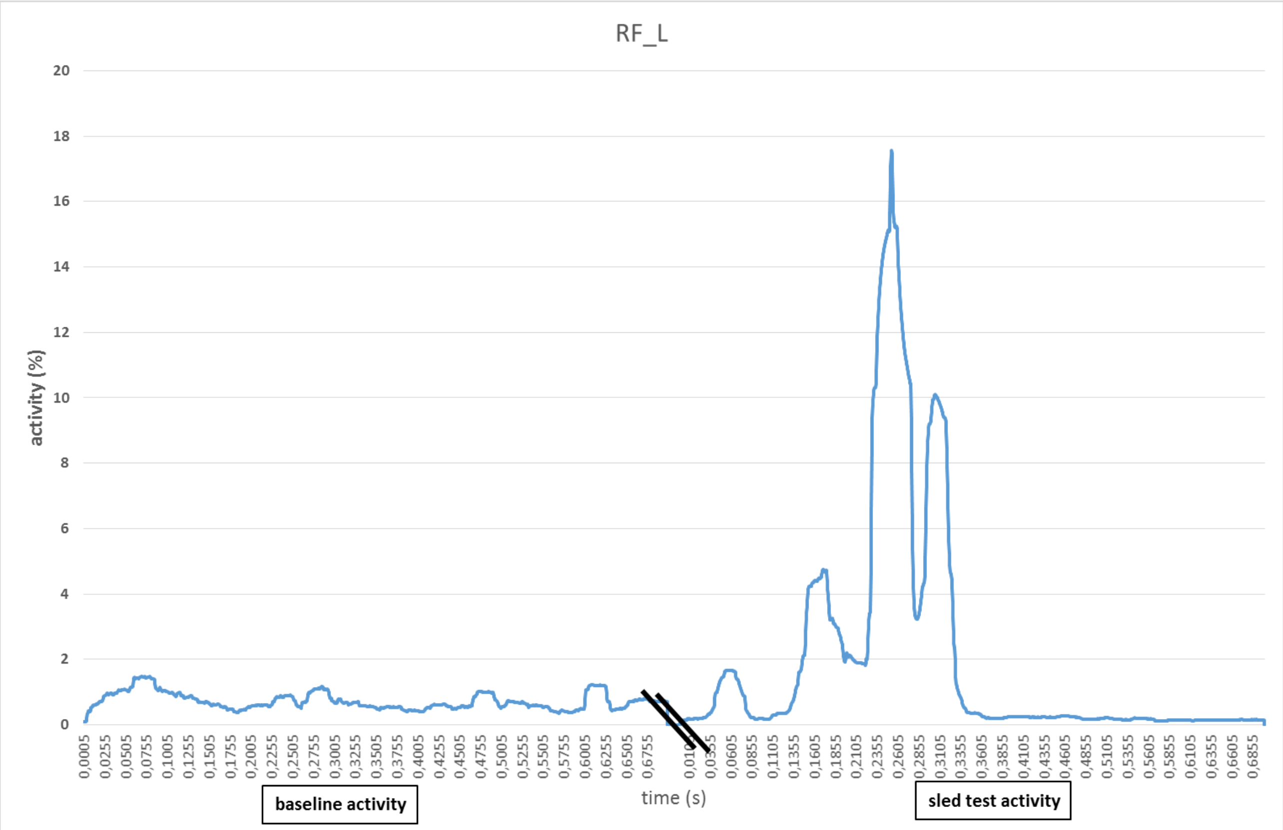

CPVM_L
activity (%)
180
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

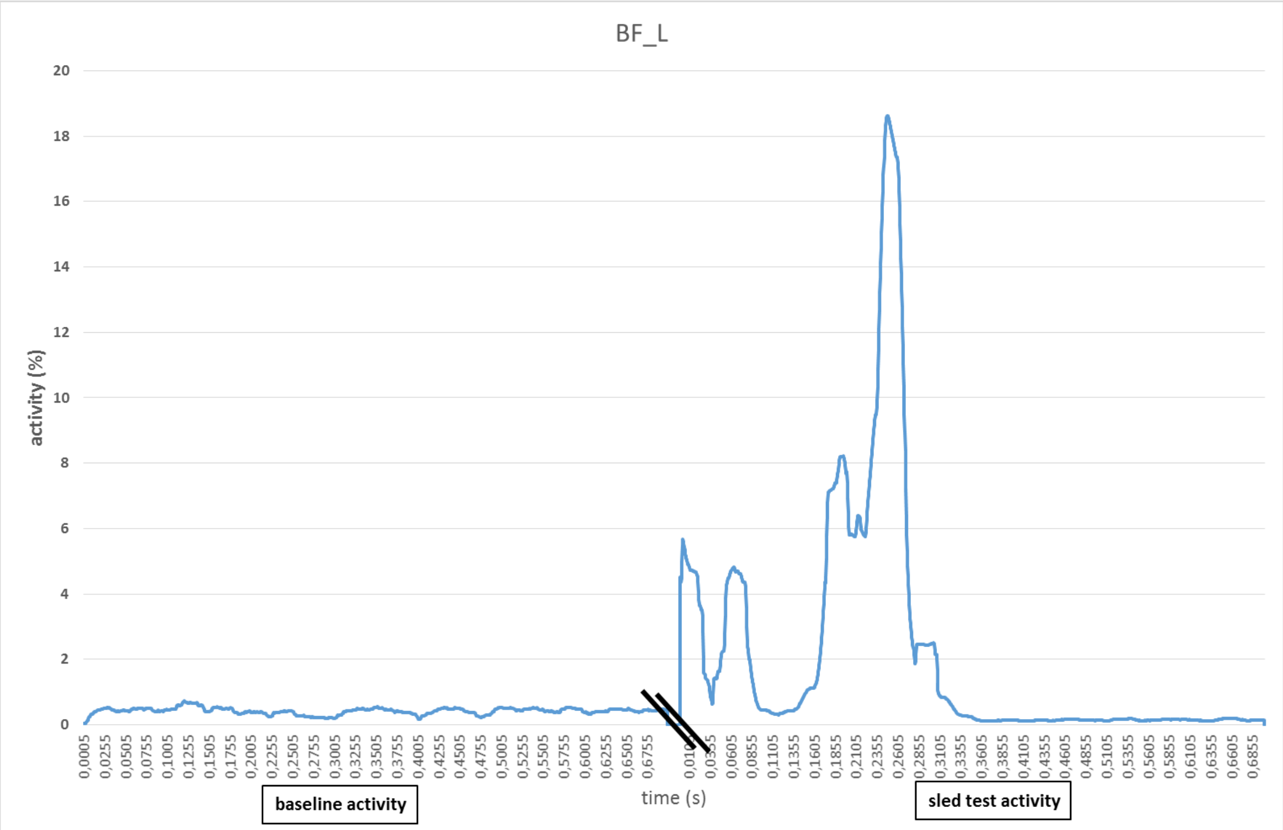

RA_L
activity (%)
time (s)
baseline activity
sled test activity

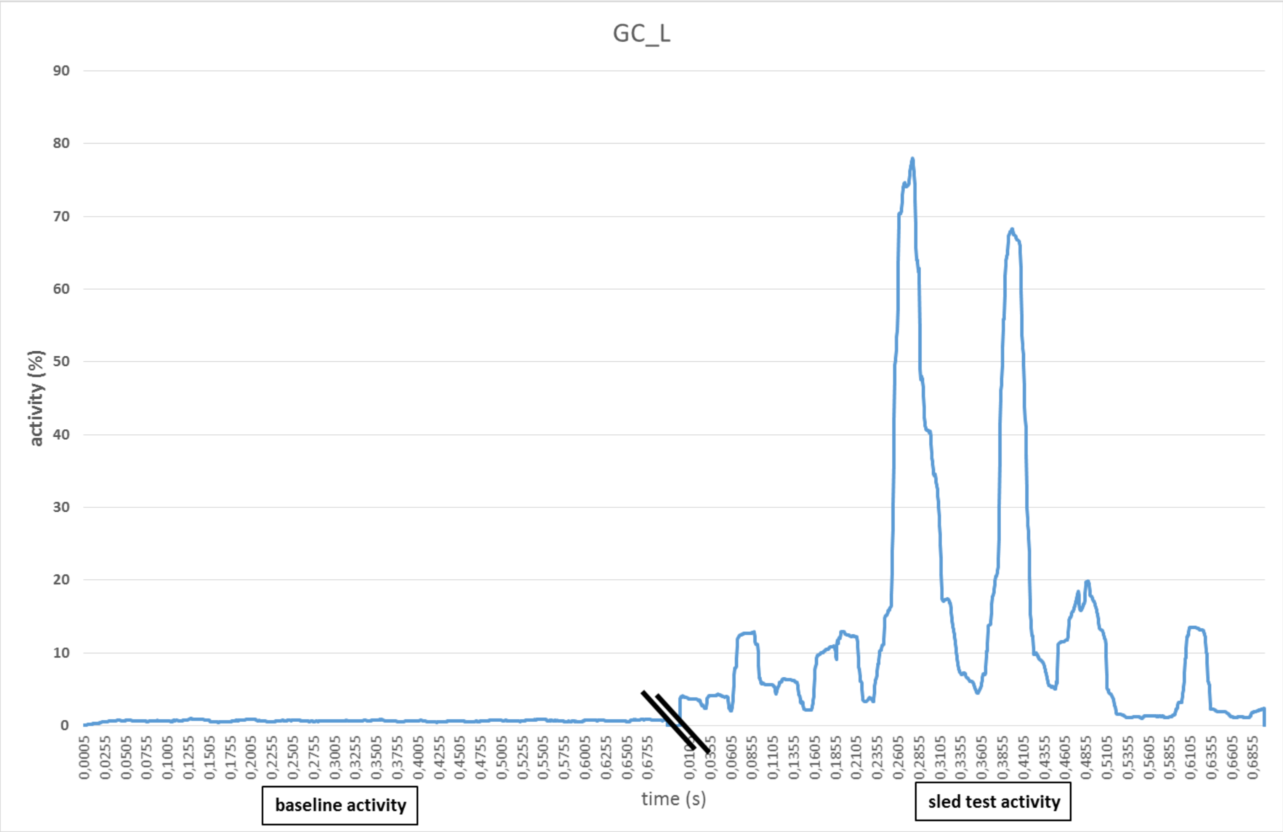

ES_R
activity (%)
time (s)
baseline activity
sled test activity


ES_L
activity (%)
time (s)
baseline activity
sled test activity

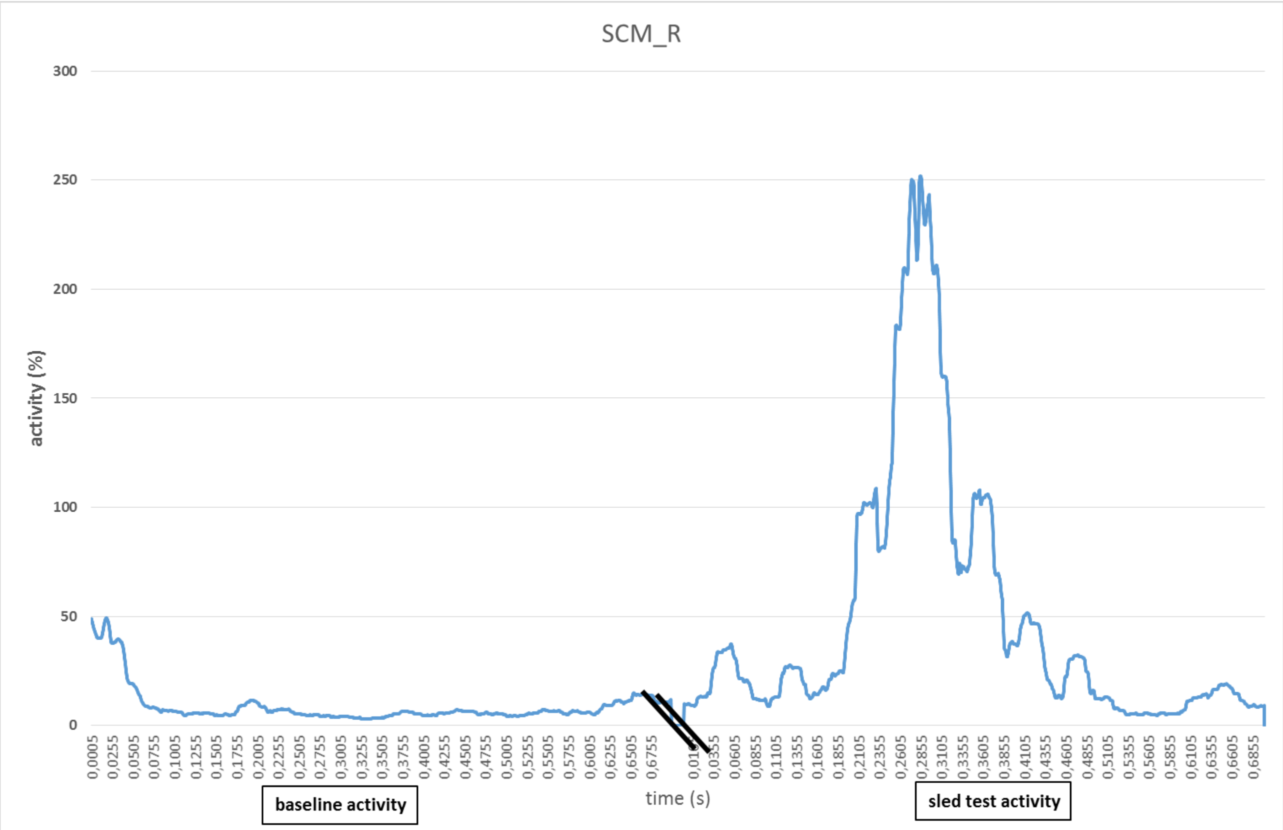

RF_R
activity (%)
time (s)
baseline activity
sled test activity

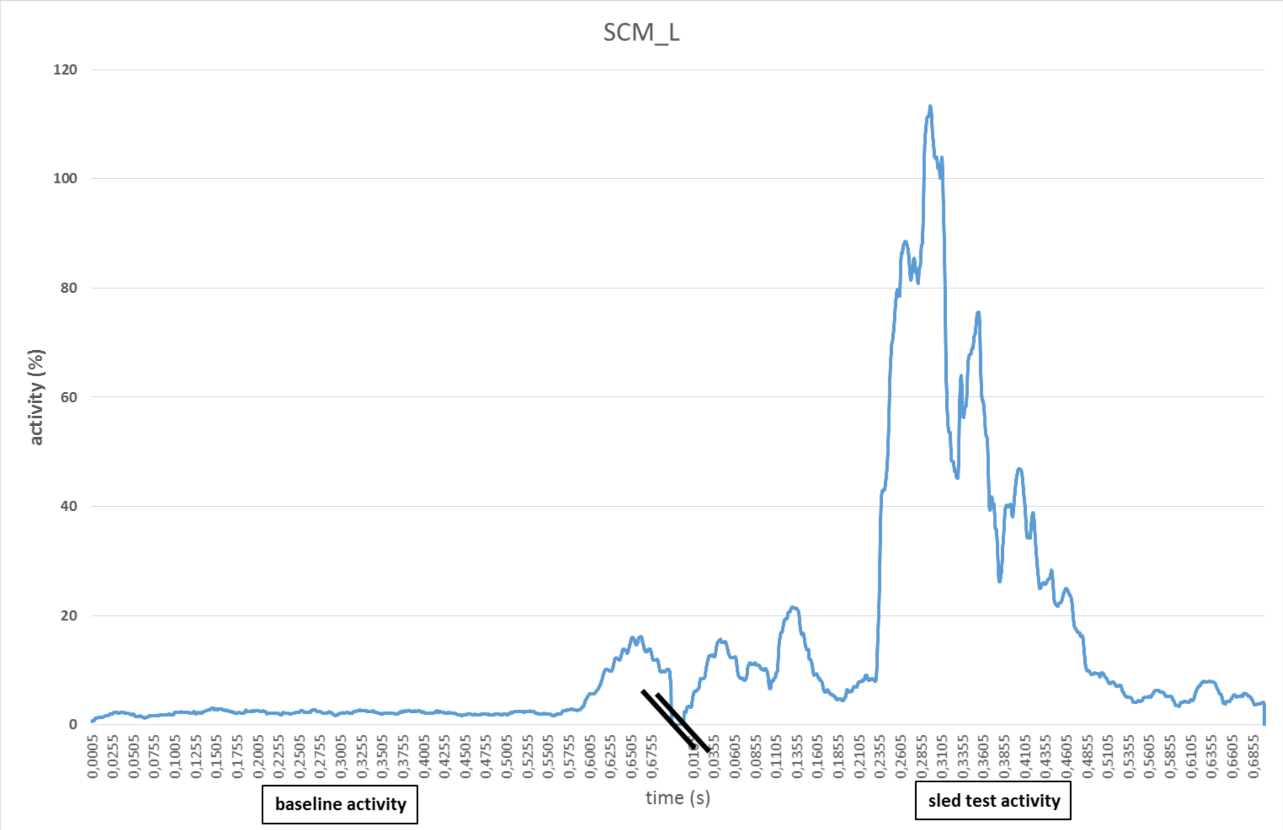

RF_L
activity (%)
time (s)
baseline activity
sled test activity

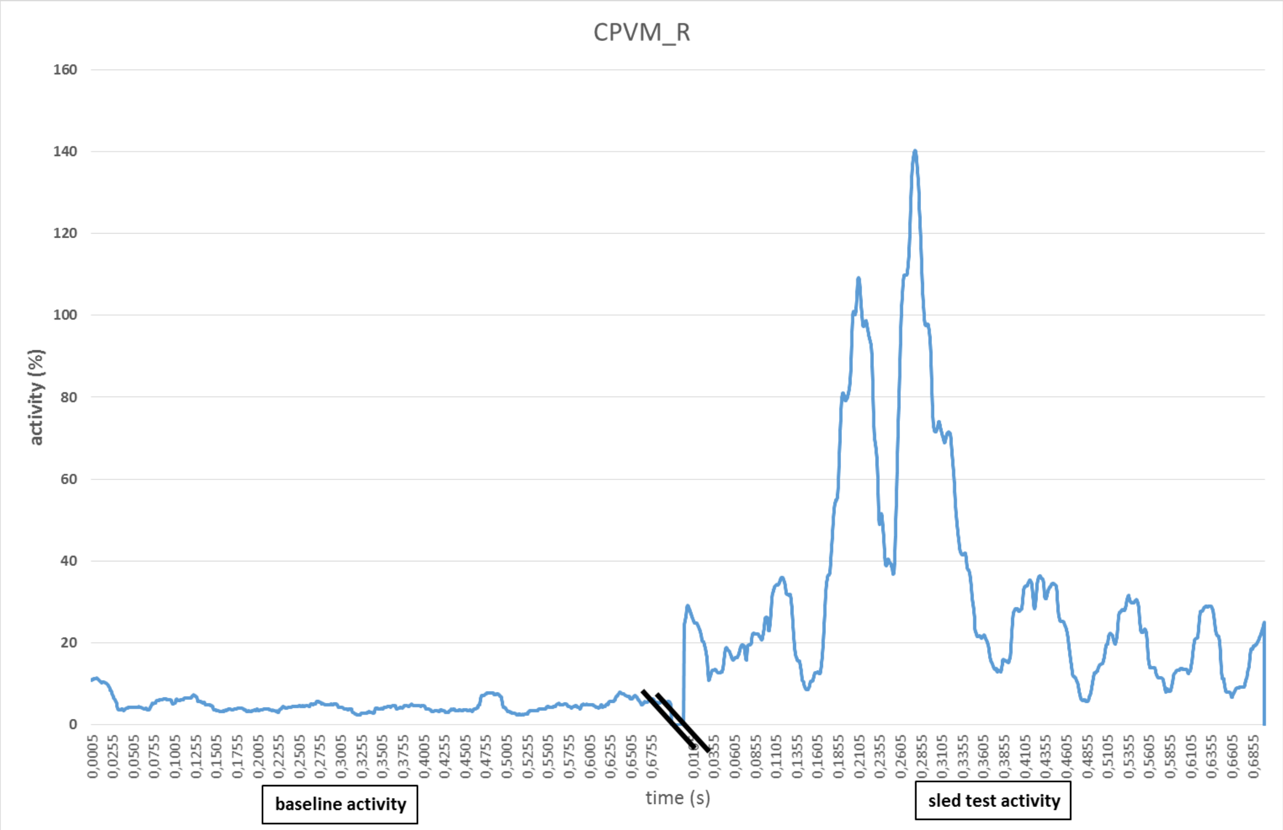

BF_L
activity (%)
time (s)
baseline activity
sled test activity

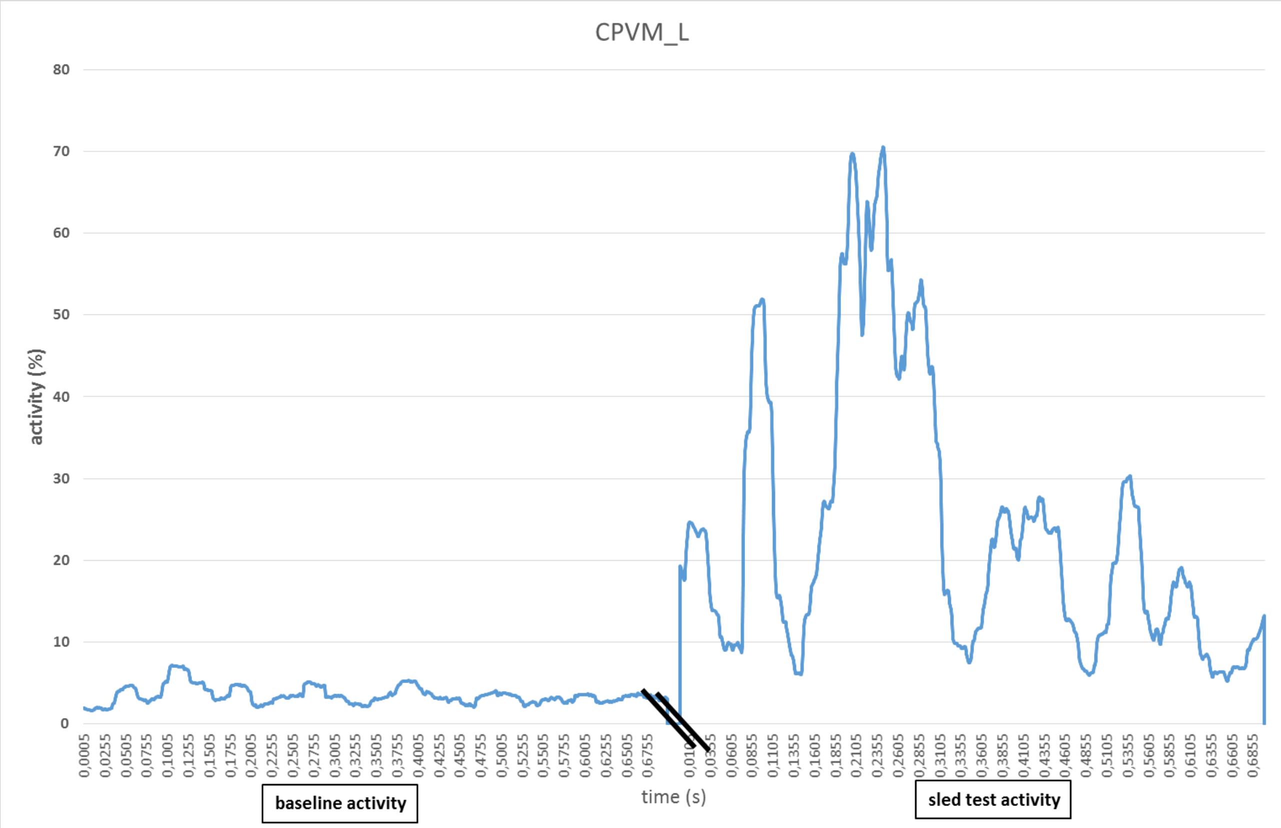

GC_L
activity (%)
90
80
70
60
50
40
30
20
10
0
time (s)
baseline activity
sled test activity

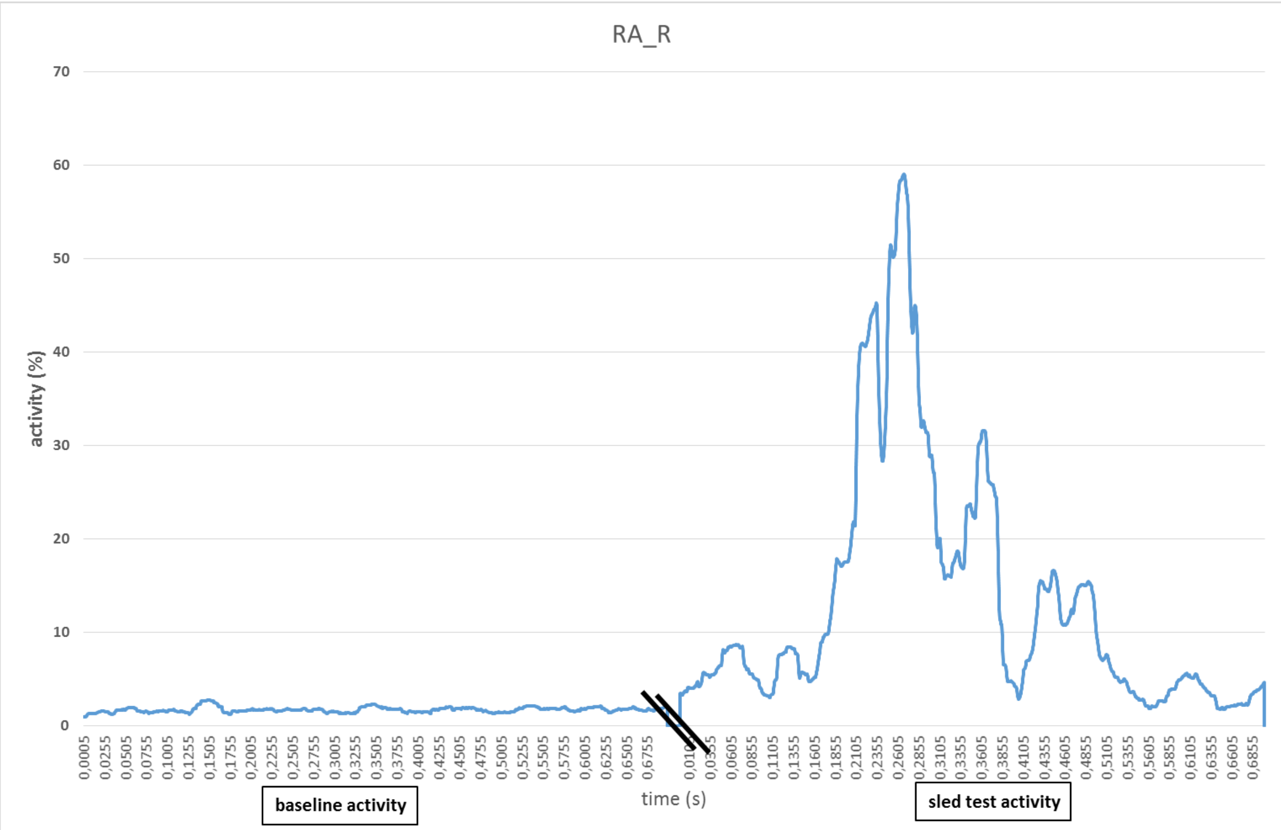
Trial 1772

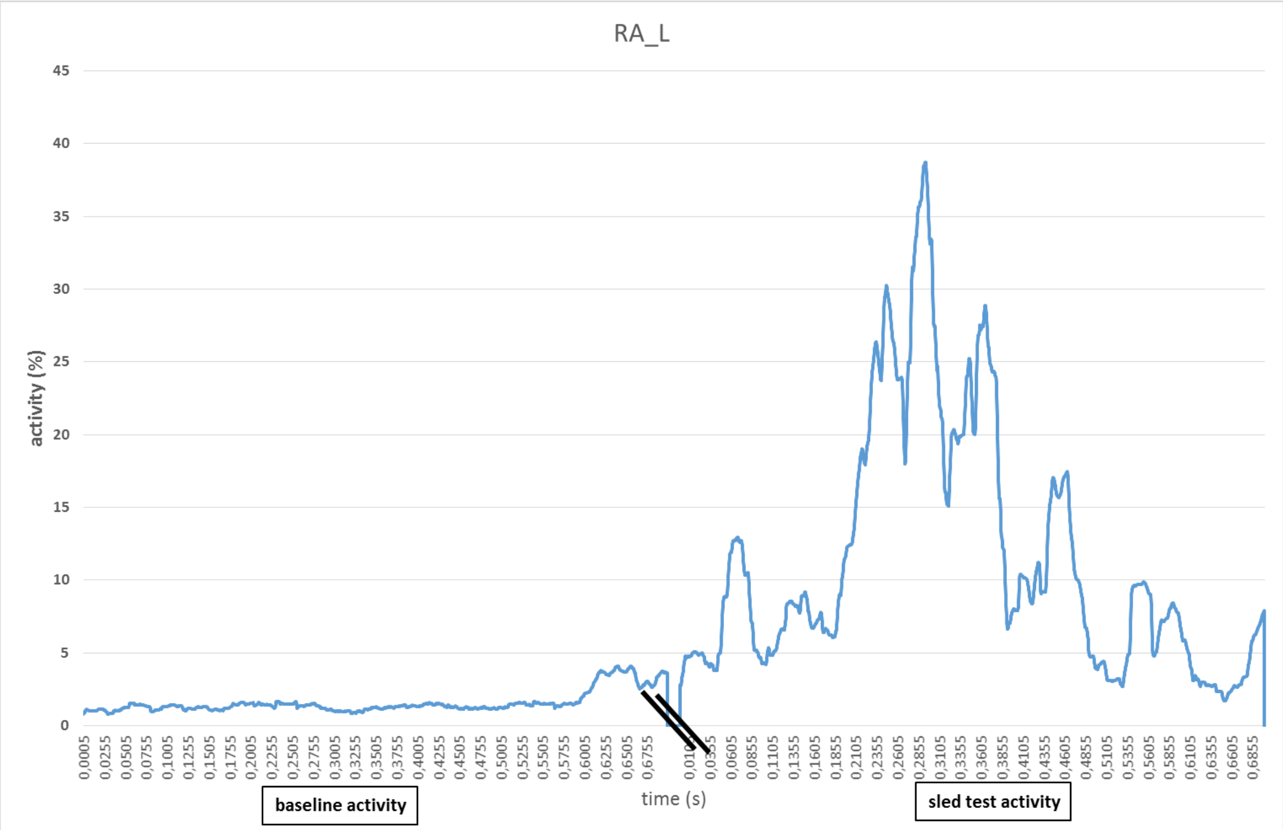

SCM_R
activity (%)
300
250
200
150
100
50
0
time (s)
baseline activity
sled test activity

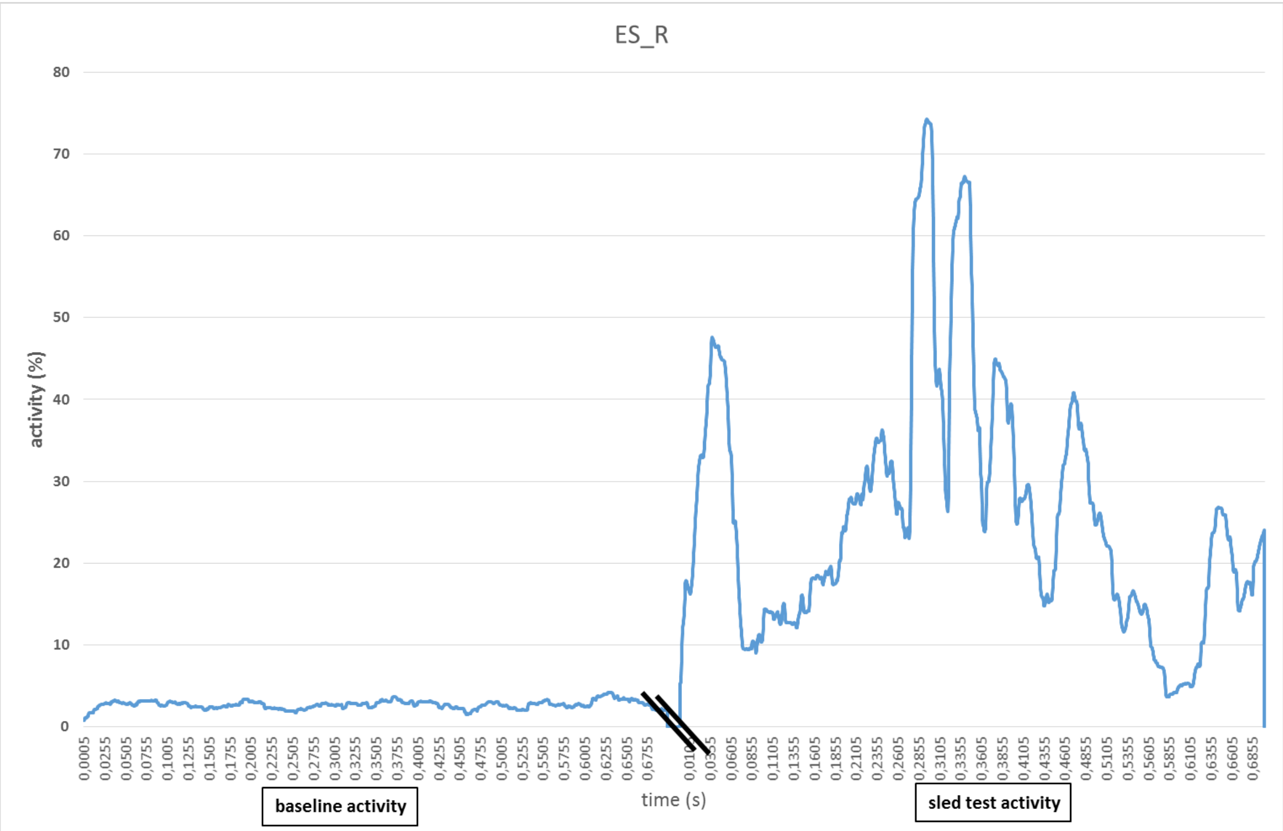

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

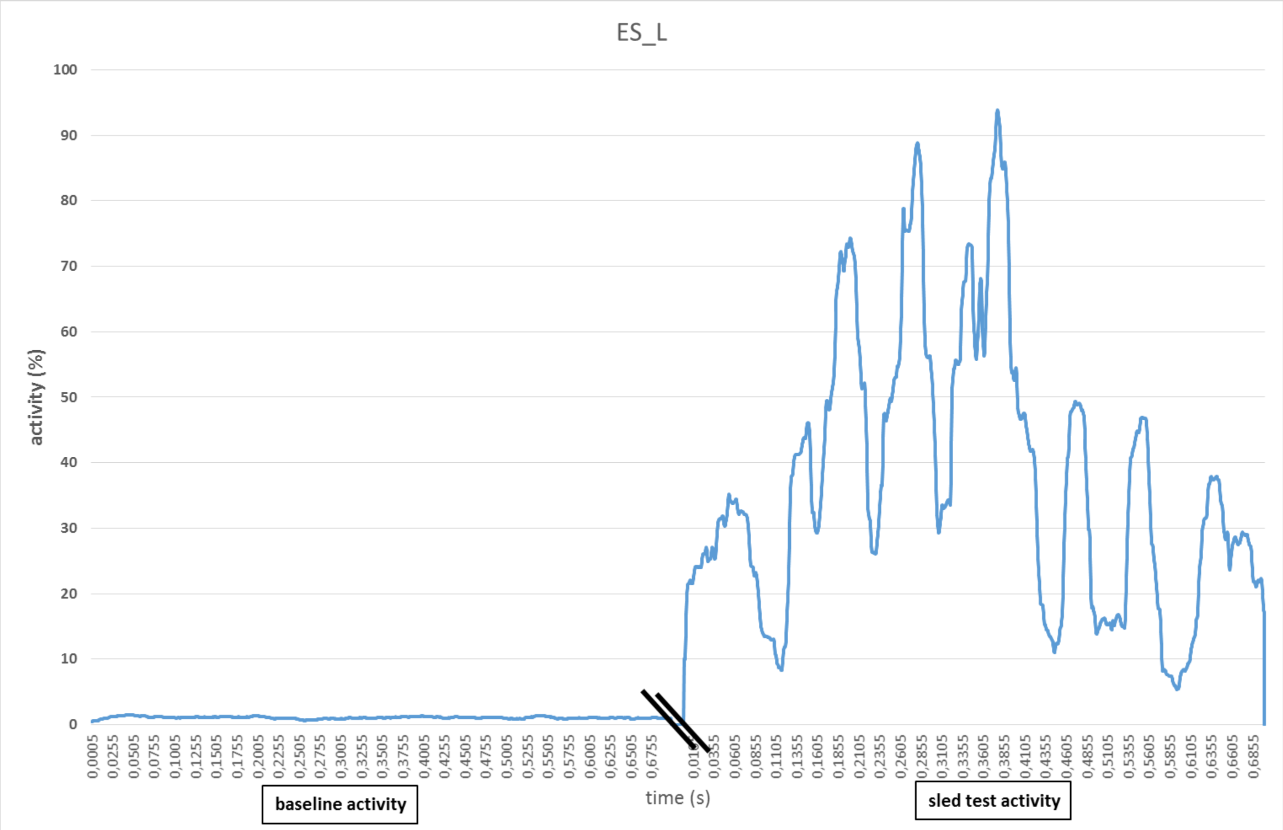

CPVM_R
activity (%)
time (s)
baseline activity
sled test activity

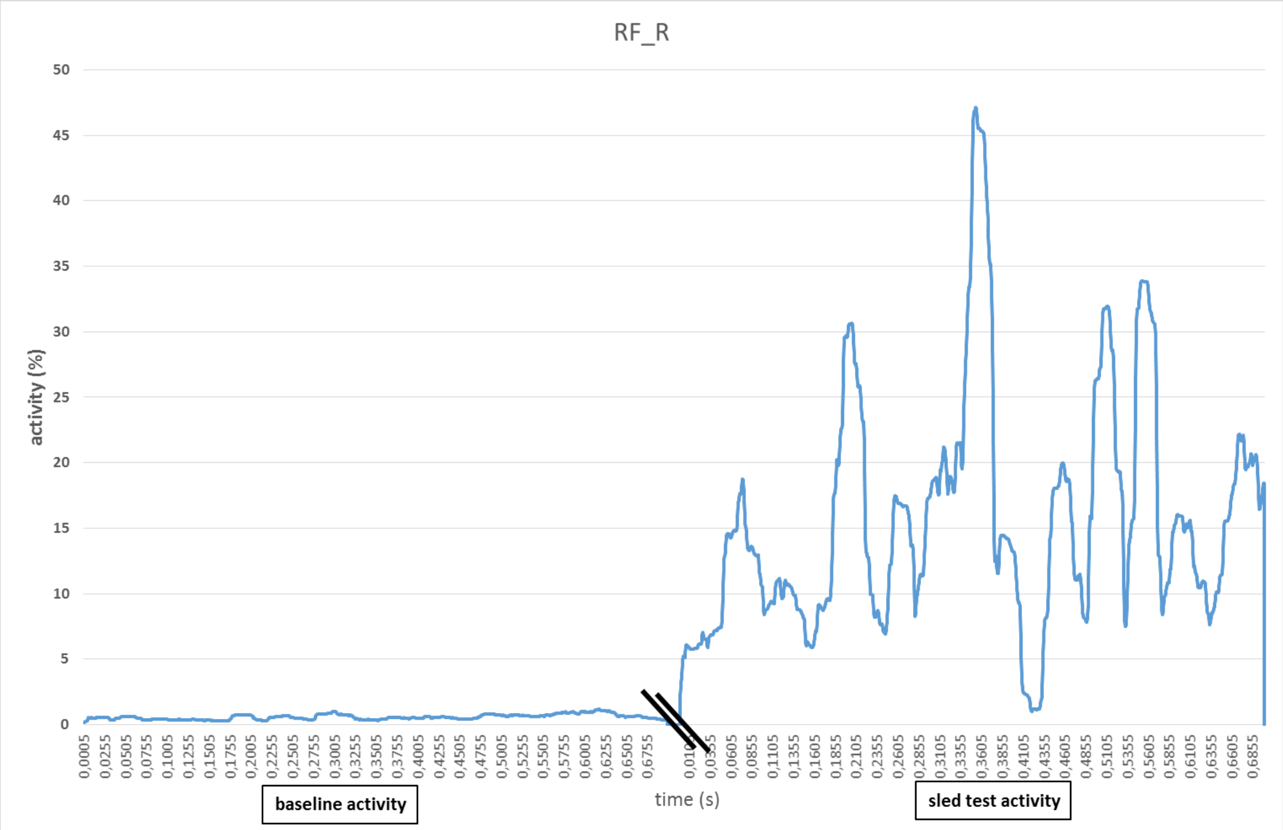

CPVM_L
activity (%)
80
70
60
50
40
30
20
10
0
time (s)
baseline activity
sled test activity

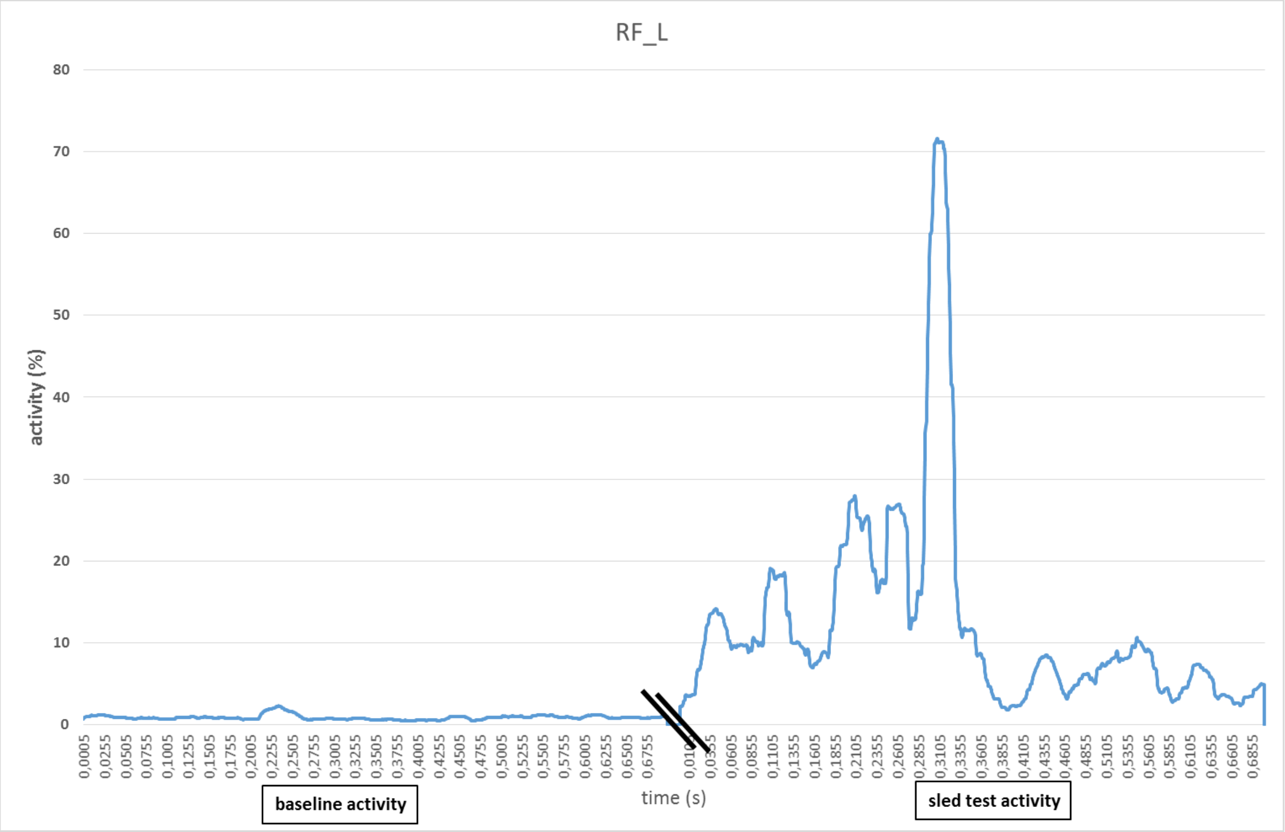

RA_R
activity (%)
70
60
50
40
30
20
10
0
time (s)
baseline activity
sled test activity

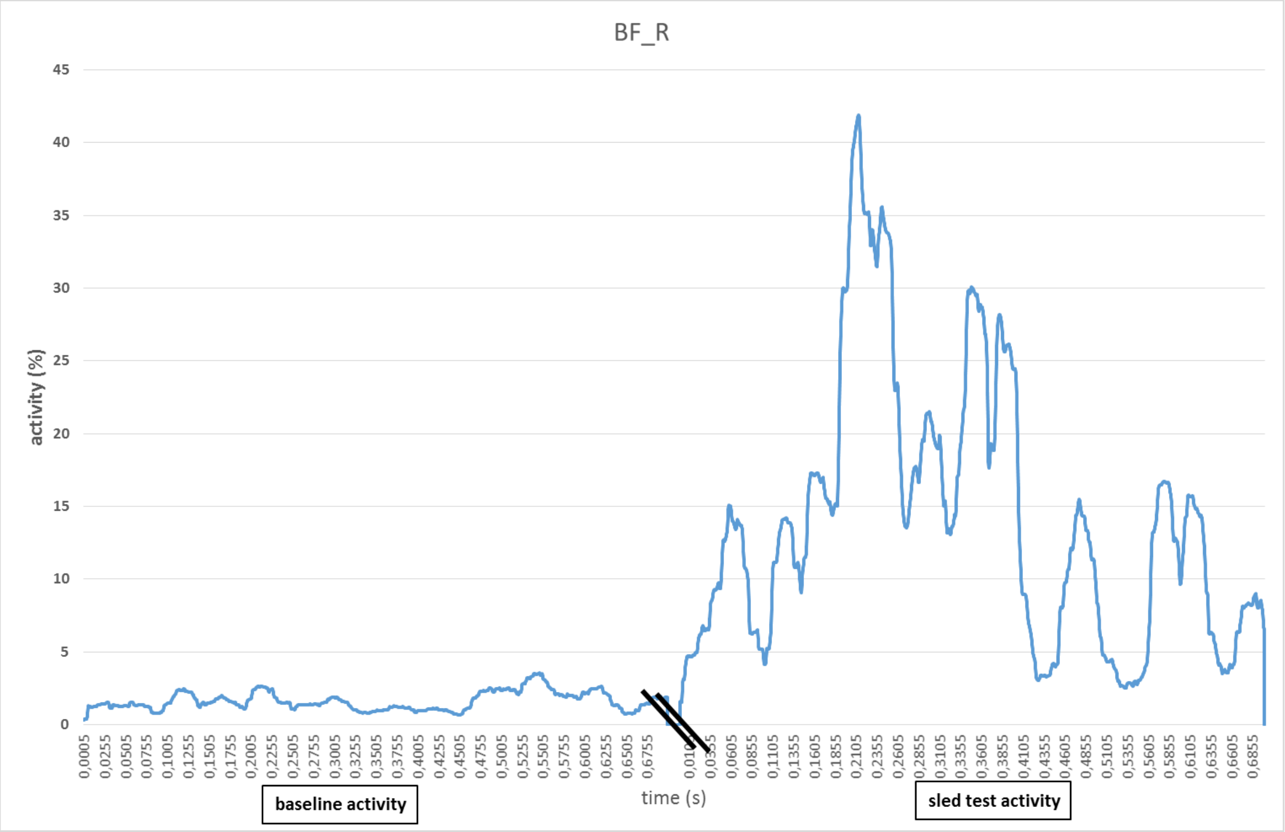

RA_L
activity (%)
0
5
10
15
20
25
30
35
40
45
time (s)
baseline activity
sled test activity

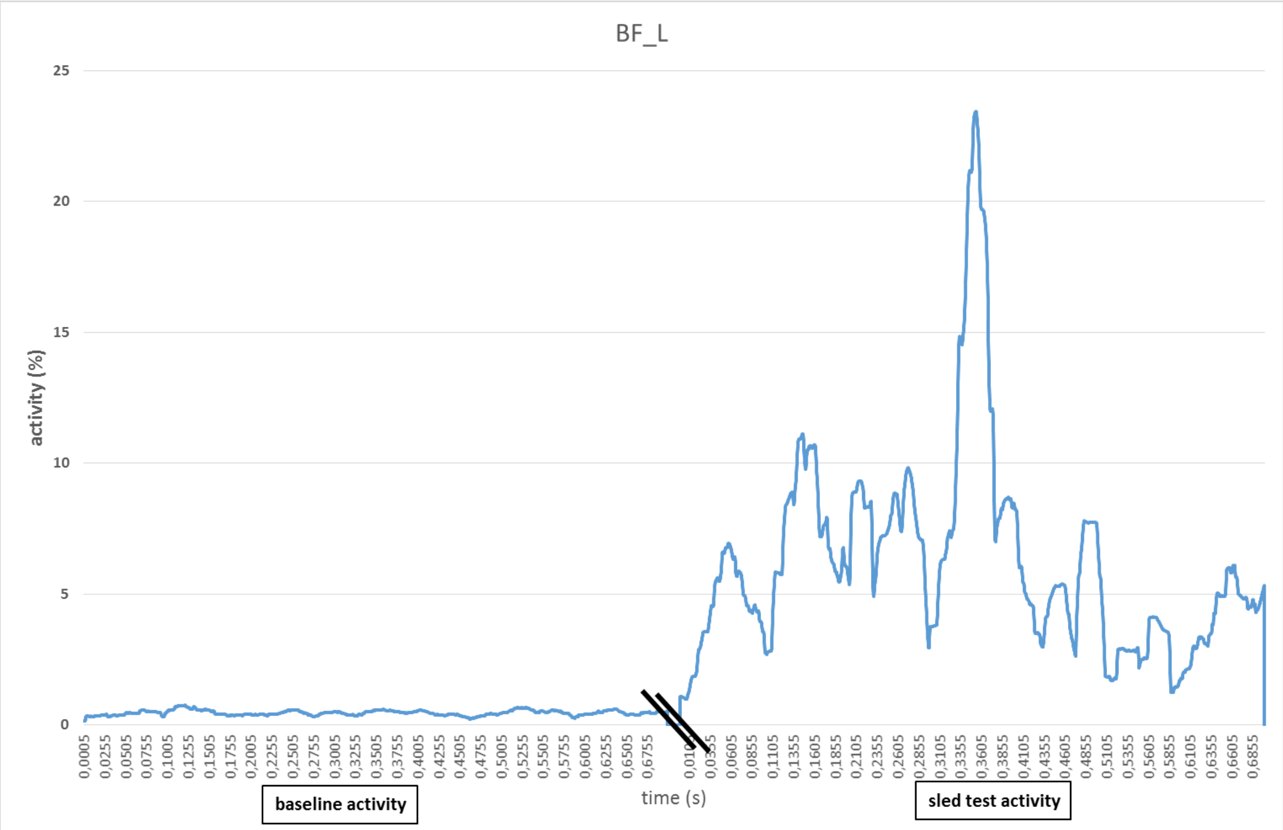

ES_R
activity (%)
0
10
20
30
40
50
60
70
80
time (s)
baseline activity
sled test activity

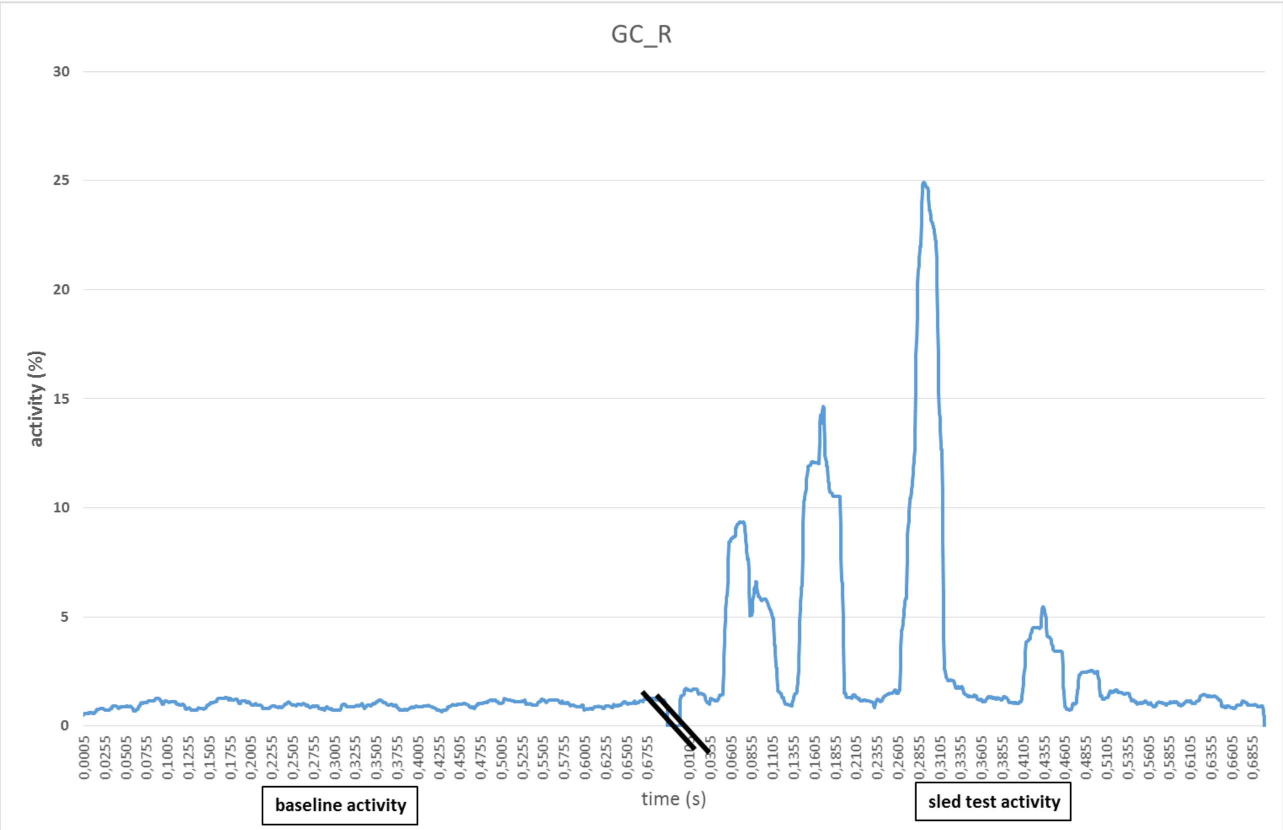

ES_L
activity (%)
time (s)
baseline activity
sled test activity

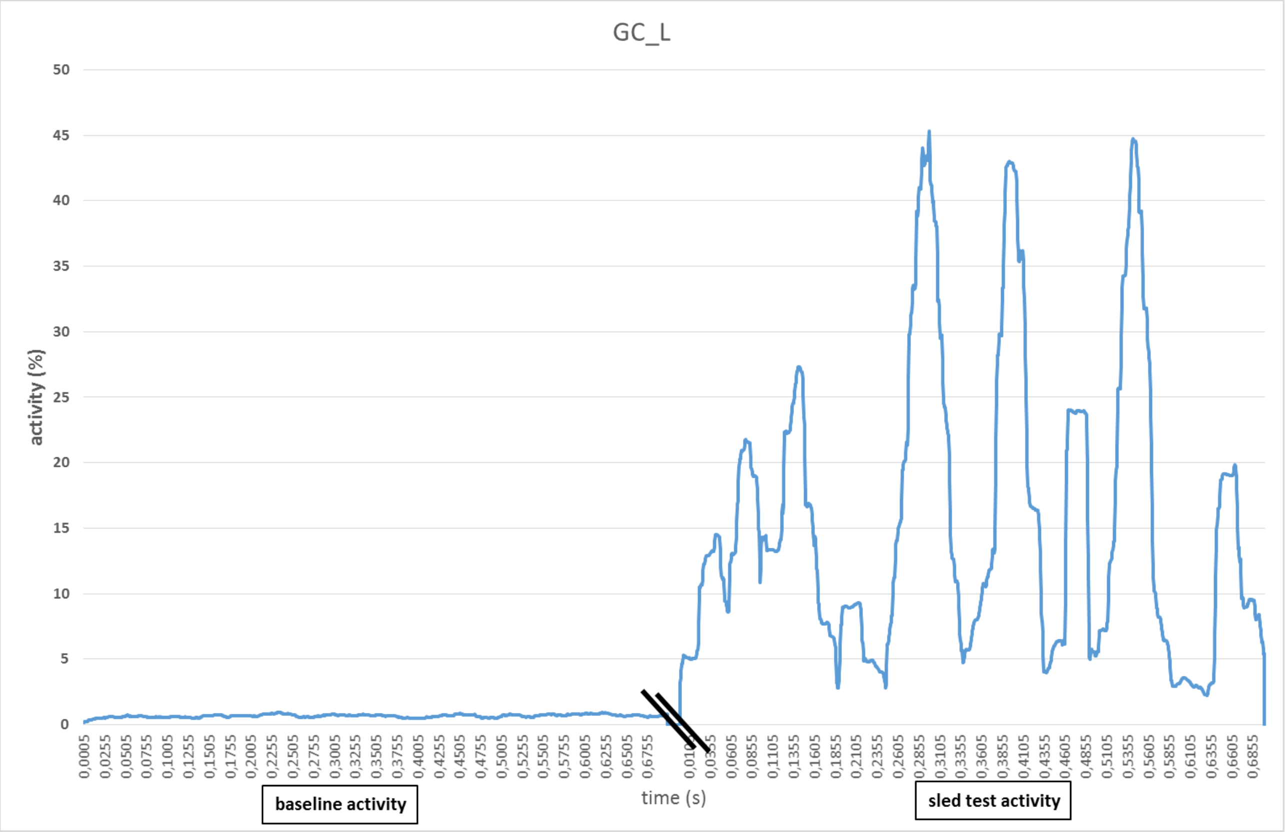

RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity

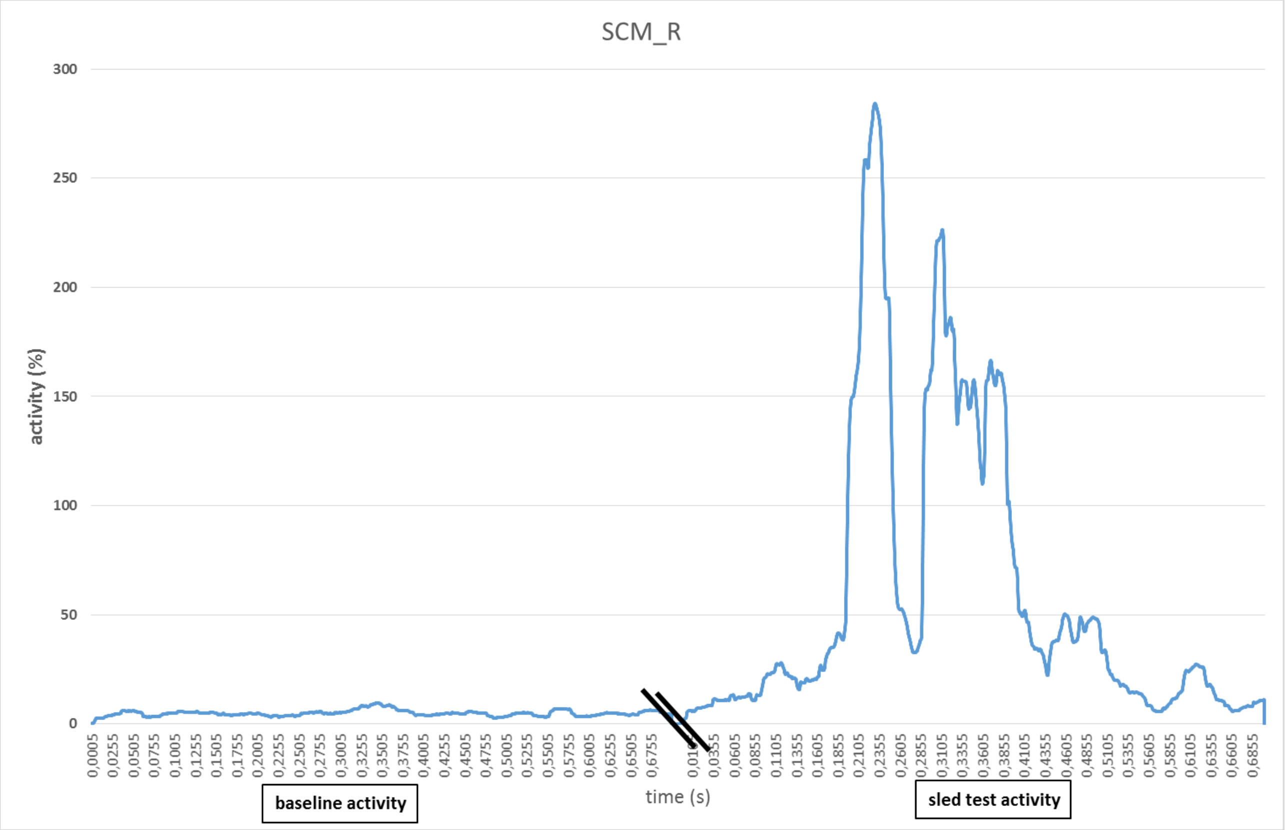

BF_R
activity (%)
time (s)
baseline activity
sled test activity

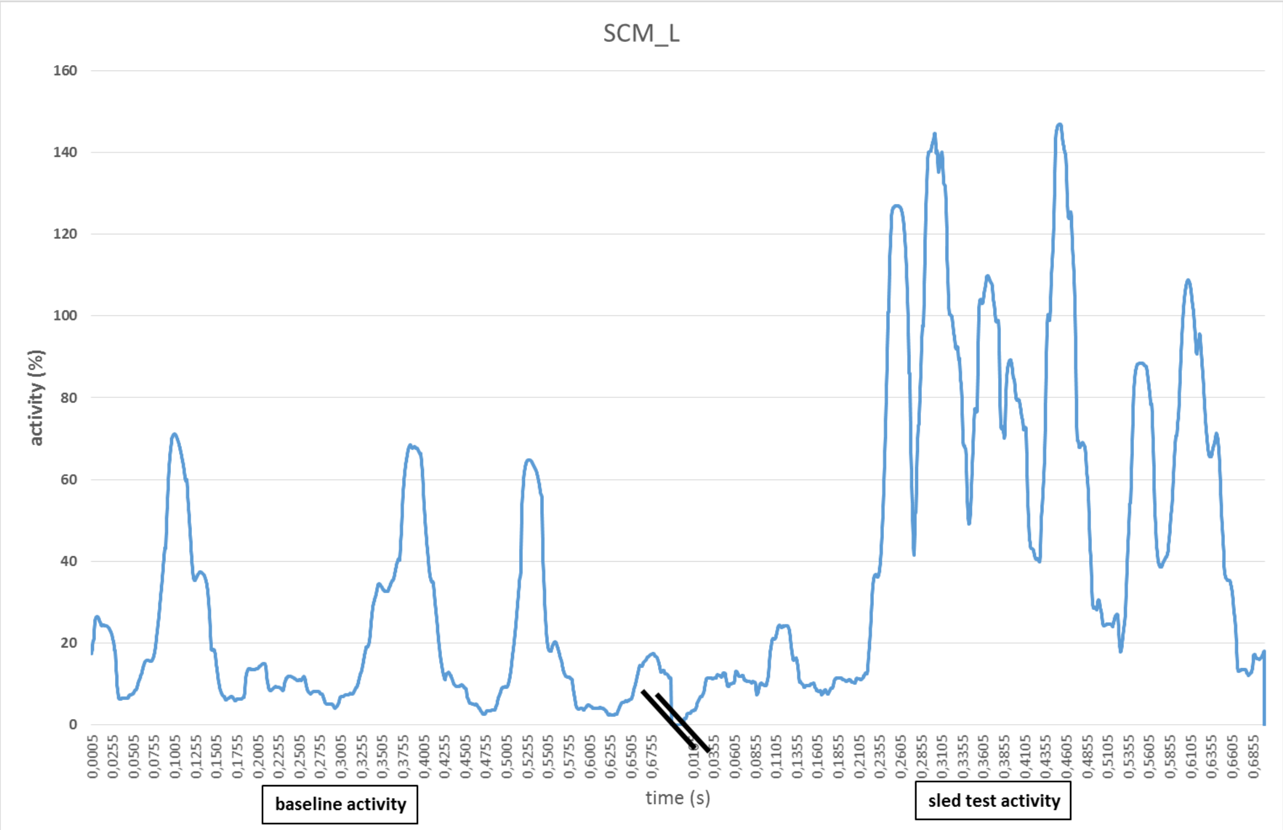

BF_L
activity (%)
time (s)
baseline activity
sled test activity

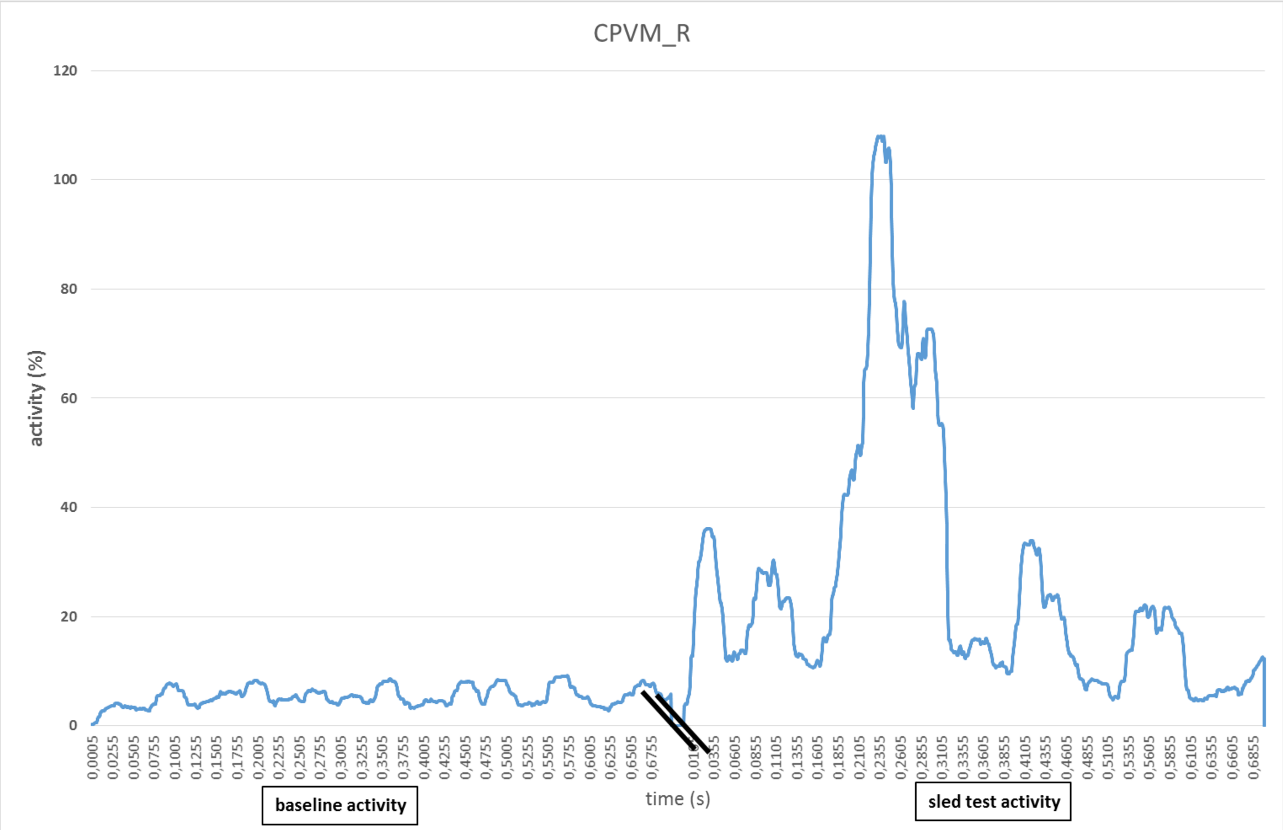

GC_R
activity (%)
time (s)
baseline activity
sled test activity

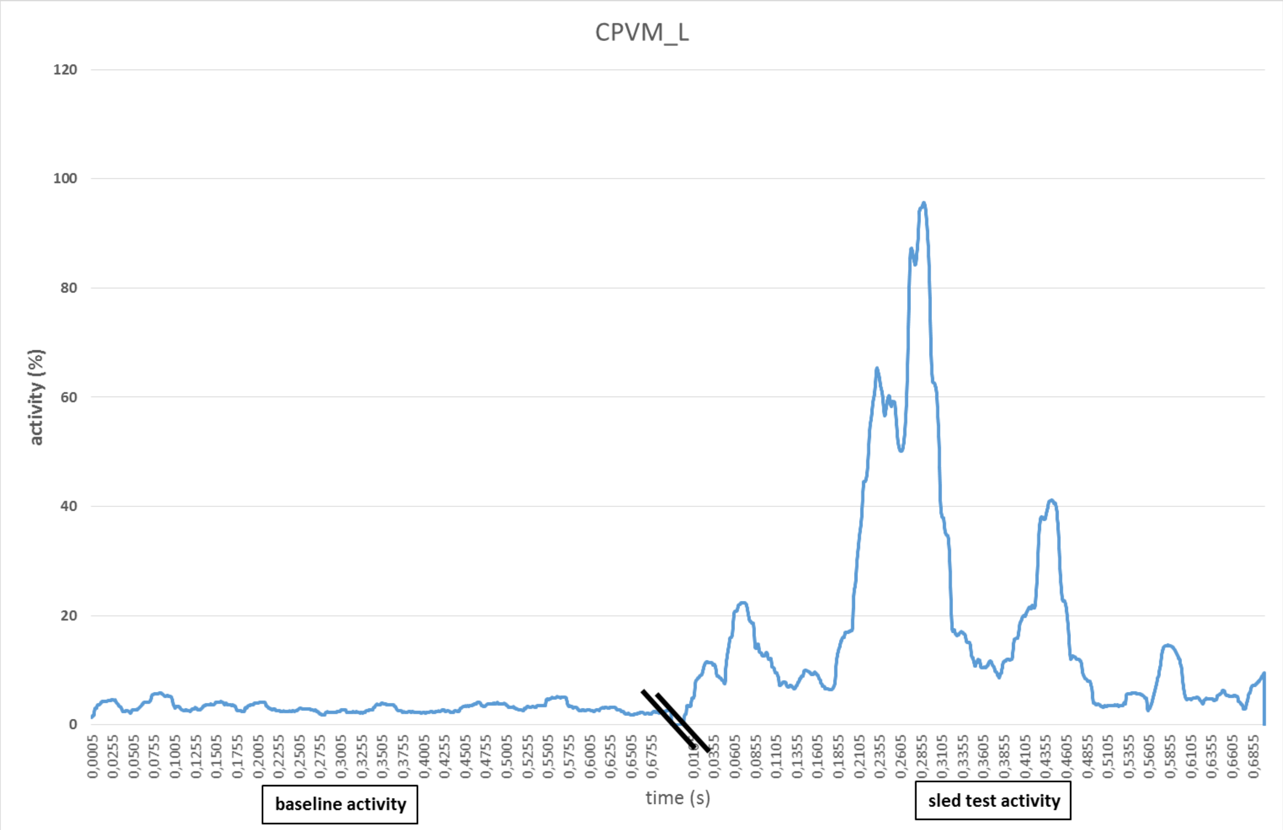

GC_L
activity (%)
time (s)
baseline activity
sled test activity

Trial 1773

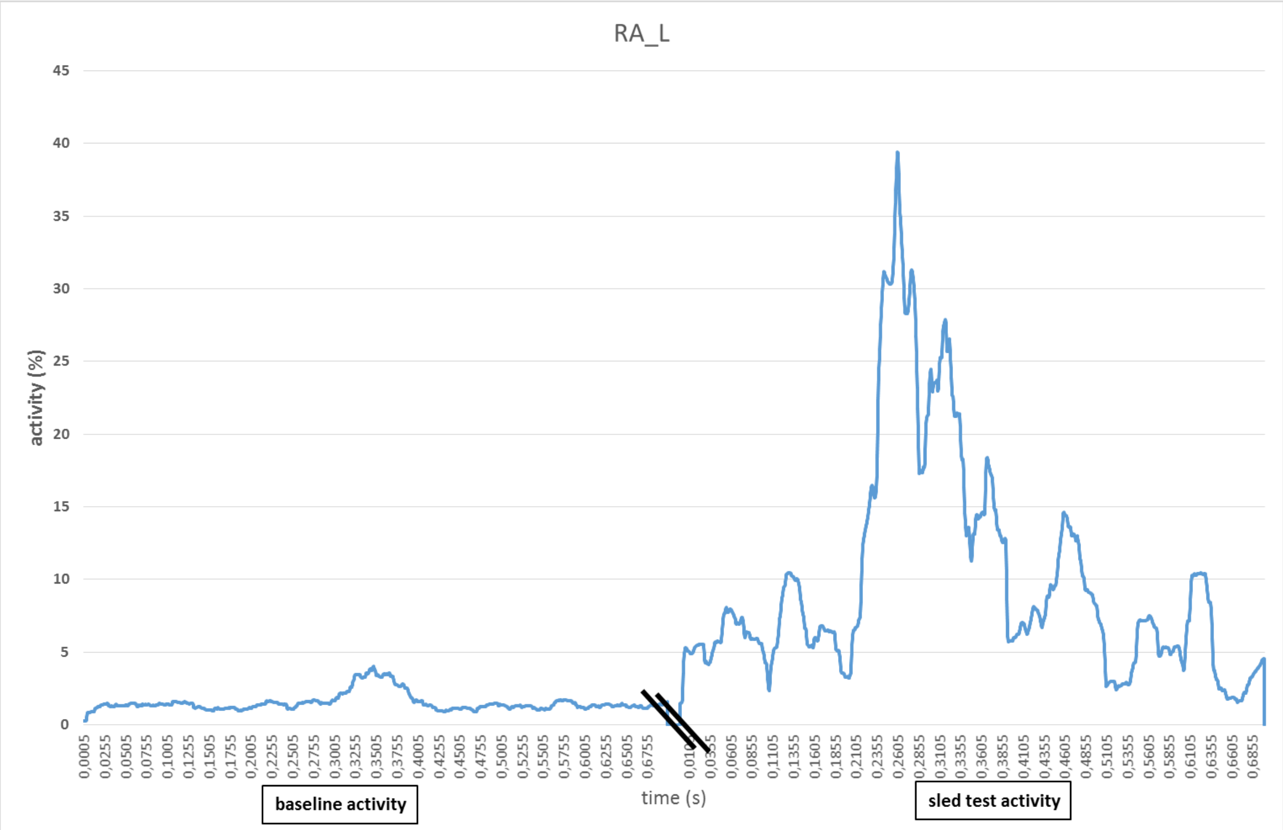

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

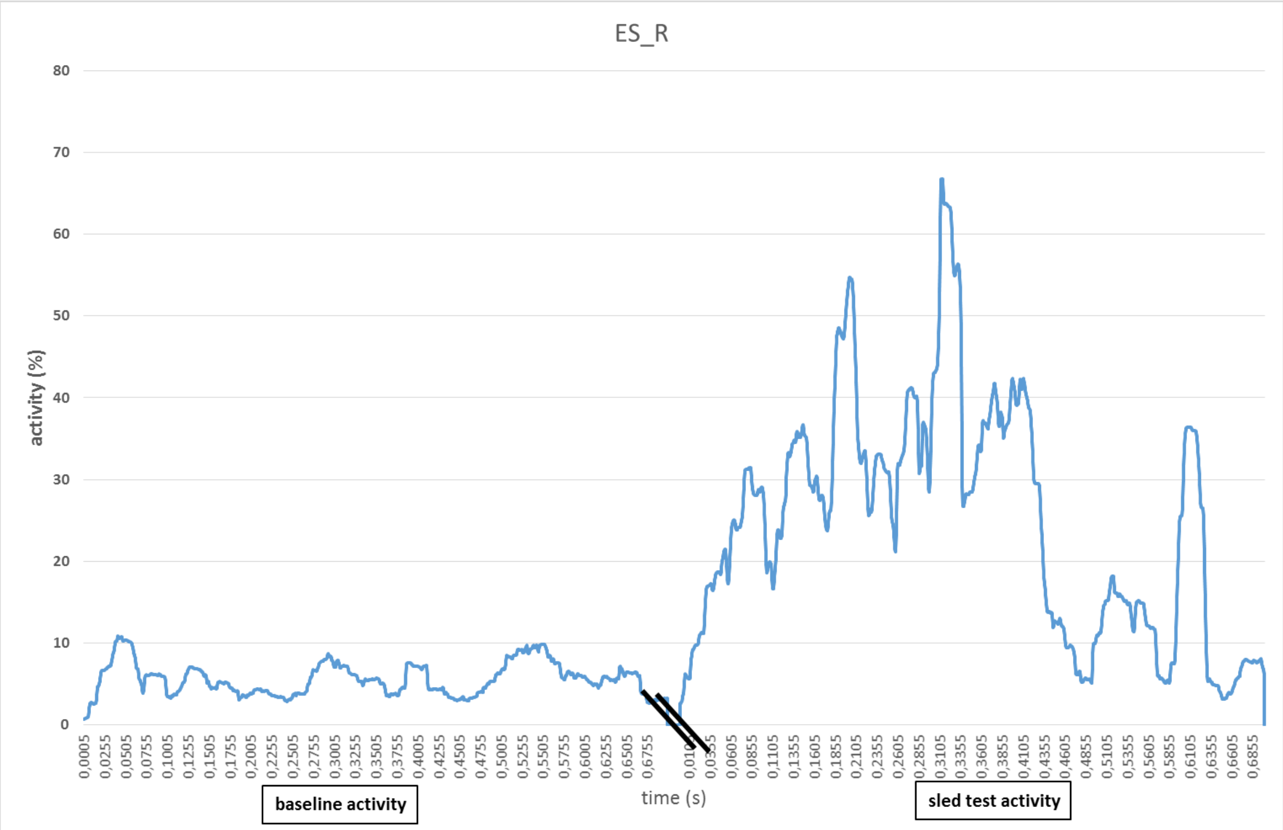

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

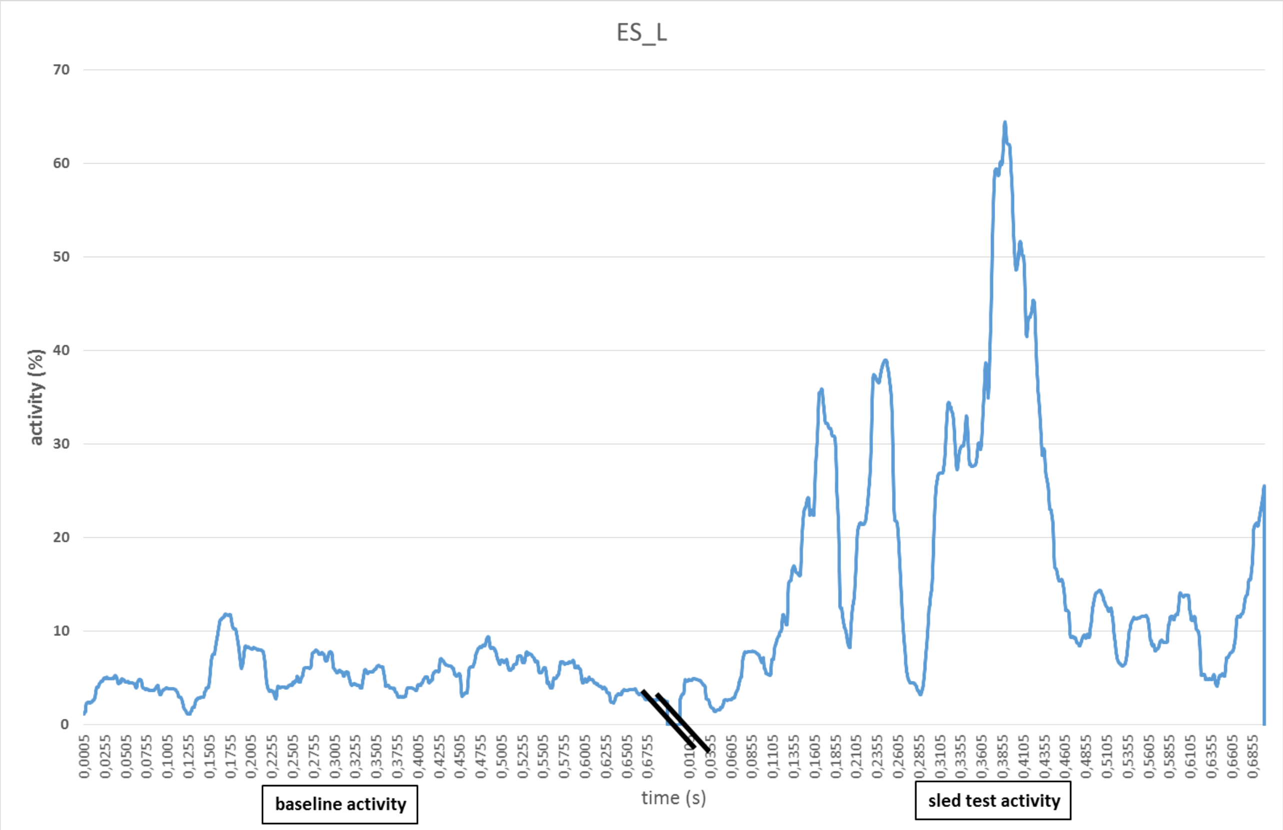

CPVM_R
activity (%)
time (s)
baseline activity
sled test activity

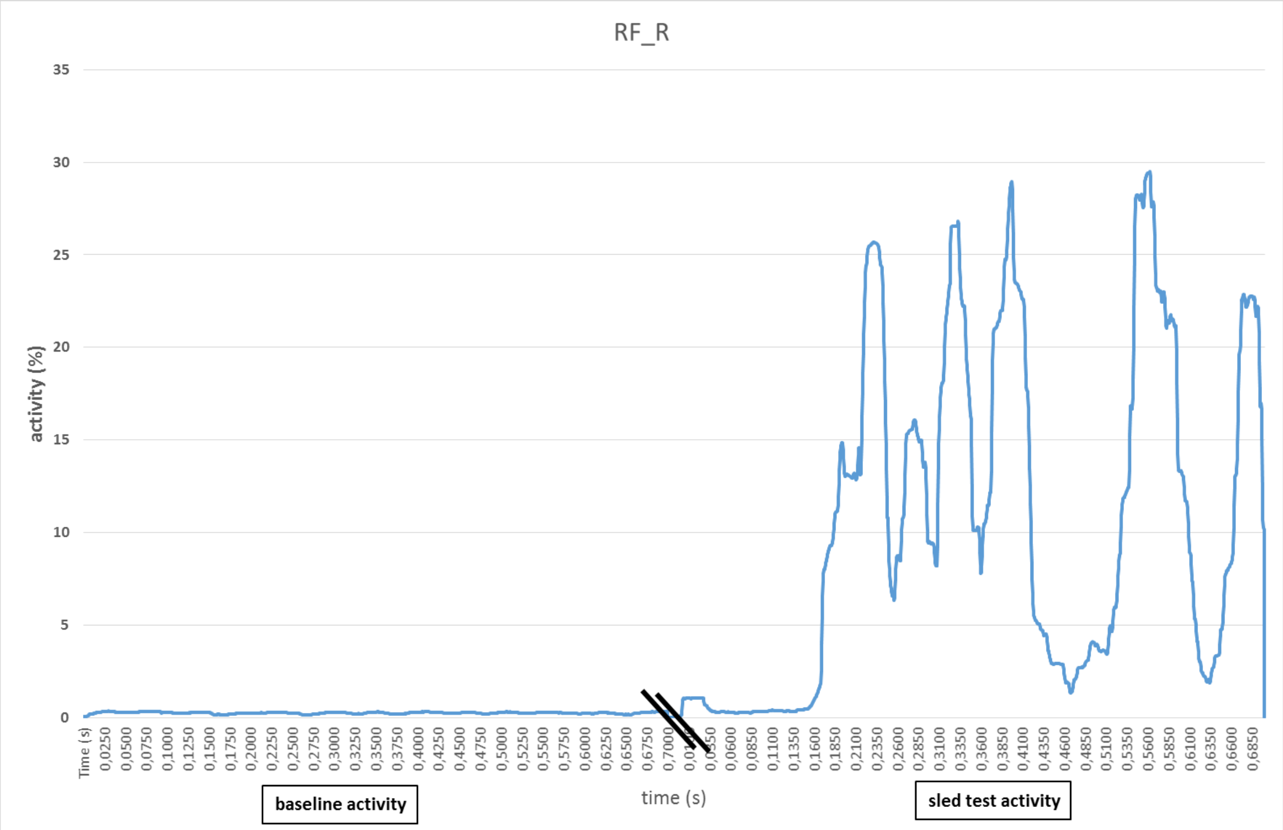

CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

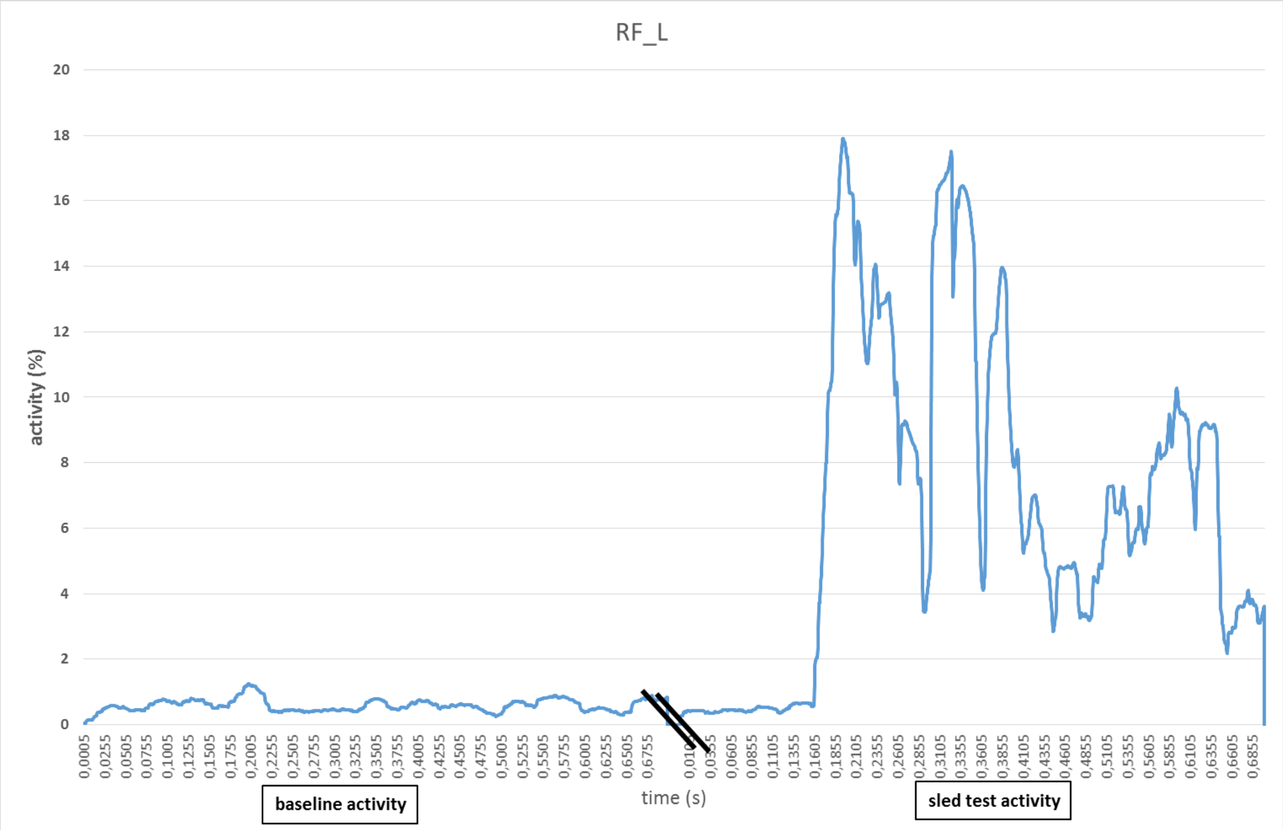

RA_R
activity (%)
time (s)
baseline activity
sled test activity

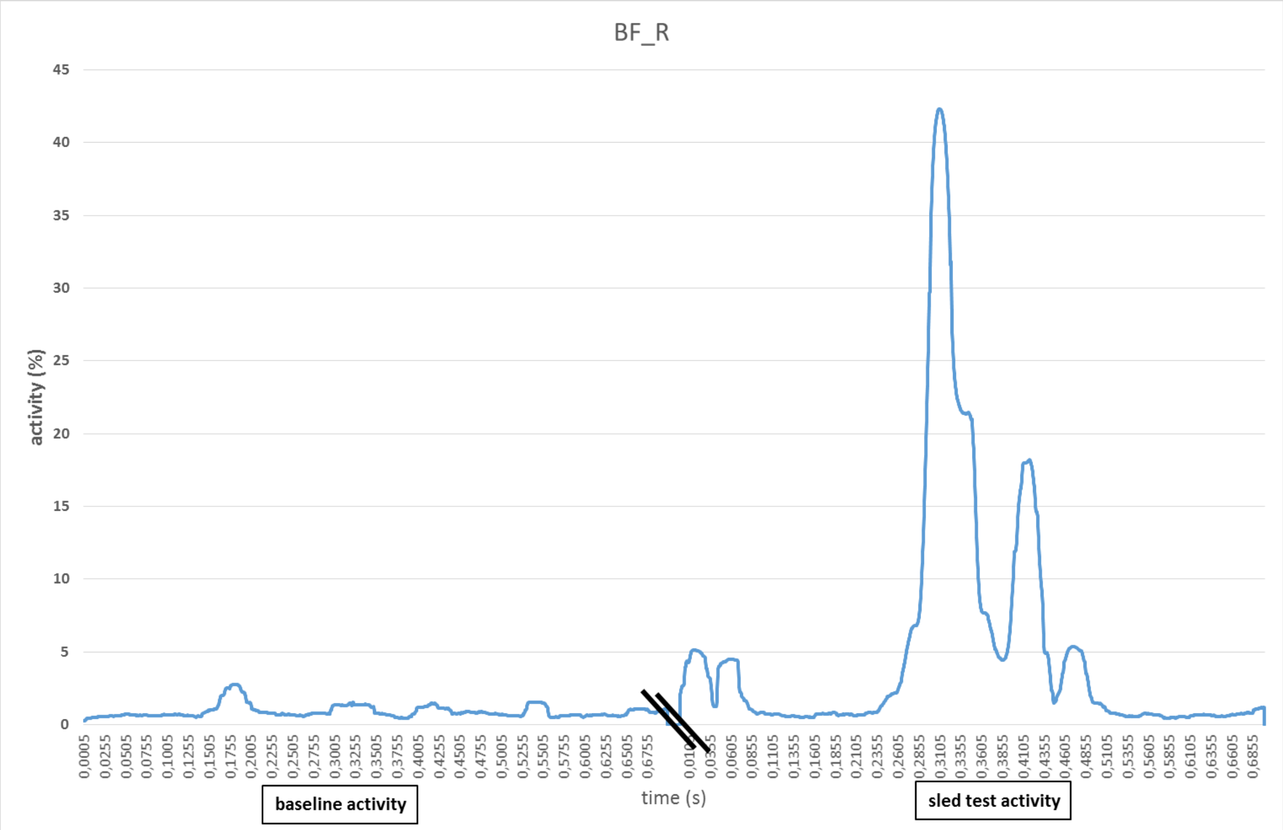

RA_L
activity (%)
time (s)
baseline activity
sled test activity

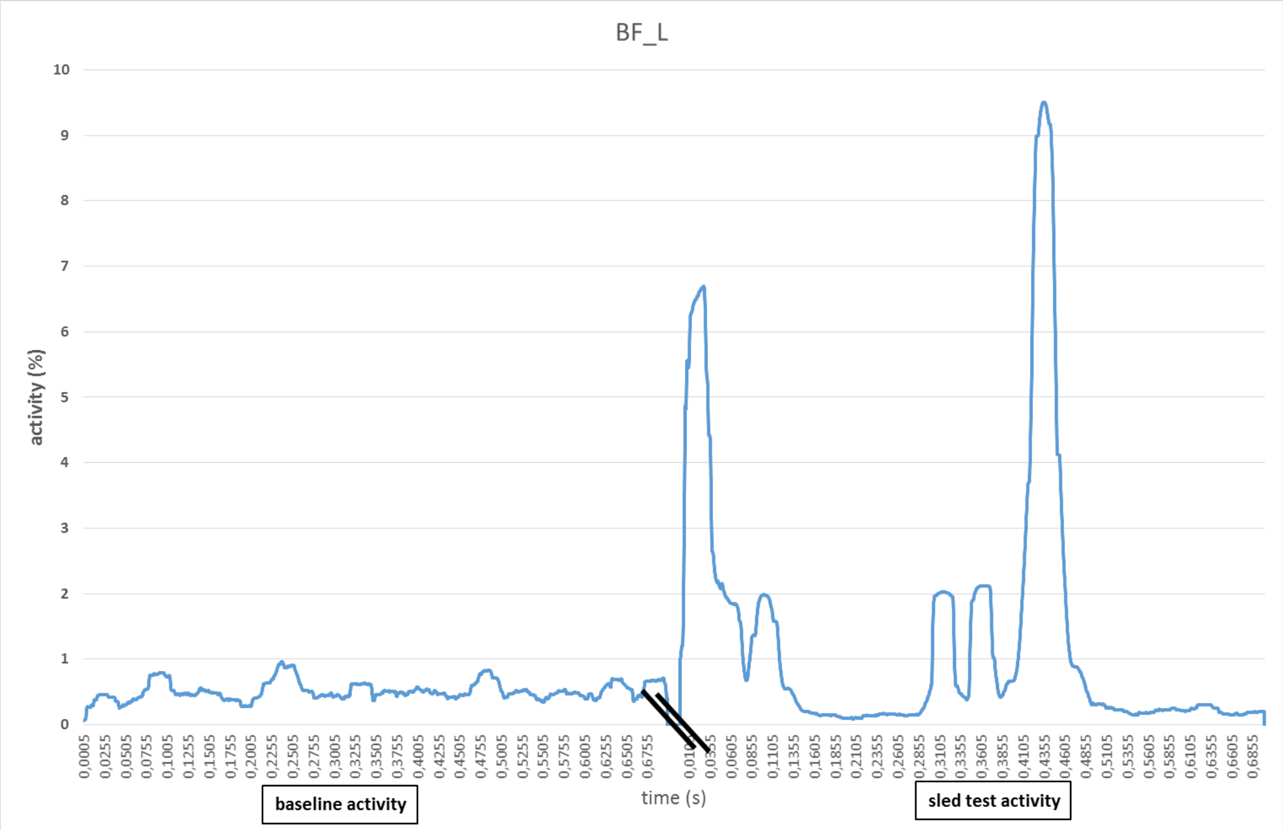

ES_R
activity (%)
time (s)
baseline activity
sled test activity

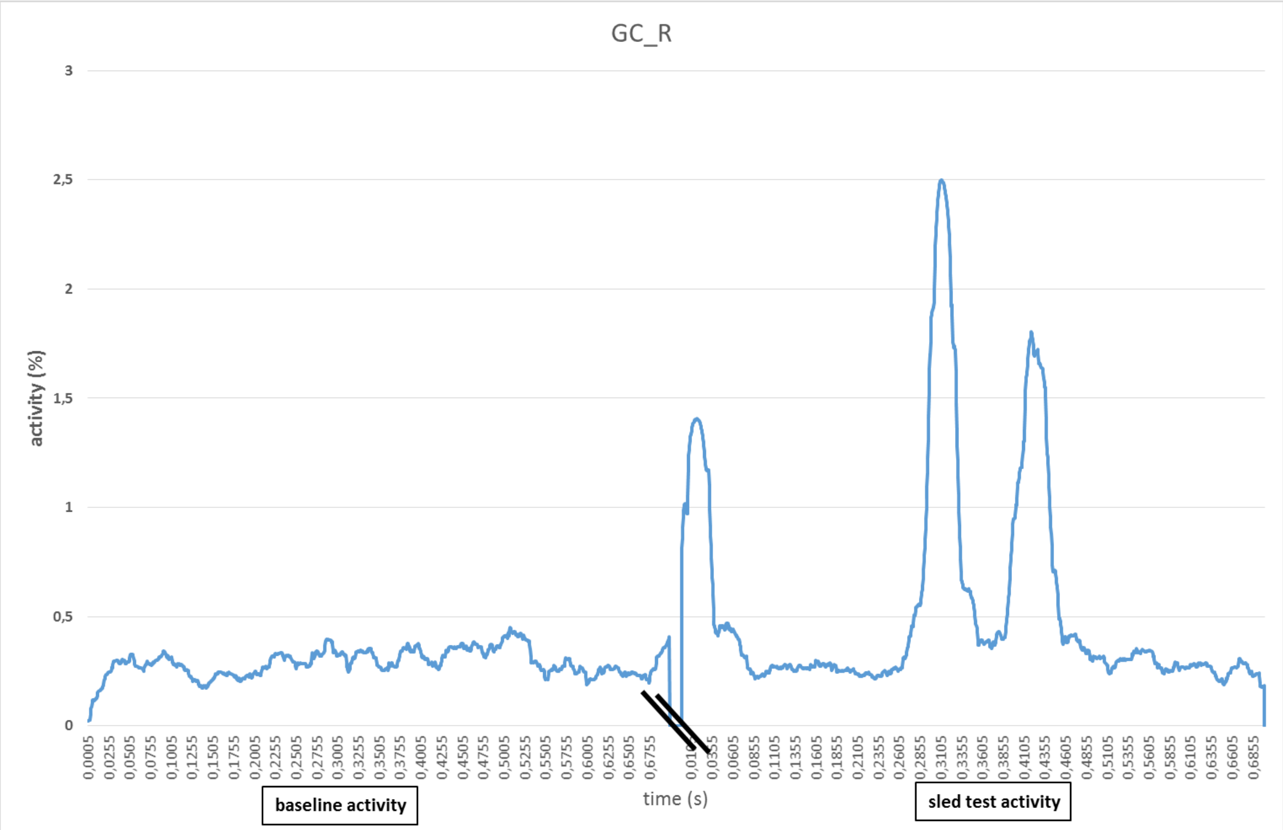

ES_L
activity (%)
time (s)
baseline activity
sled test activity

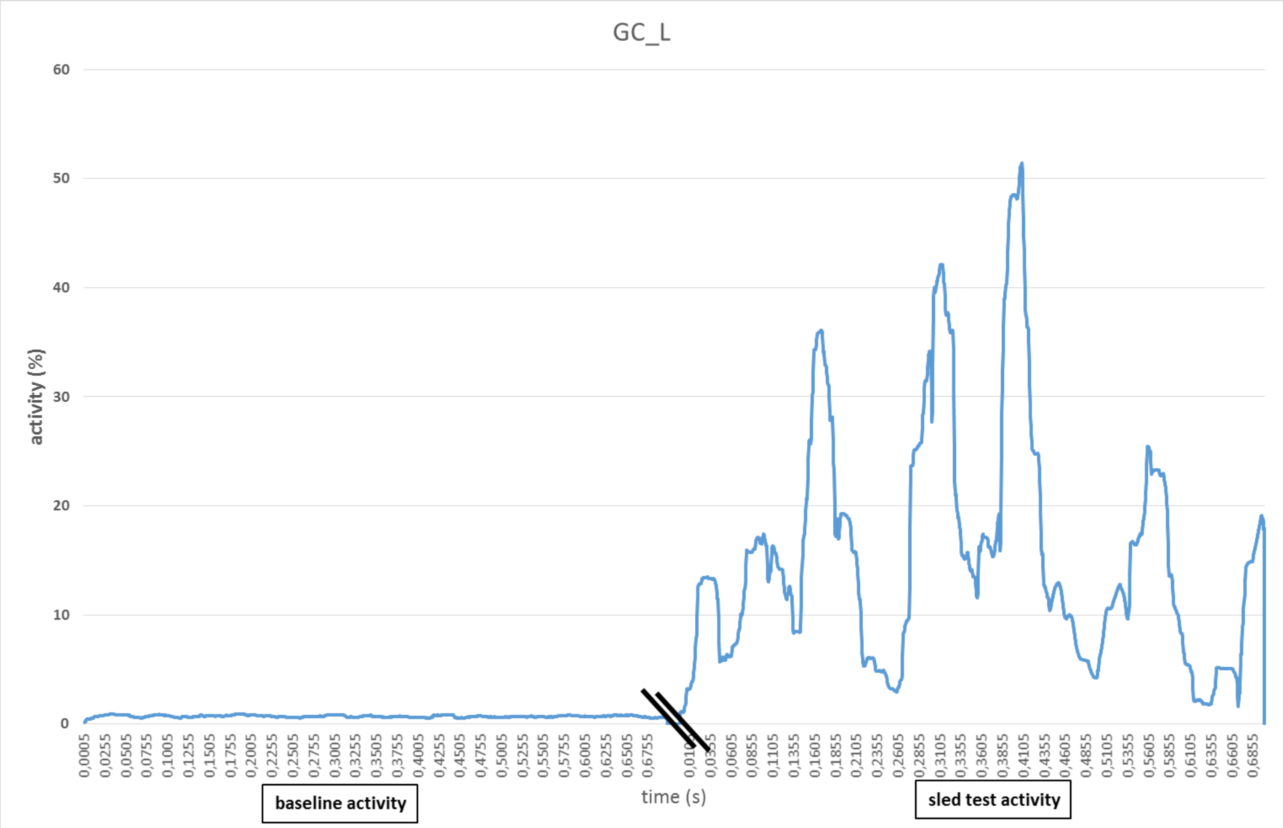

RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity

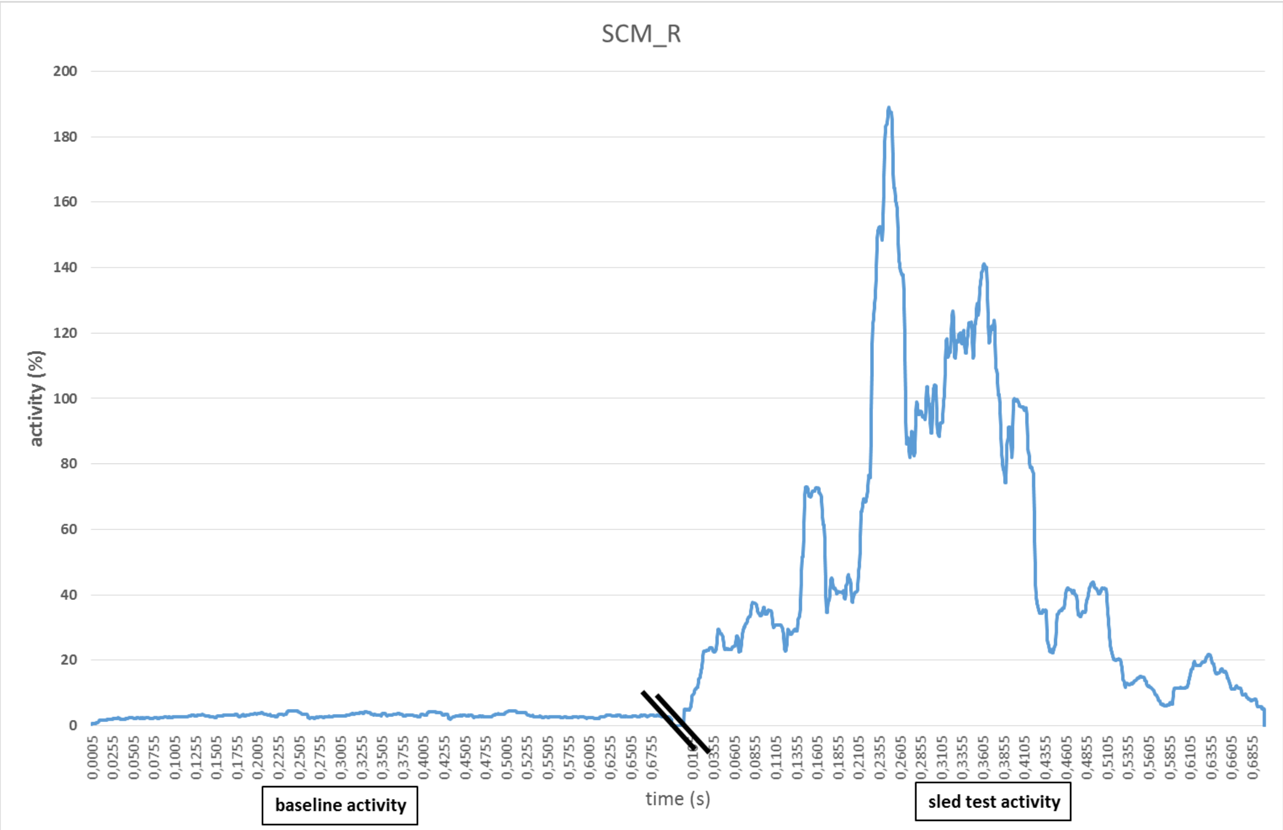

BF_R
activity (%)
time (s)
baseline activity
sled test activity


BF_L
activity (%)
time (s)
baseline activity
sled test activity

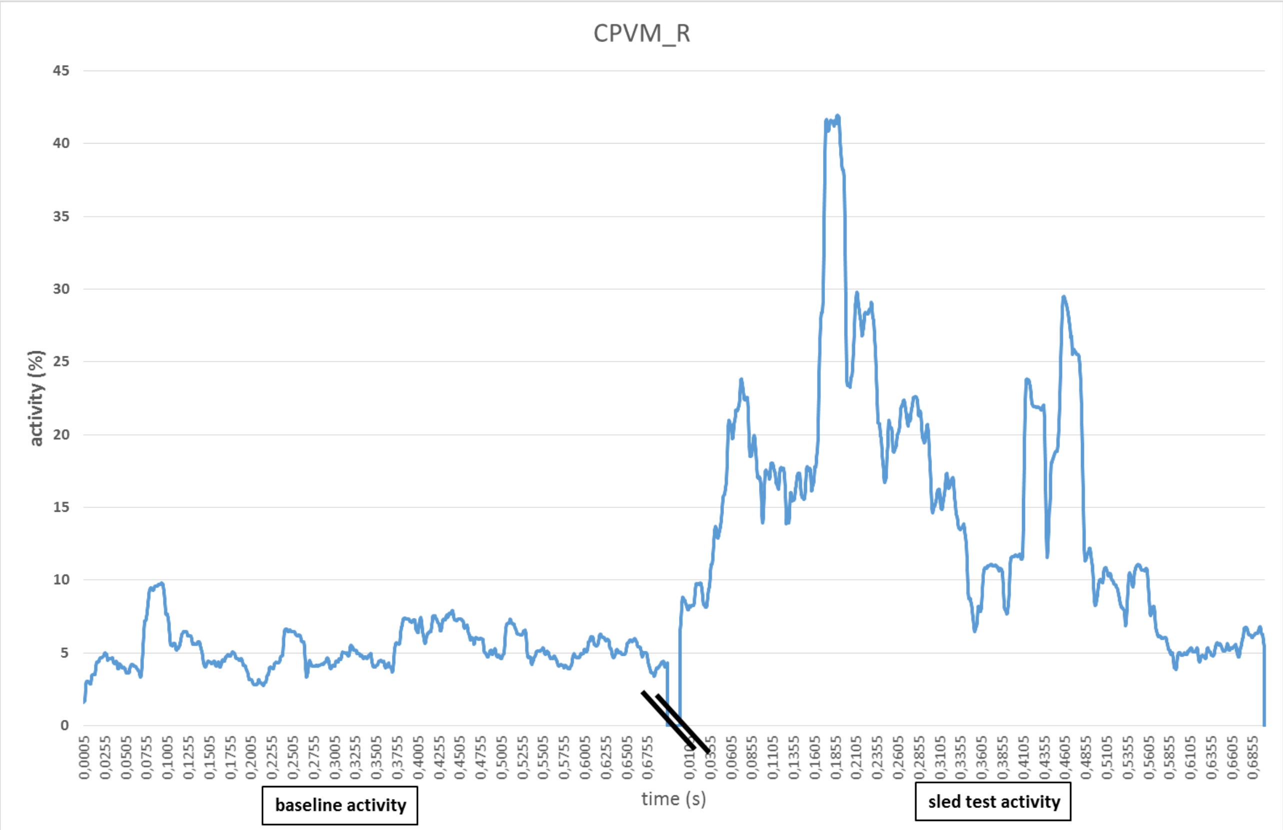

GC_R
activity (%)
time (s)
baseline activity
sled test activity

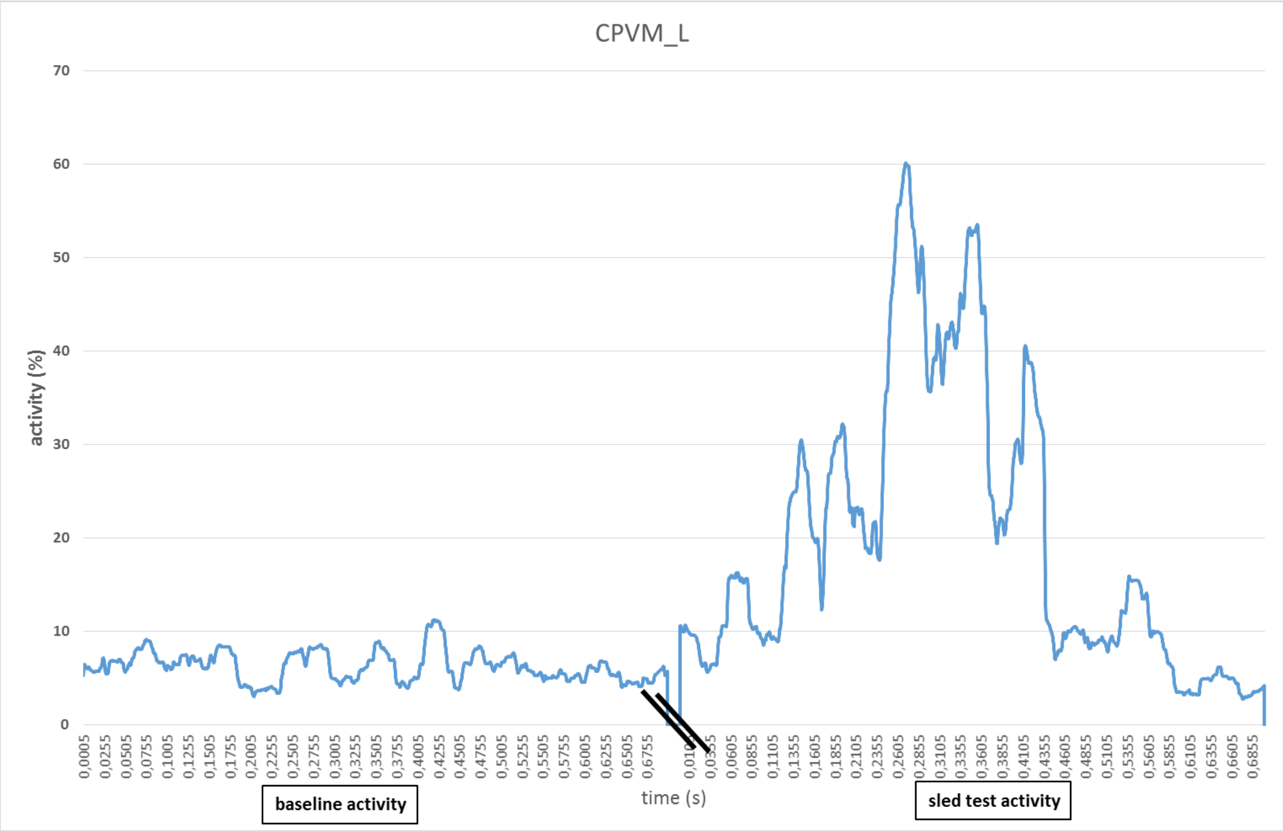

GC_L
activity (%)
60
50
40
30
20
10
0
time (s)
baseline activity
sled test activity

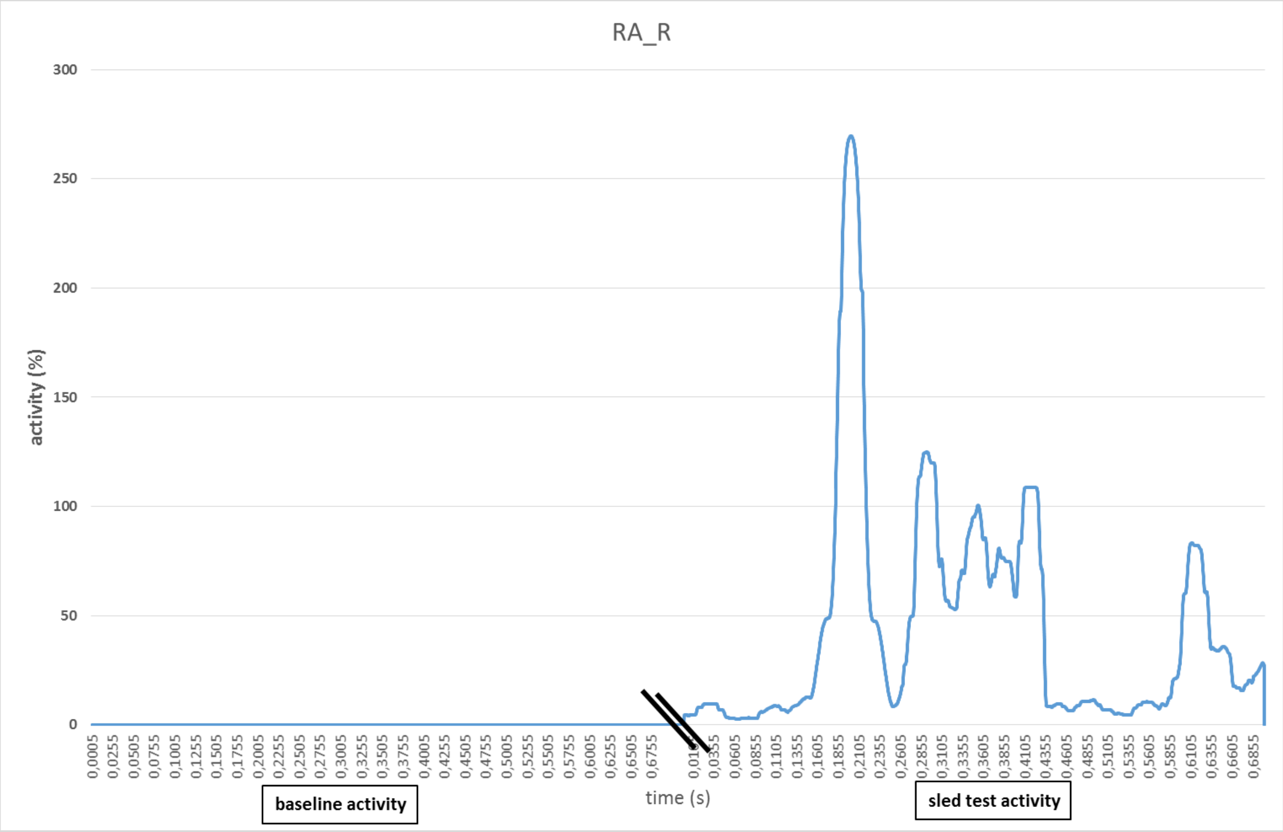
Trial 1774

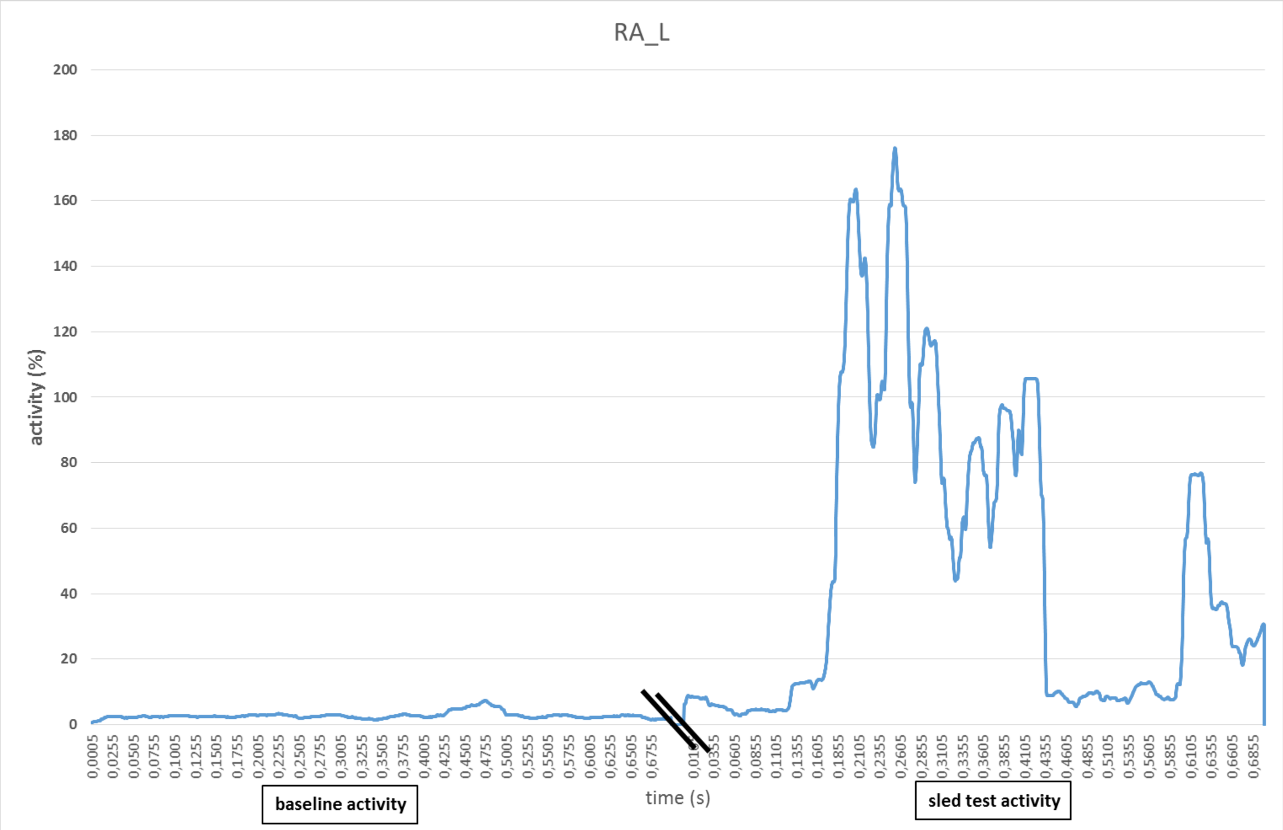

SCM_R
activity (%)
200
180
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

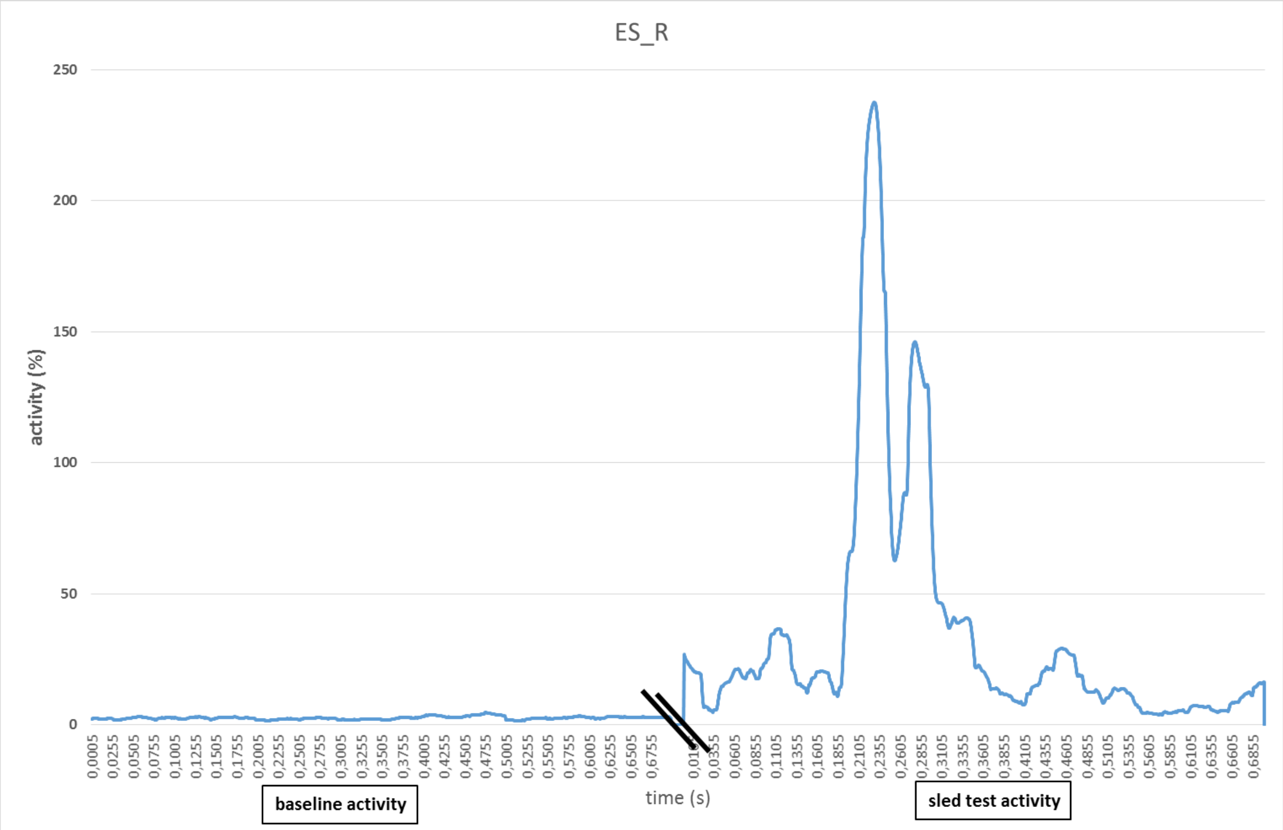

SCM_L
activity (%)
180
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

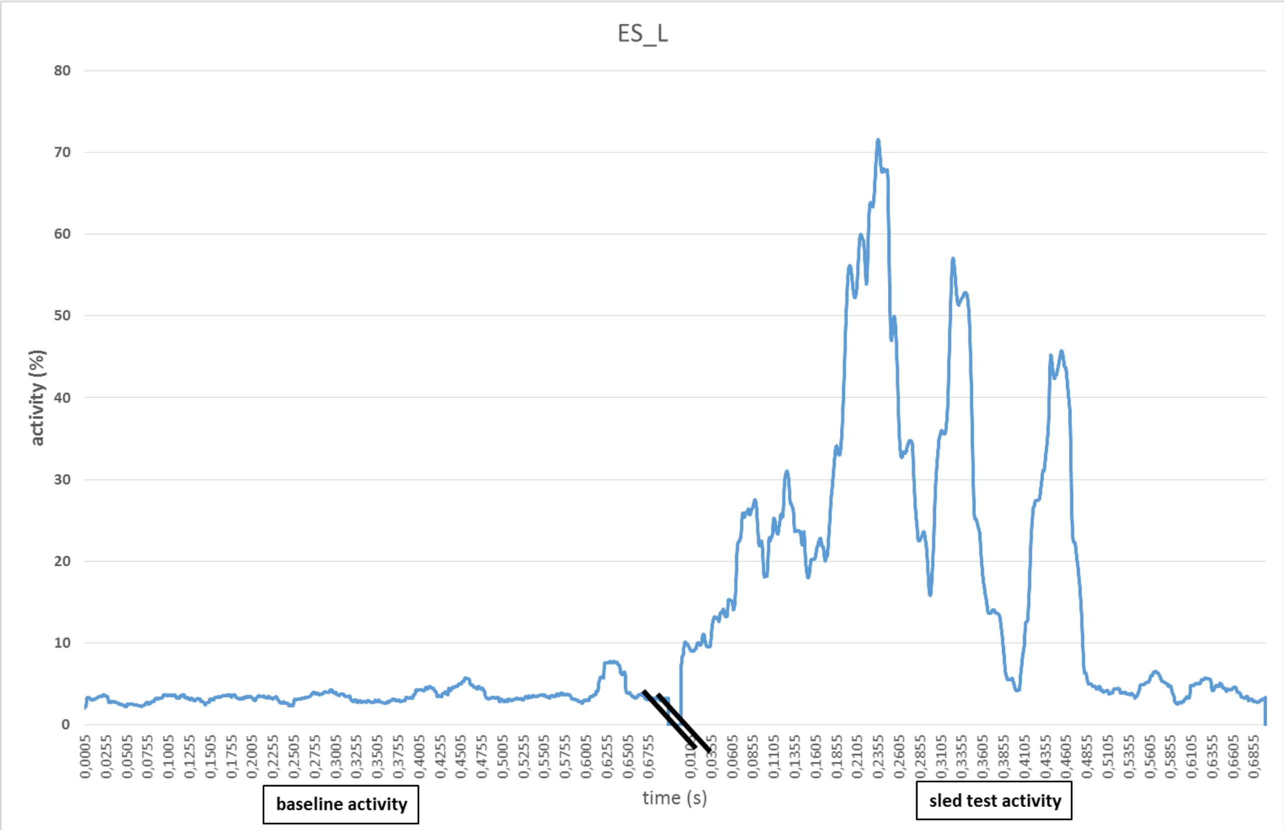

CPVM_R
activity (%)
45
40
35
30
25
20
15
10
5
0
time (s)
baseline activity
sled test activity

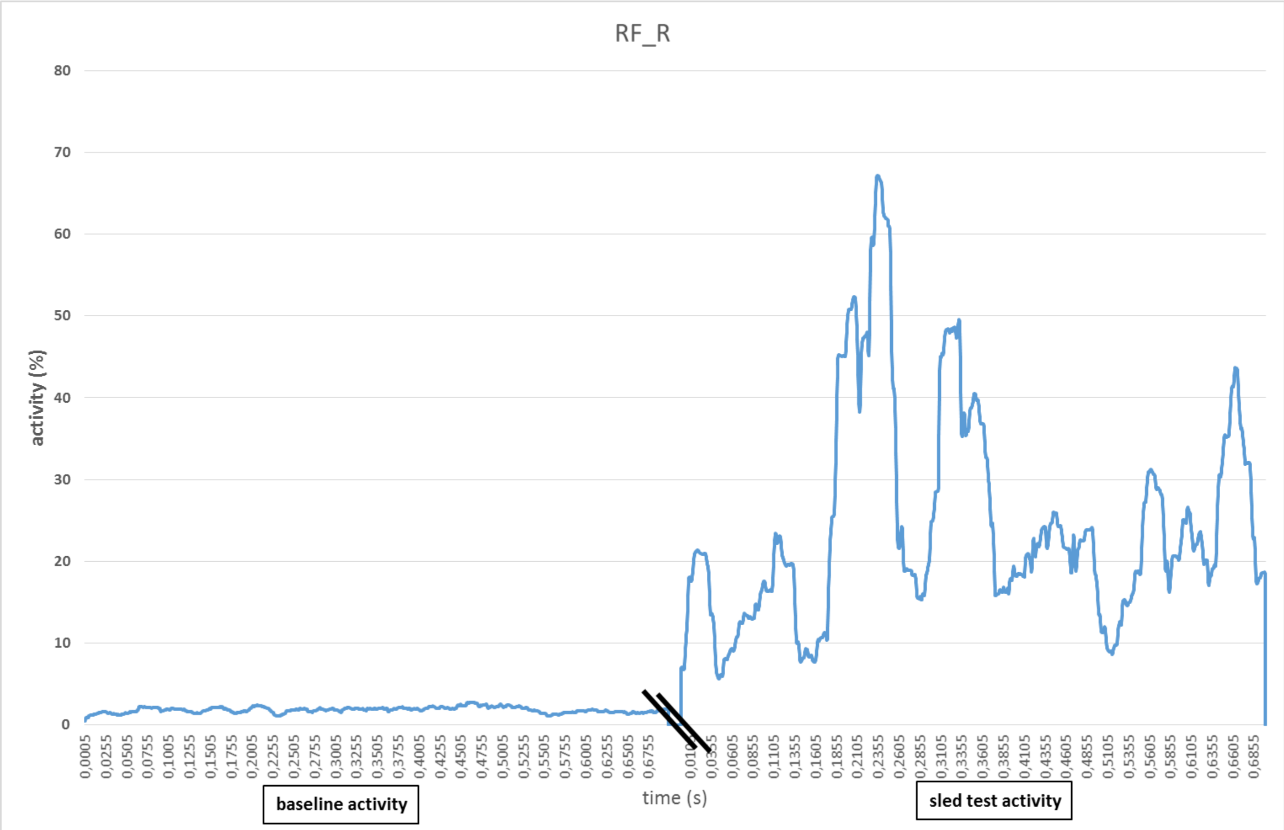

CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

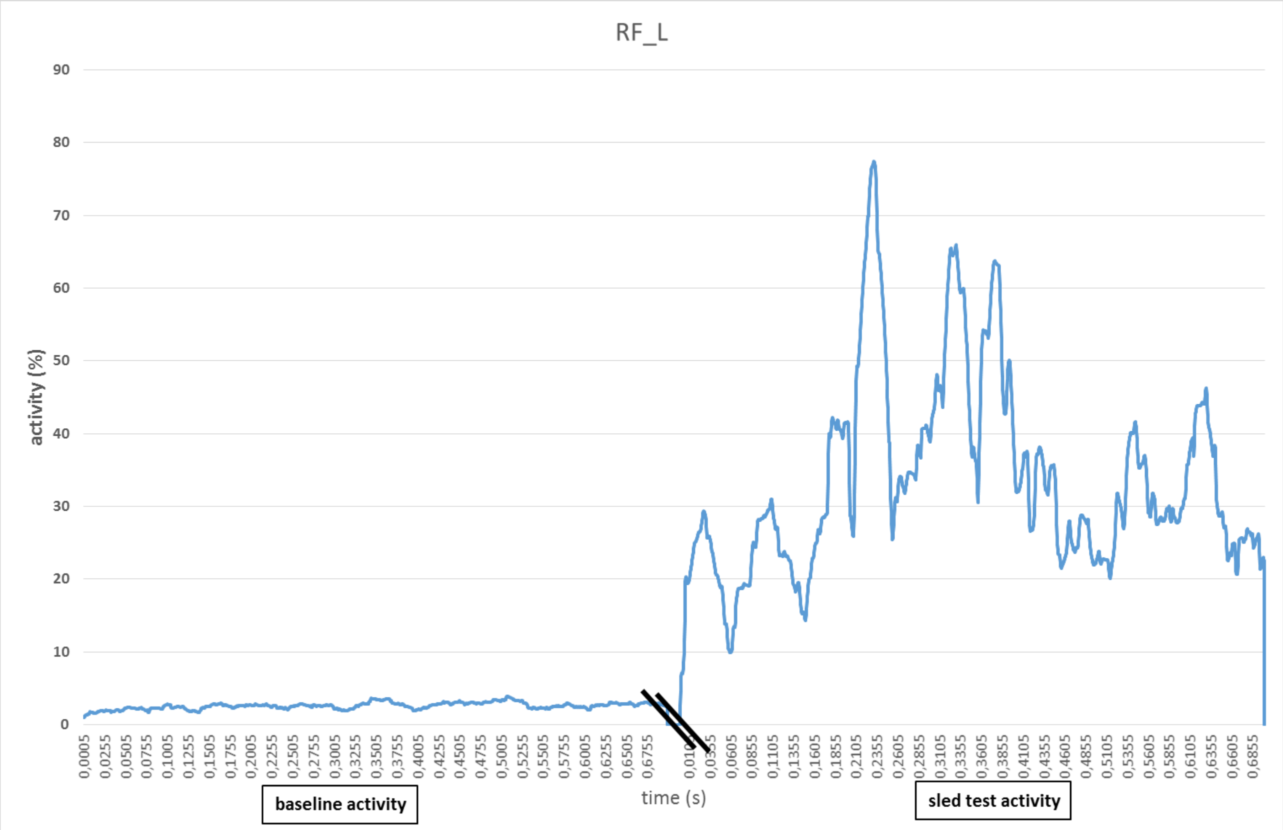

RA_R
activity (%)
time (s)
baseline activity
sled test activity

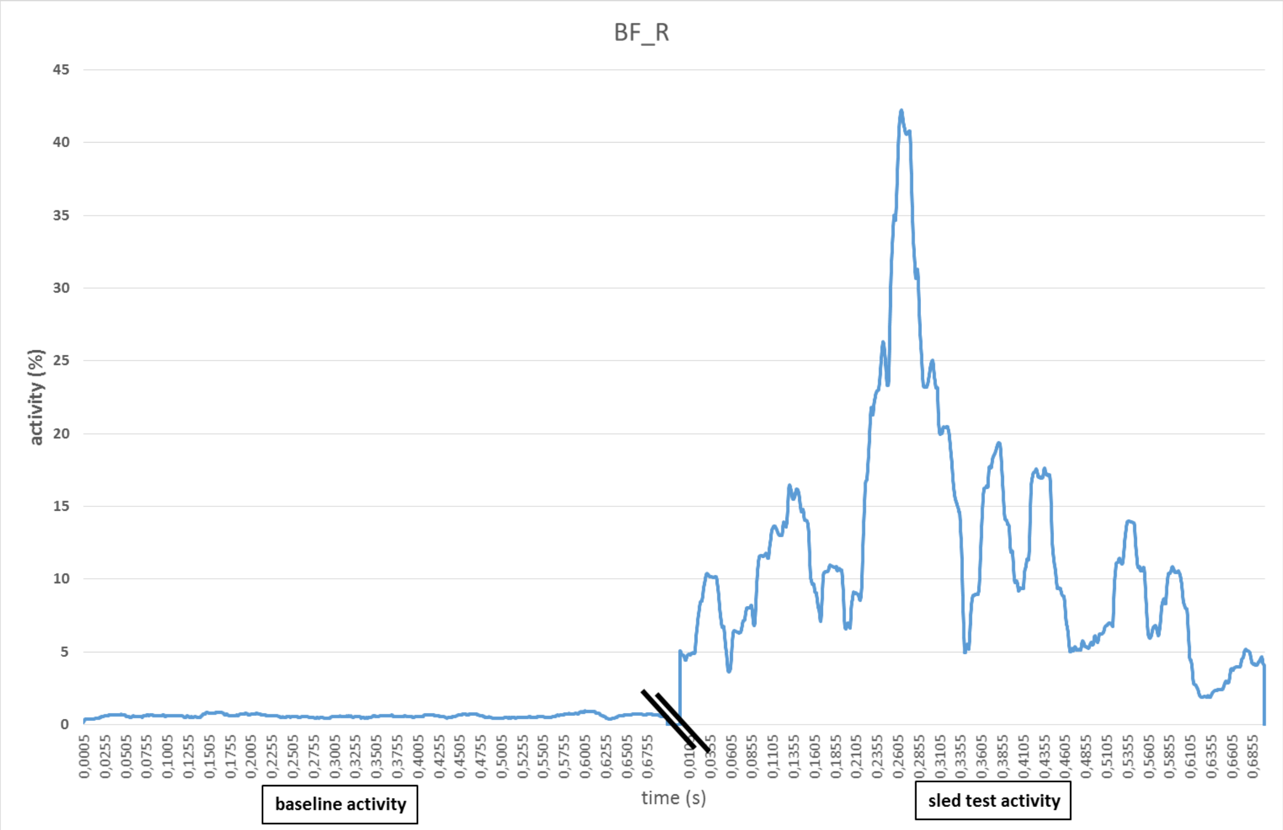

RA_L
activity (%)
time (s)
baseline activity
sled test activity

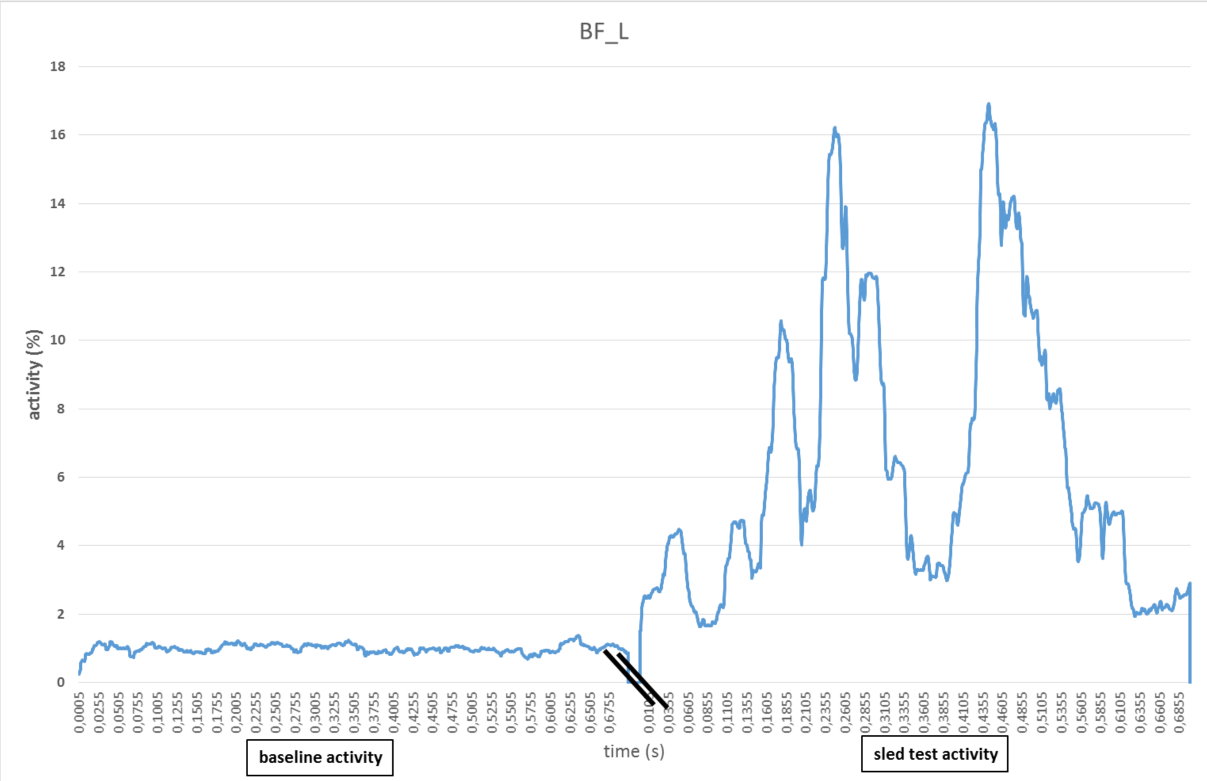

ES_R
activity (%)
time (s)
baseline activity
sled test activity

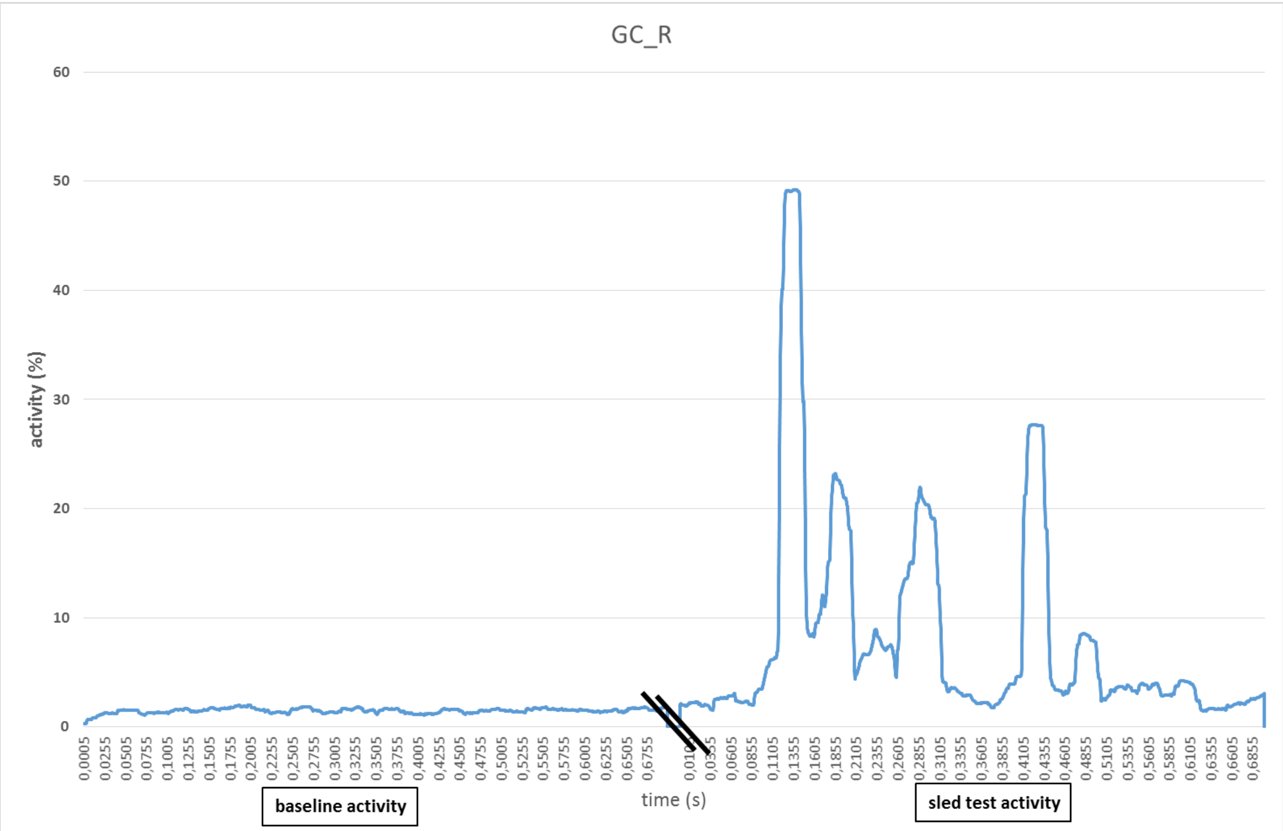

ES_L
activity (%)
time (s)
baseline activity
sled test activity

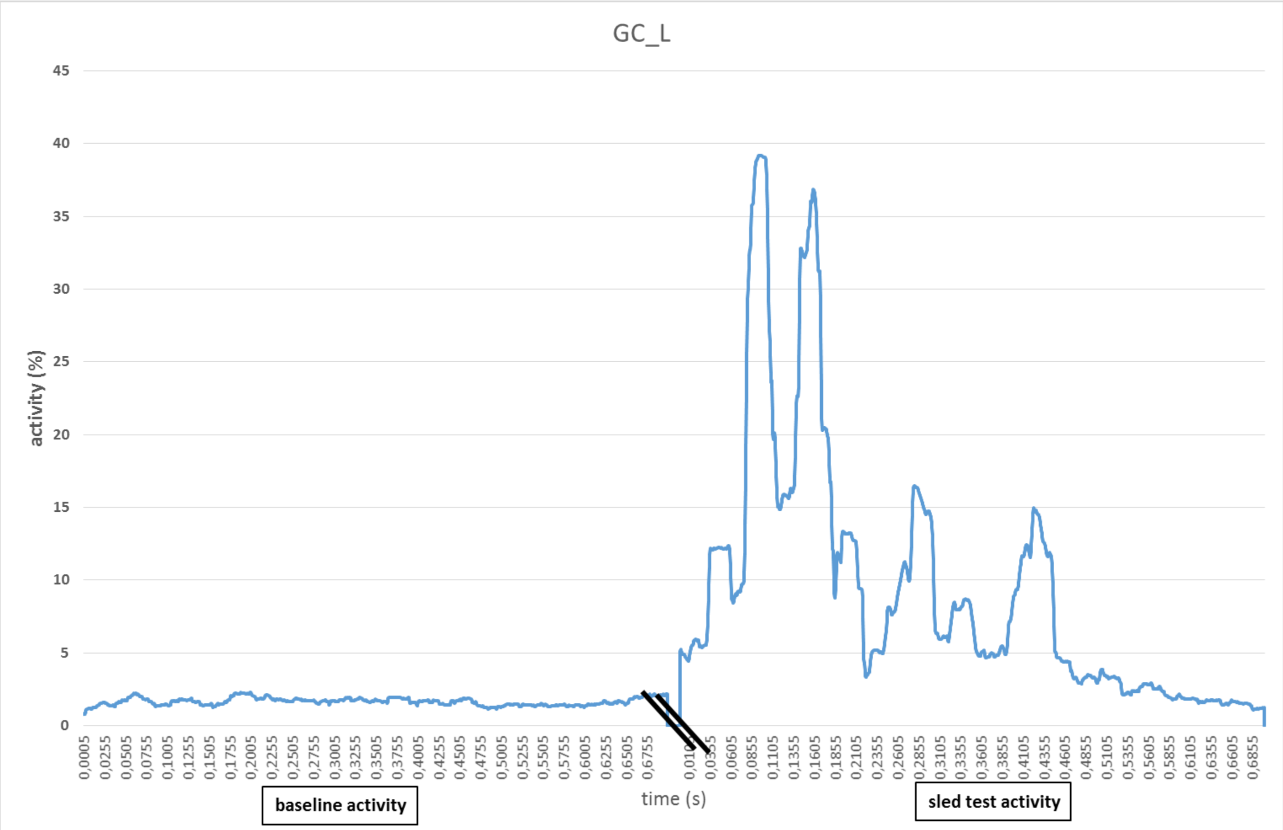

RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity

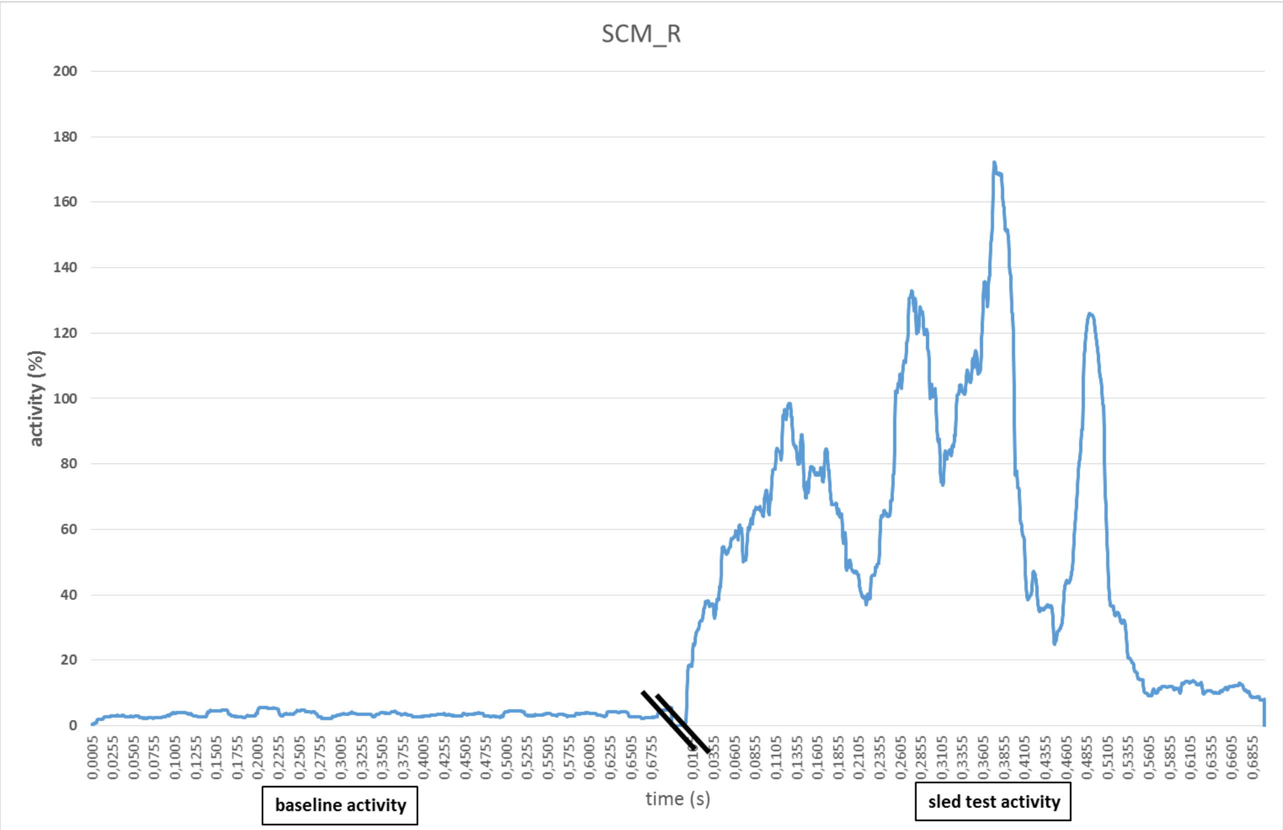

BF_R
activity (%)
time (s)
baseline activity
sled test activity

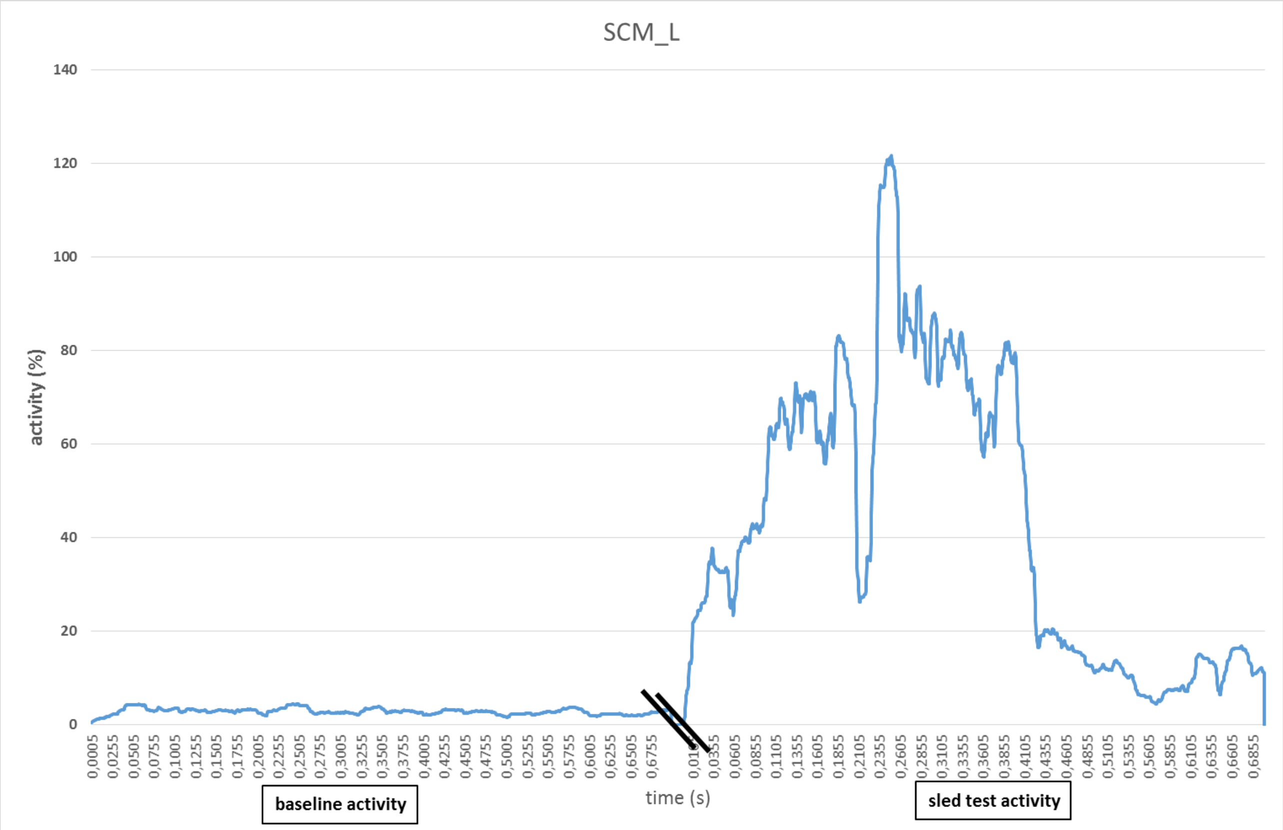

BF_L
activity (%)
time (s)
baseline activity
sled test activity

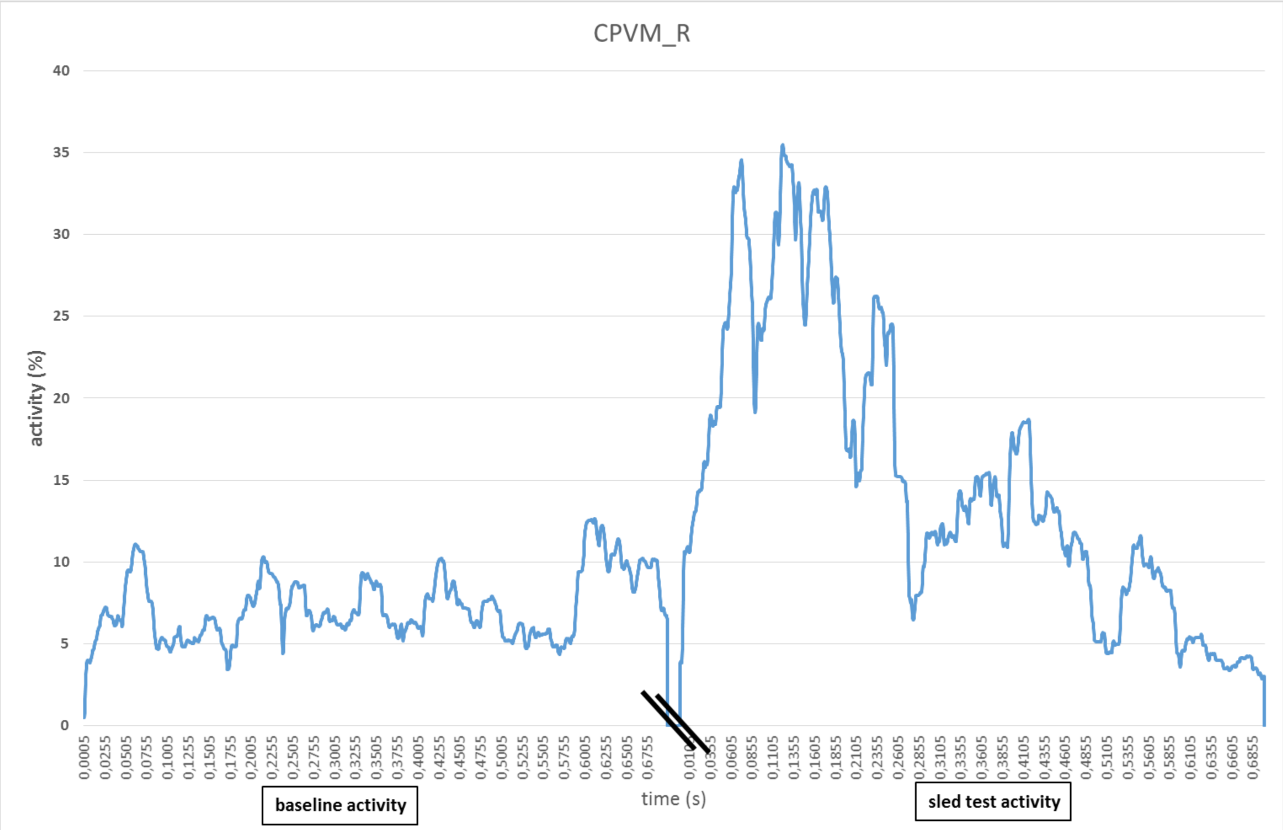

GC_R
activity (%)
time (s)
baseline activity
sled test activity

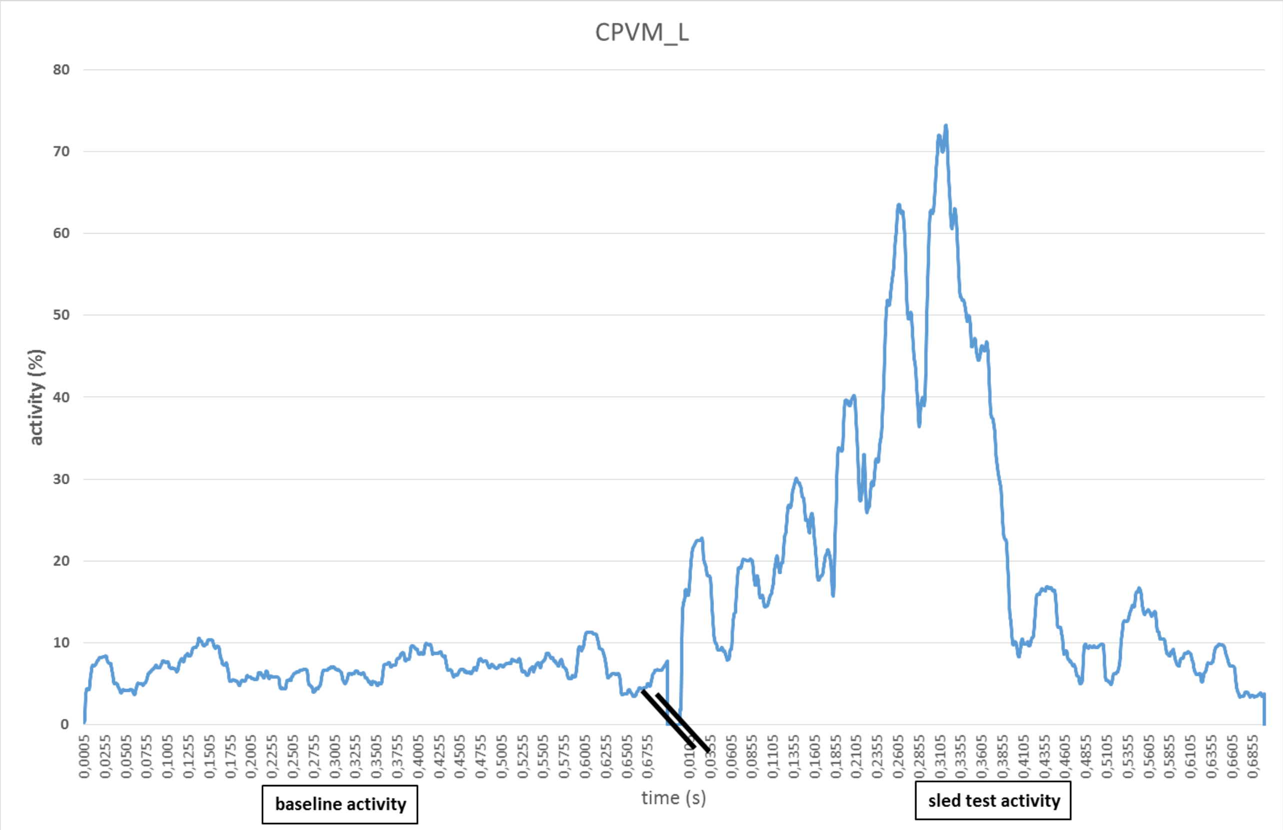

GC_L
activity (%)
time (s)
baseline activity
sled test activity

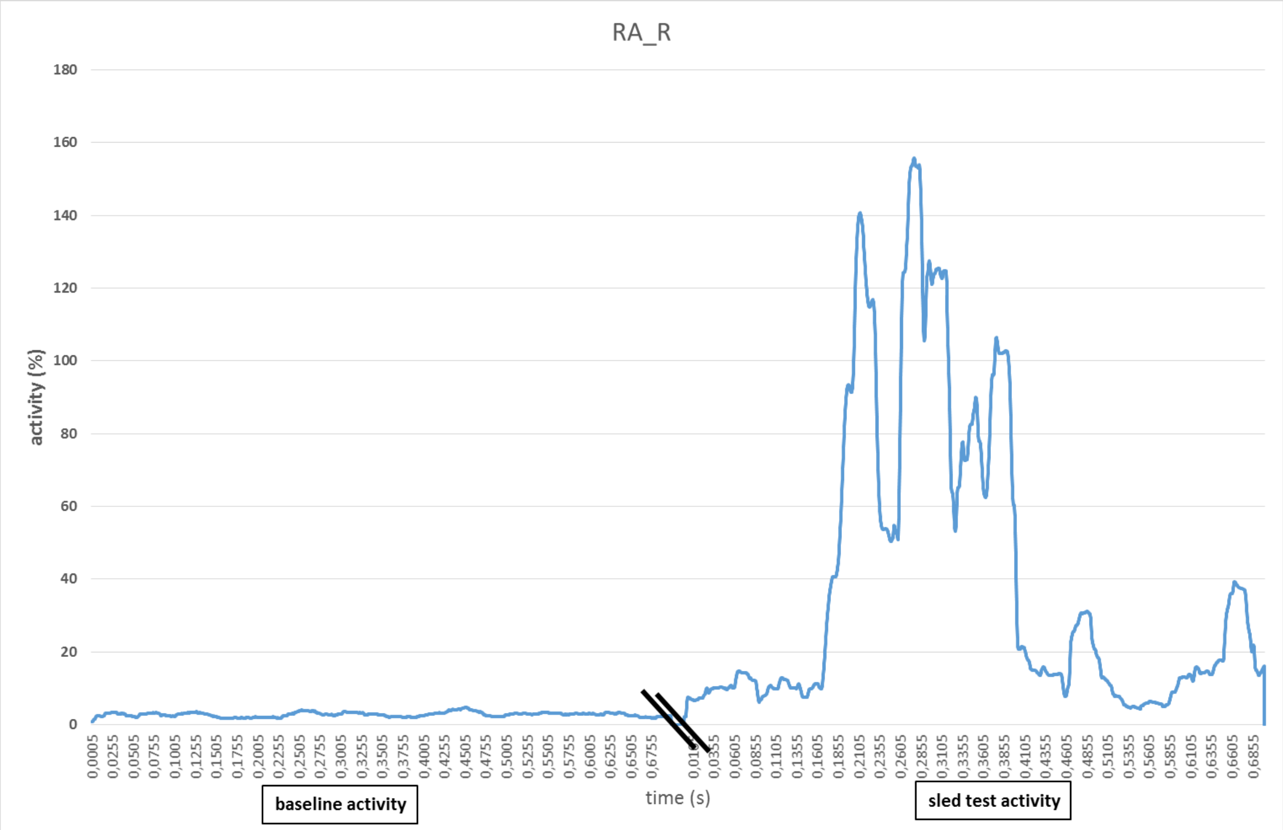
Trial 1775

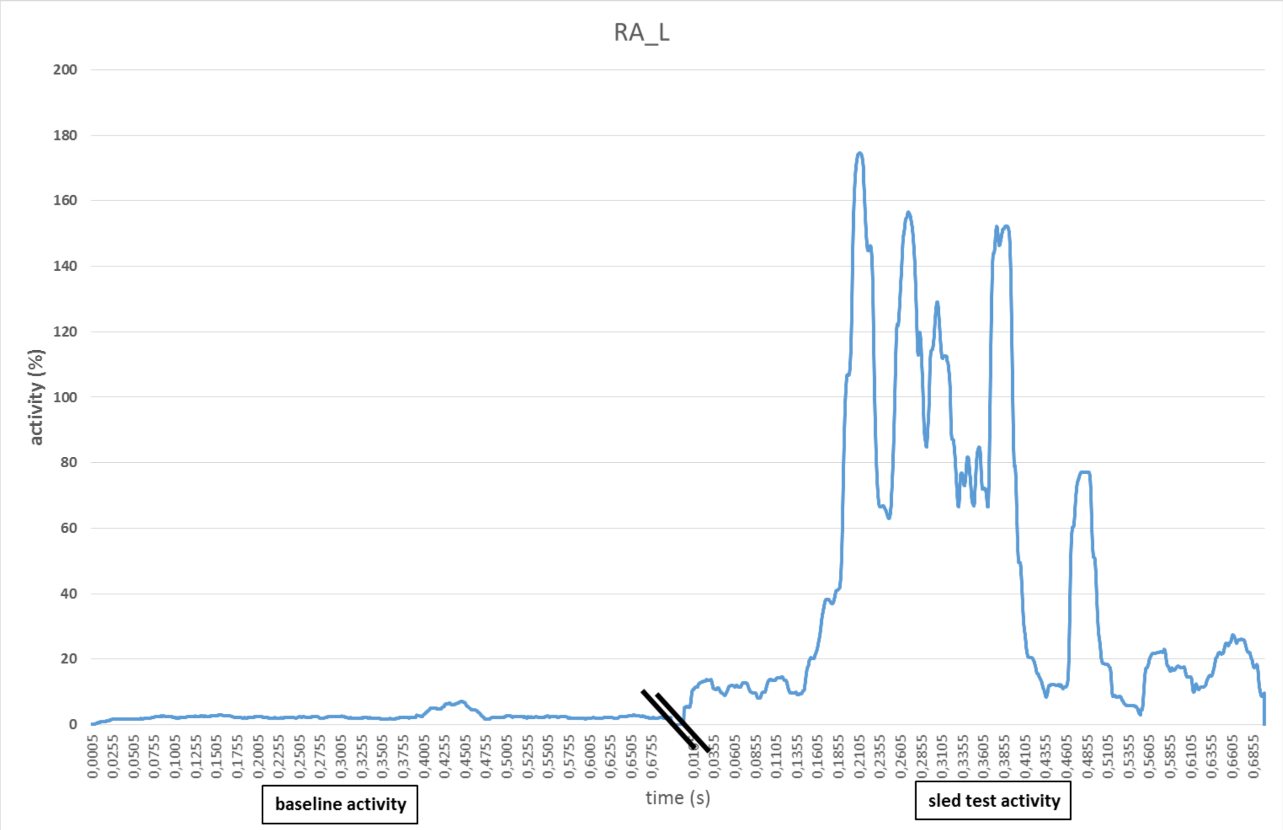

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

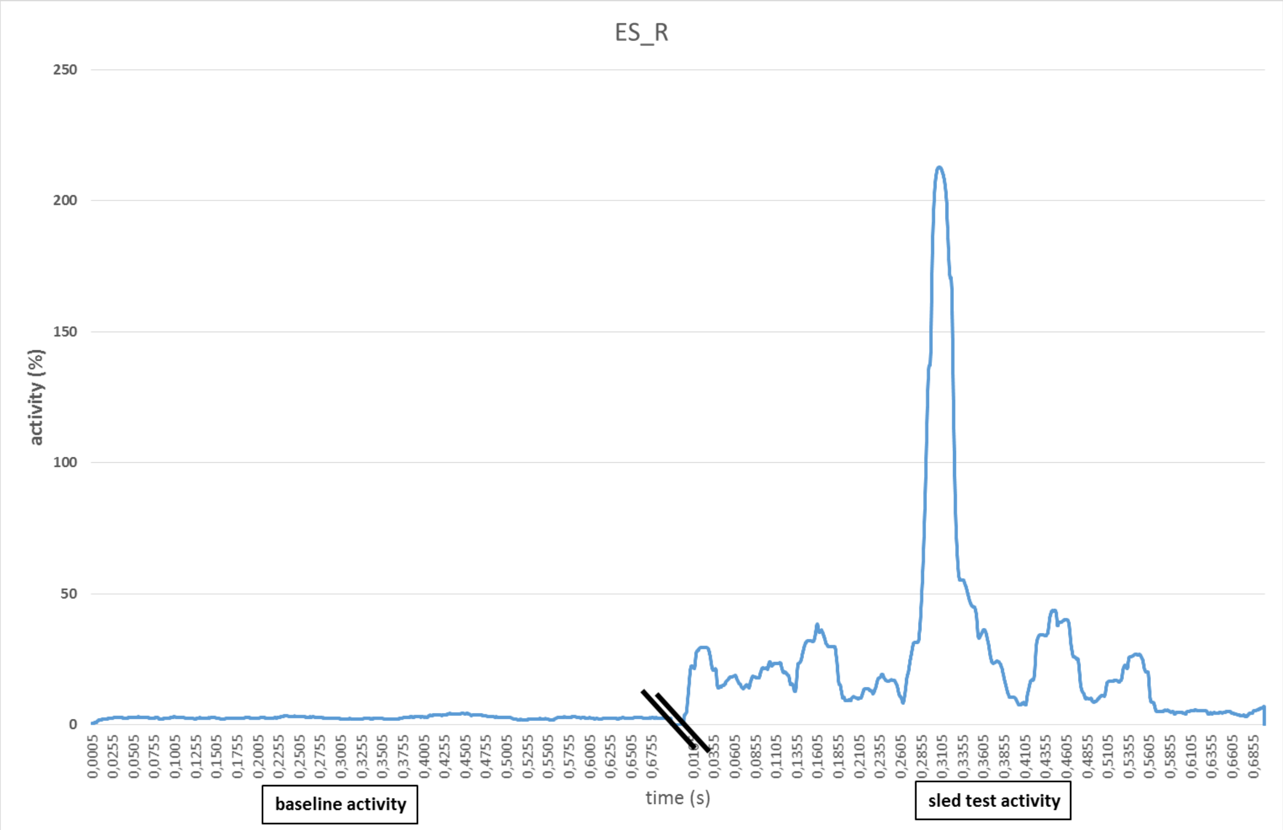

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

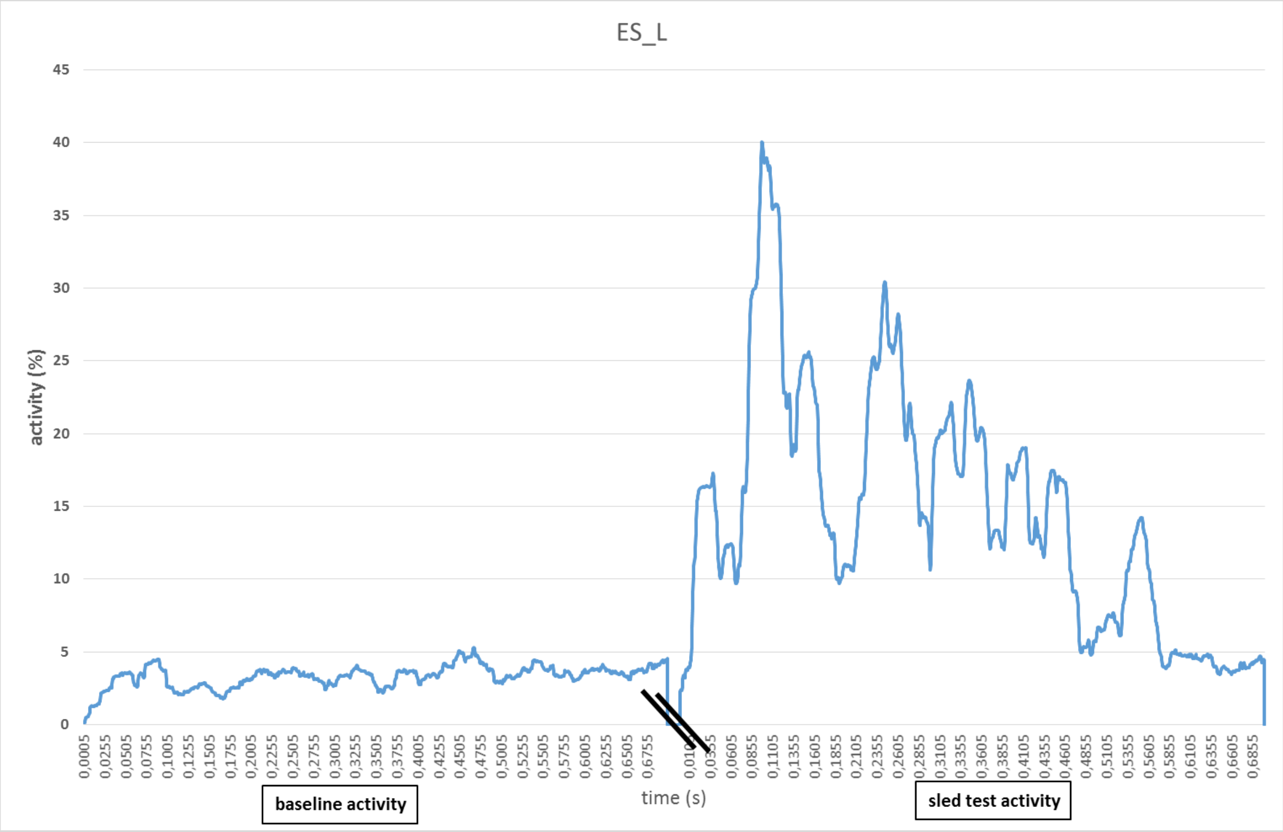

CPVM_R
activity (%)
time (s)
baseline activity
sled test activity

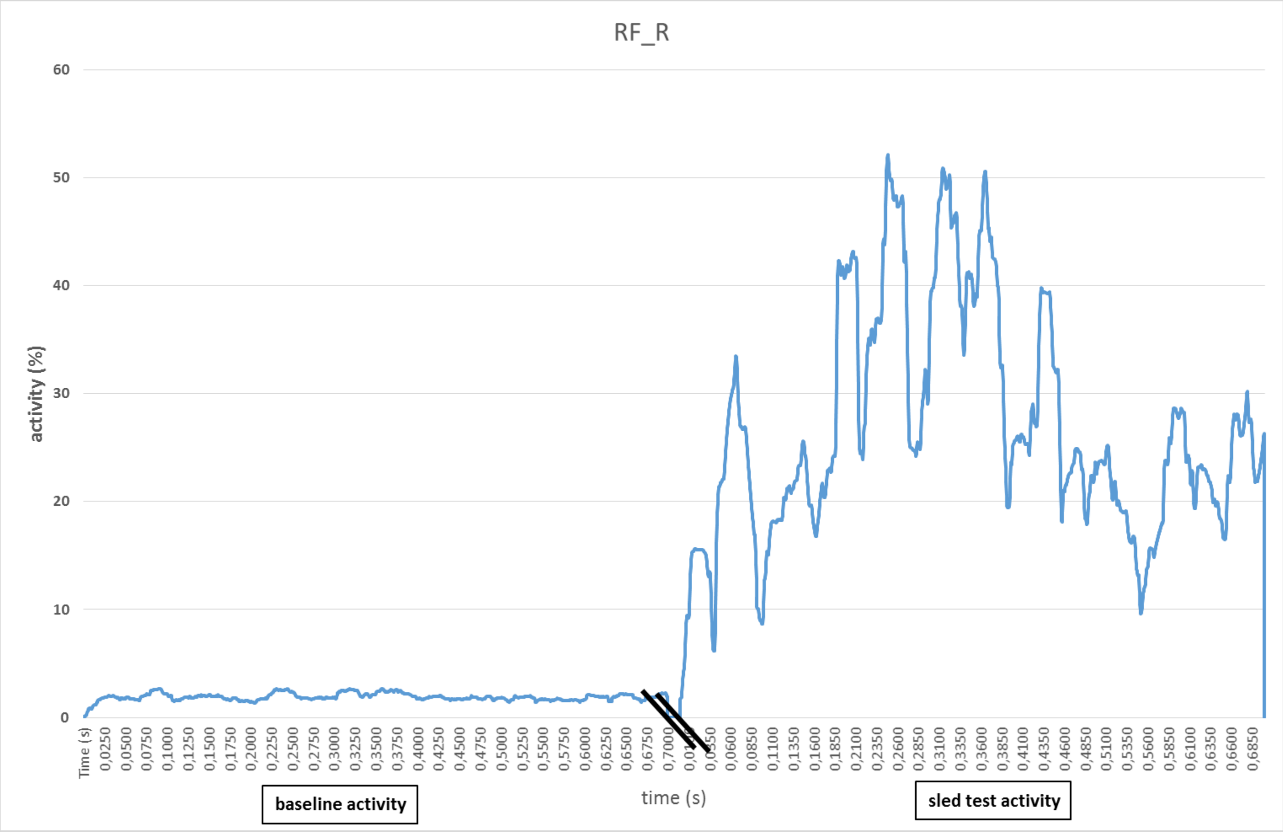

CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

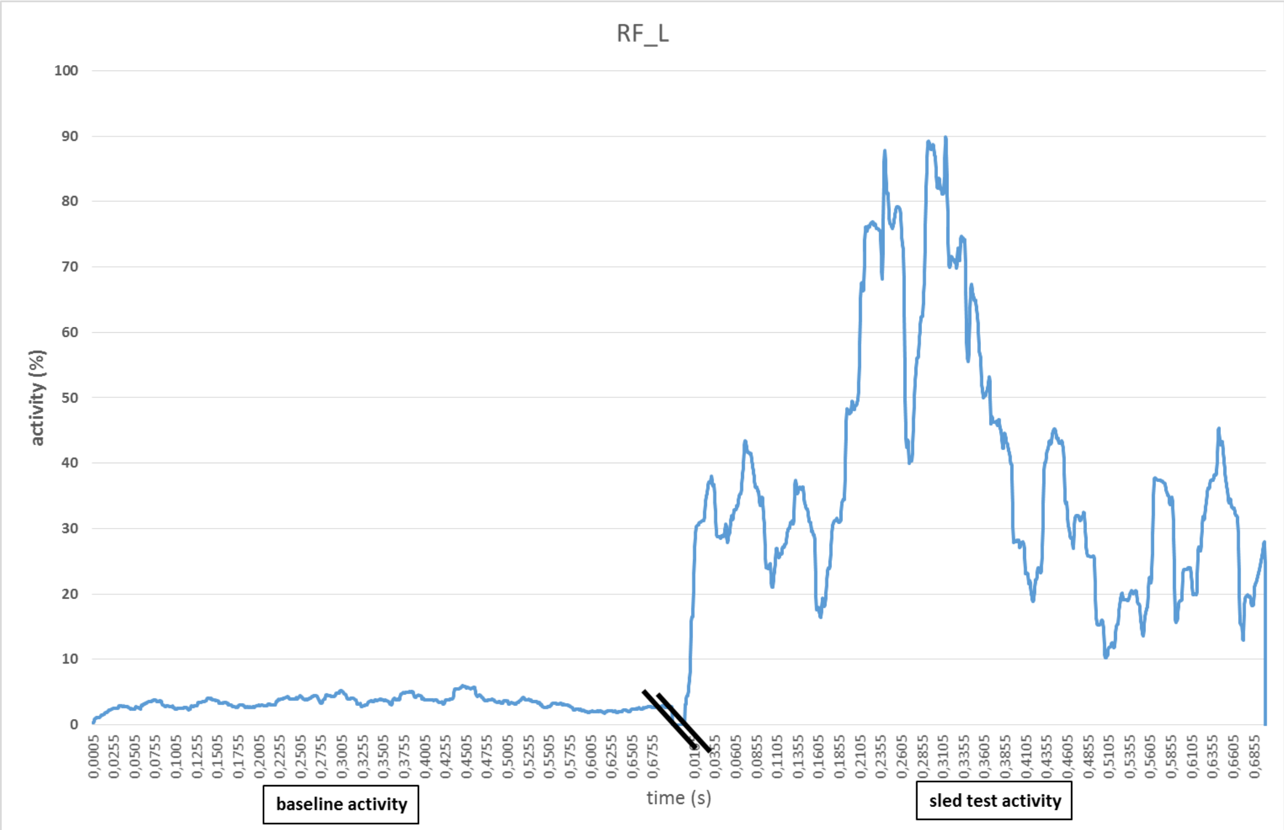

RA_R
activity (%)
time (s)
baseline activity
sled test activity

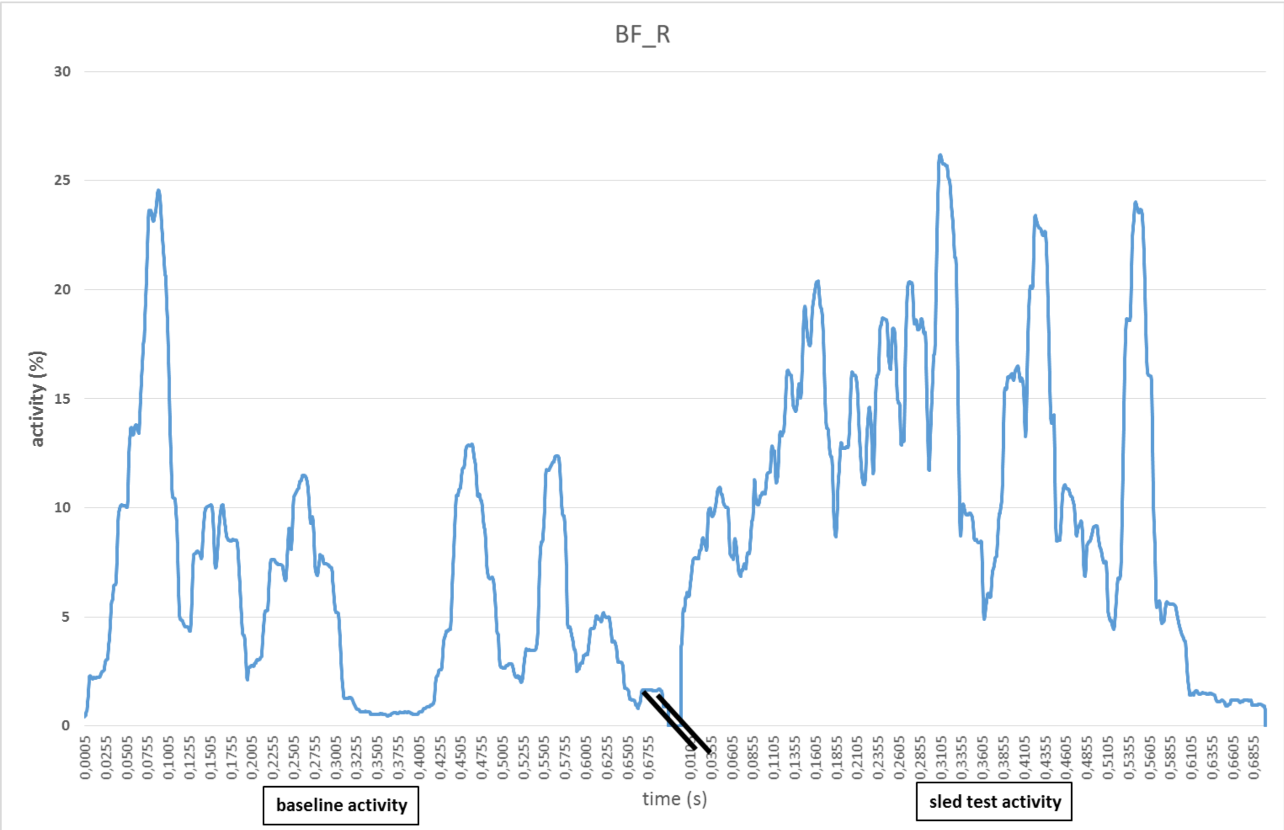

RA_L
activity (%)
time (s)
baseline activity
sled test activity

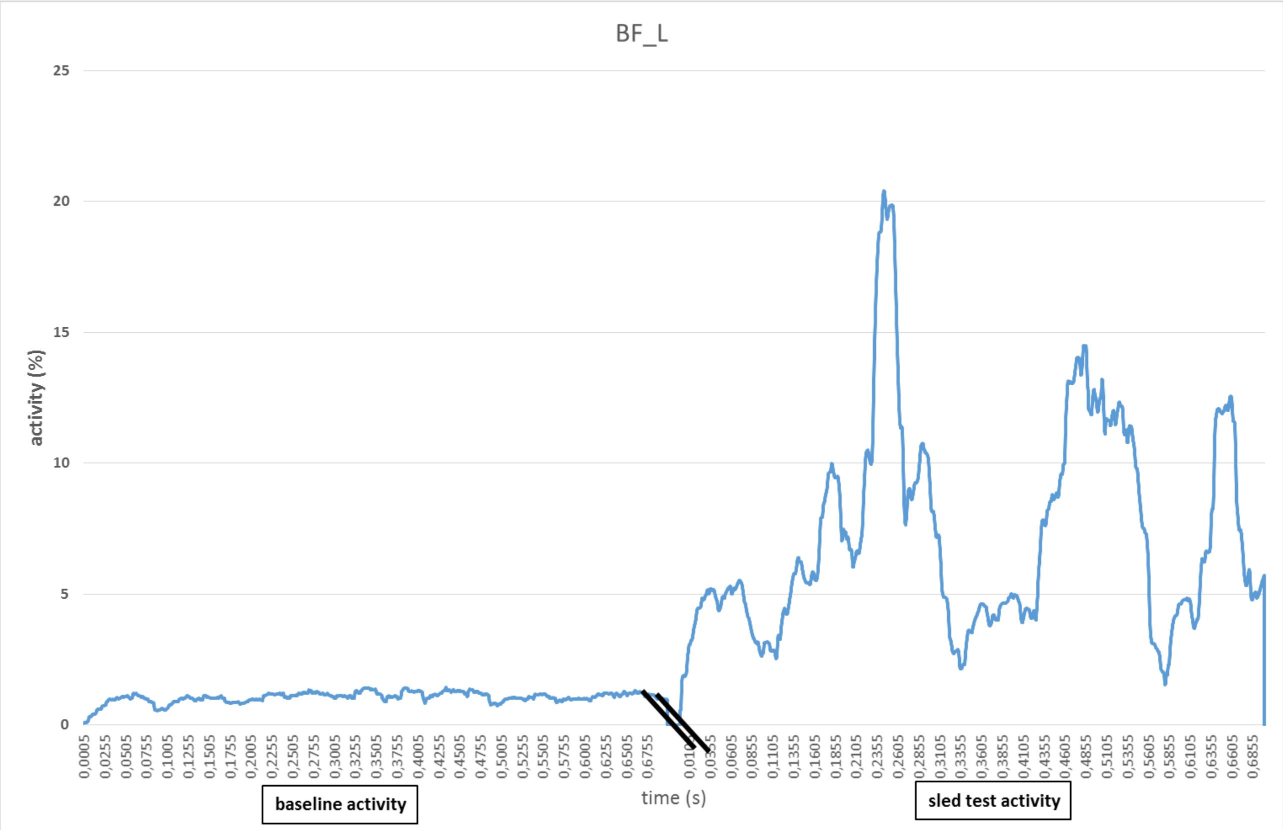

ES_R
activity (%)
time (s)
baseline activity
sled test activity

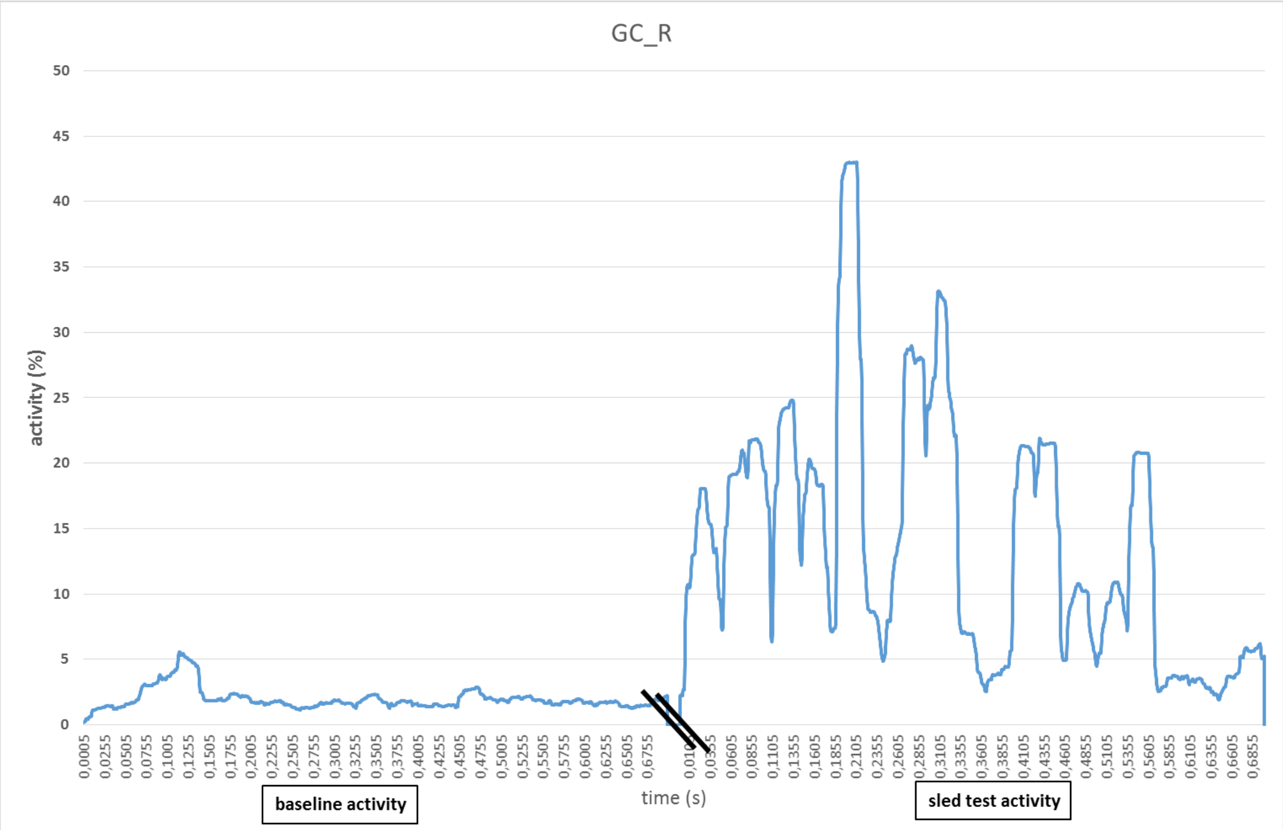

ES_L
activity (%)
time (s)
baseline activity
sled test activity

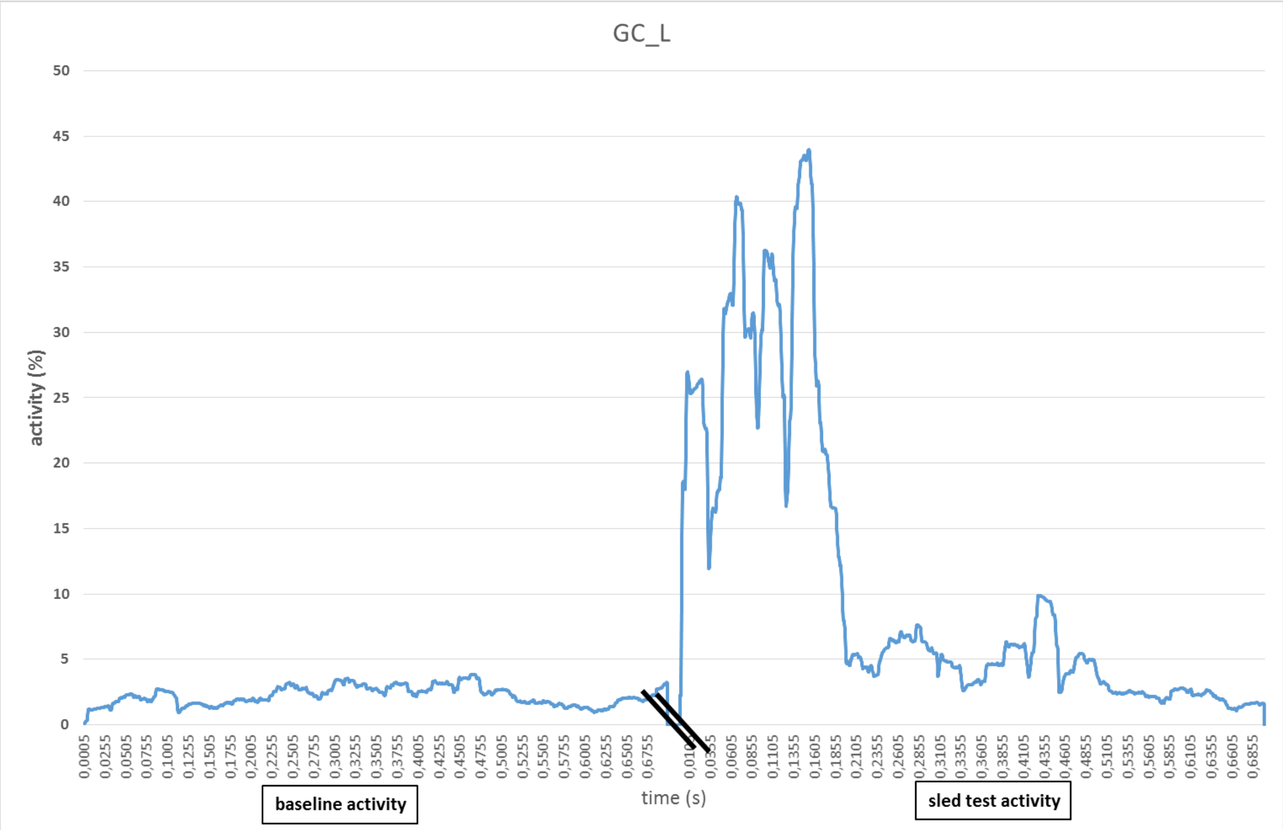

RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity

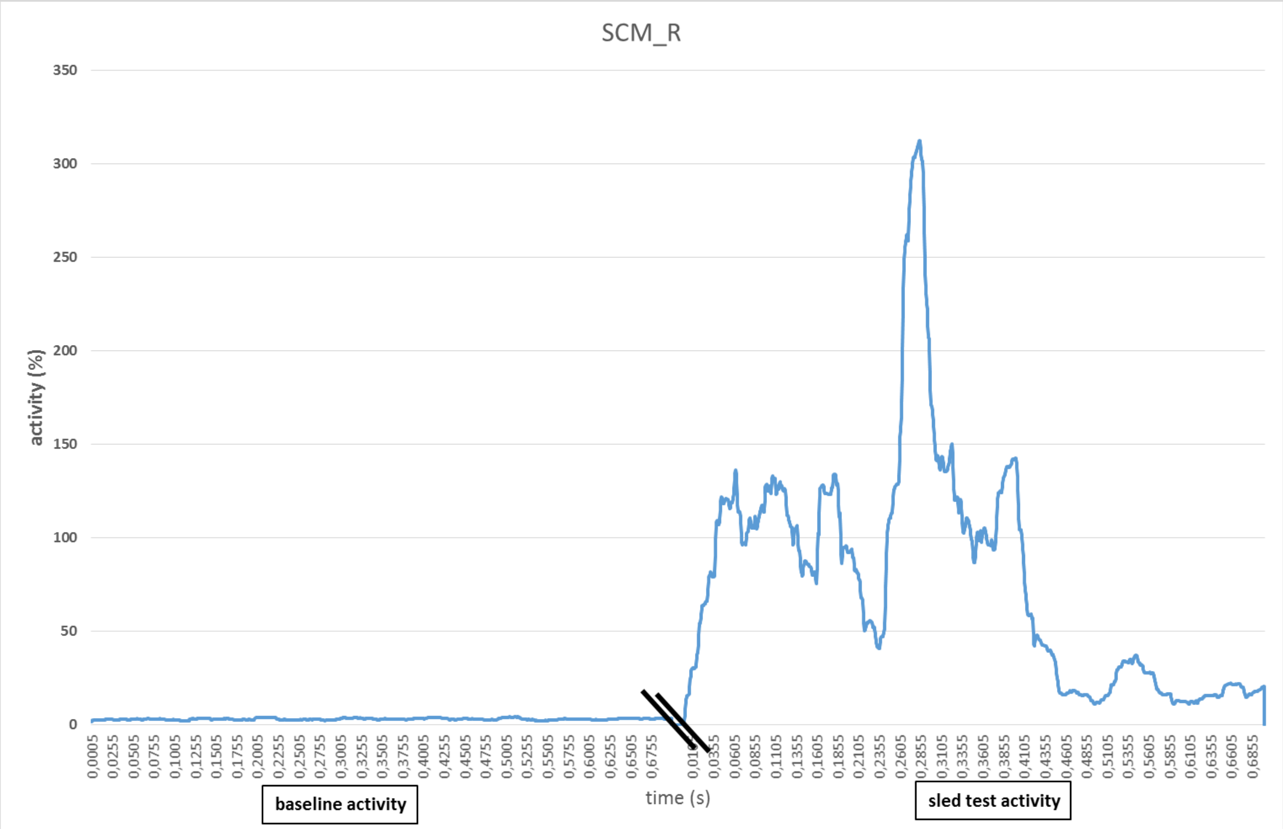

BF_R
activity (%)
time (s)
baseline activity
sled test activity

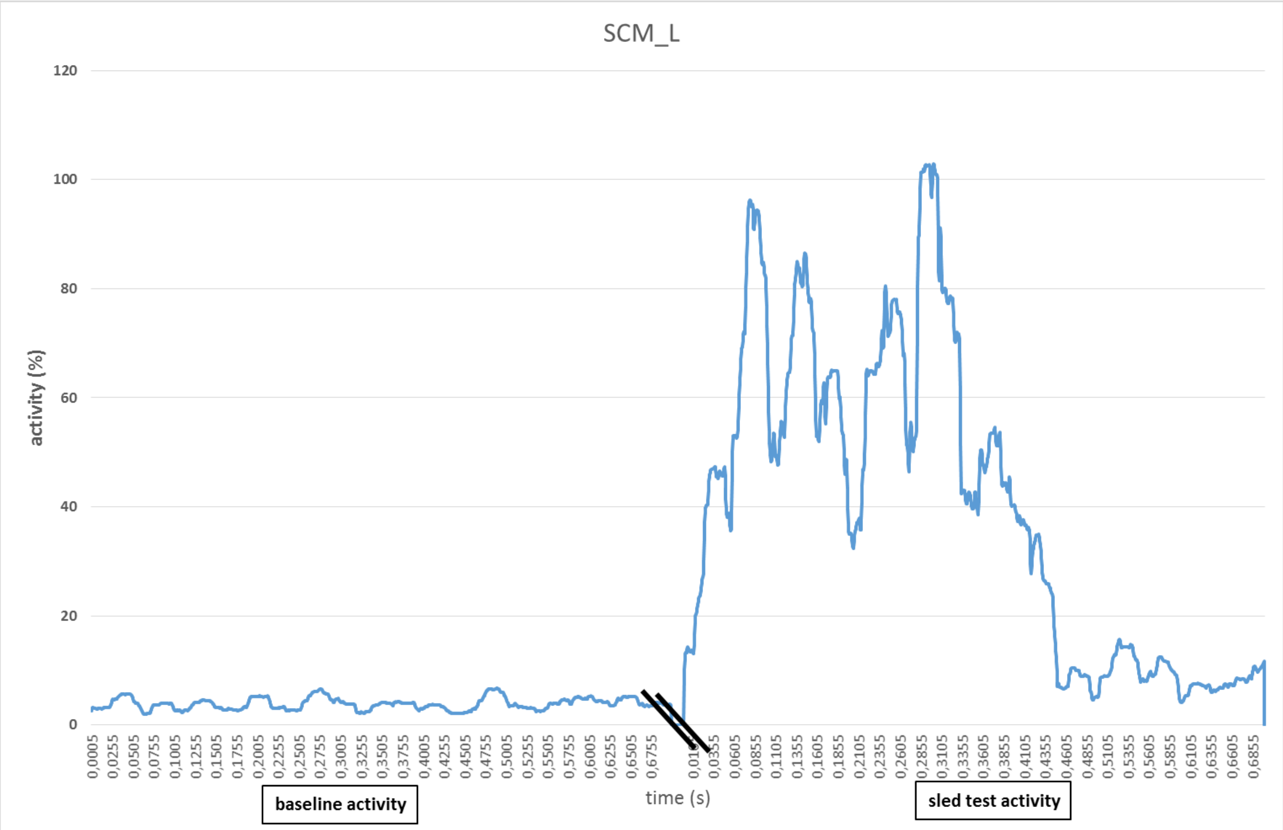

BF_L
activity (%)
time (s)
baseline activity
sled test activity

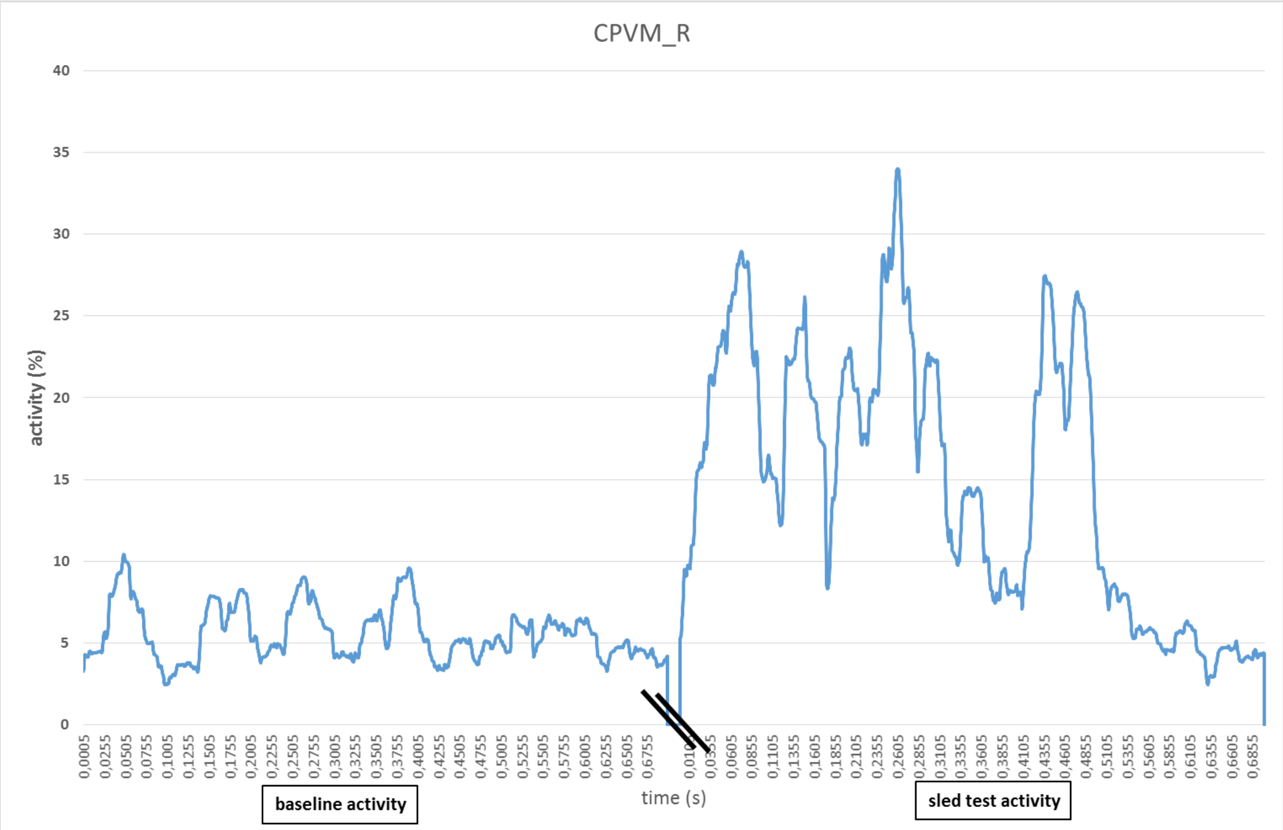

GC_R
activity (%)
time (s)
baseline activity
sled test activity

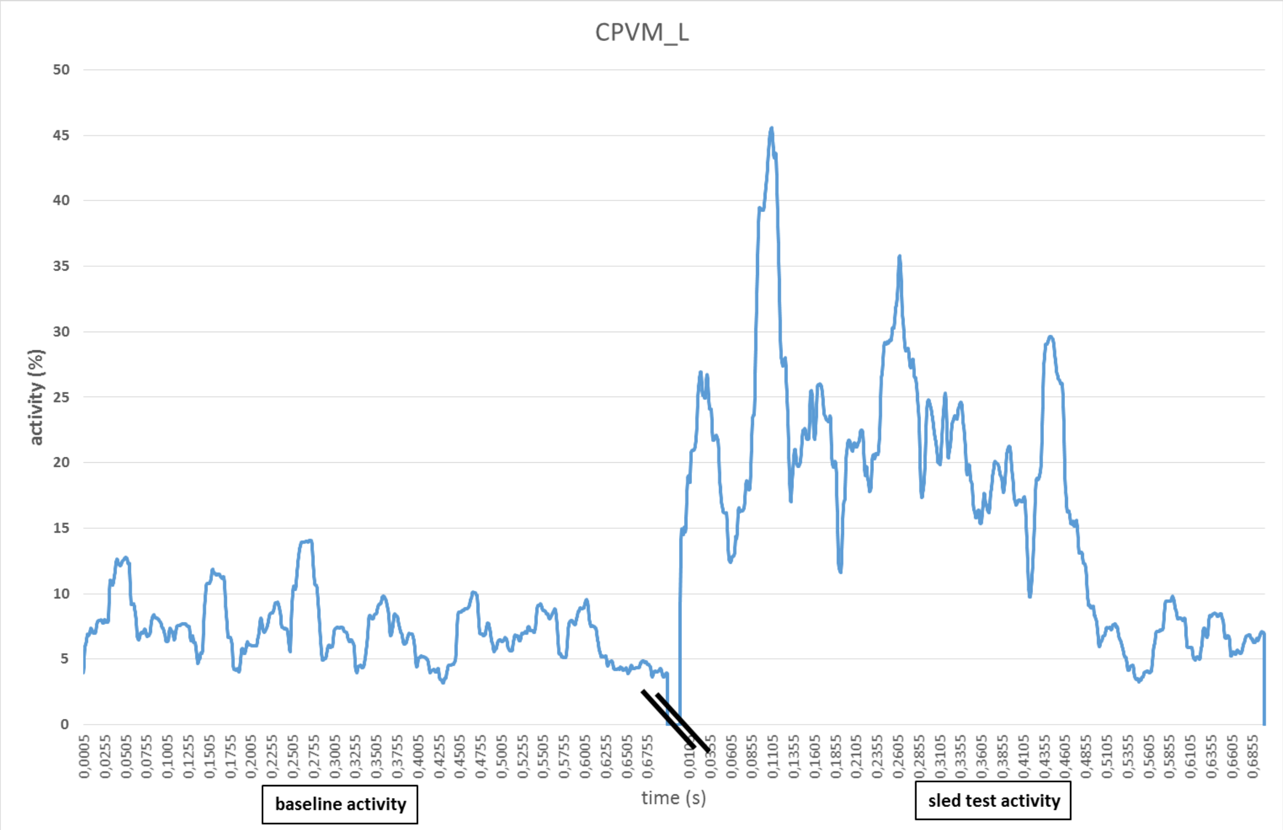

GC_L
activity (%)
time (s)
baseline activity
sled test activity

Trial 1776

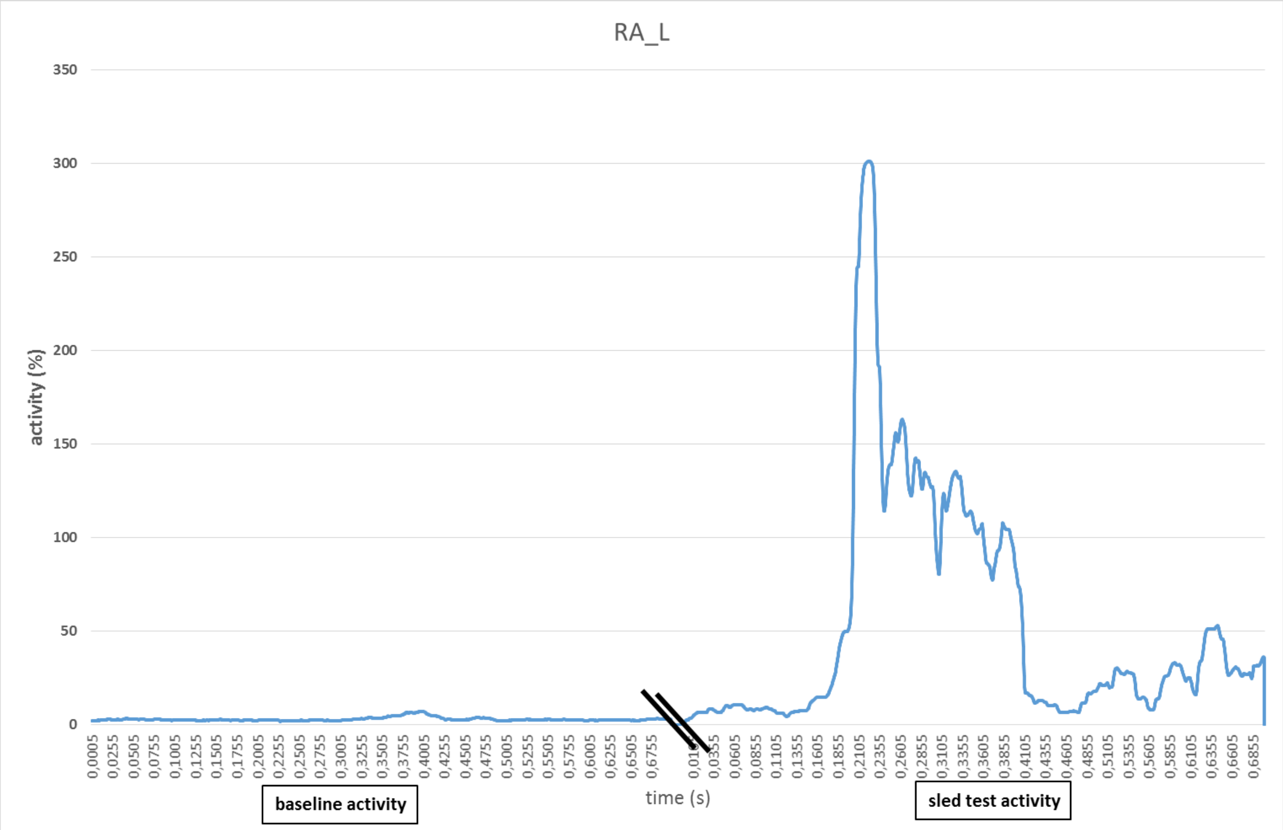

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

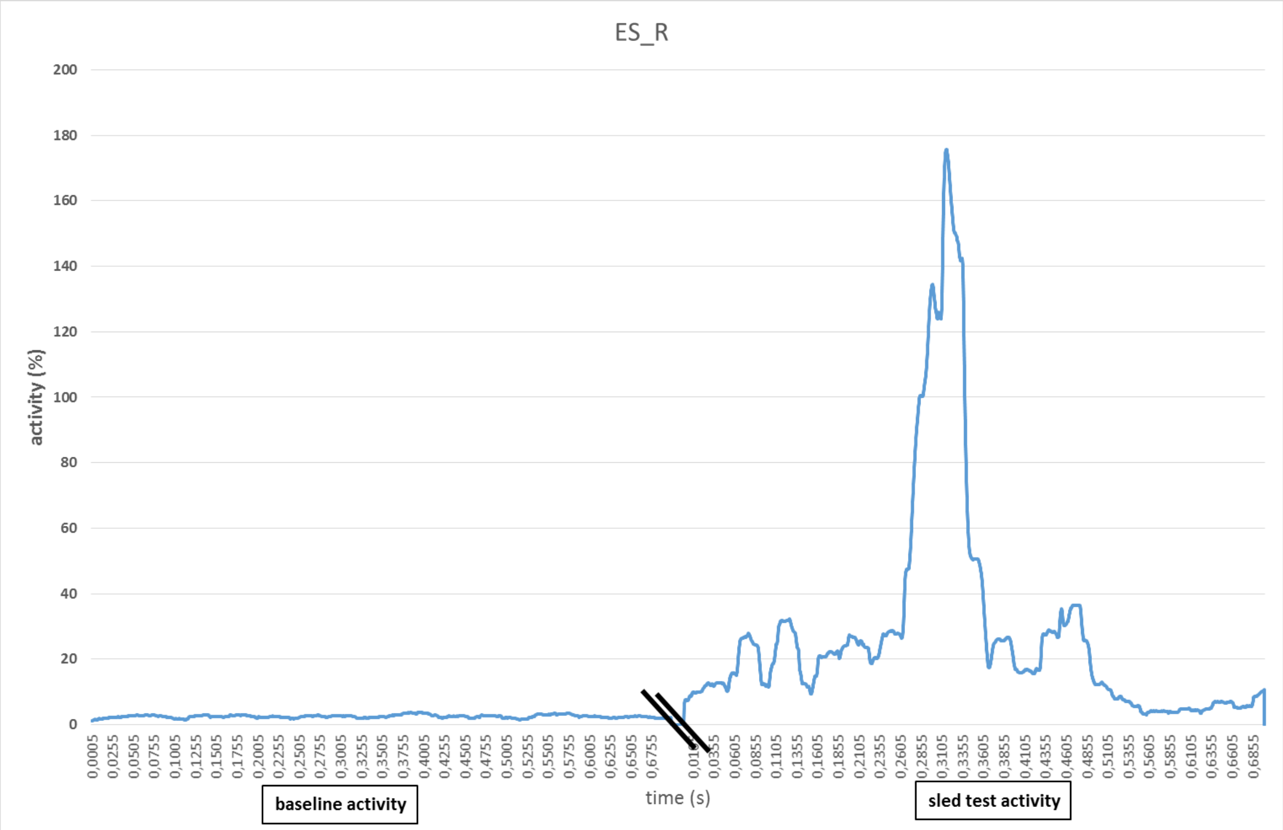

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

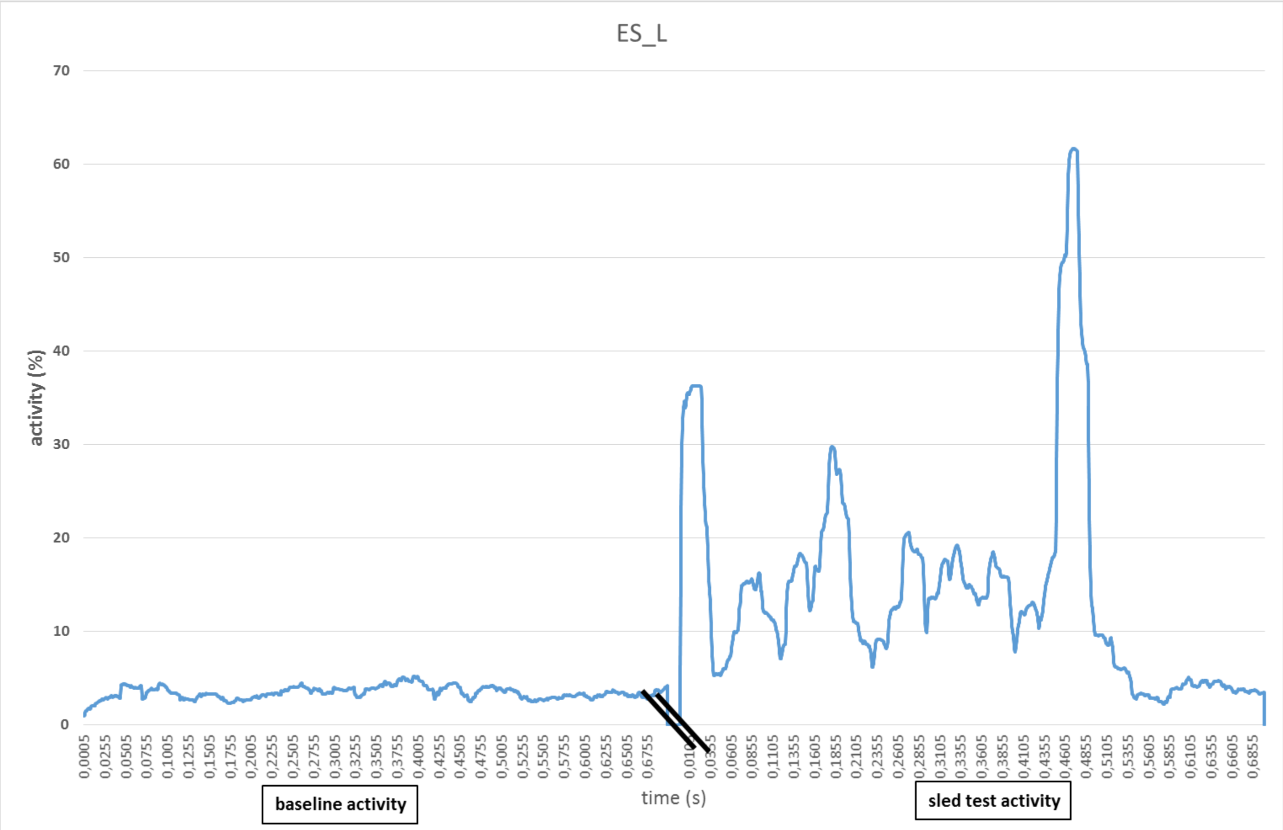

CPVM_R
activity (%)
time (s)
baseline activity
sled test activity

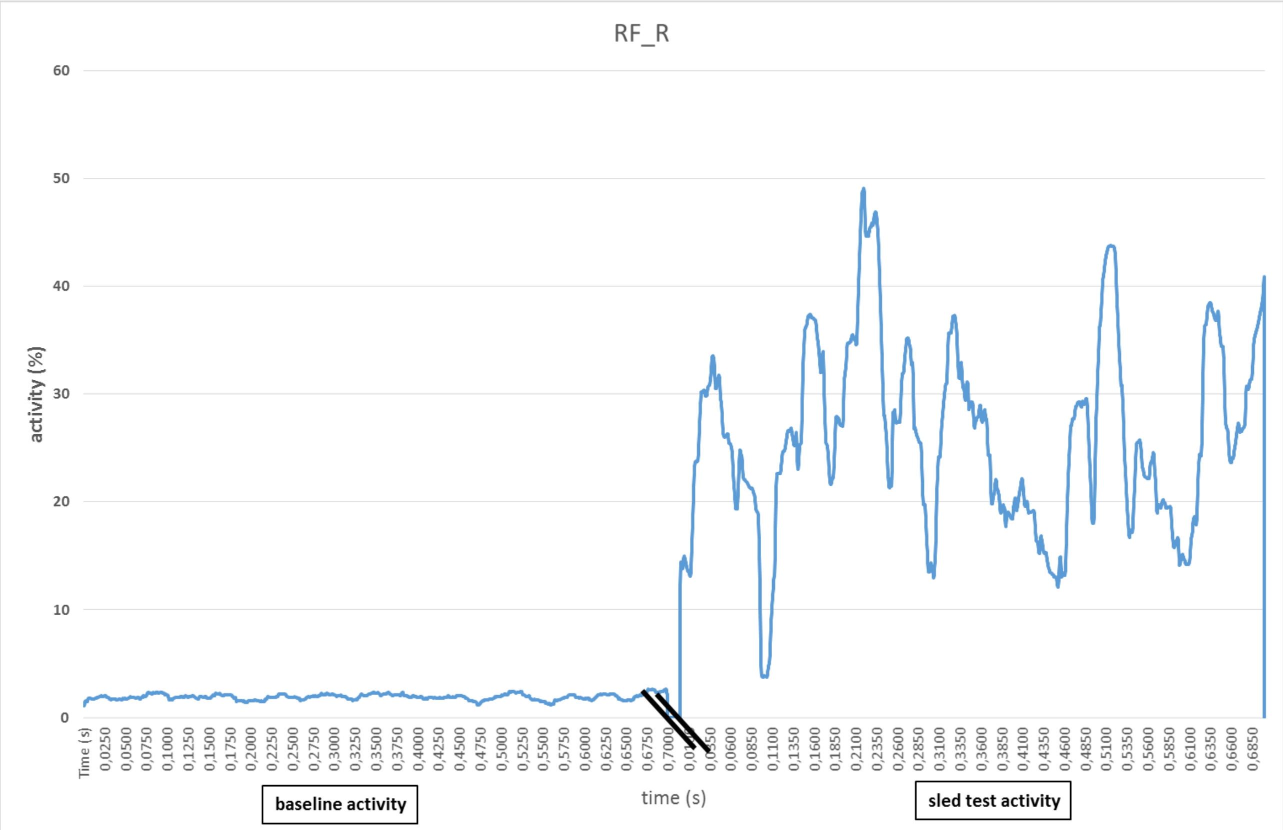

CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

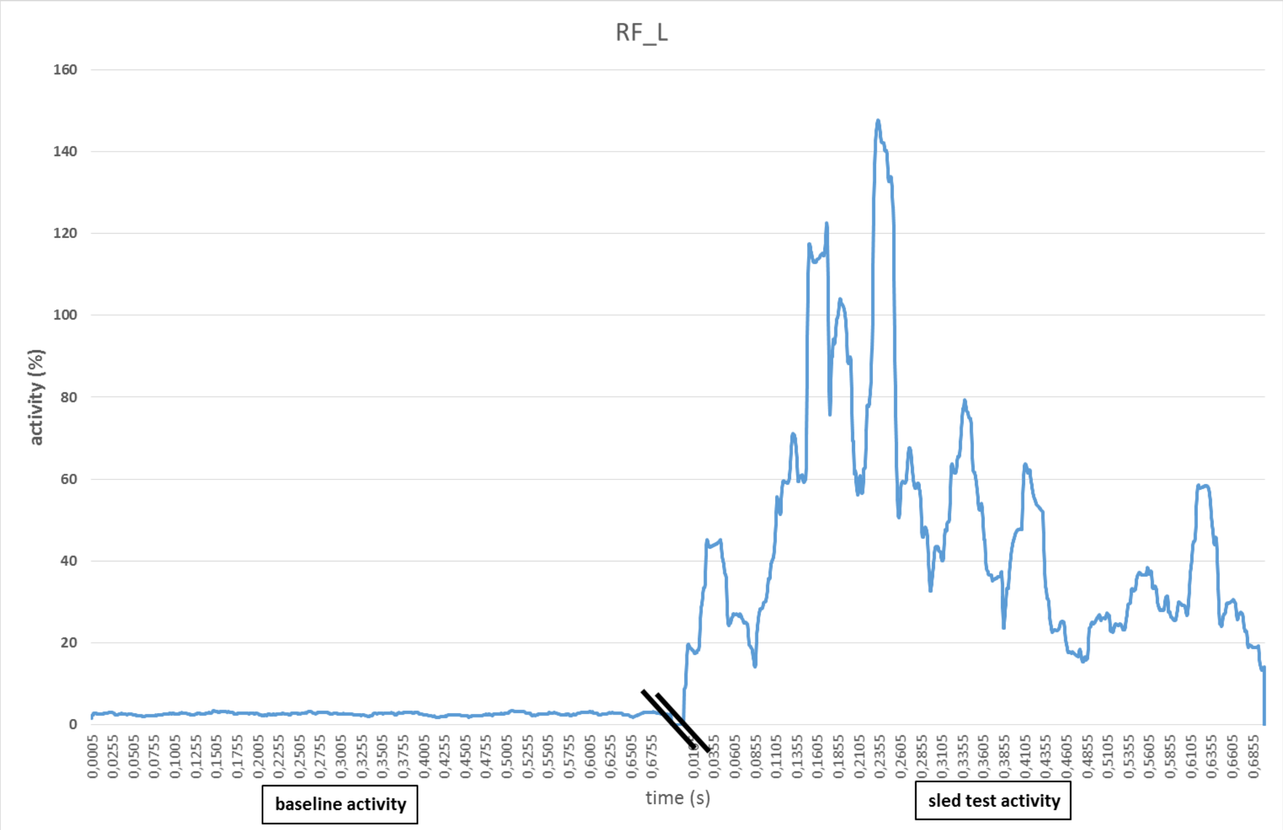

RA_R
activity (%)
time (s)
baseline activity
sled test activity

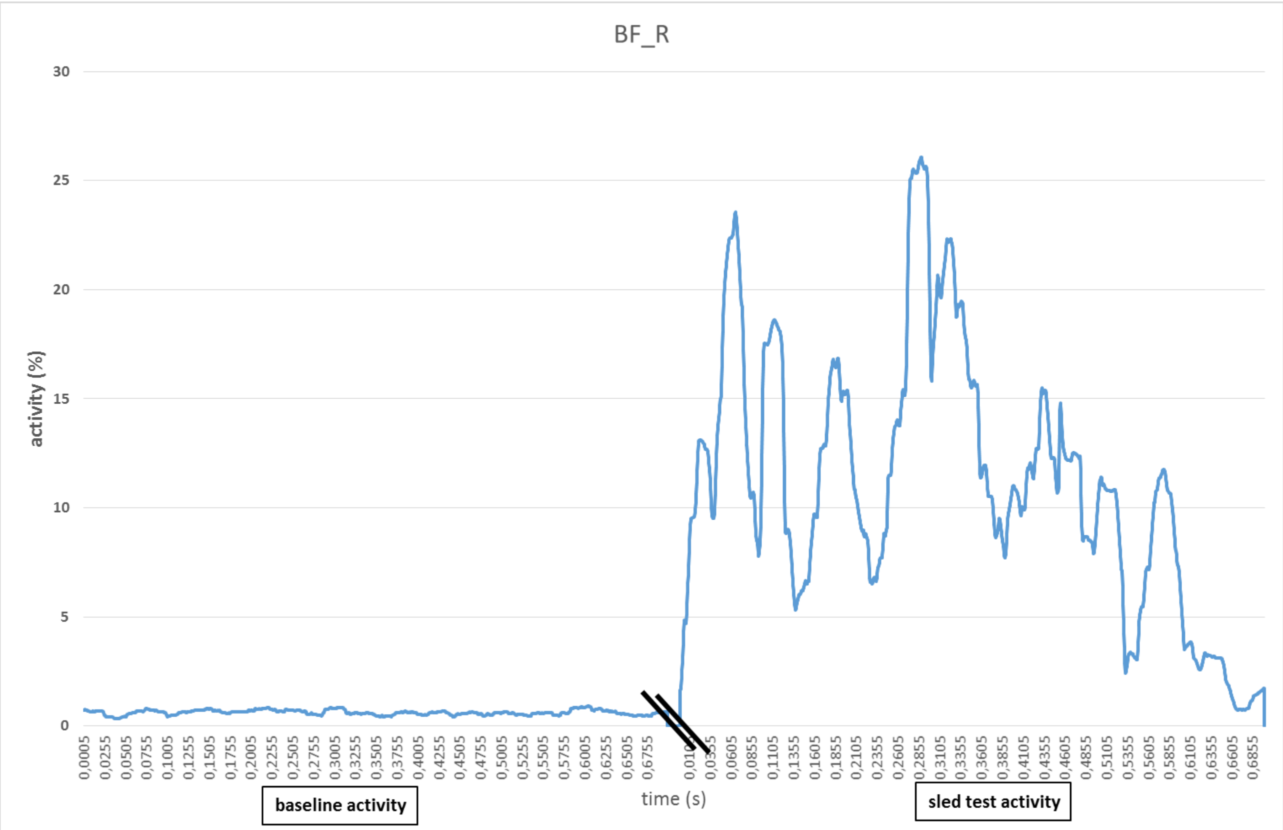

RA_L
activity (%)
time (s)
baseline activity
sled test activity

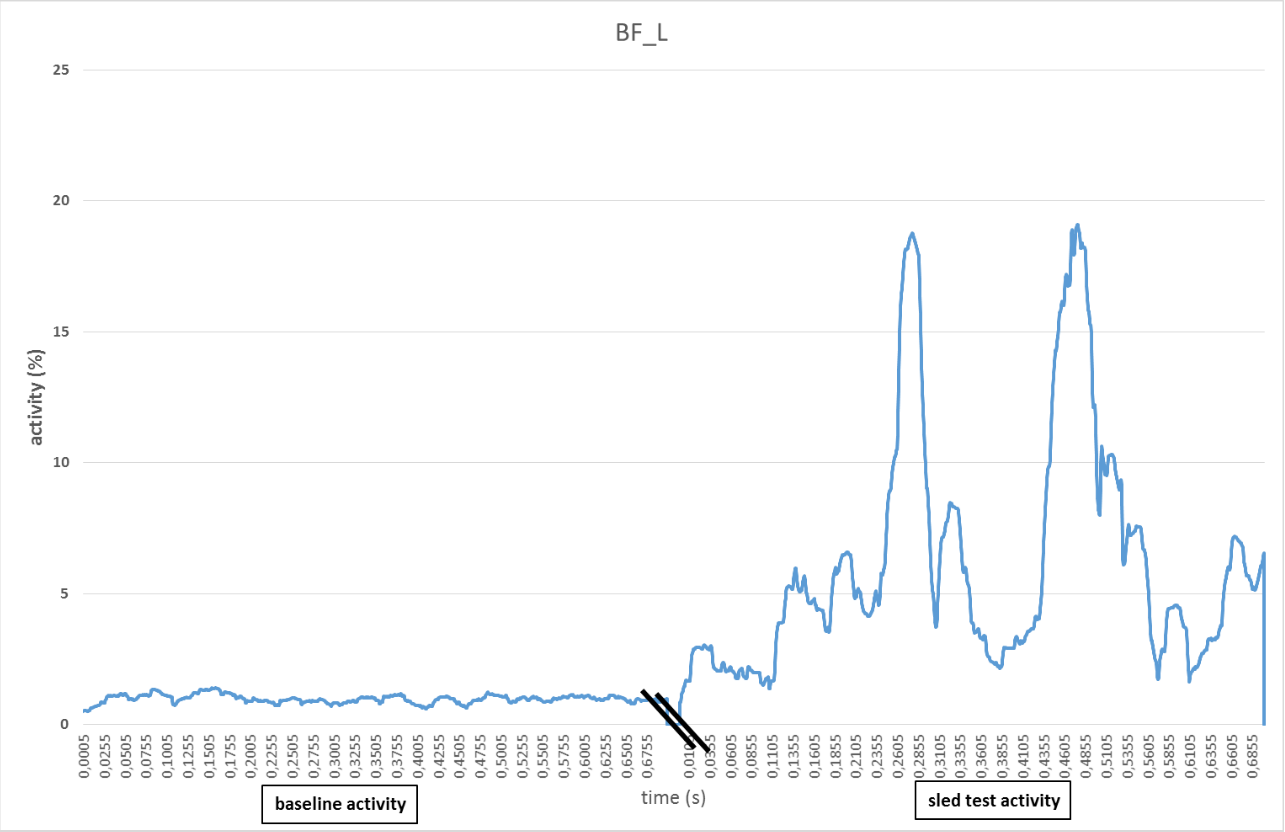

ES_R
activity (%)
time (s)
baseline activity
sled test activity

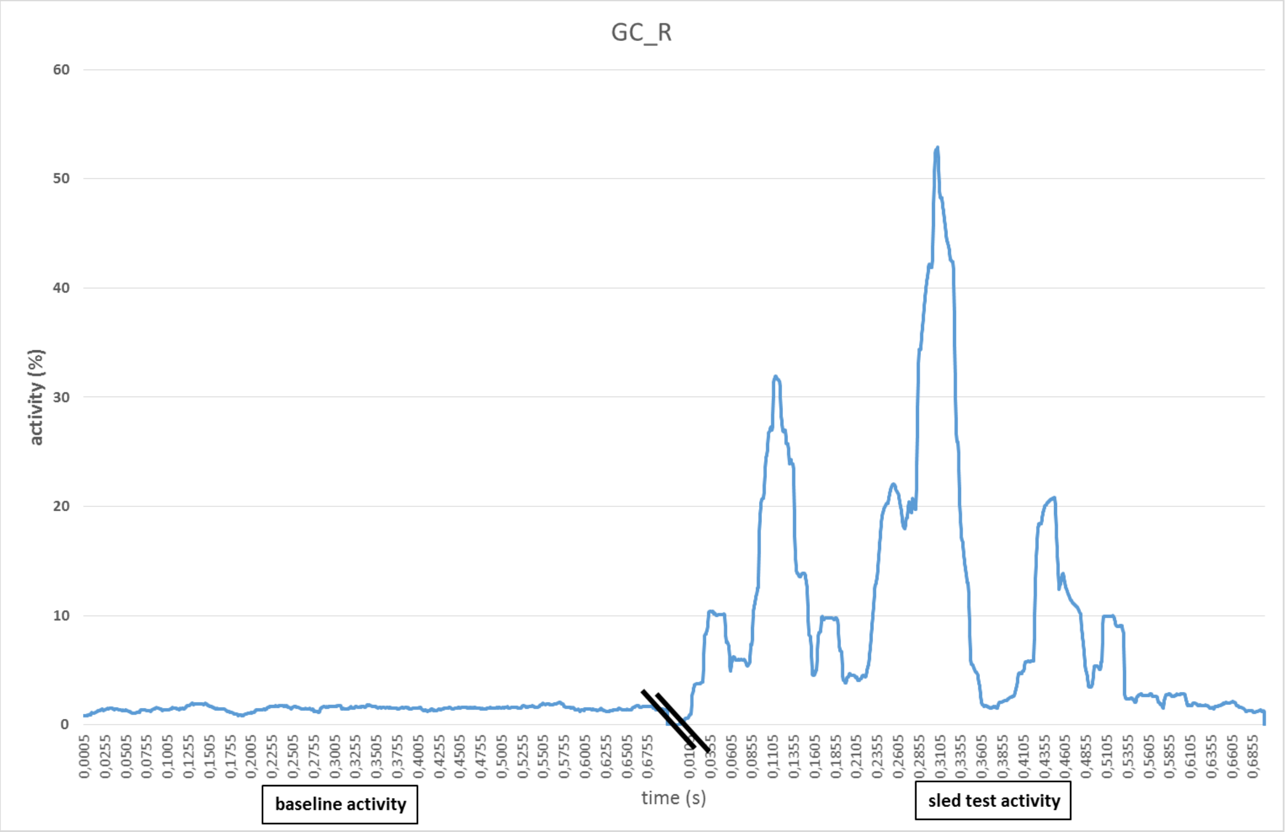

ES_L
activity (%)
time (s)
baseline activity
sled test activity

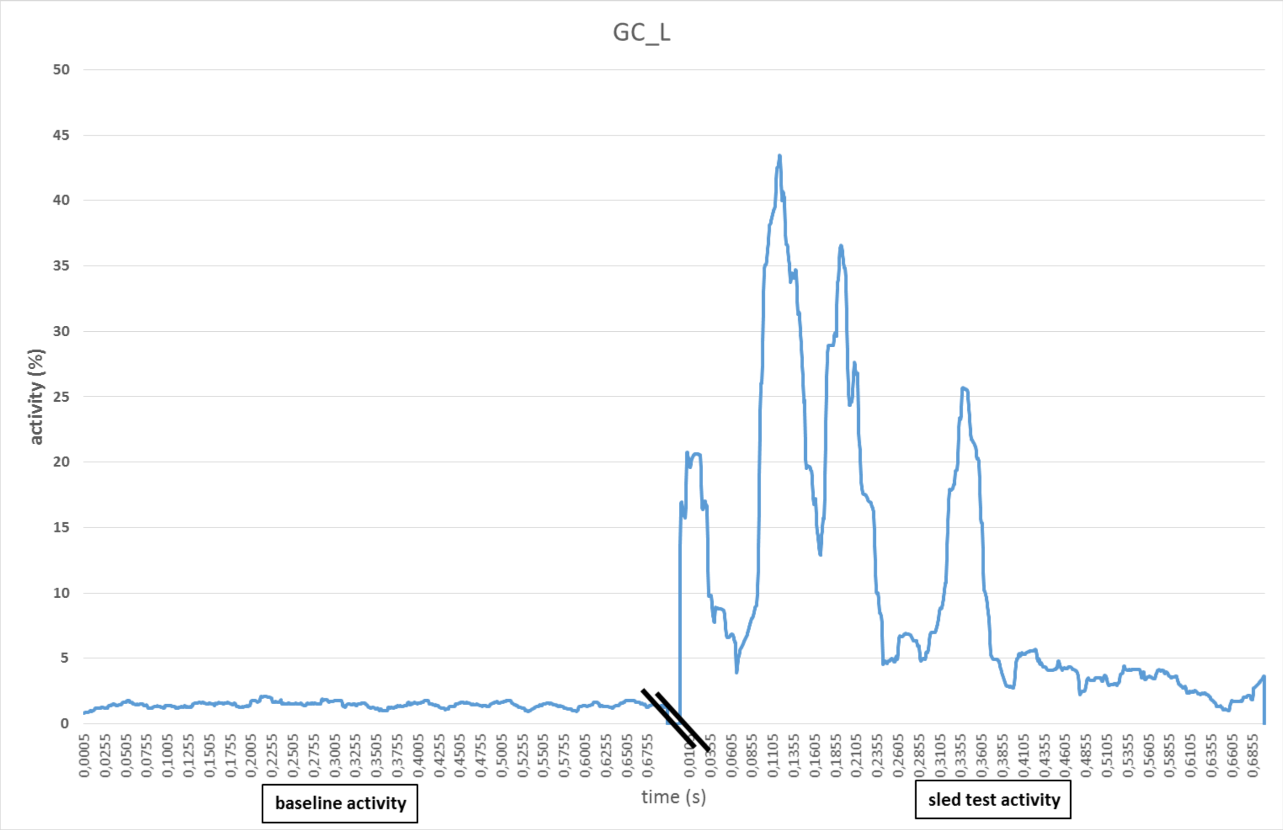

RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity

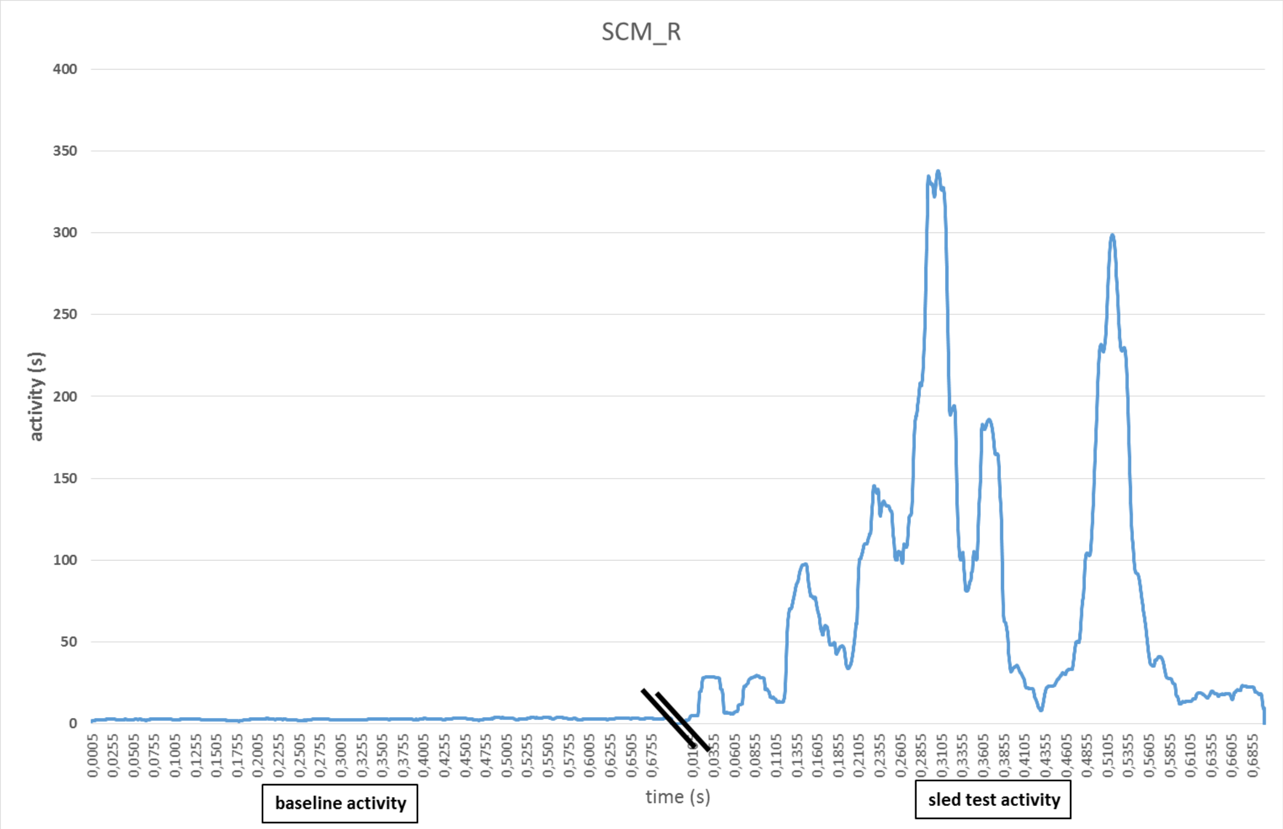

BF_R
activity (%)
time (s)
baseline activity
sled test activity

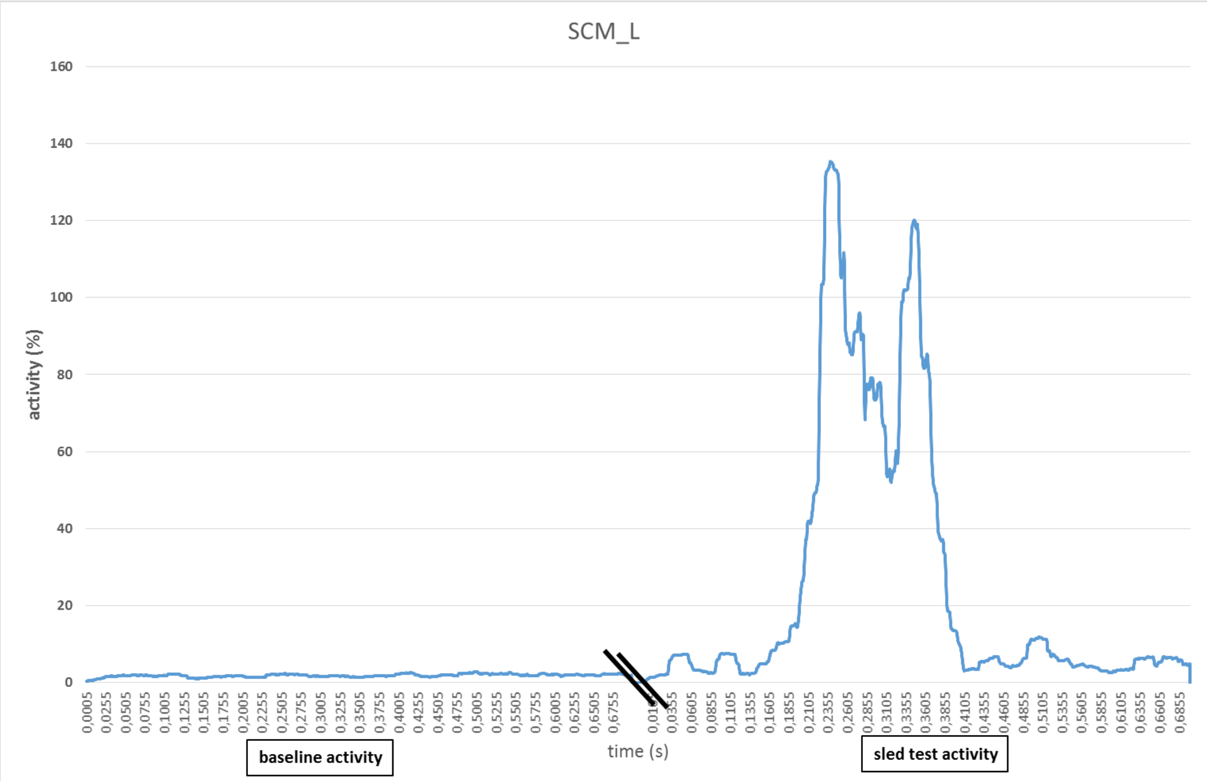

BF_L
activity (%)
time (s)
baseline activity
sled test activity


GC_R
activity (%)
time (s)
baseline activity
sled test activity

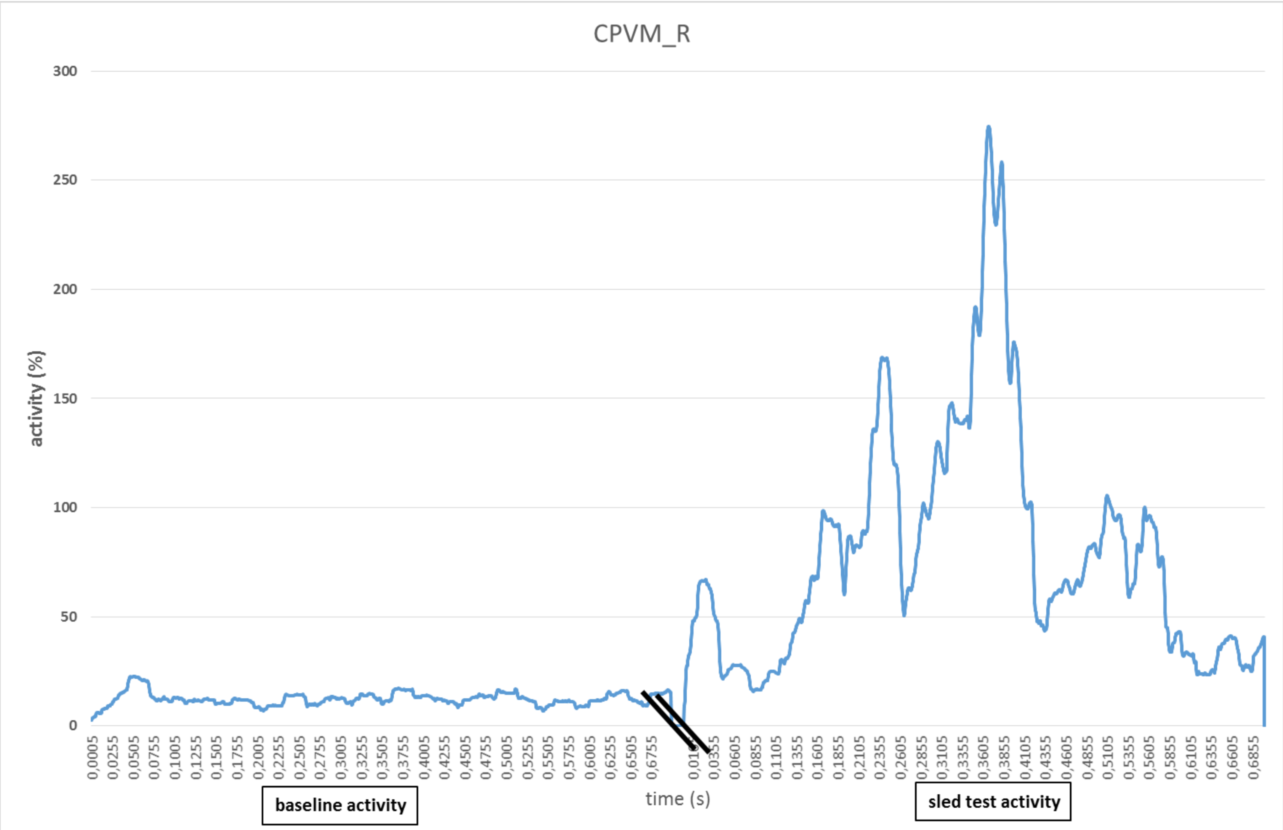

GC_L
activity (%)
time (s)
baseline activity
sled test activity

Trial 1778

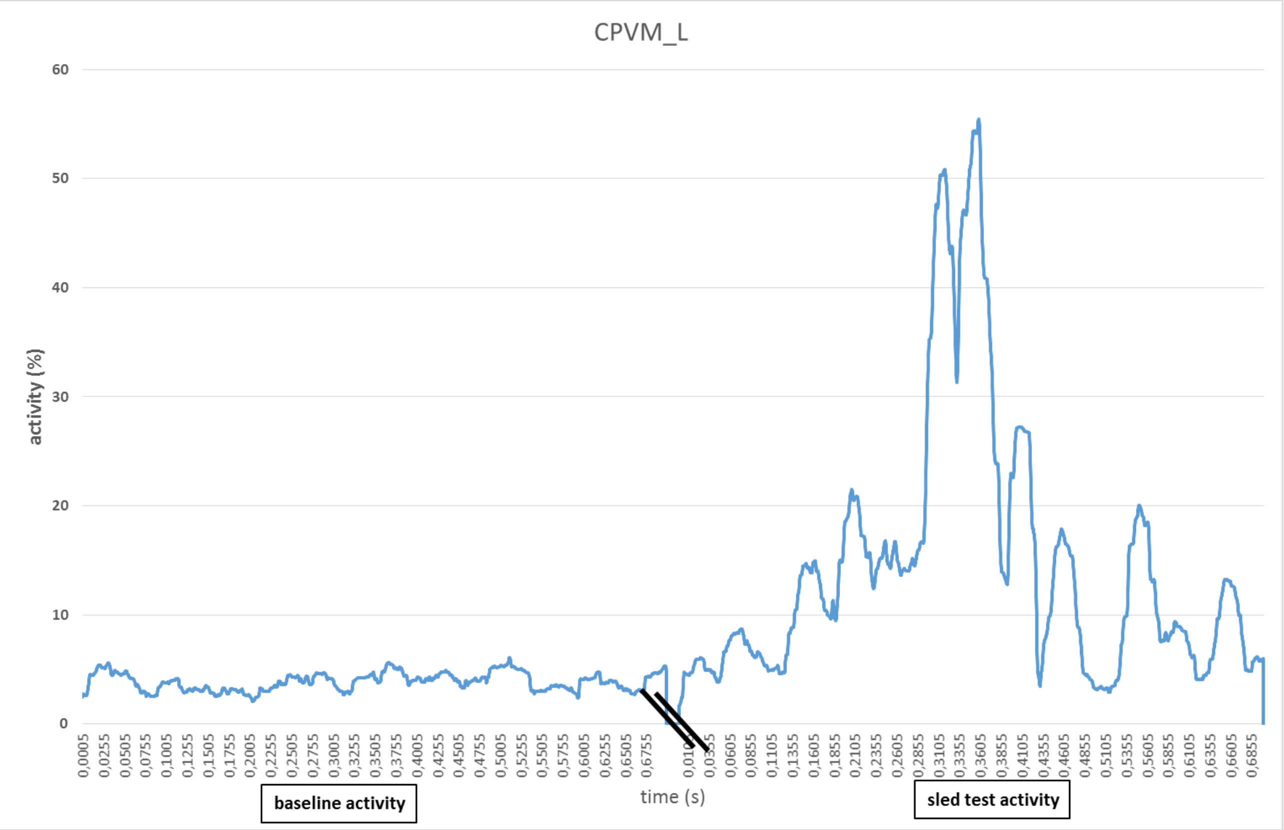

SCM_R
activity (s)
time (s)
baseline activity
sled test activity

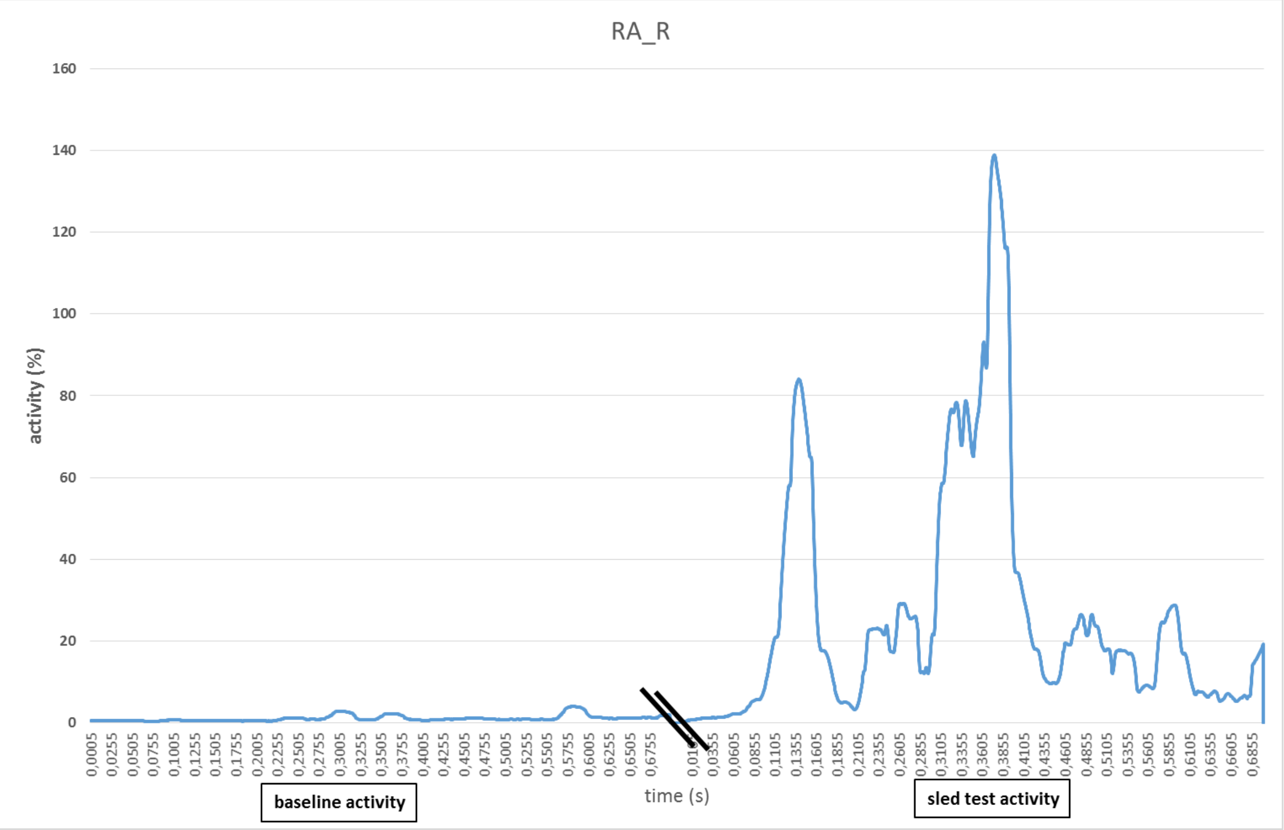


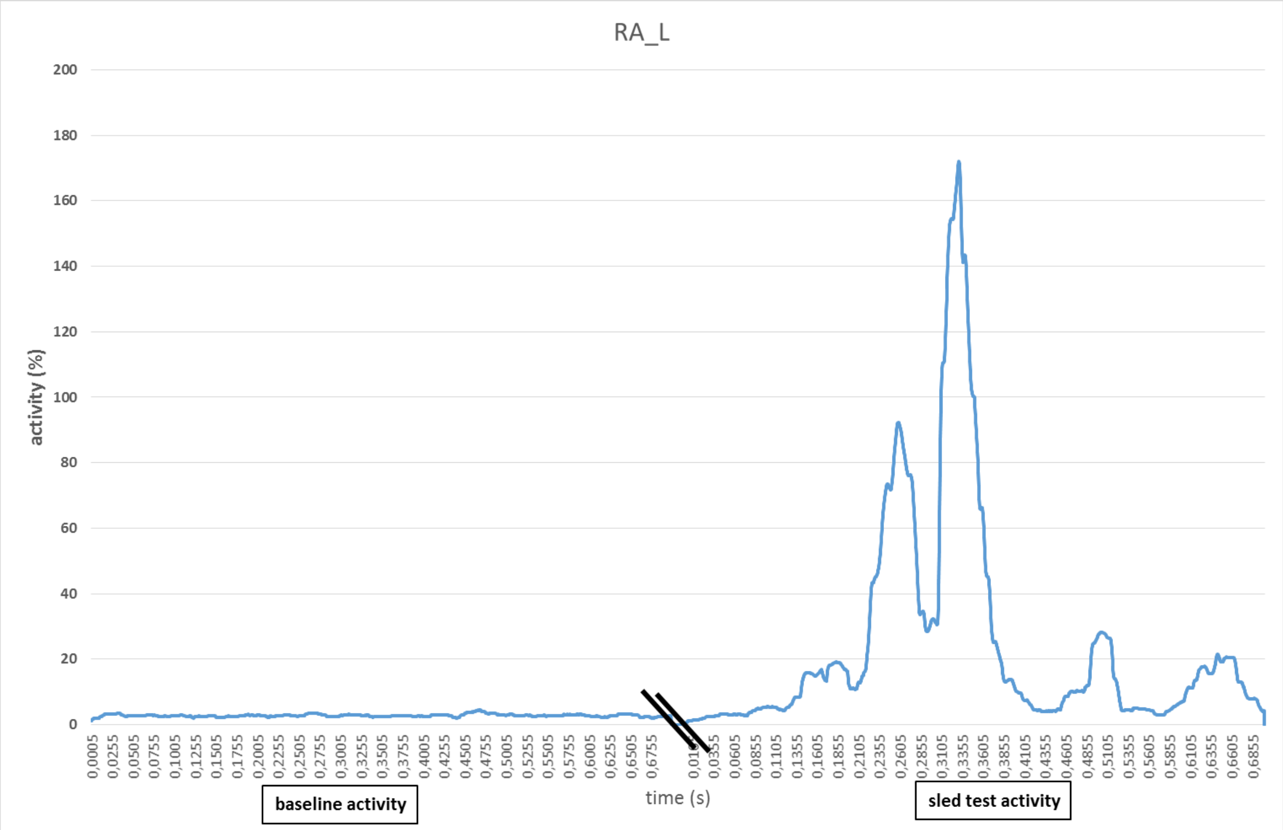
SCM_L
activity (%)
time (s)
baseline activity
sled test activity

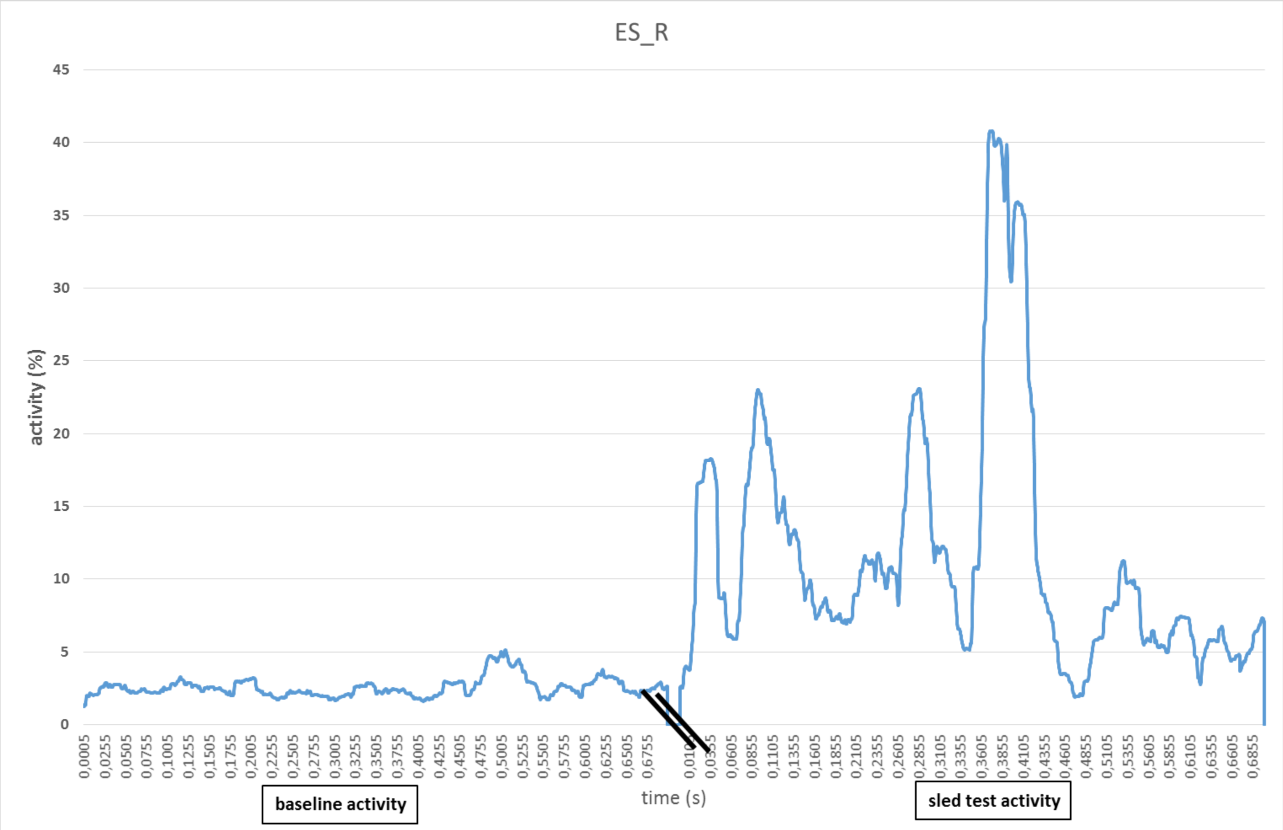



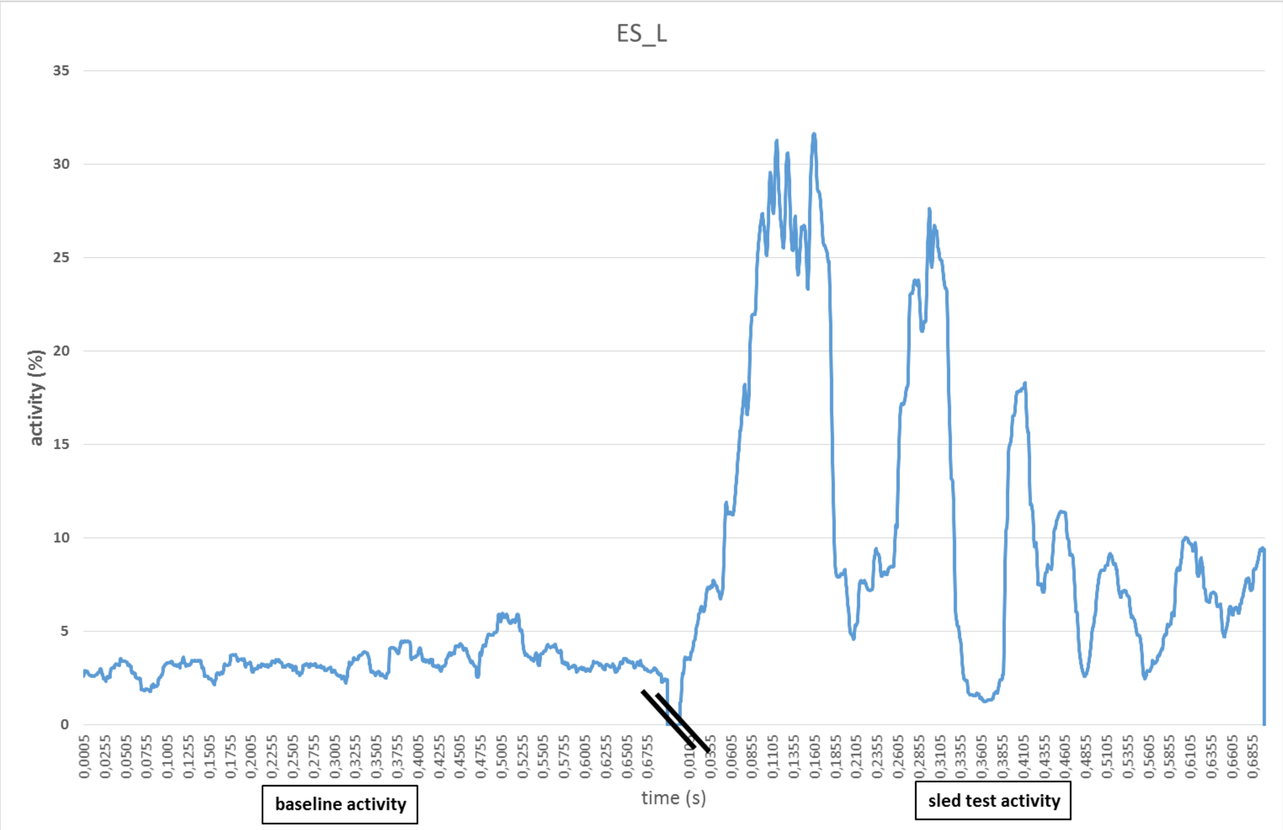
CPVM_R
activity (%)
time (s)
baseline activity
sled test activity

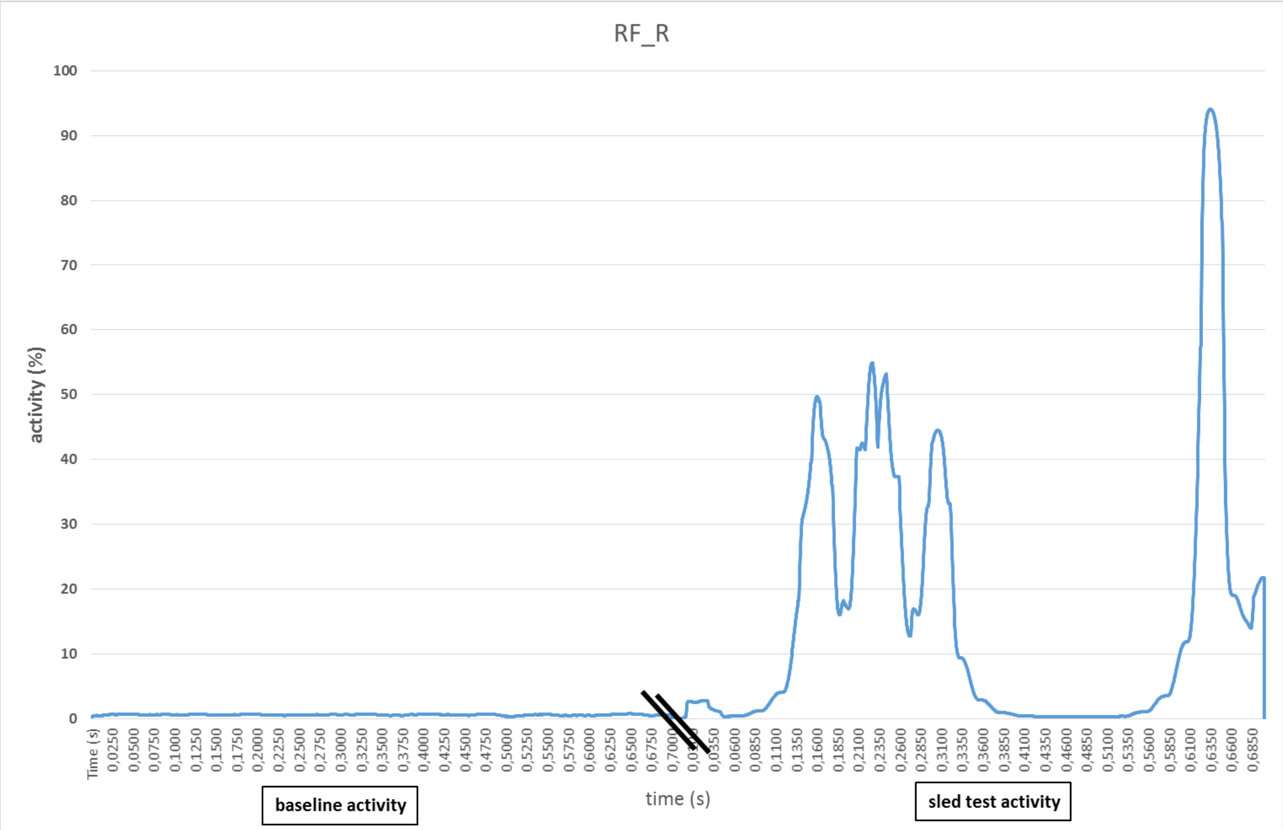

CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

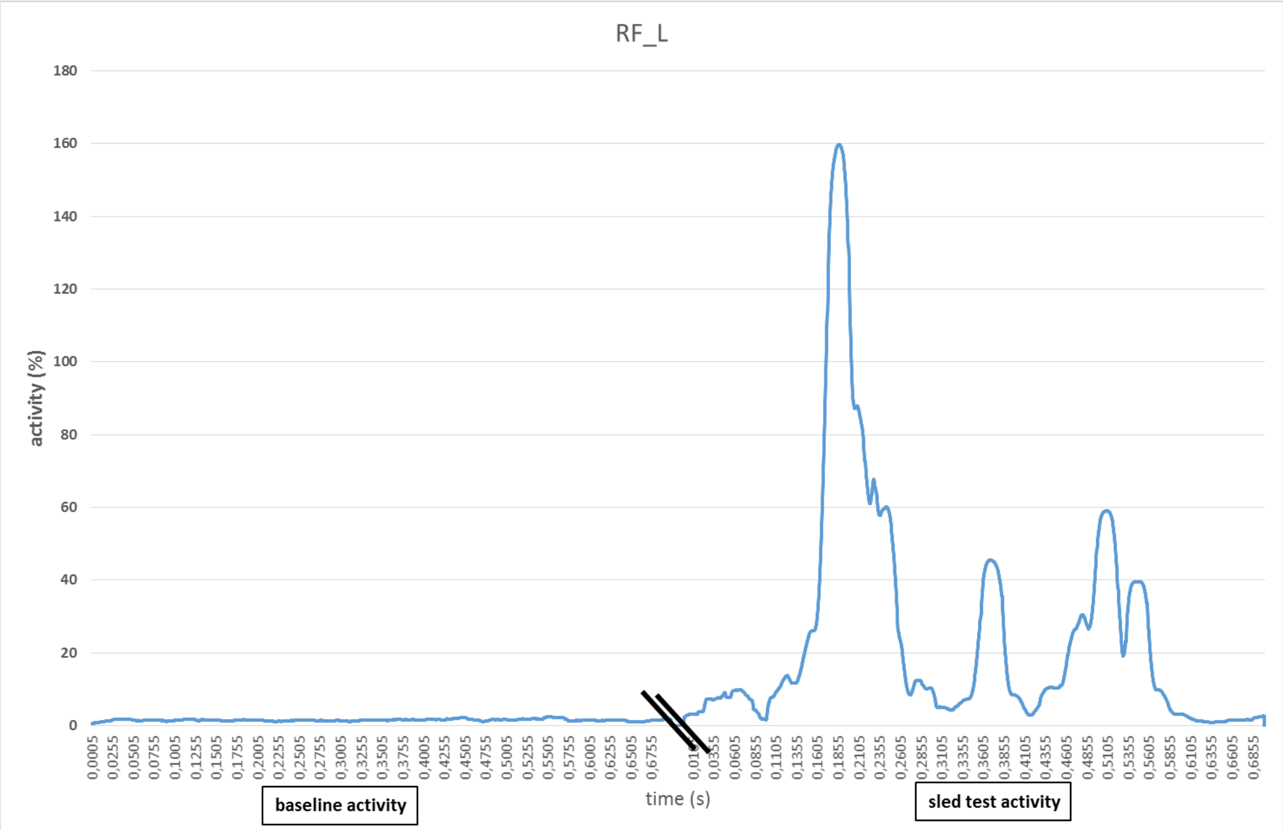

RA_R
activity (%)
time (s)
baseline activity
sled test activity

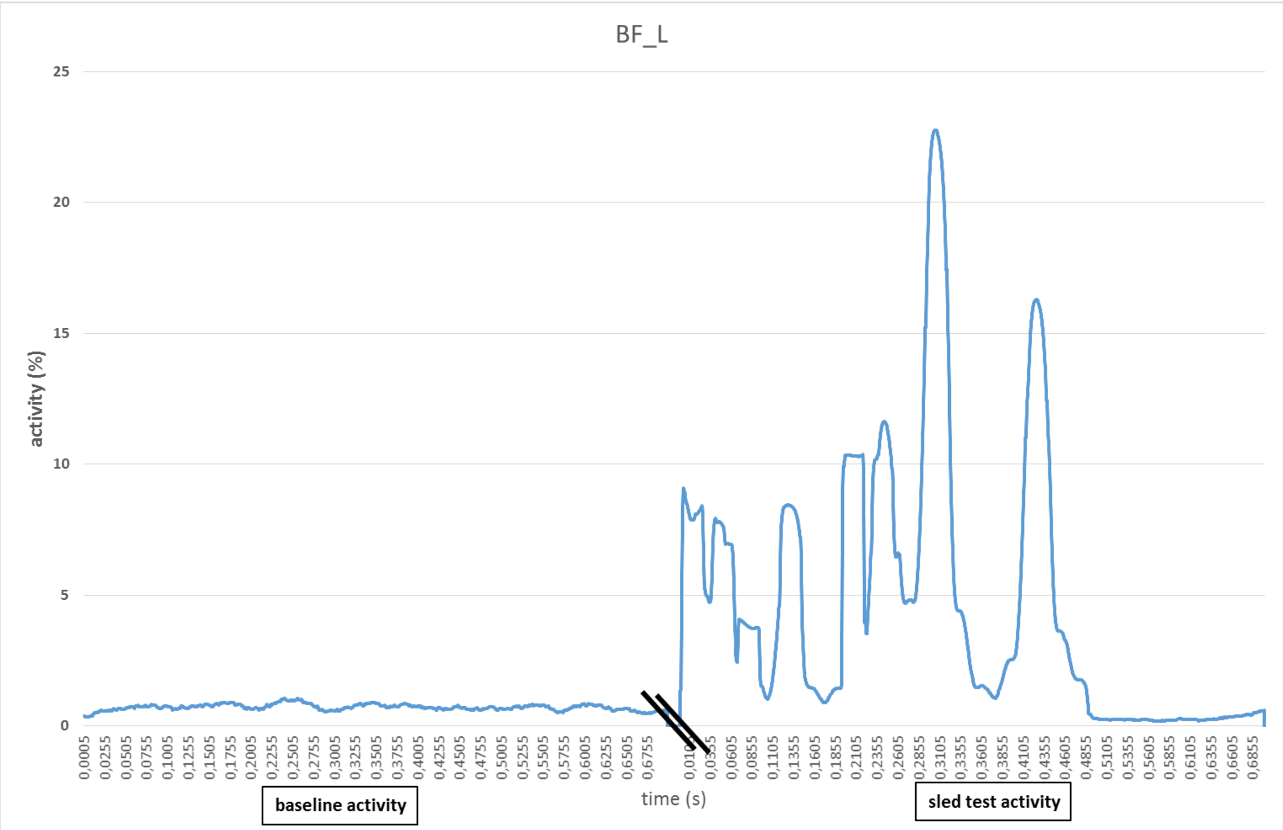

RA_L
activity (%)
200
180
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

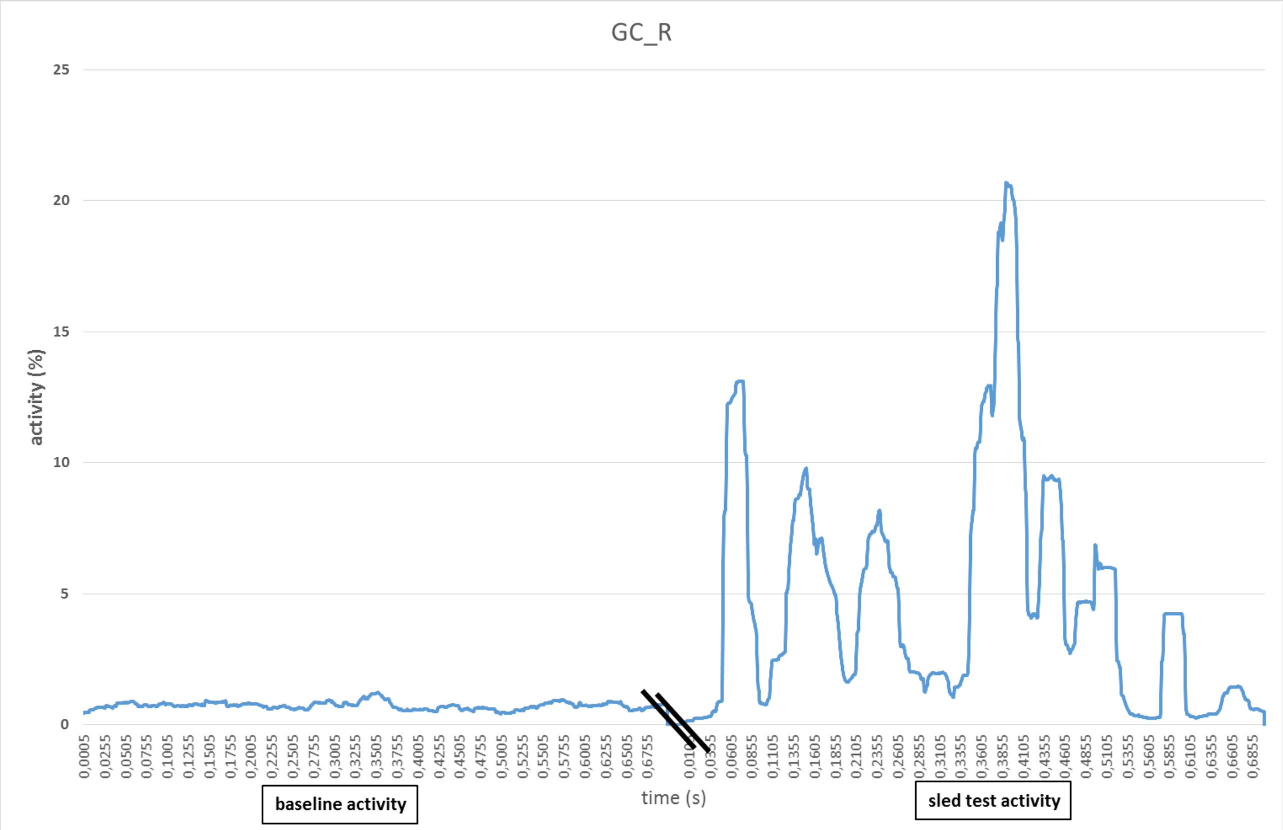

ES_R
activity (%)
45
40
35
30
25
20
15
10
5
0
time (s)
baseline activity
sled test activity

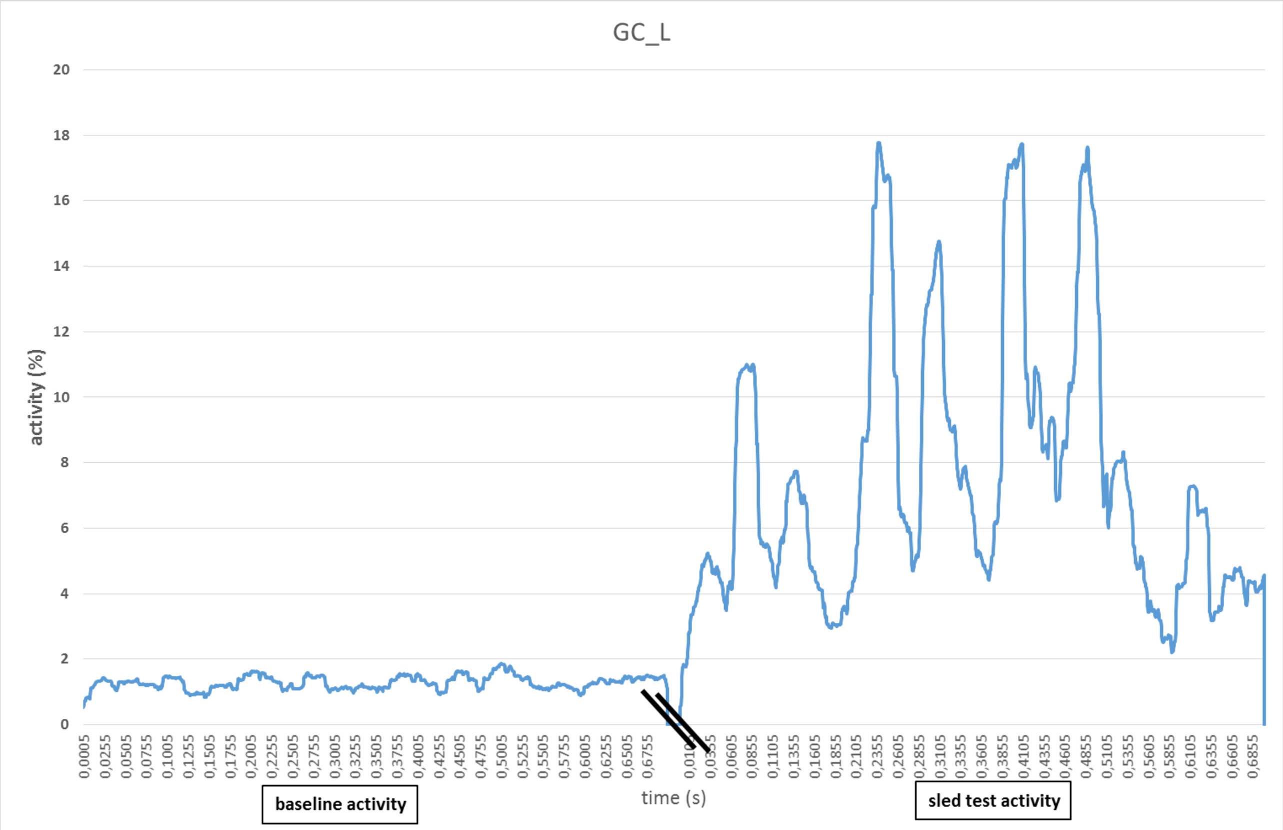

ES_L
activity (%)
time (s)
baseline activity
sled test activity


RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
180
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

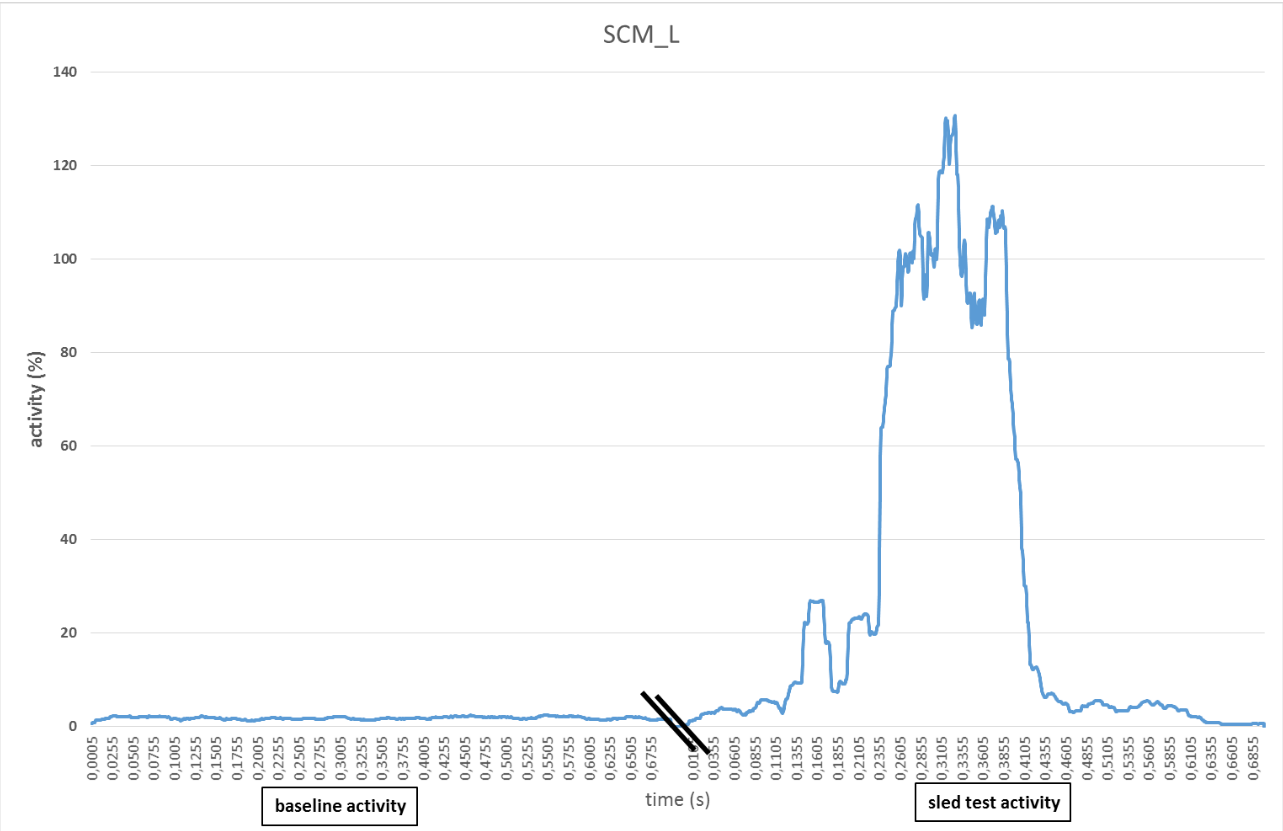

BF_L
activity (%)
25
20
15
10
5
0
time (s)
baseline activity
sled test activity

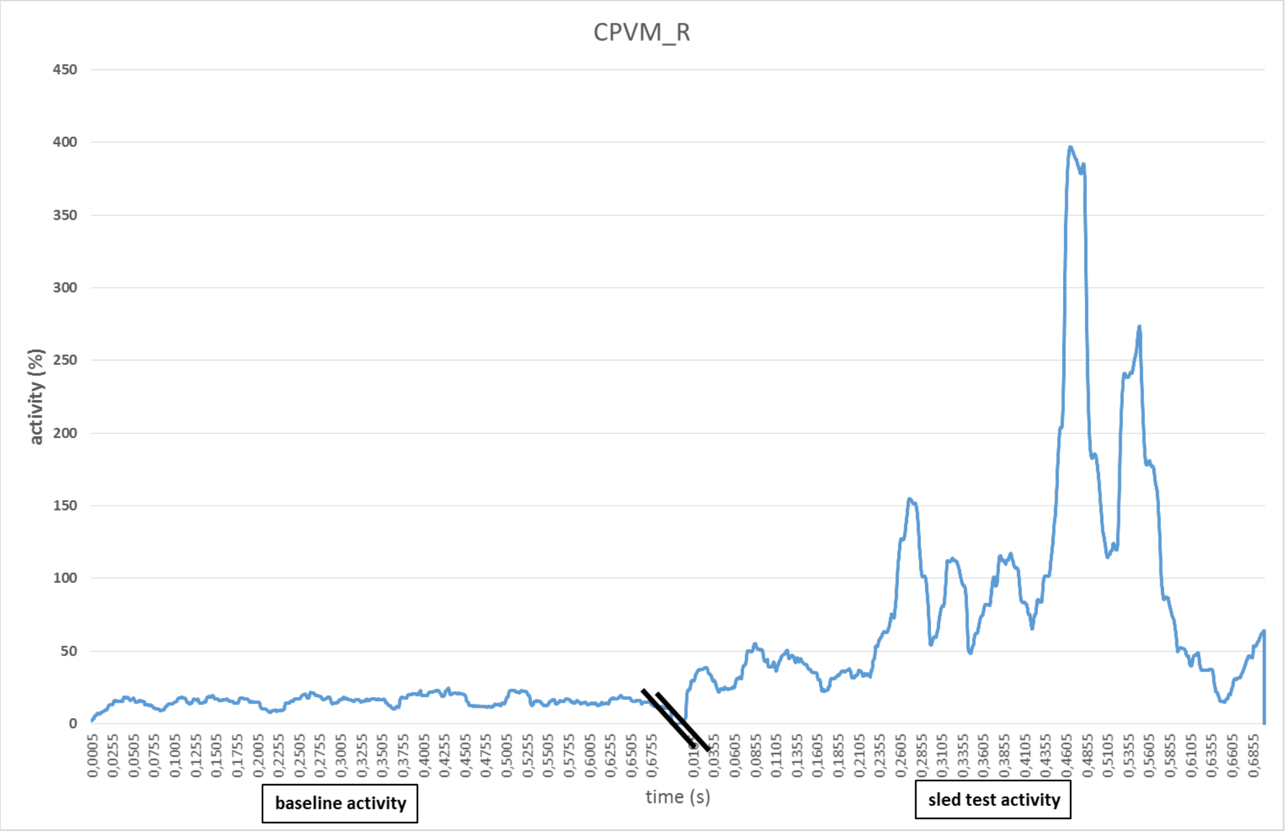

GC_R
25
20
15
10
5
0
activity (%)
time (s)
baseline activity
sled test activity

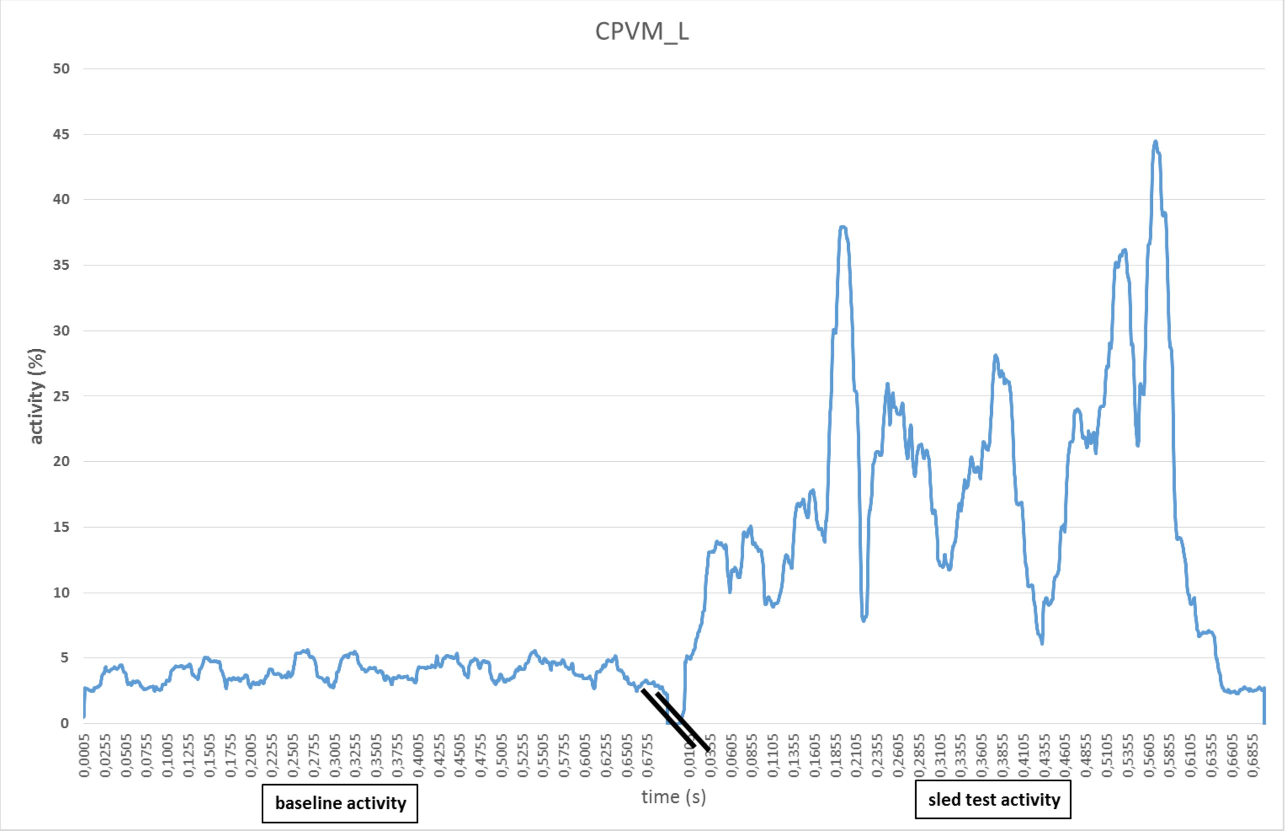

GC_L
20
18
16
14
12
10
8
6
4
2
0
activity (%)
time (s)
baseline activity
sled test activity

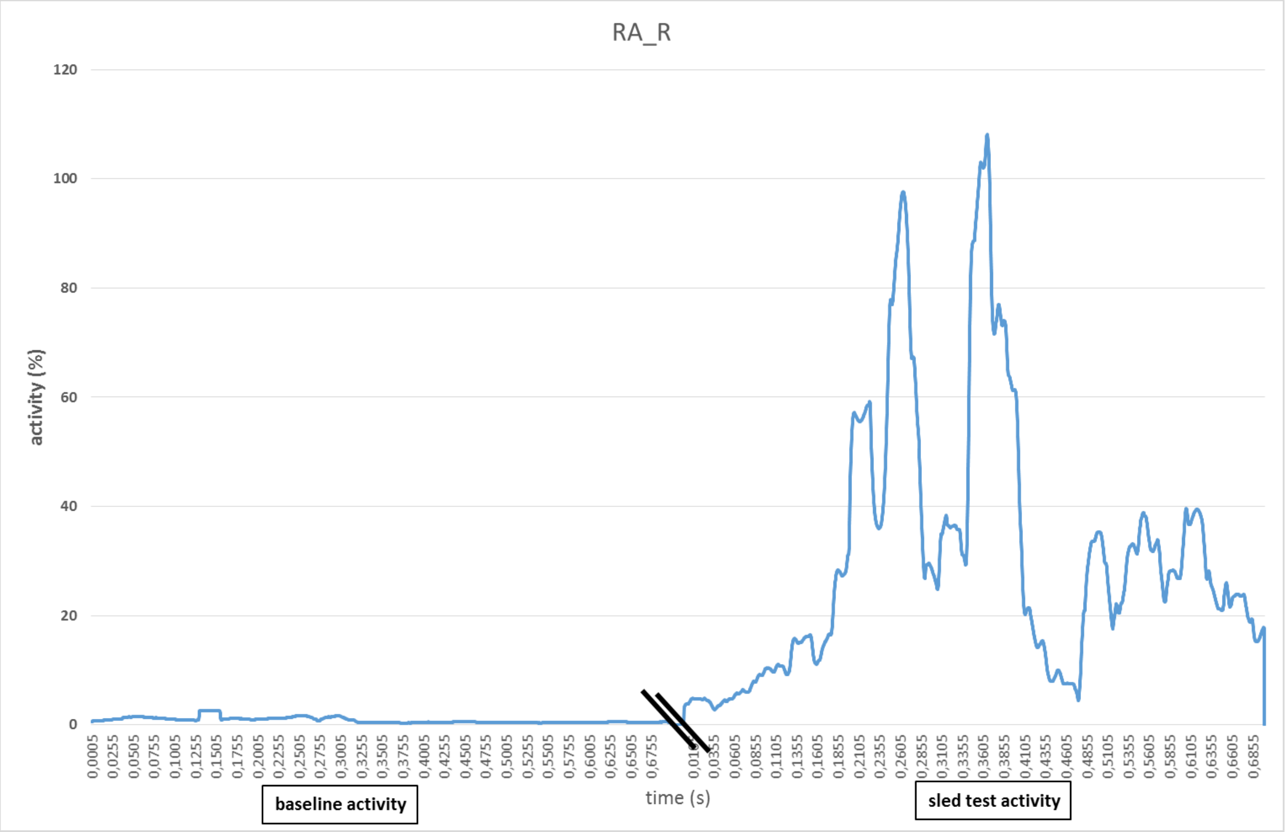
Trial 1779


SCM_R
activity (%)
400
350
300
250
200
150
100
50
0
time (s)
baseline activity
sled test activity

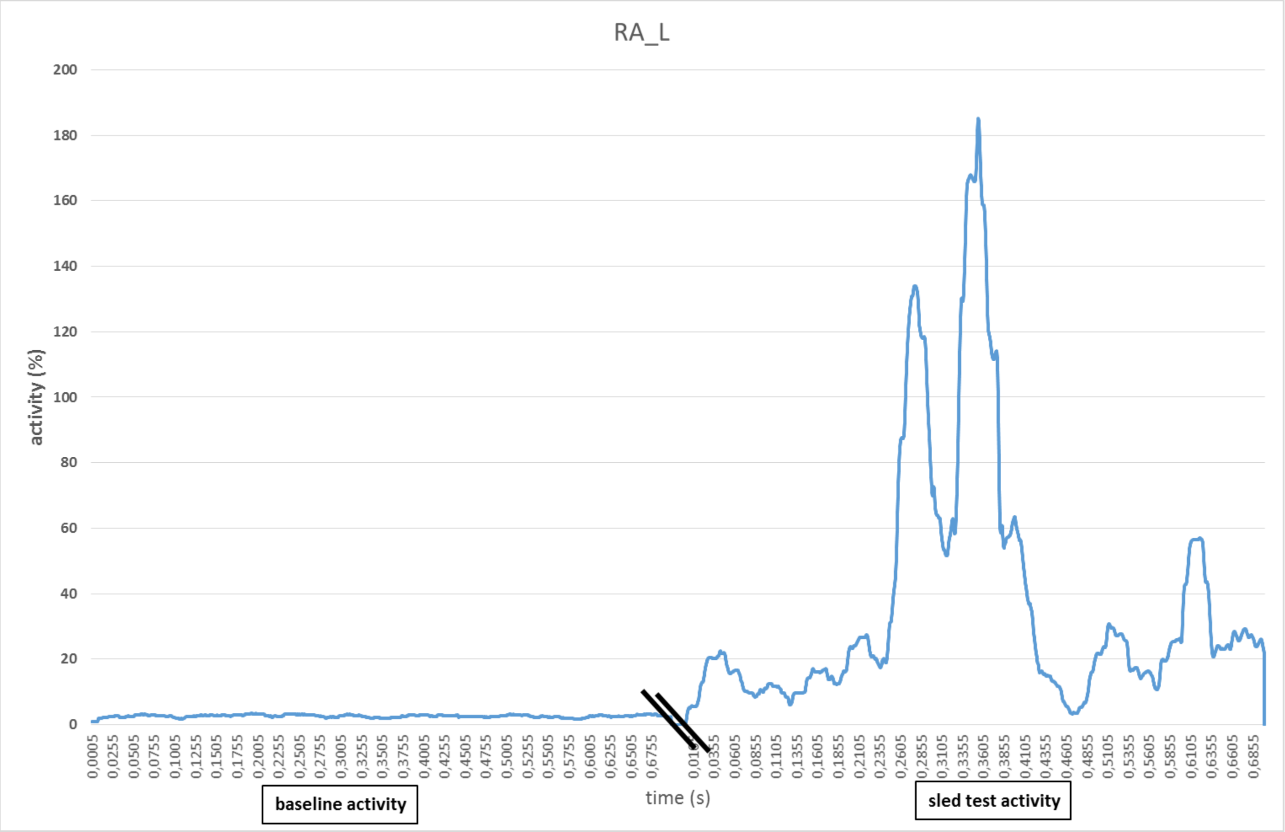

SCM_L
activity (%)
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity


CPVM_R
activity (%)
time (s)
baseline activity
sled test activity

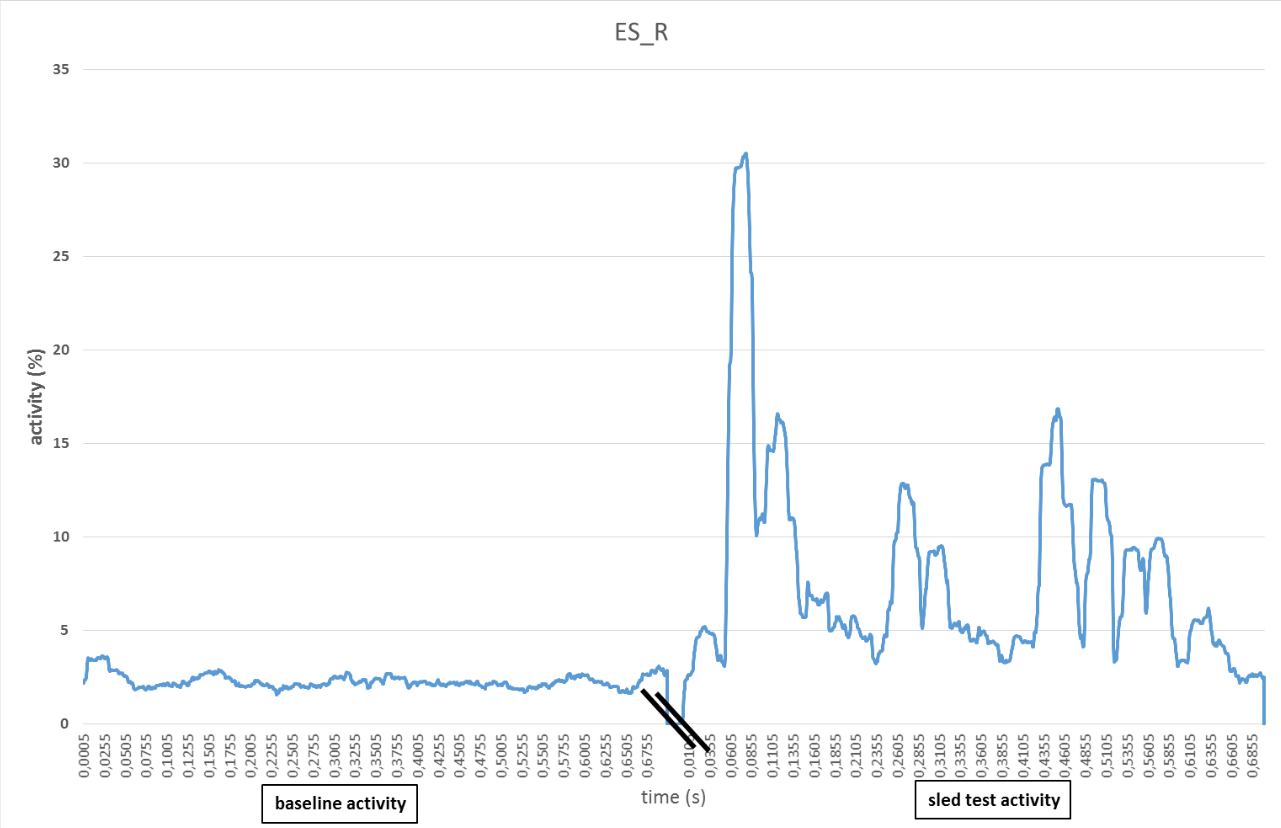

CPVM_L
activity (%)
time (s)
baseline activity
sled test activity

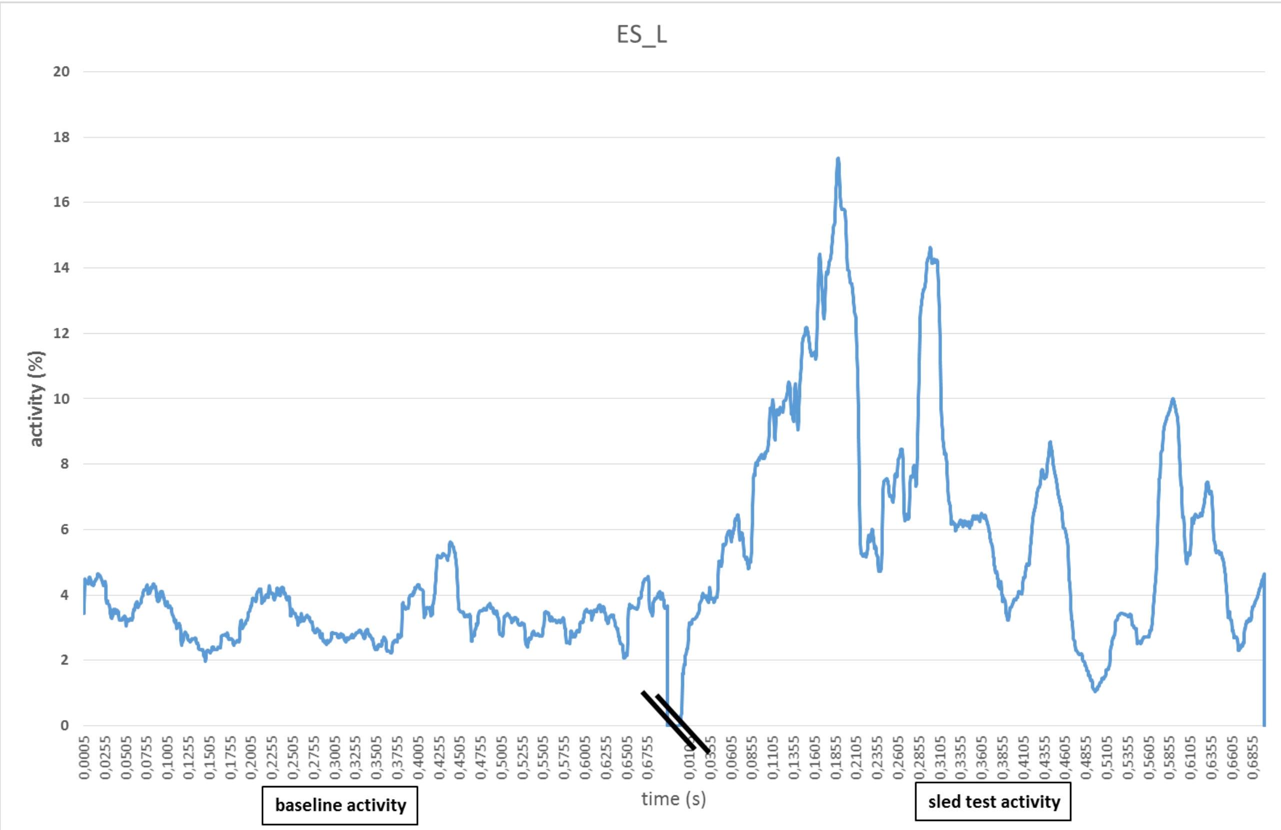


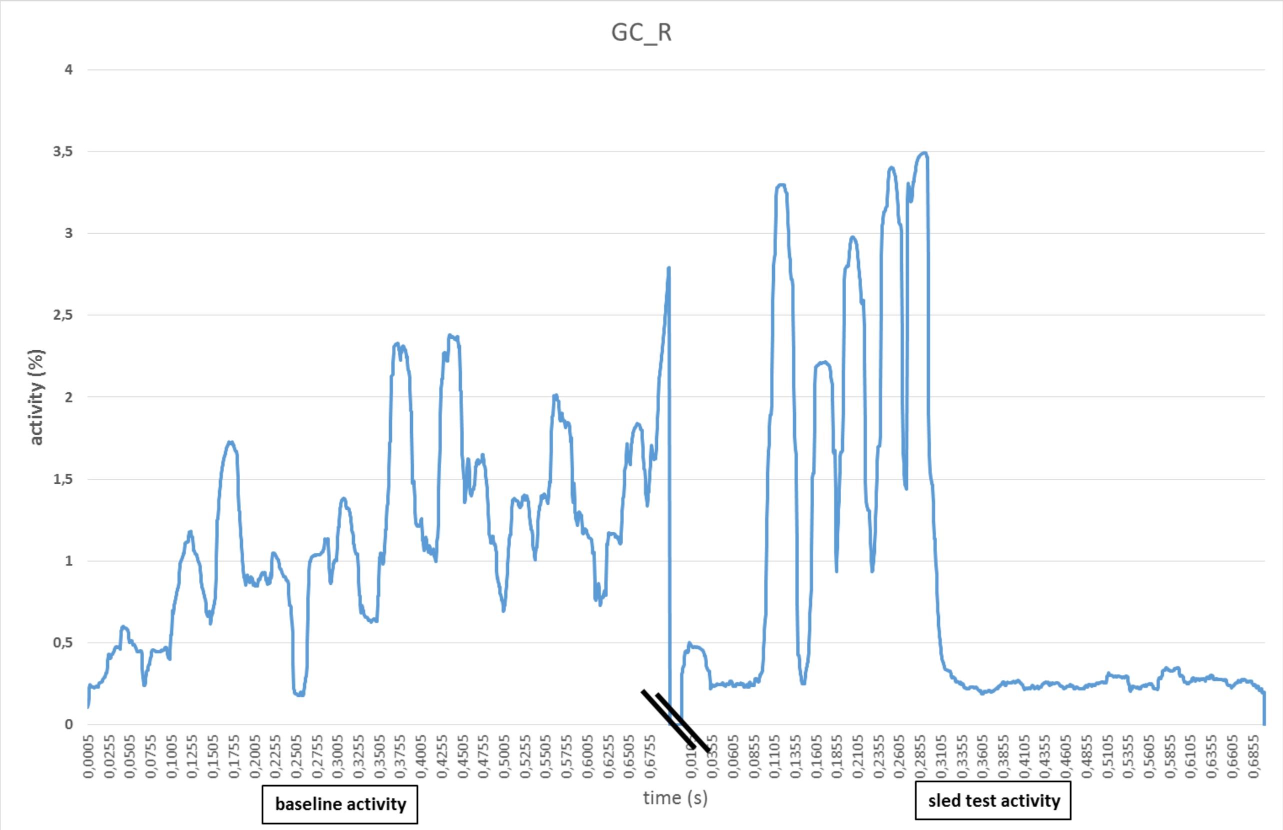
RA_R
activity (%)
time (s)
baseline activity
sled test activity

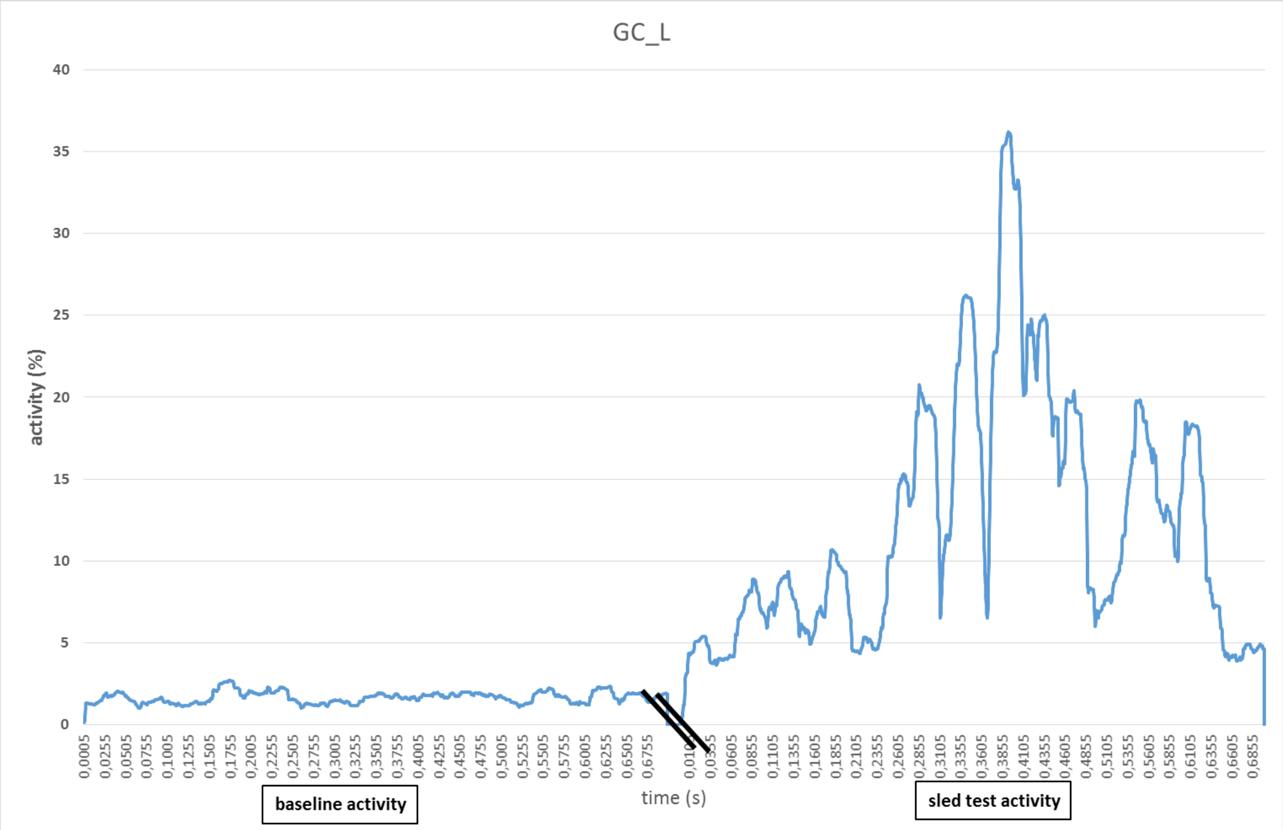



RA_L
activity (%)
time (s)
baseline activity
sled test activity

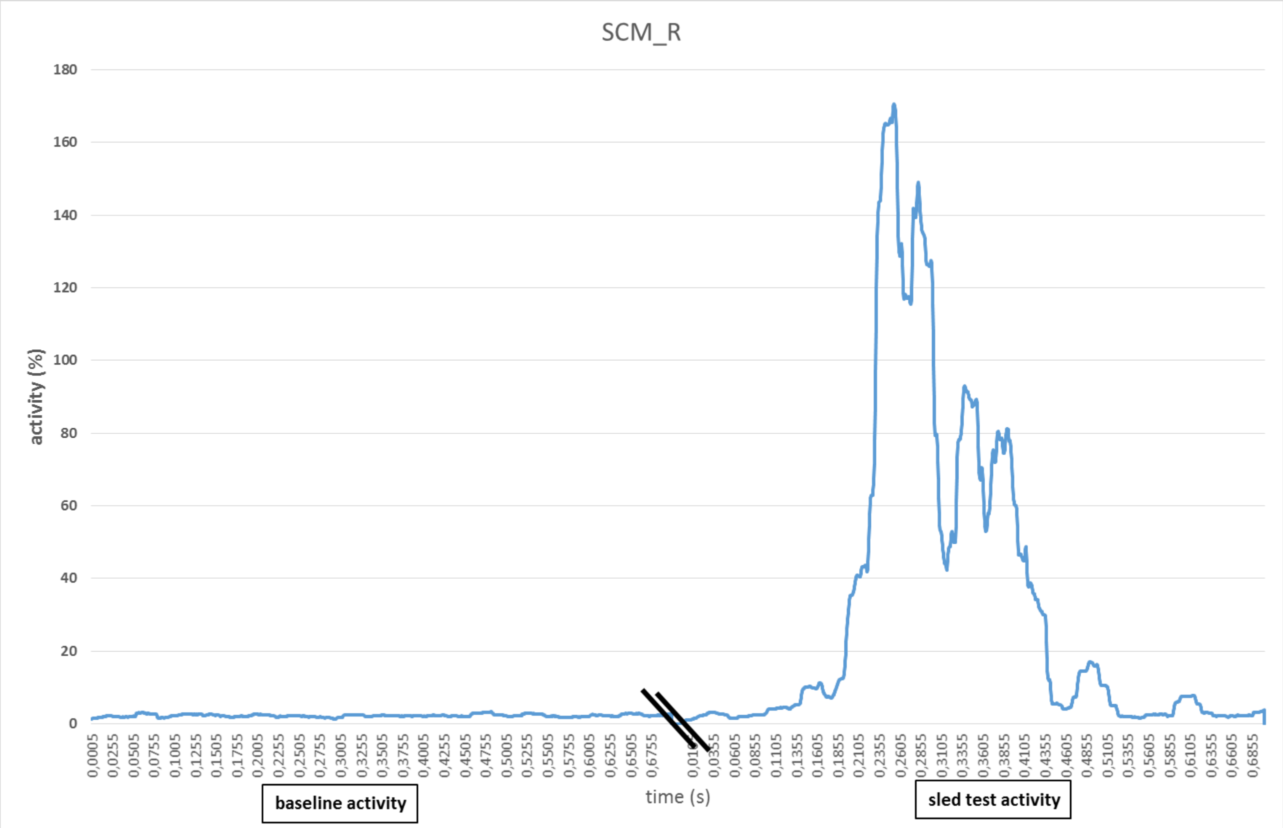

ES_R
activity (%)
time (s)
baseline activity
sled test activity

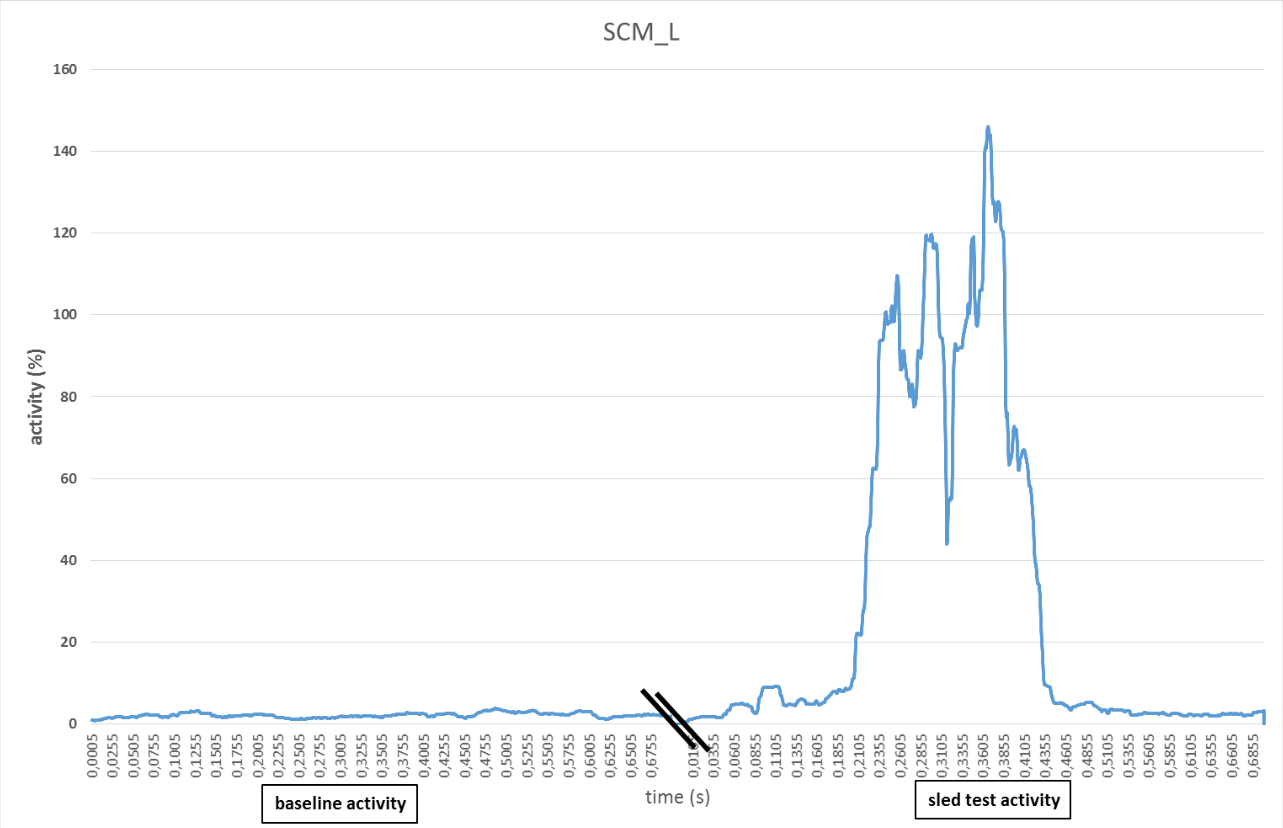

ES_L
activity (%)
time (s)
baseline activity
sled test activity

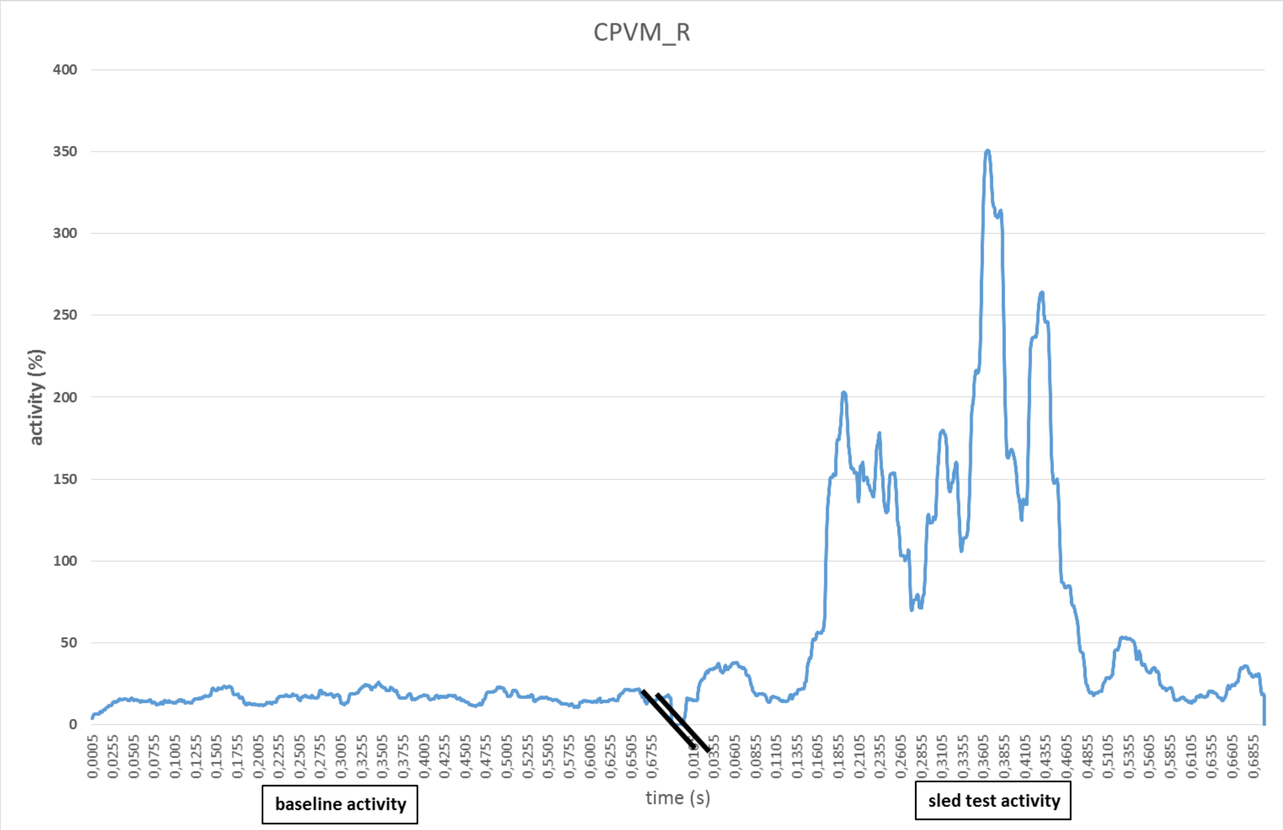

GC_R
activity (%)
time (s)
baseline activity
sled test activity

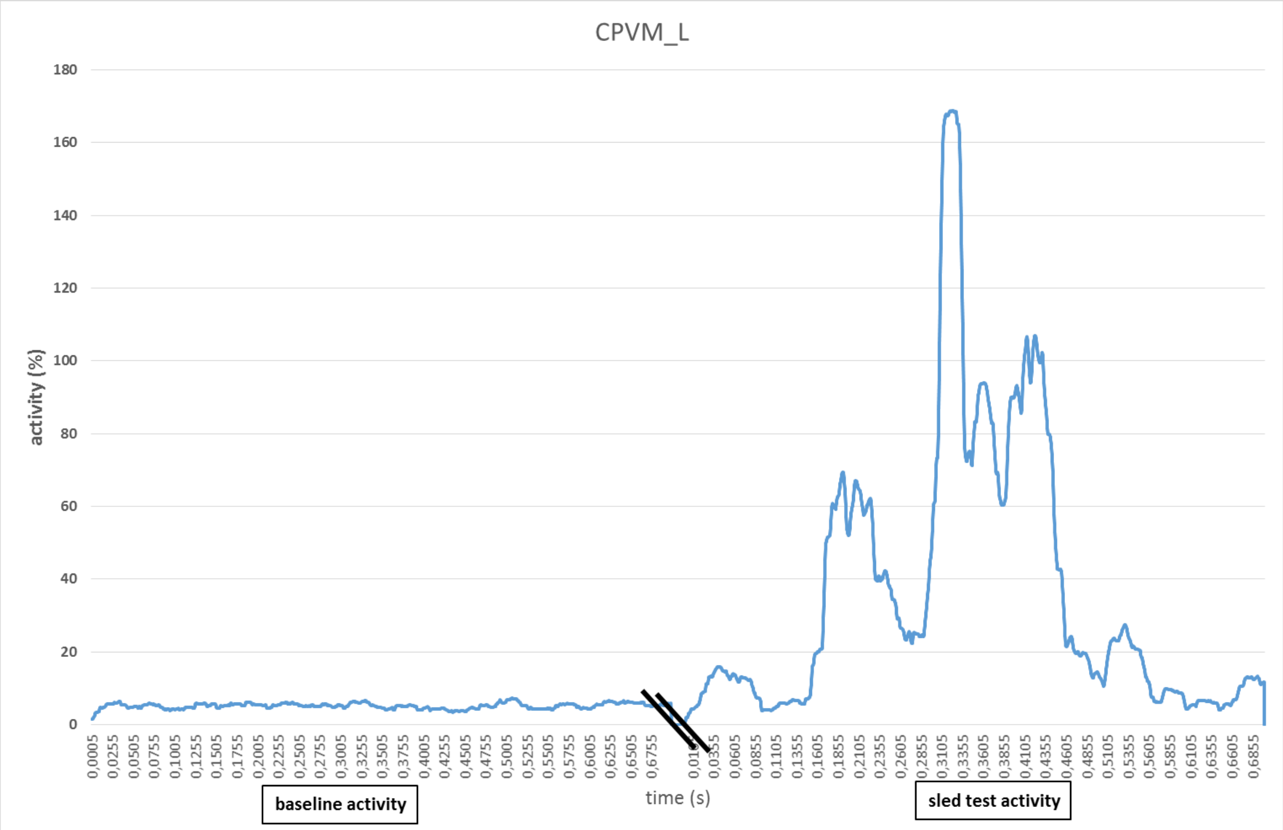

GC_L
activity (%)
time (s)
baseline activity
sled test activity

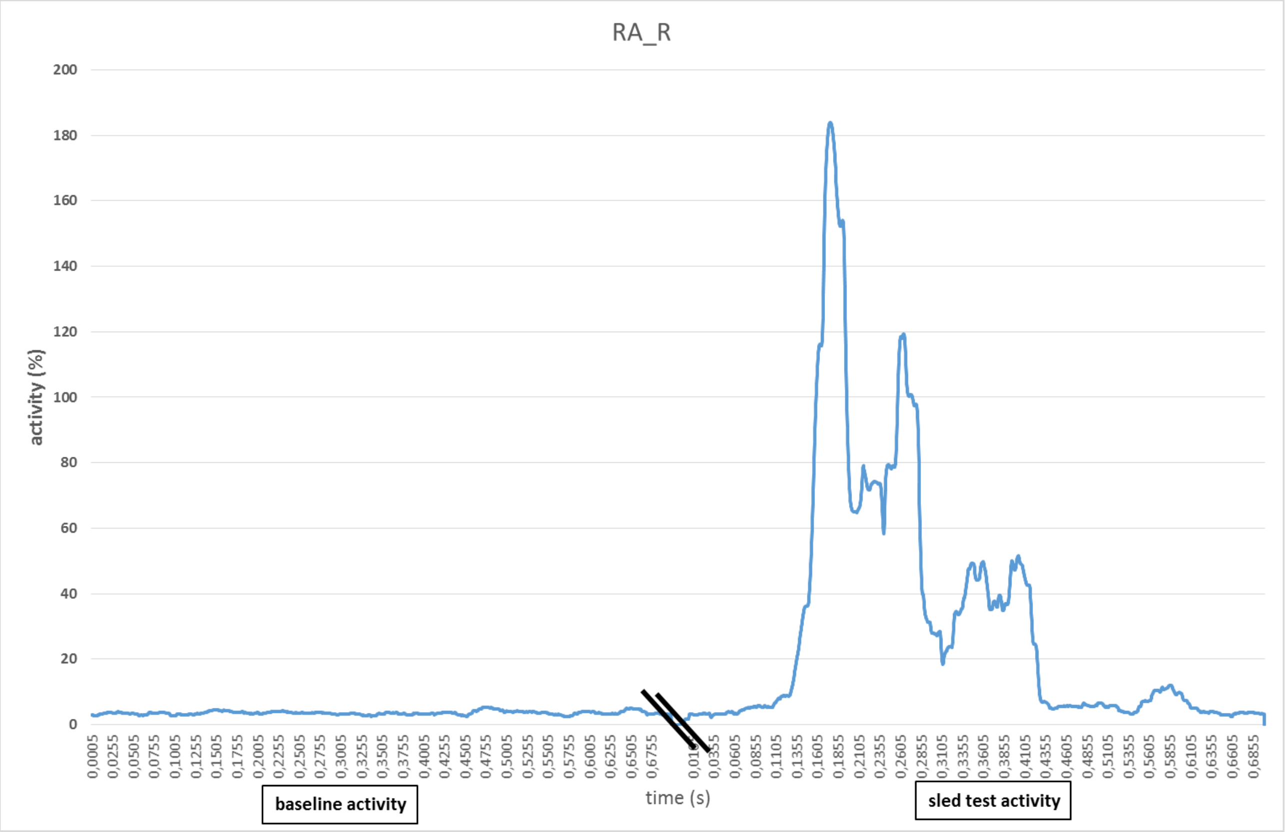
Trial 1780

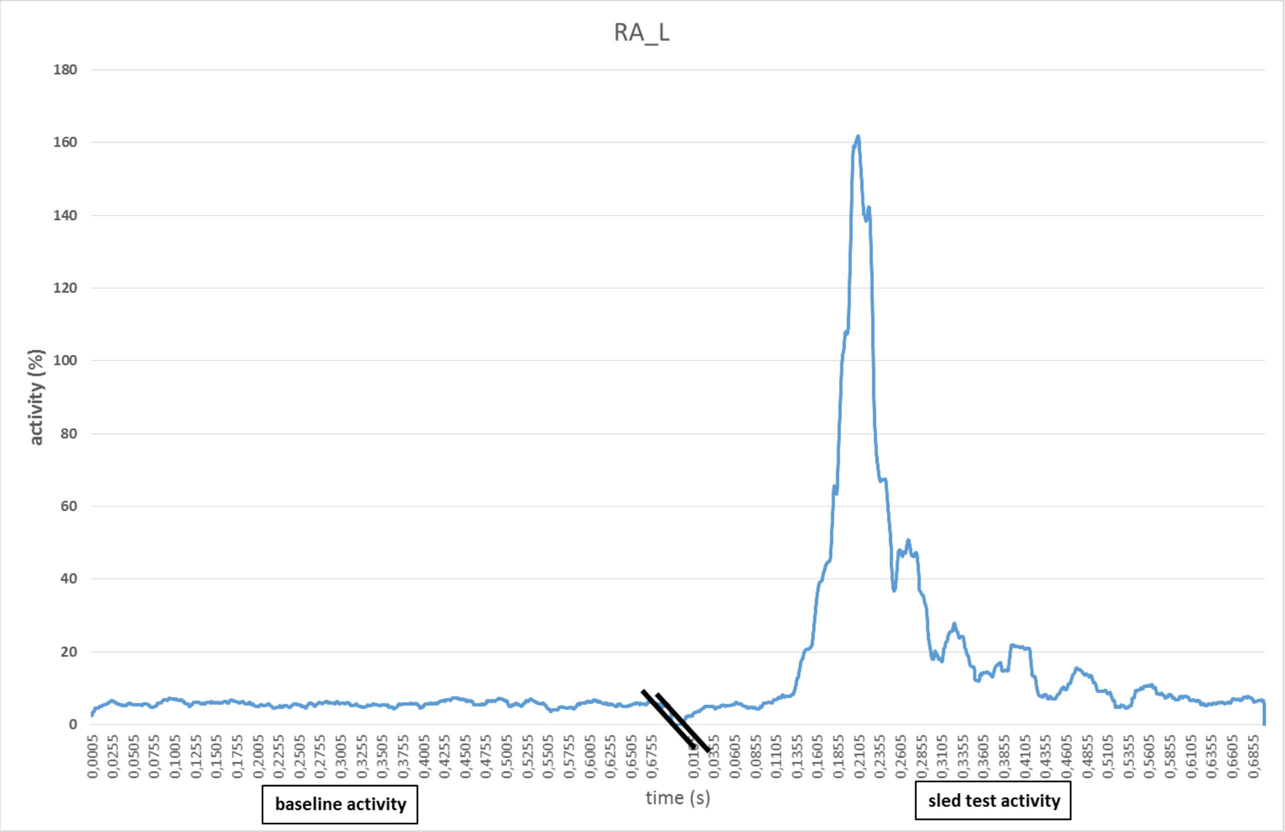

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

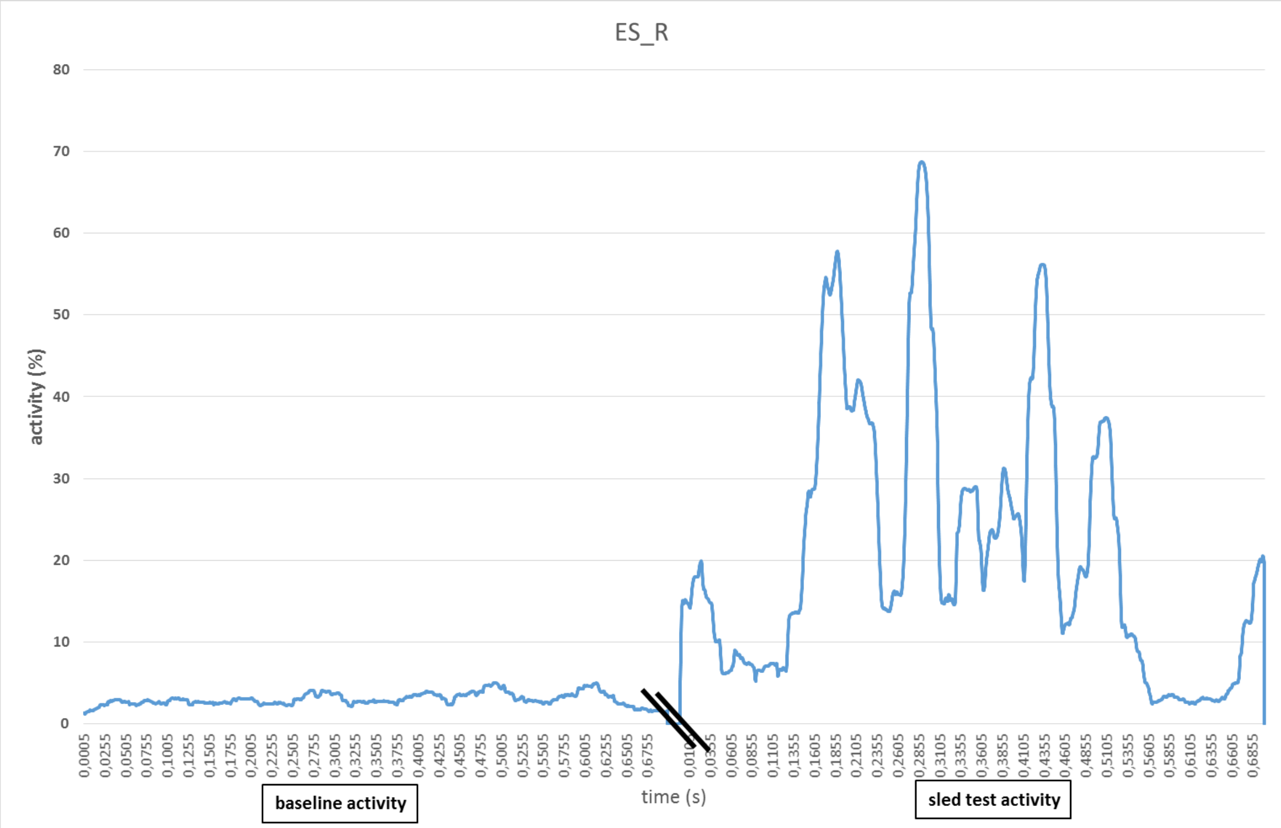

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

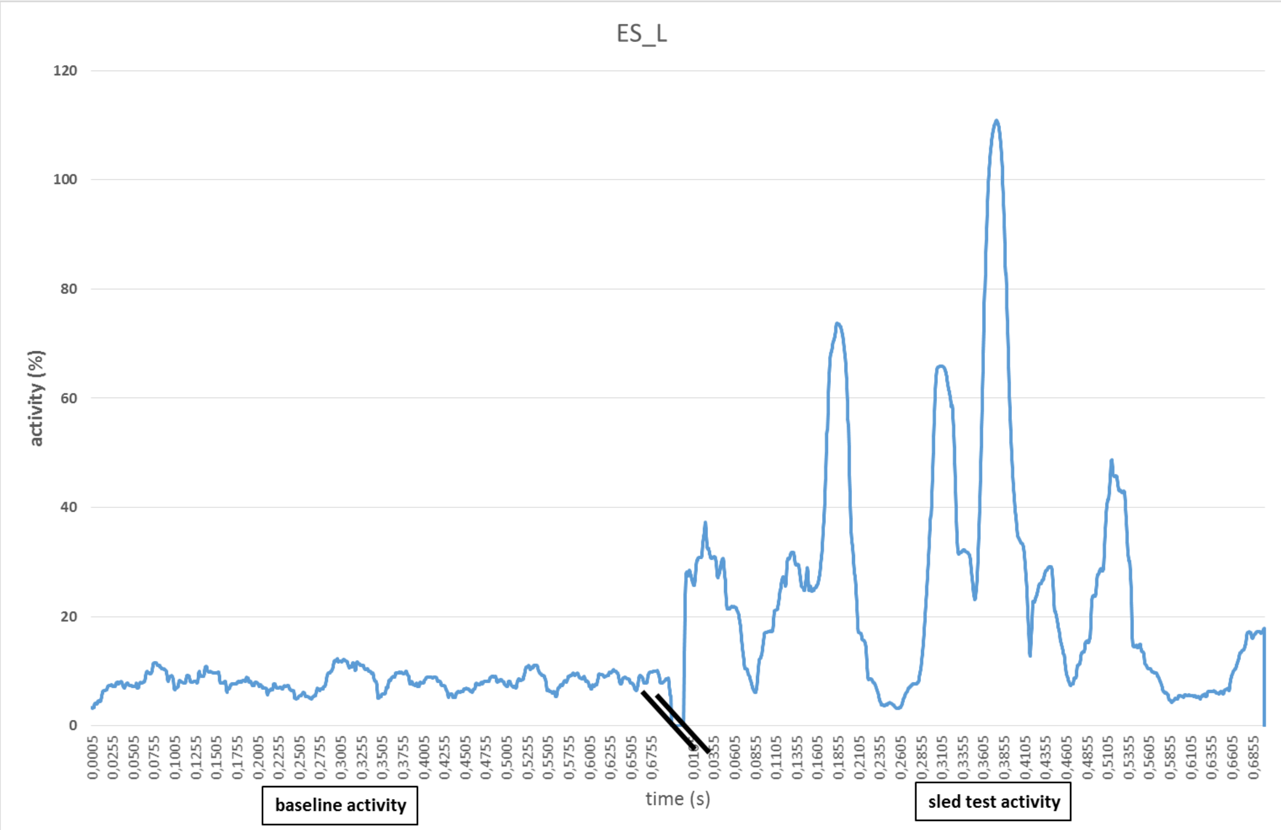

CPVM_R
activity (%)
400
350
300
250
200
150
100
50
0
time (s)
baseline activity
sled test activity

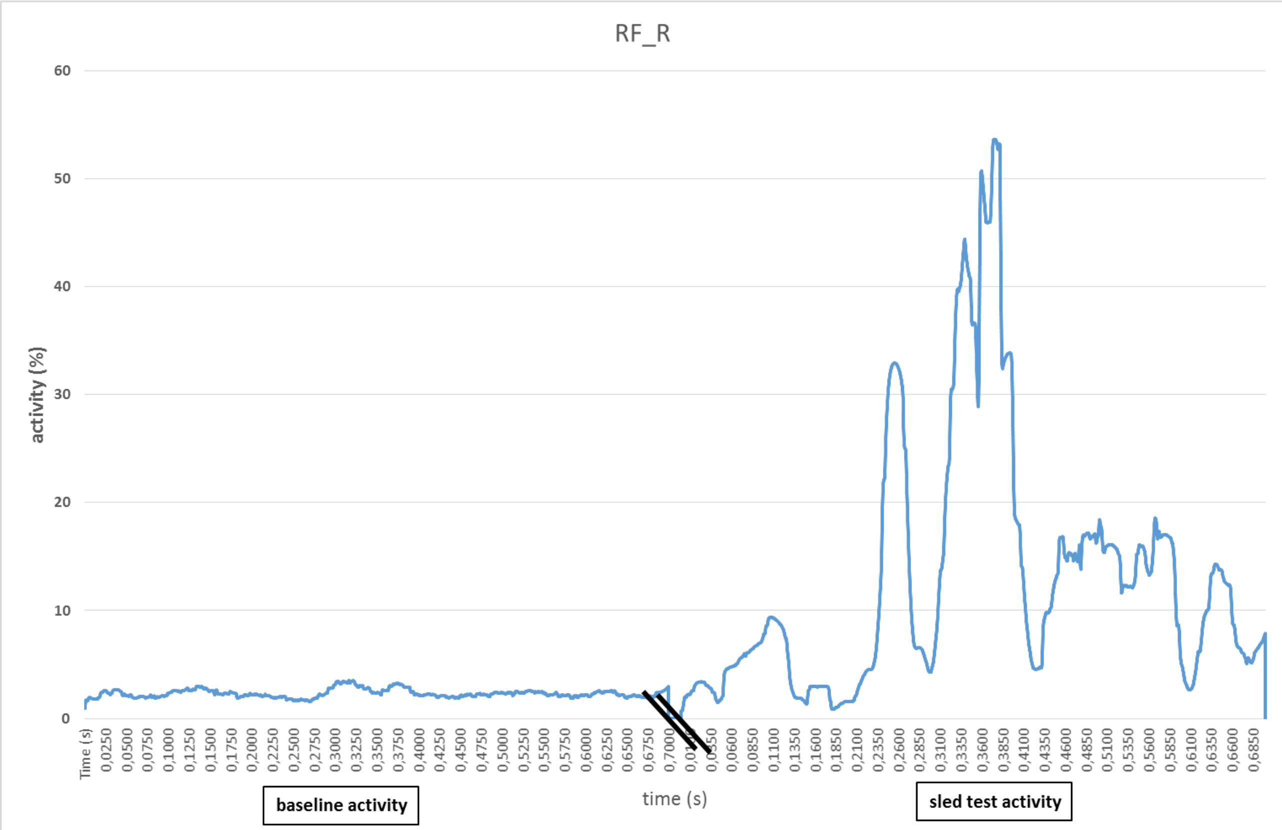

CPVM_L
activity (%)
180
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

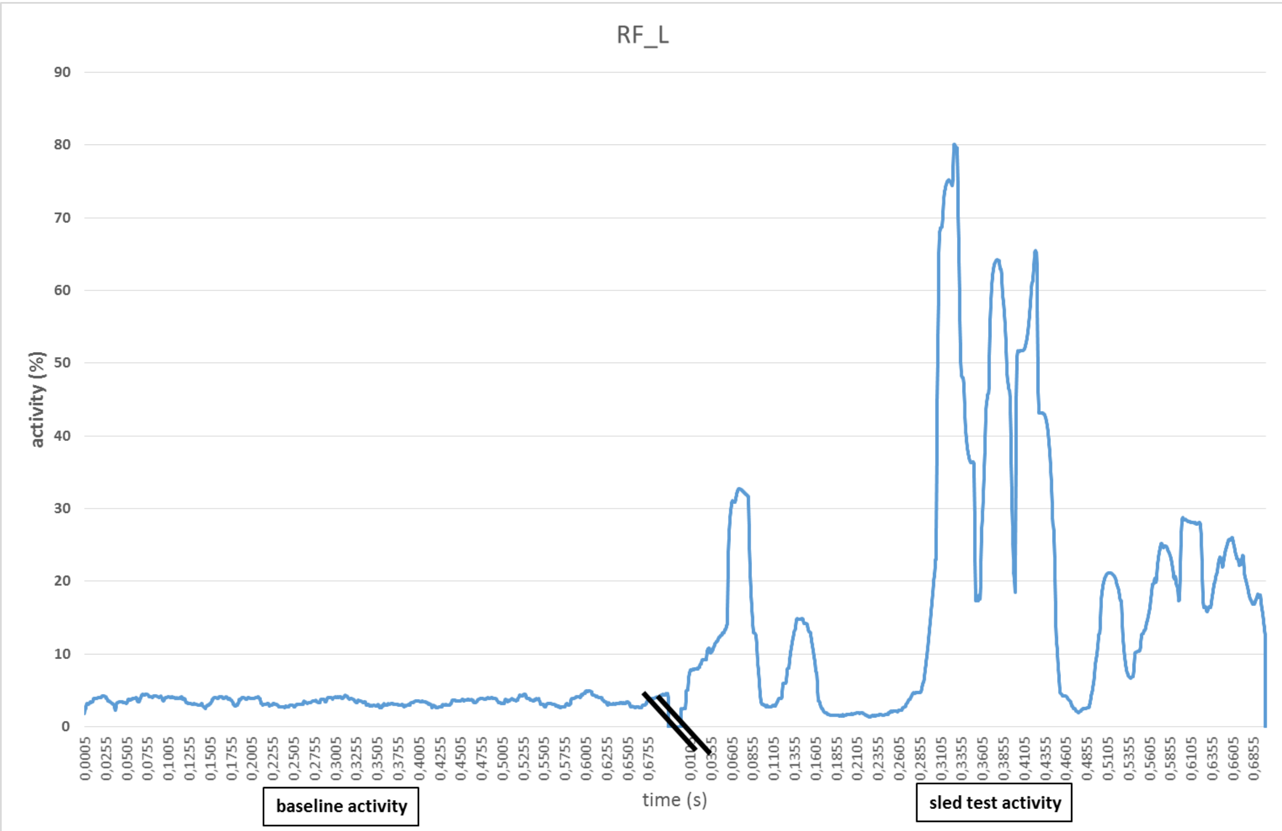

RA_R
activity (%)
time (s)
baseline activity
sled test activity

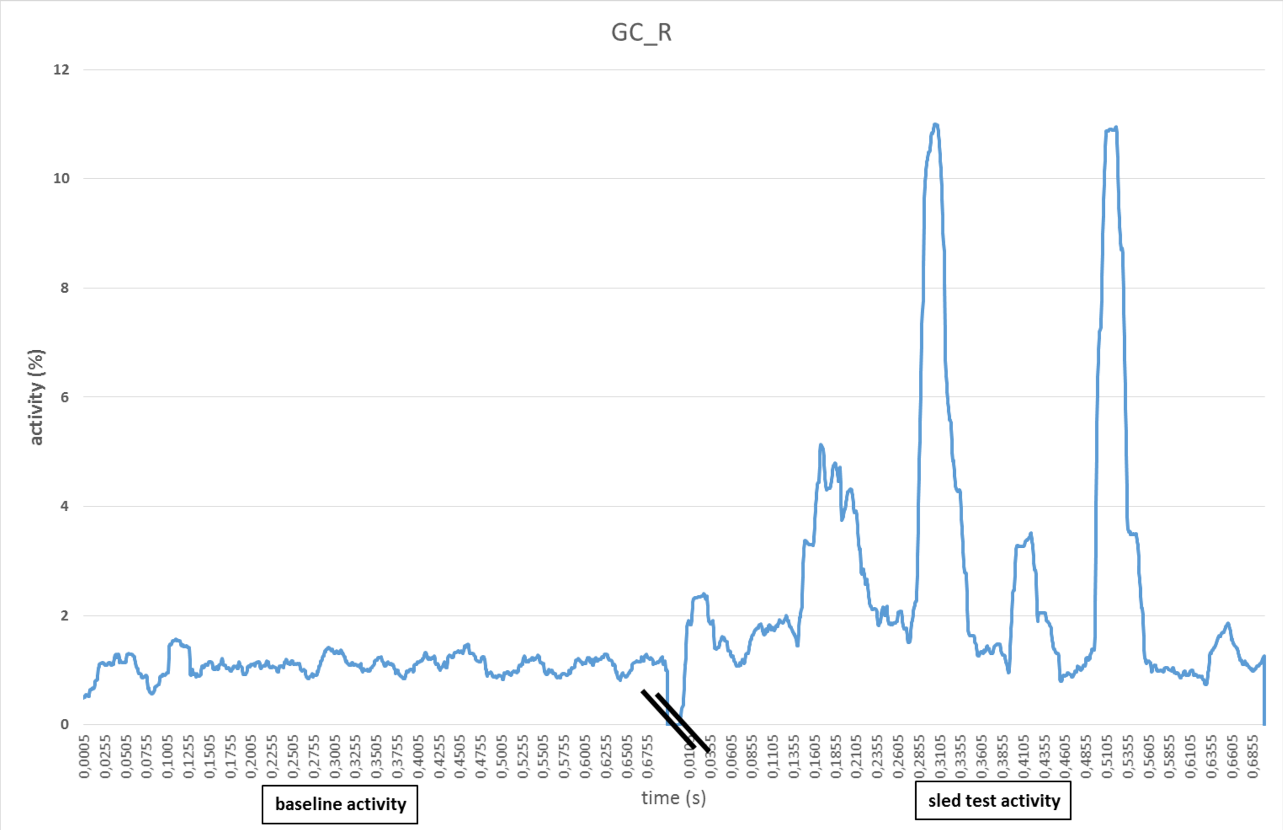

RA_L
activity (%)
time (s)
baseline activity
sled test activity

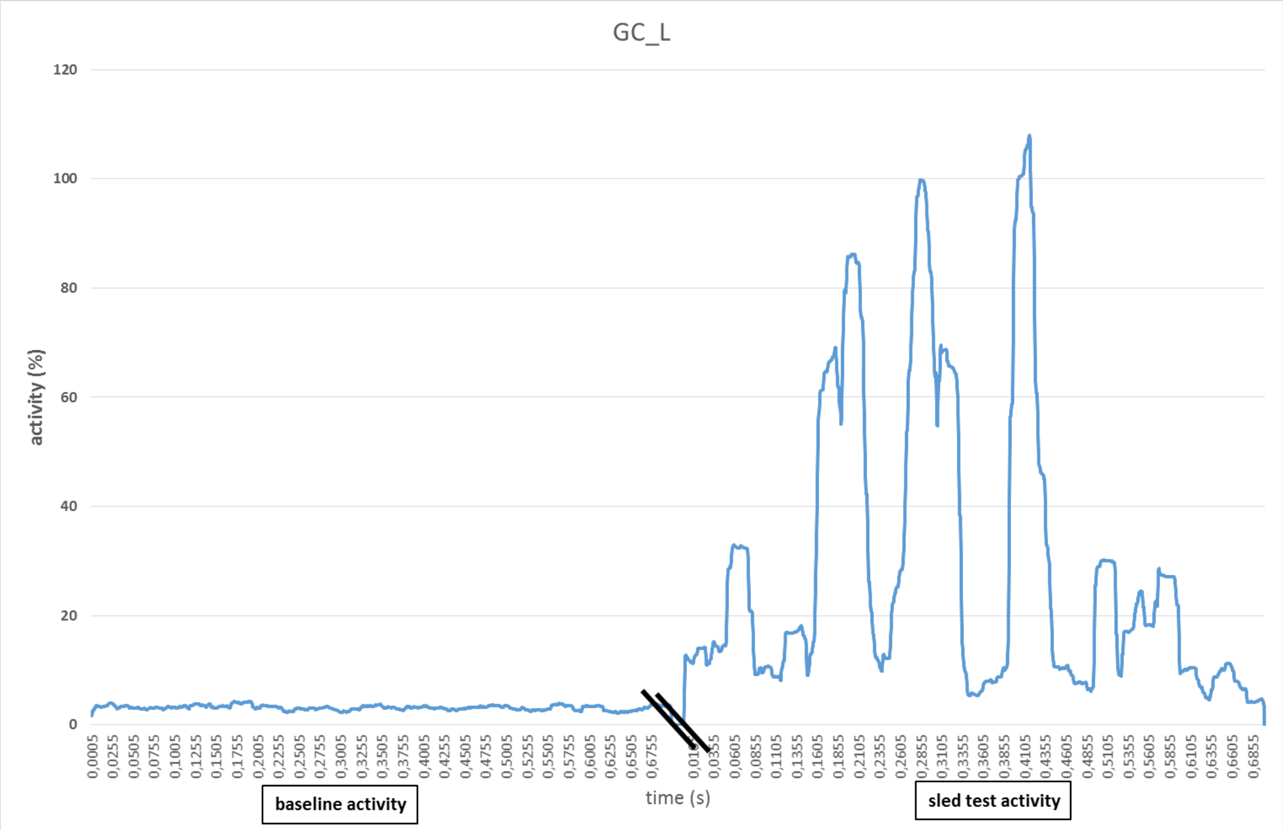

ES_R
activity (%)
time (s)
baseline activity
sled test activity


ES_L
activity (%)
time (s)
baseline activity
sled test activity

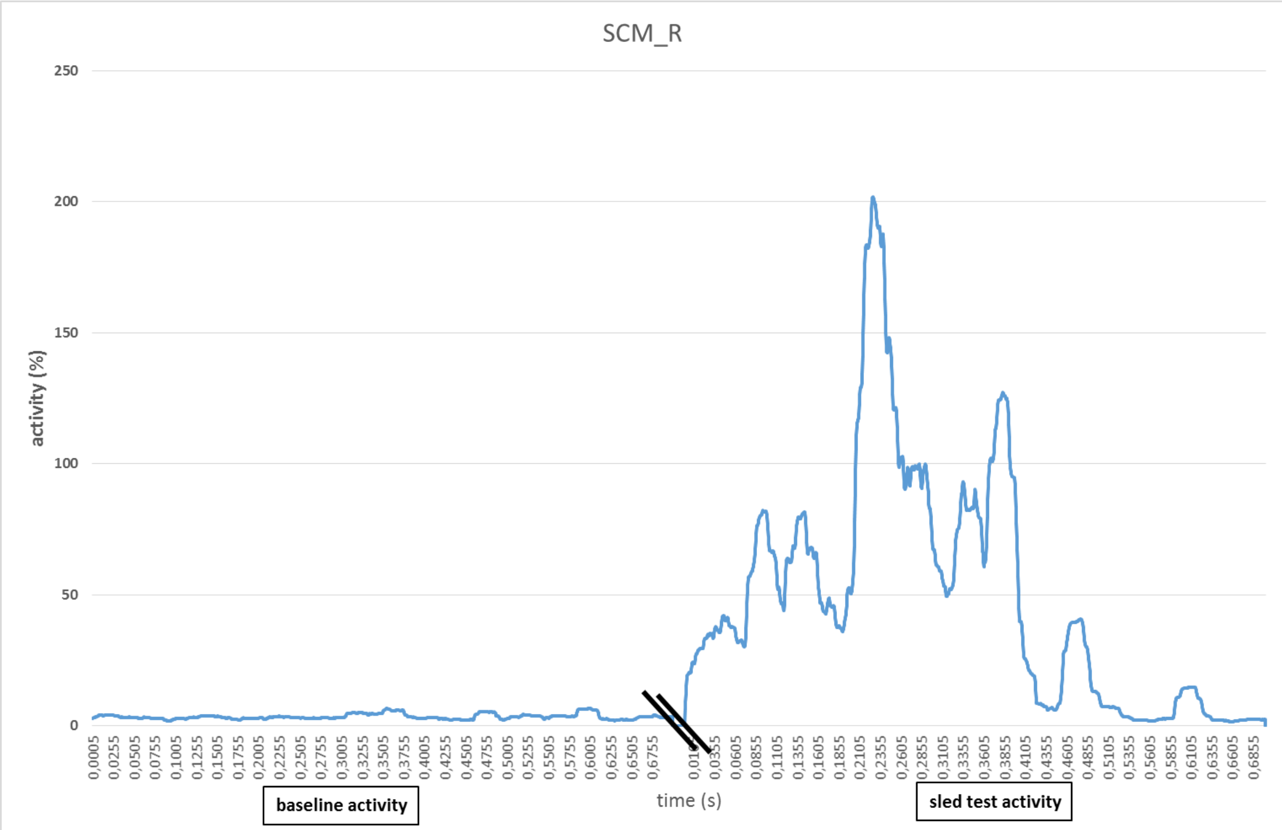

RF_R
activity (%)
time (s)
baseline activity
sled test activity

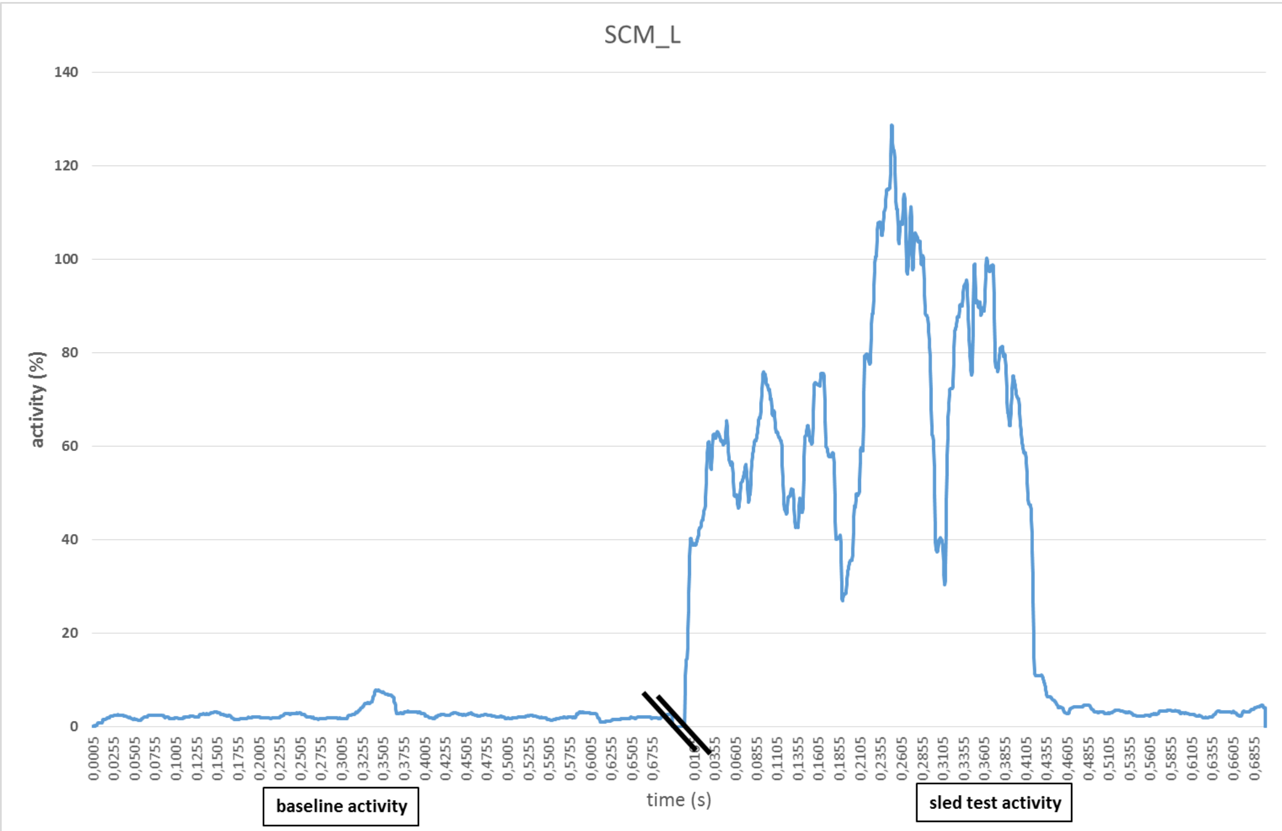

RF_L
activity (%)
time (s)
baseline activity
sled test activity

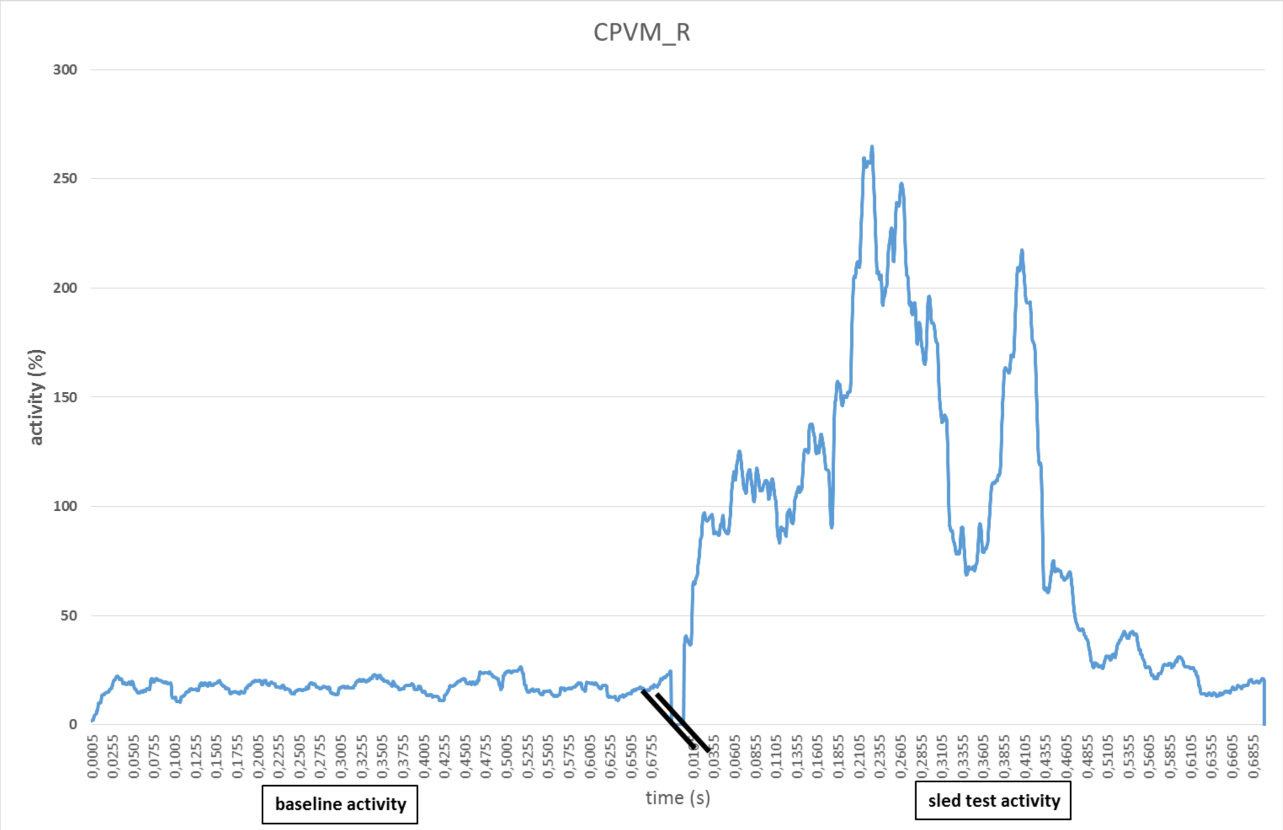

GC_R
activity (%)
time (s)
baseline activity
sled test activity

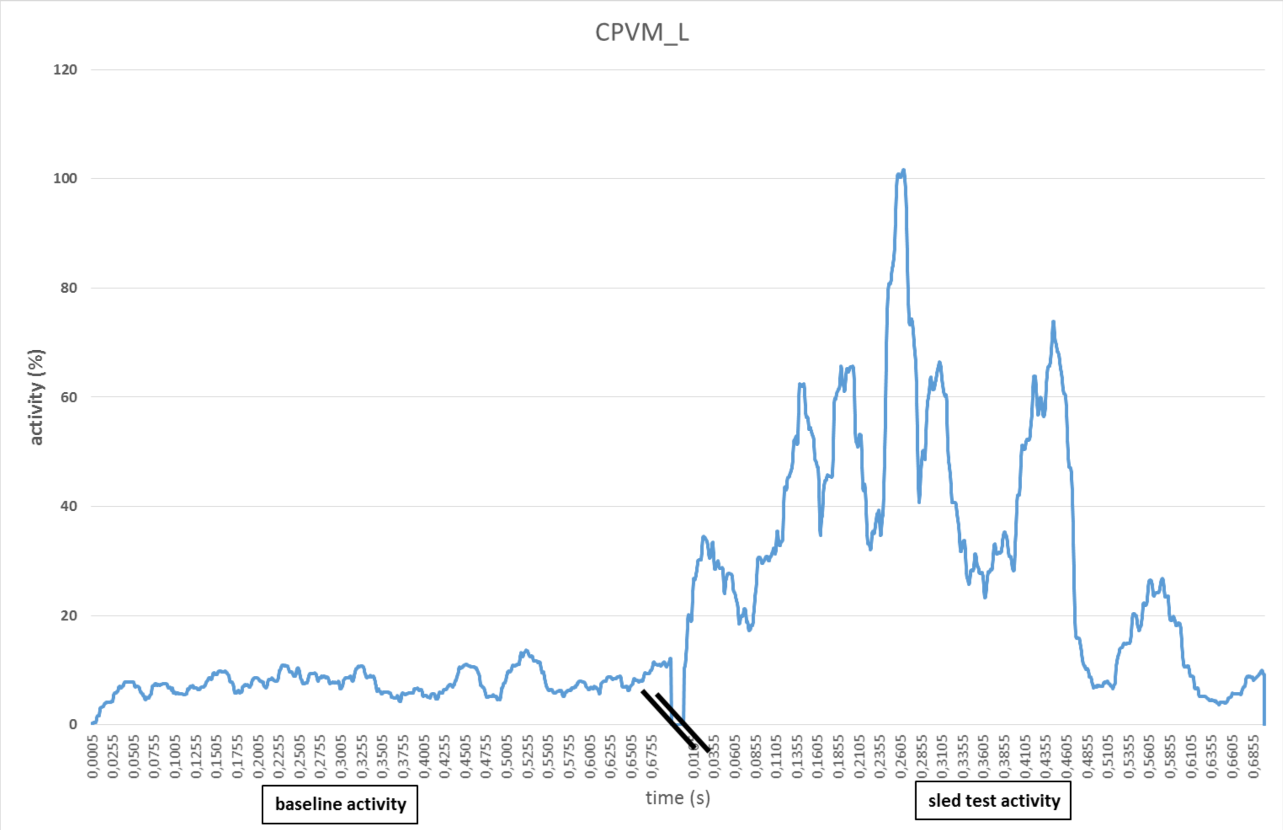

GC_L
activity (%)
time (s)
baseline activity
sled test activity

Trial 1781

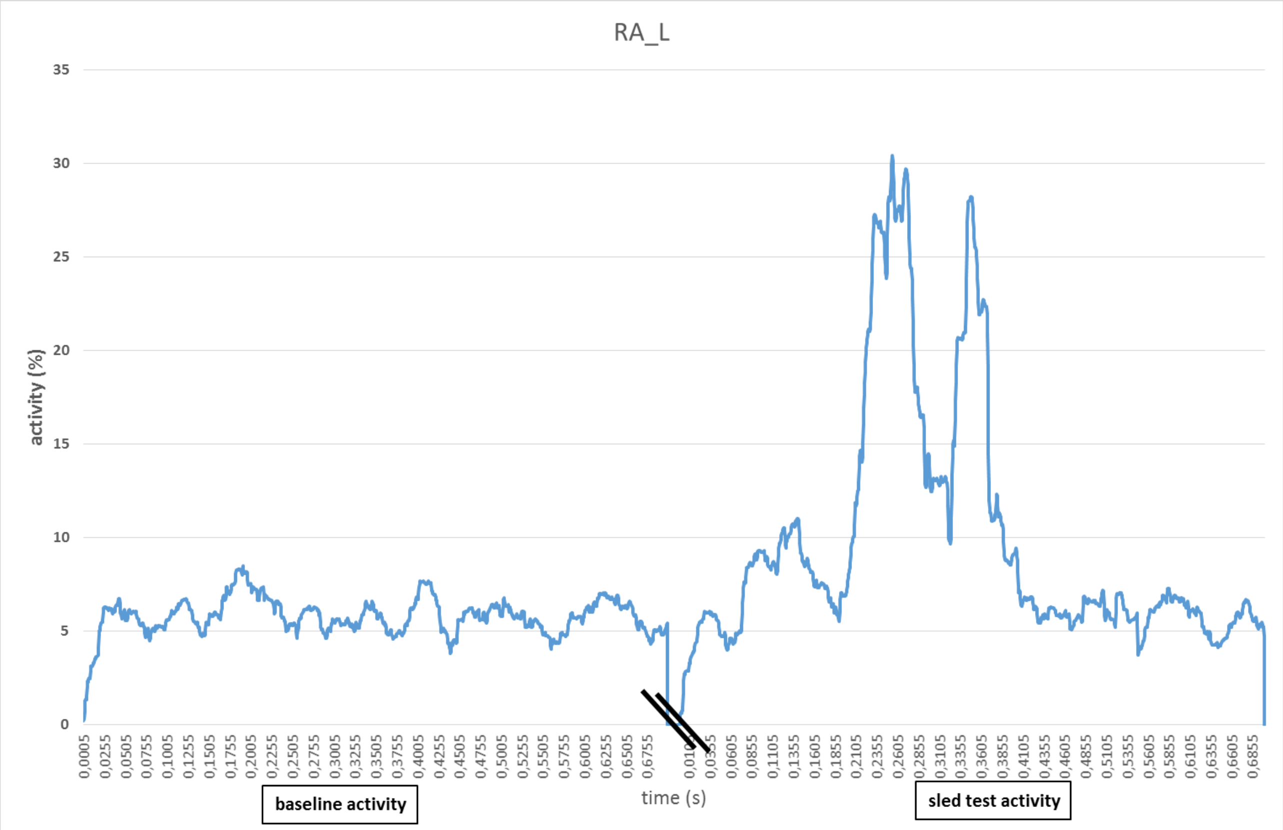

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

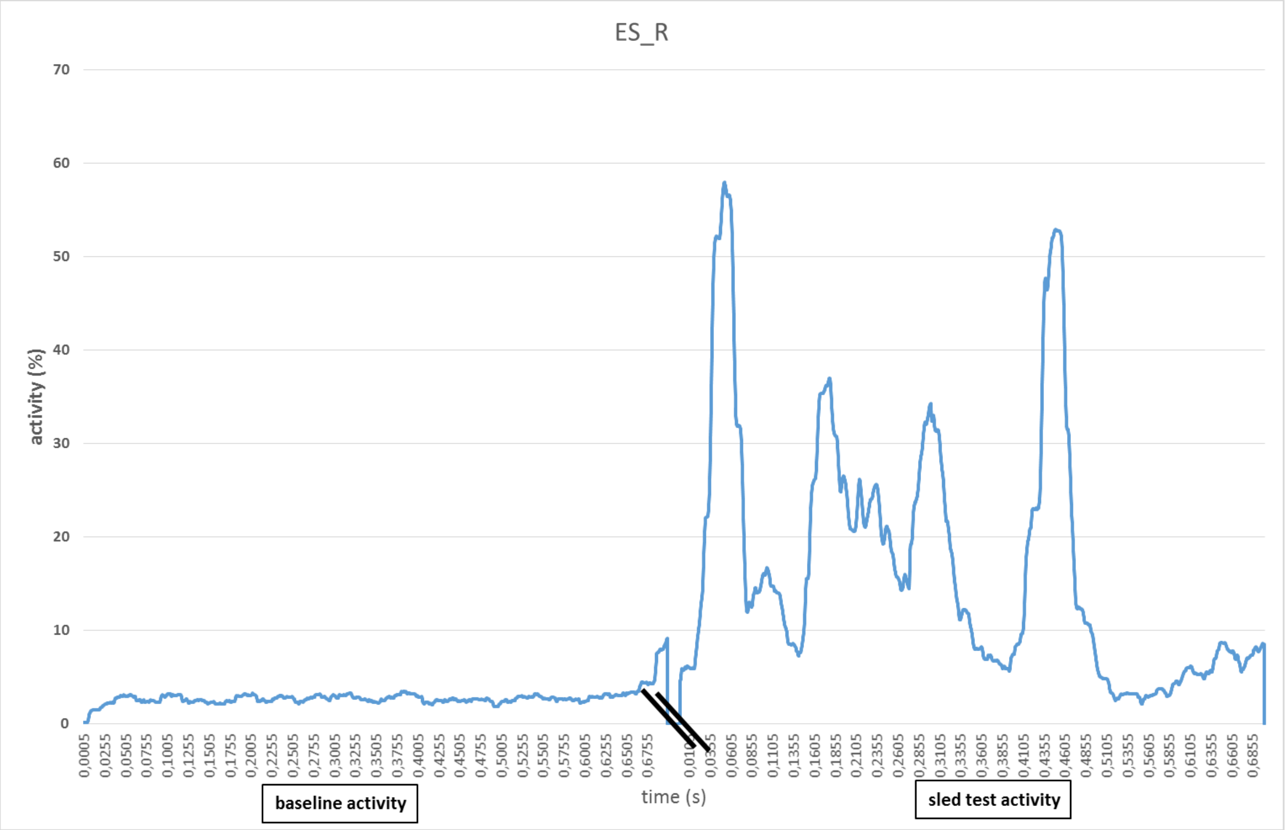

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

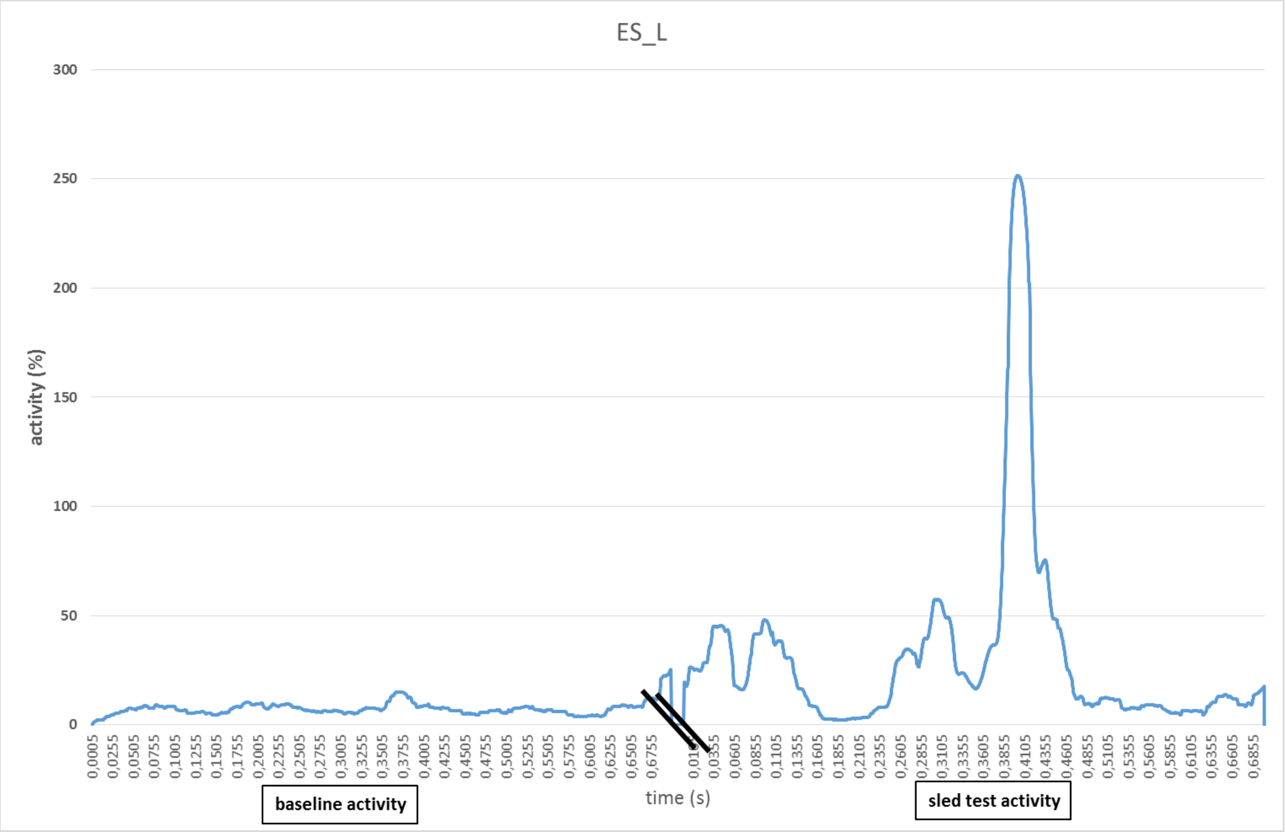

CPVM_R
300
250
200
150
100
50
0
activity (%)
time (s)
baseline activity
sled test activity

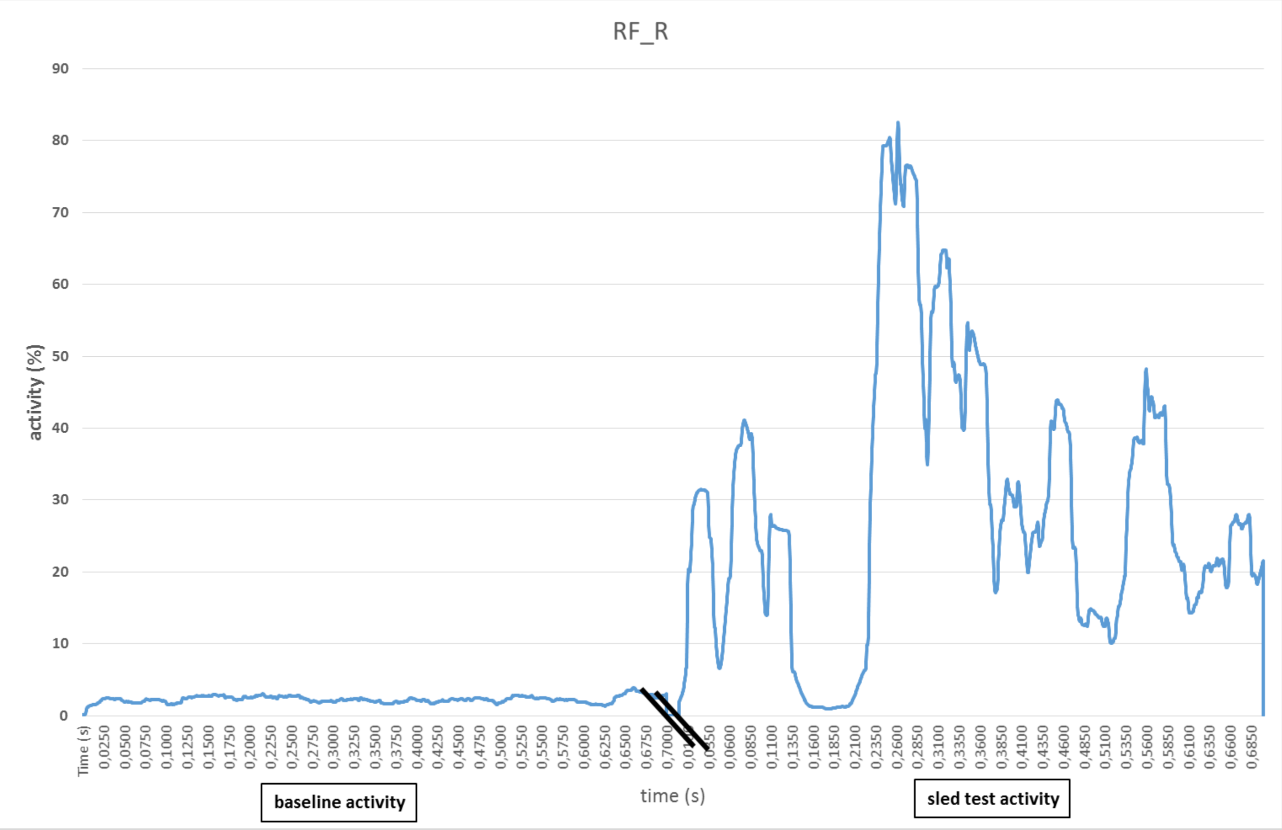

CPVM_L
120
100
80
60
40
20
0
activity (%)
time (s)
baseline activity
sled test activity

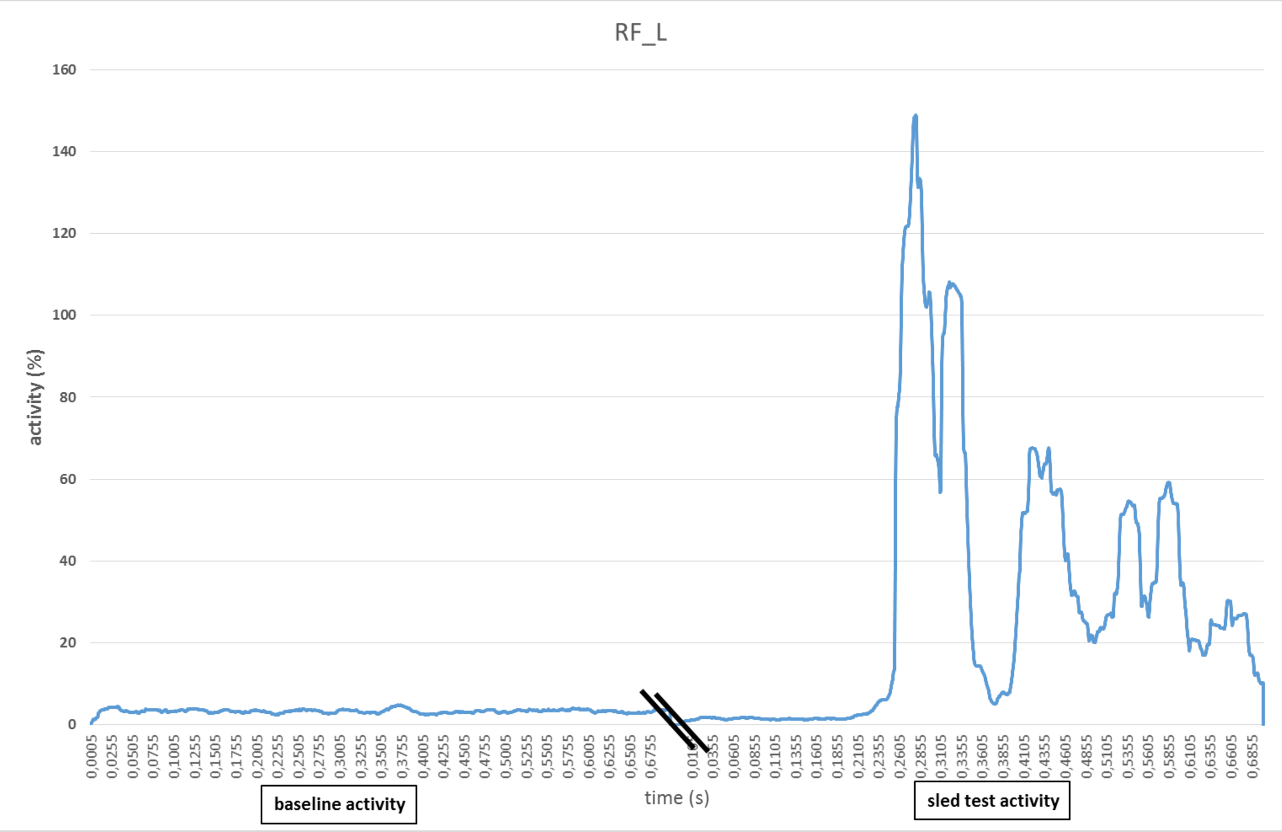

RA_R
activity (%)
time (s)
baseline activity
sled test activity

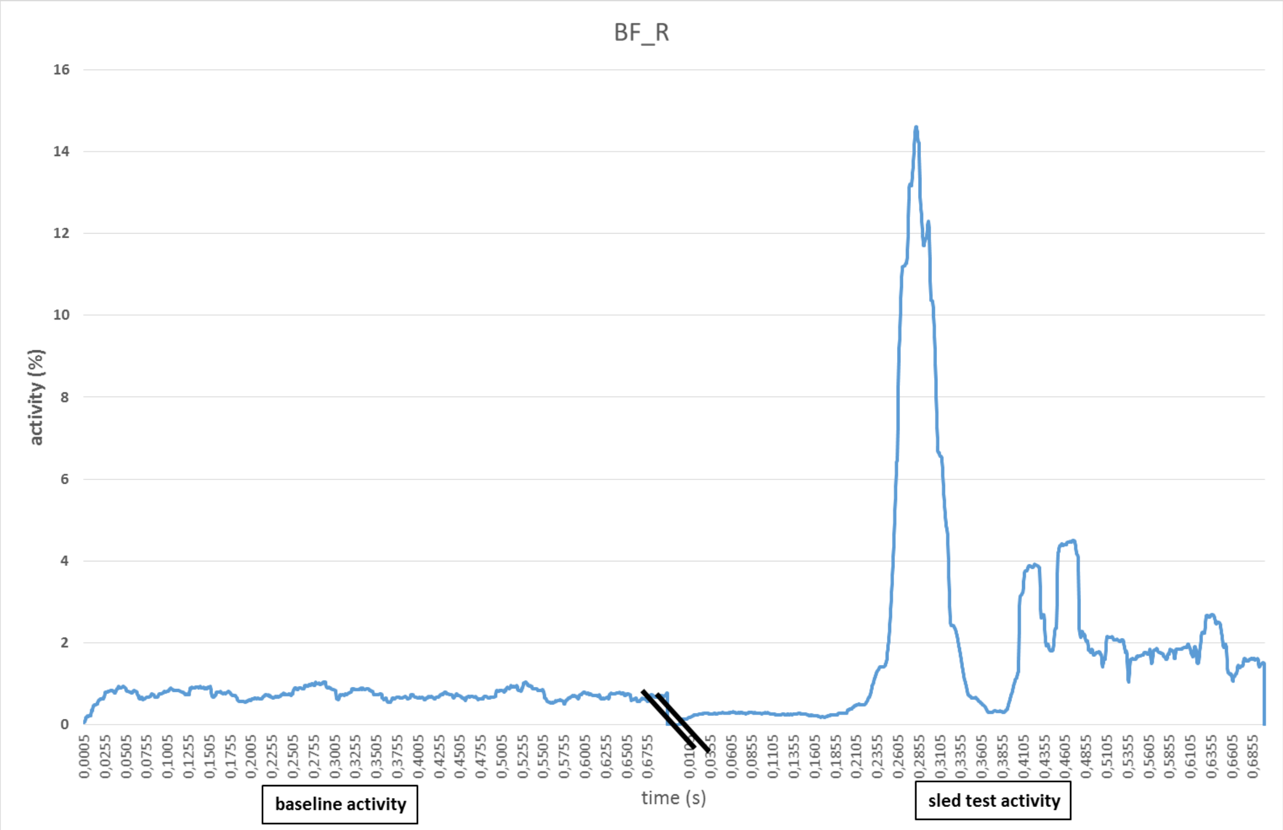

RA_L
activity (%)
time (s)
baseline activity
sled test activity

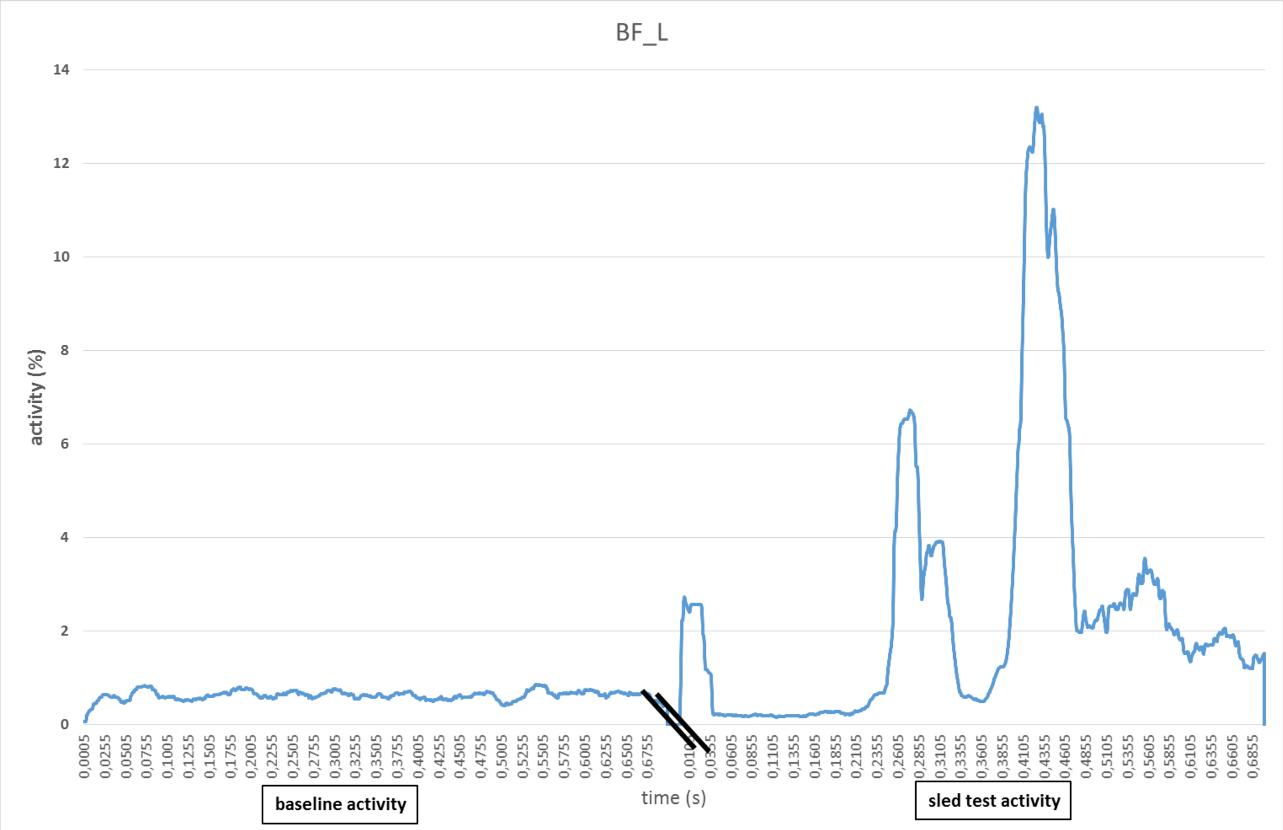

ES_R
activity (%)
time (s)
baseline activity
sled test activity

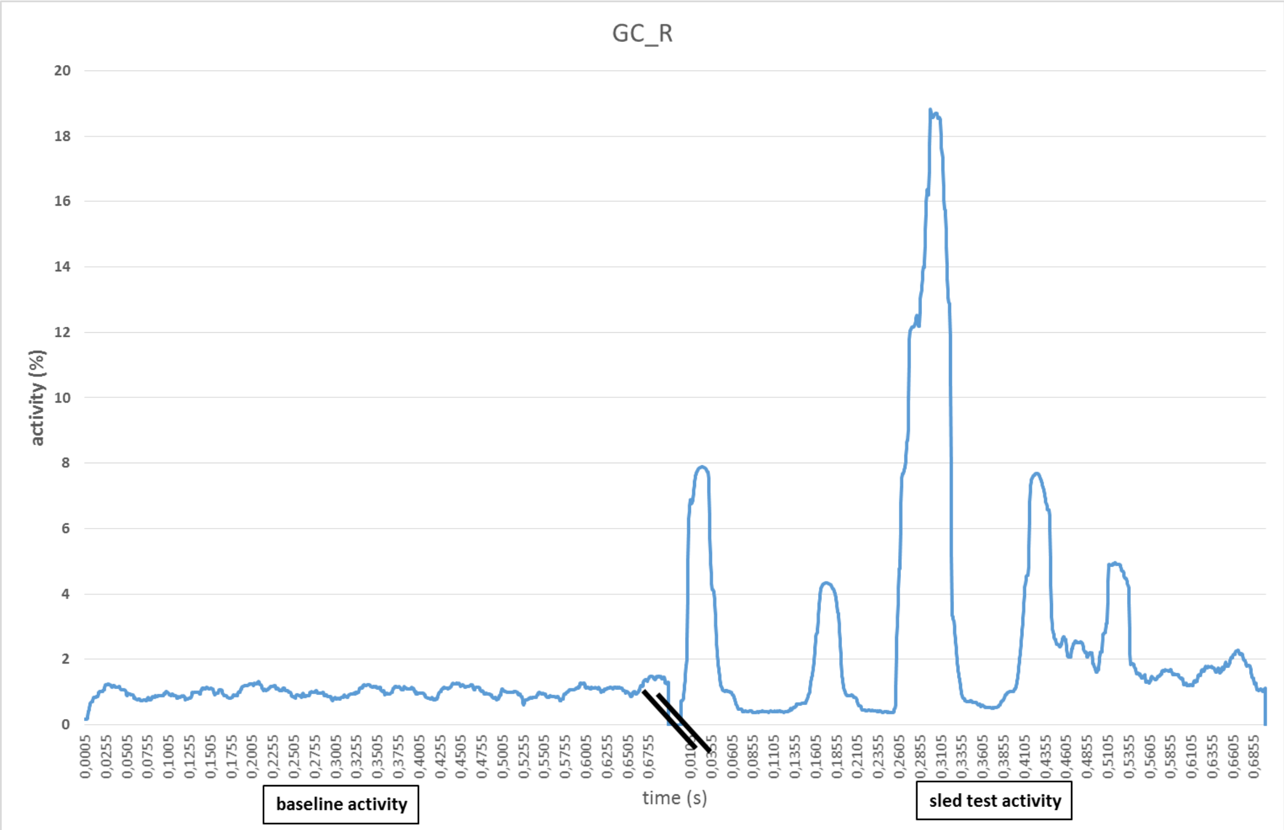

ES_L
activity (%)
time (s)
baseline activity
sled test activity

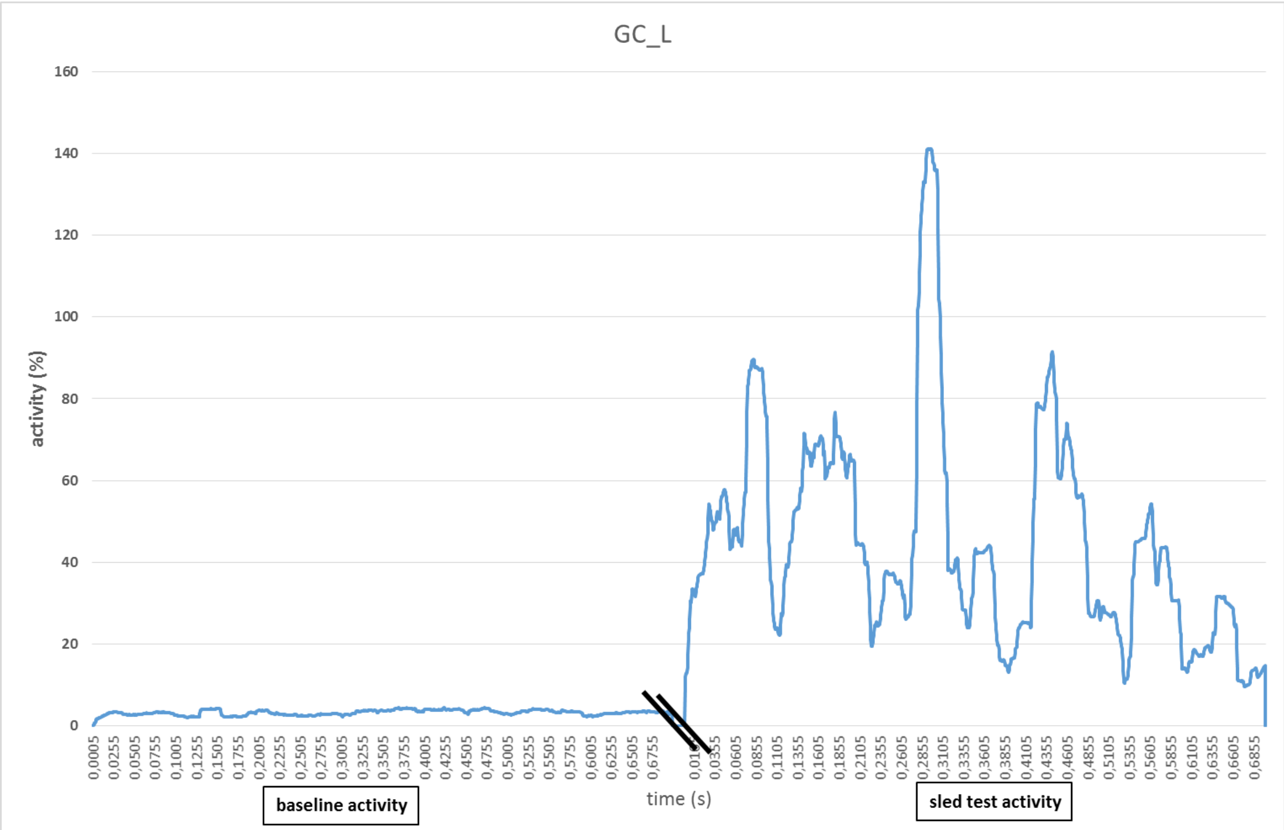

RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity

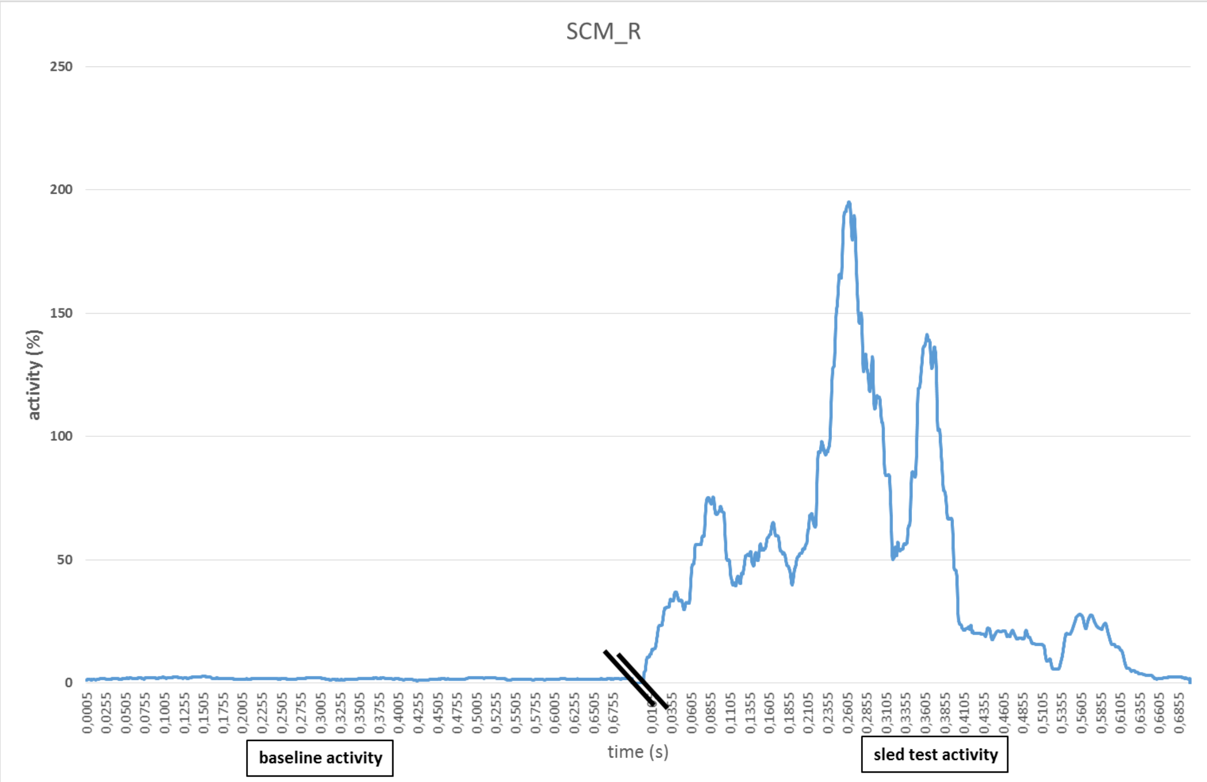

BF_R
activity (%)
time (s)
baseline activity
sled test activity

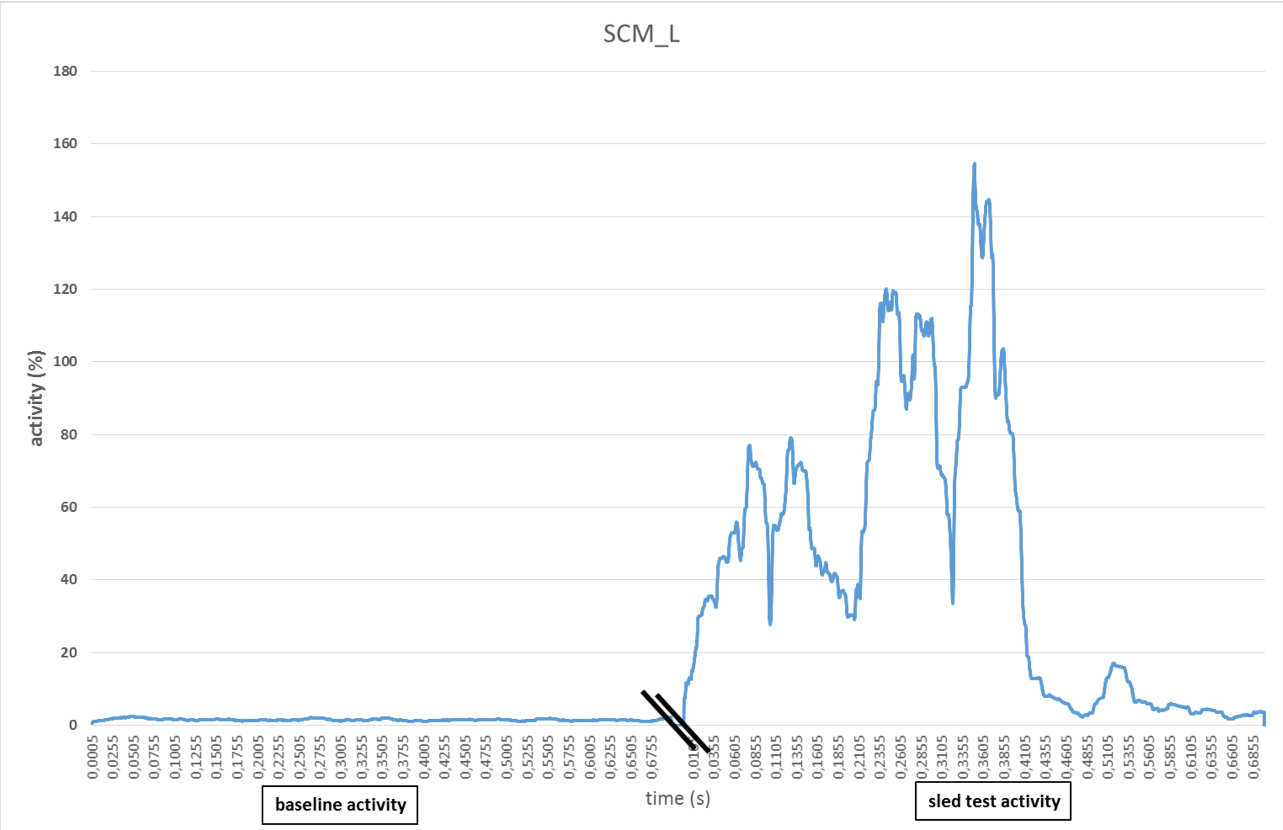

BF_L
activity (%)
time (s)
baseline activity
sled test activity

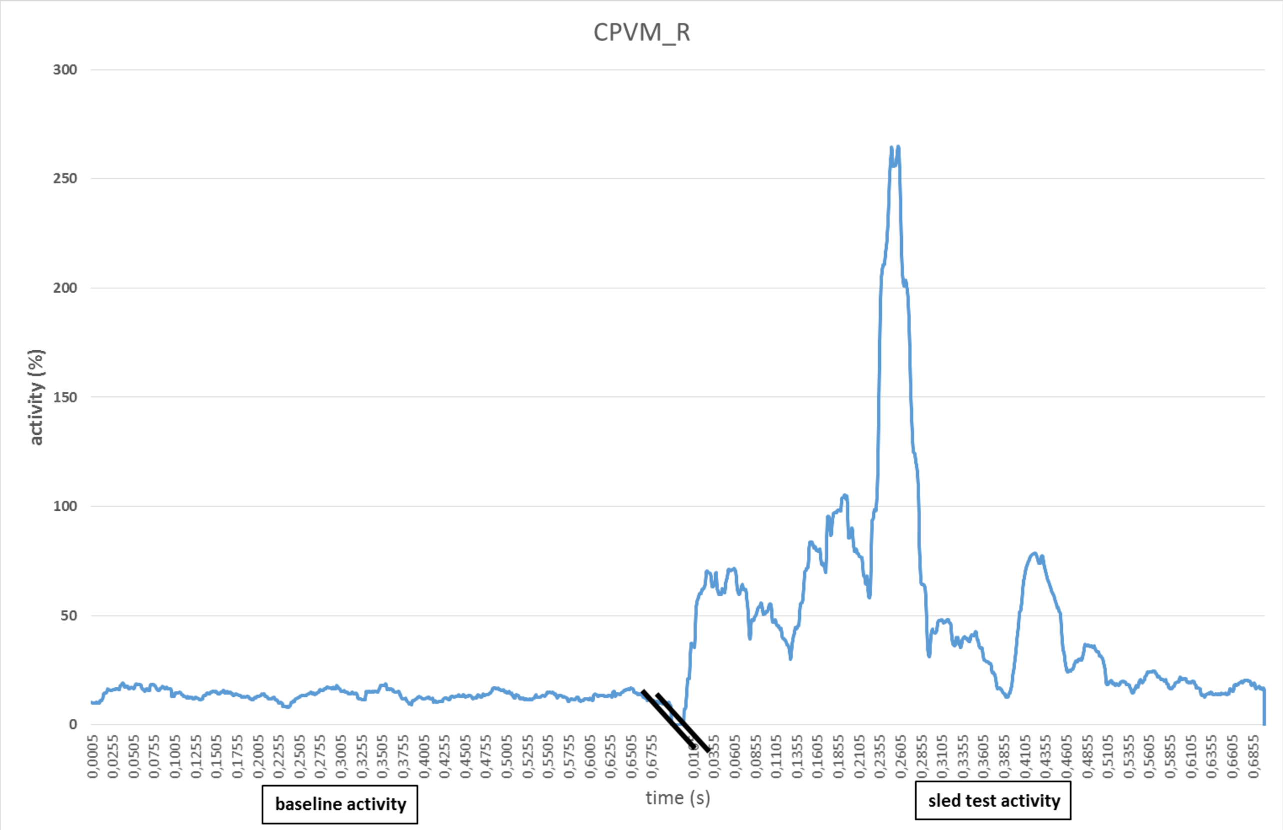

GC_R
activity (%)
time (s)
baseline activity
sled test activity

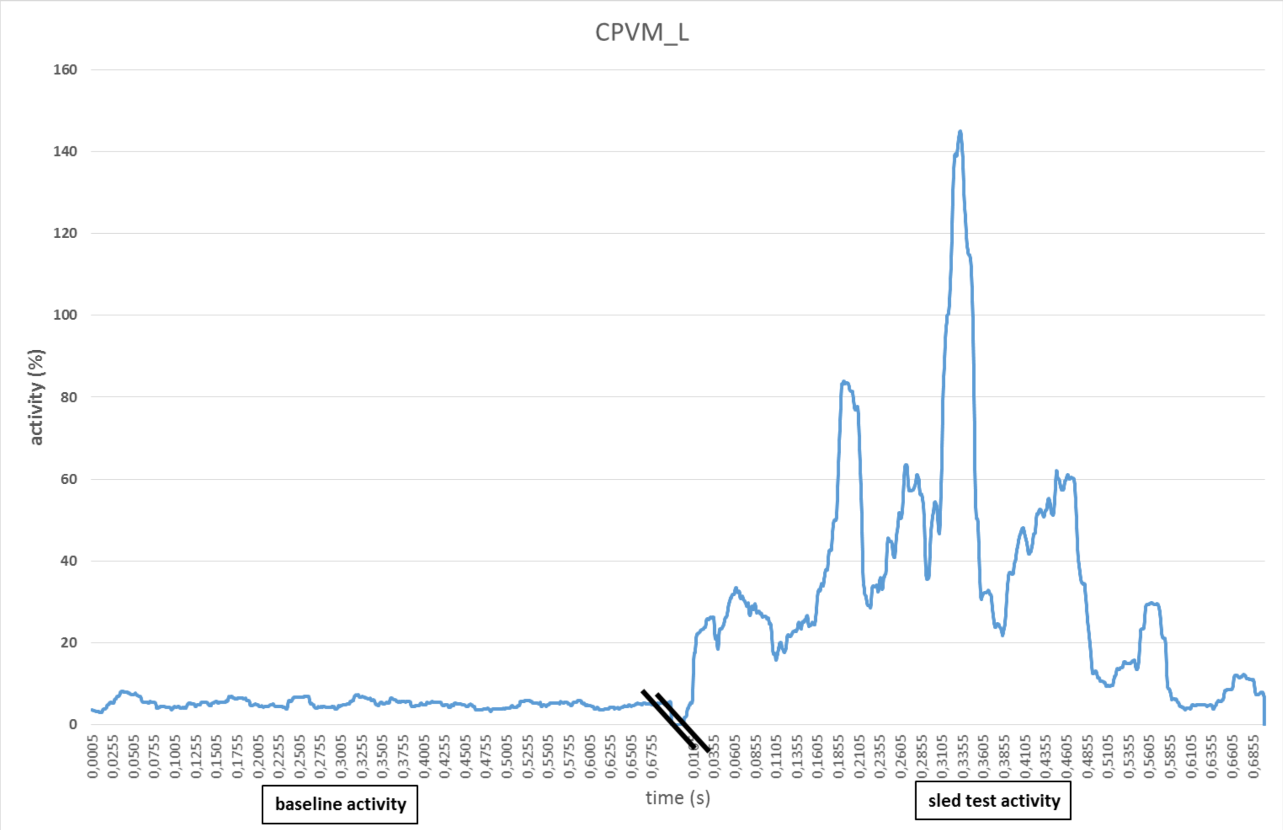

GC_L
activity (%)
time (s)
baseline activity
sled test activity

Trial 1782

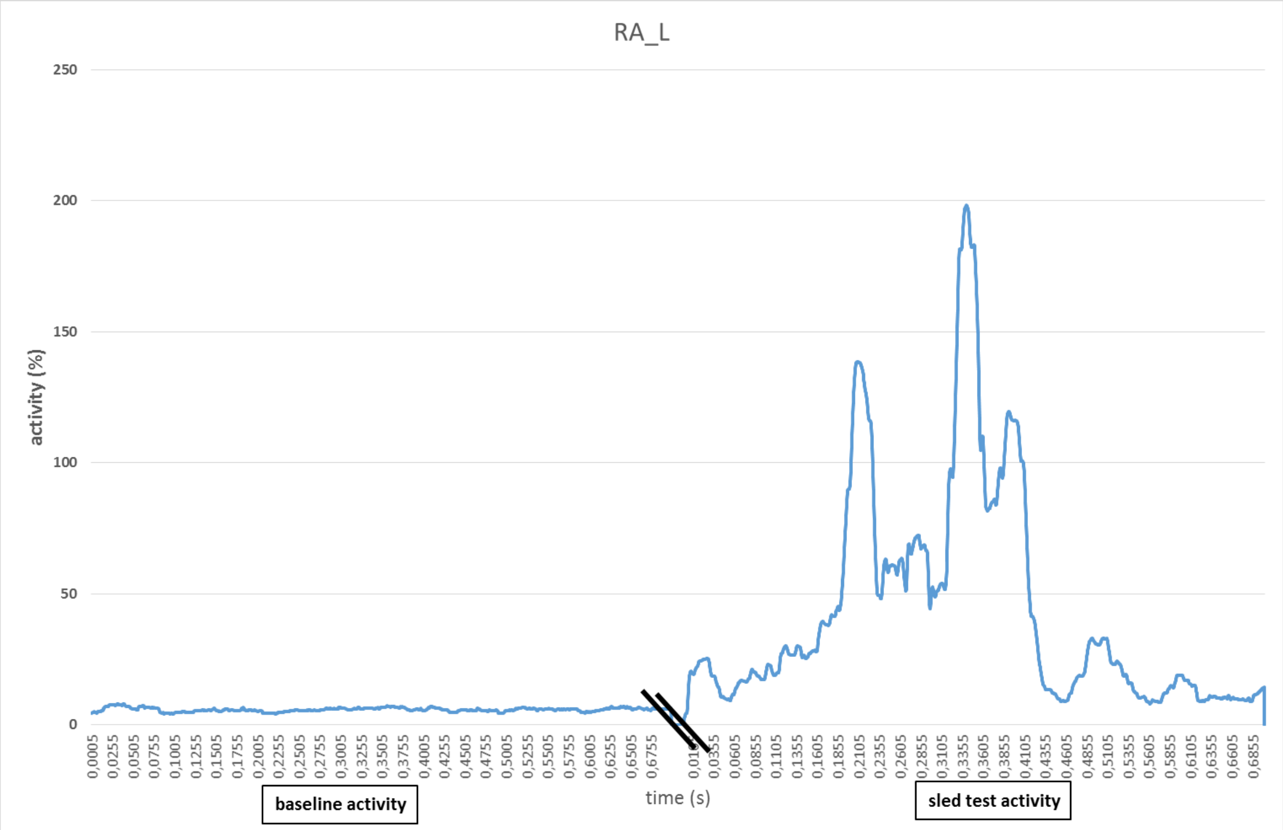

SCM_R
activity (%)
time (s)
baseline activity
sled test activity

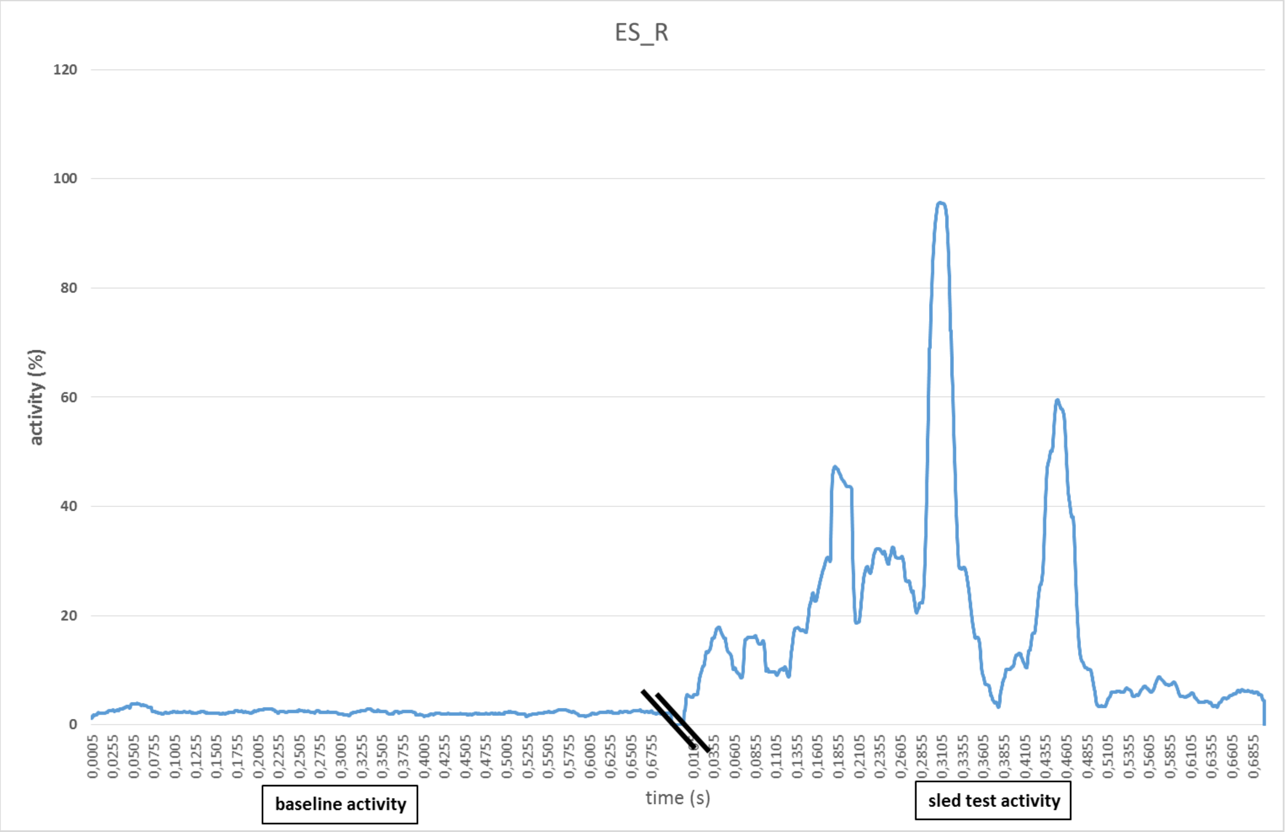

SCM_L
activity (%)
time (s)
baseline activity
sled test activity

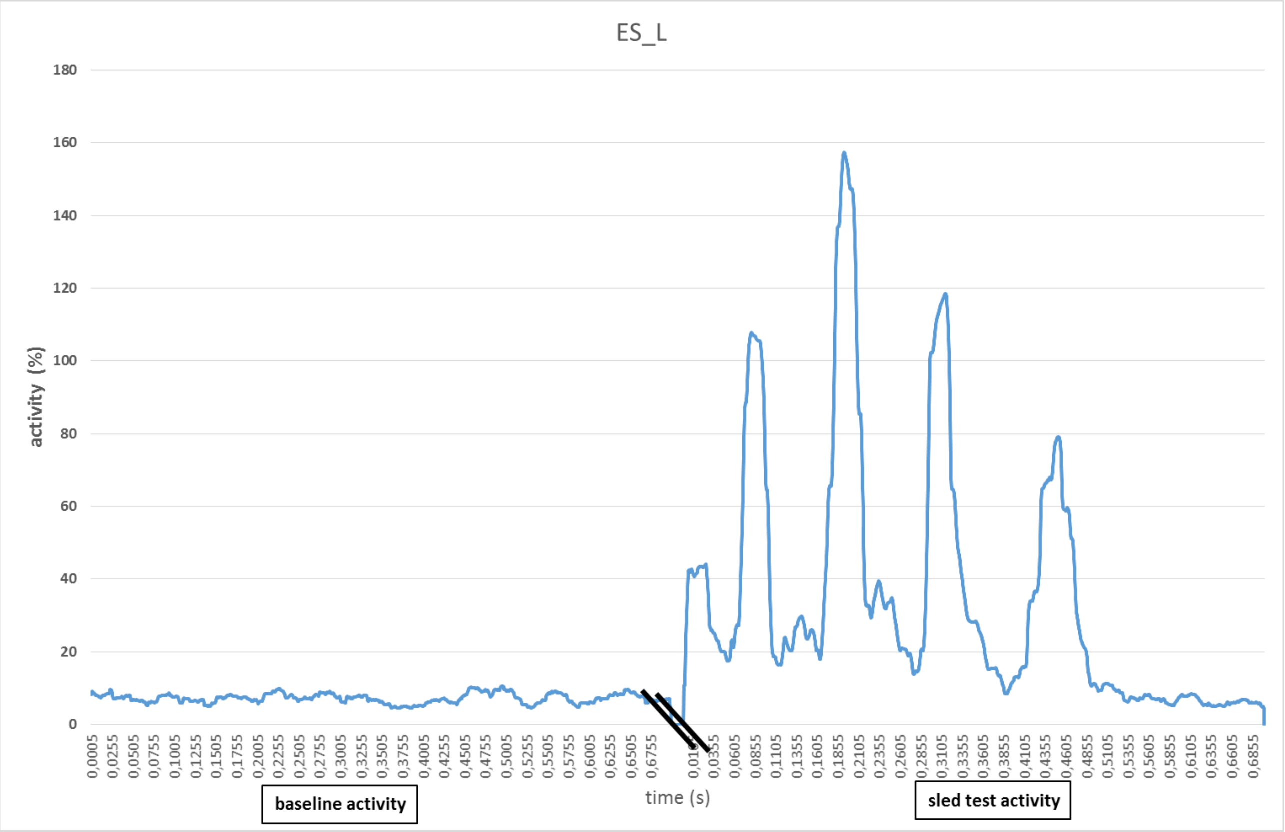

CPVM_R
activity (%)
300
250
200
150
100
50
0
time (s)
baseline activity
sled test activity

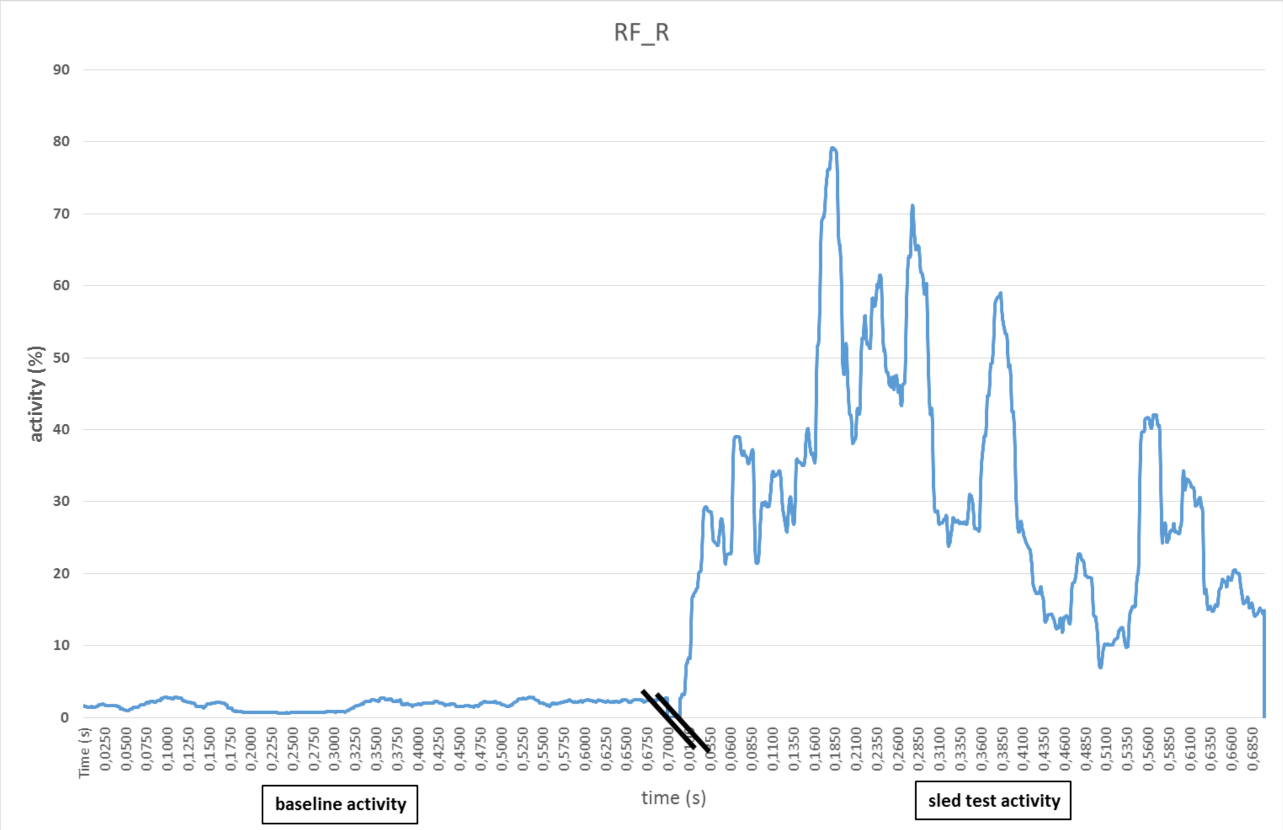

CPVM_L
activity (%)
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

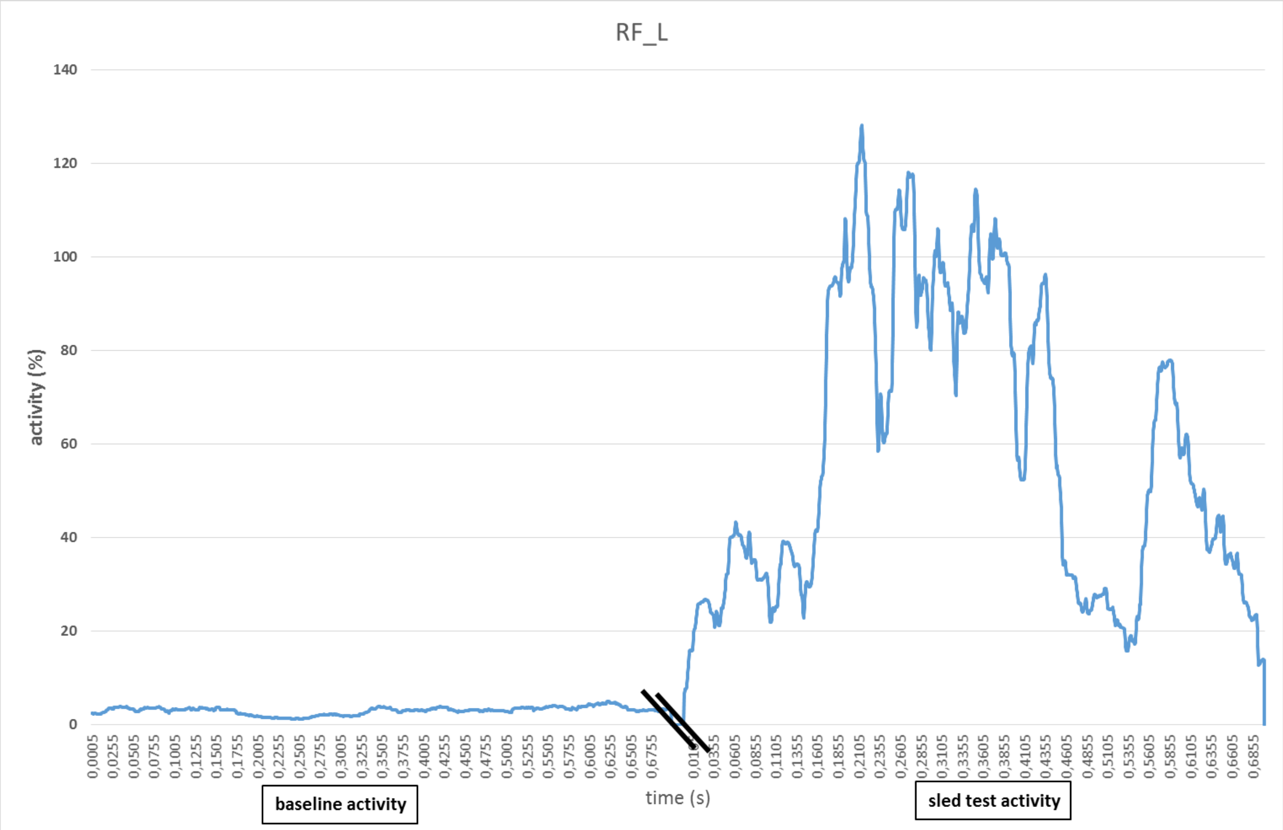

RA_R
140
120
100
80
60
40
20
0
activity (%)
time (s)
baseline activity
sled test activity

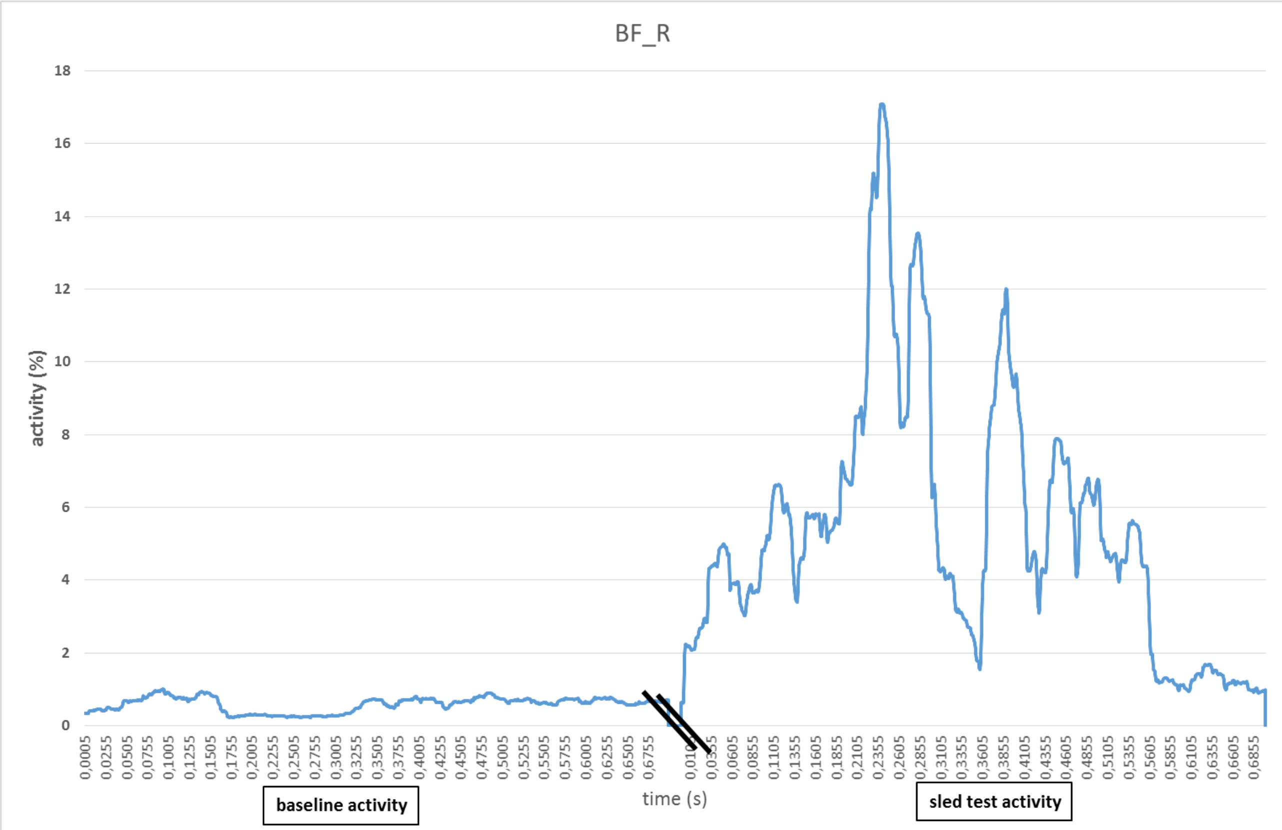

RA_L
250
200
150
100
50
0
activity (%)
time (s)
baseline activity
sled test activity

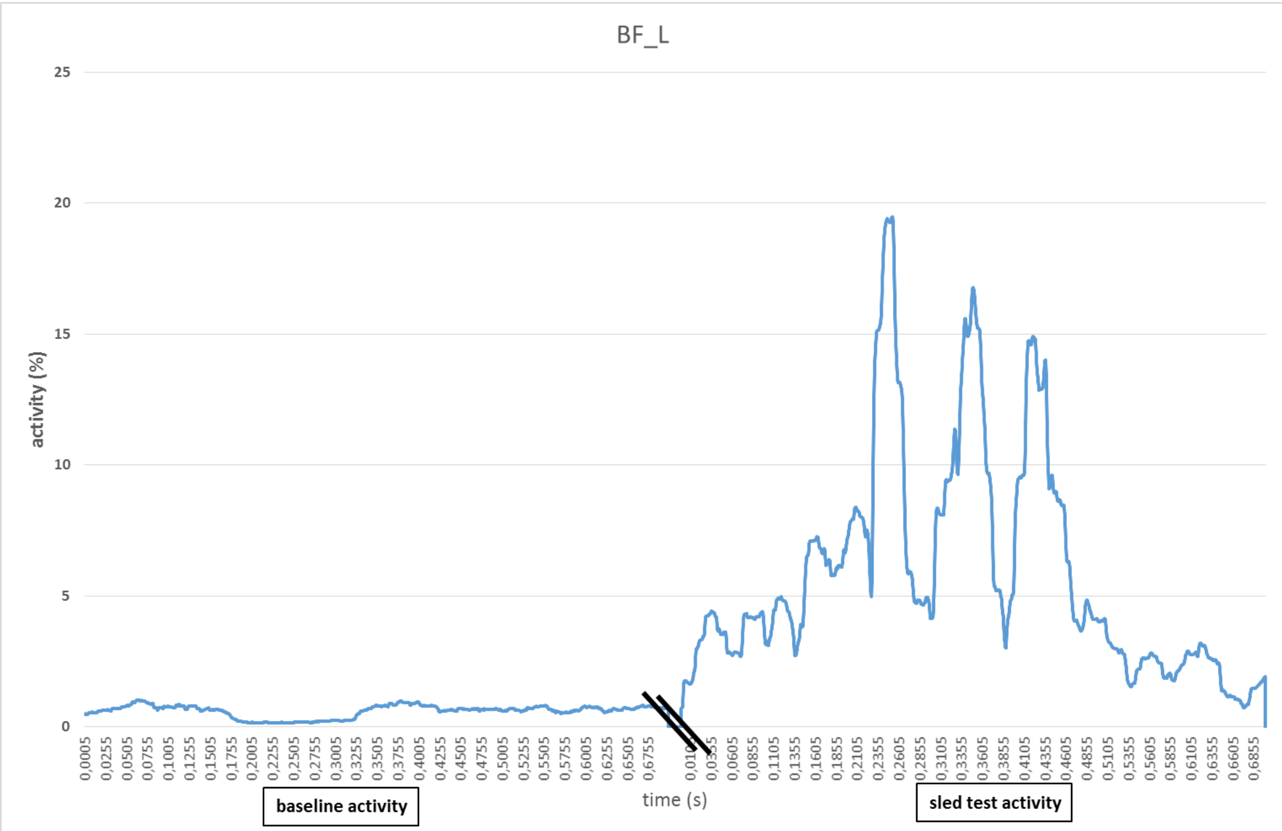

ES_R
activity (%)
time (s)
baseline activity
sled test activity

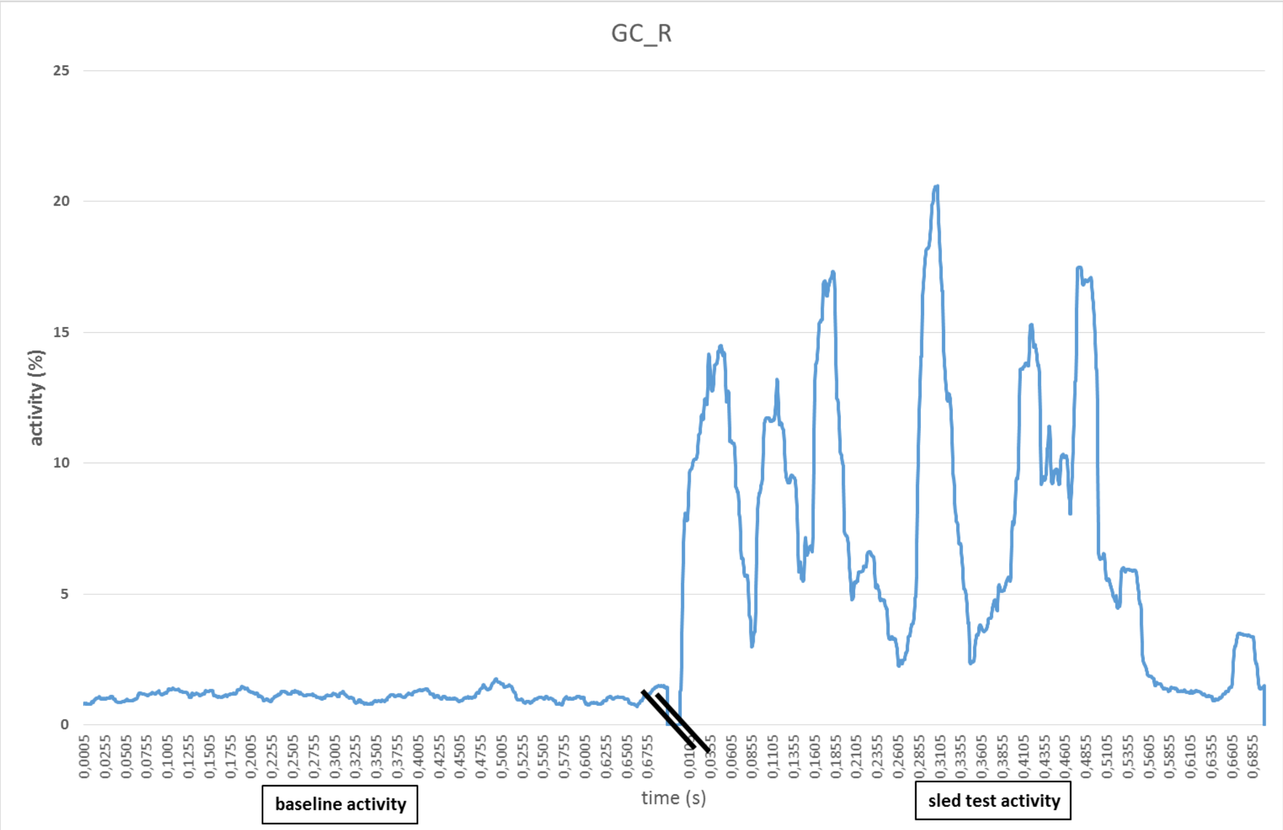

ES_L
activity (%)
time (s)
baseline activity
sled test activity

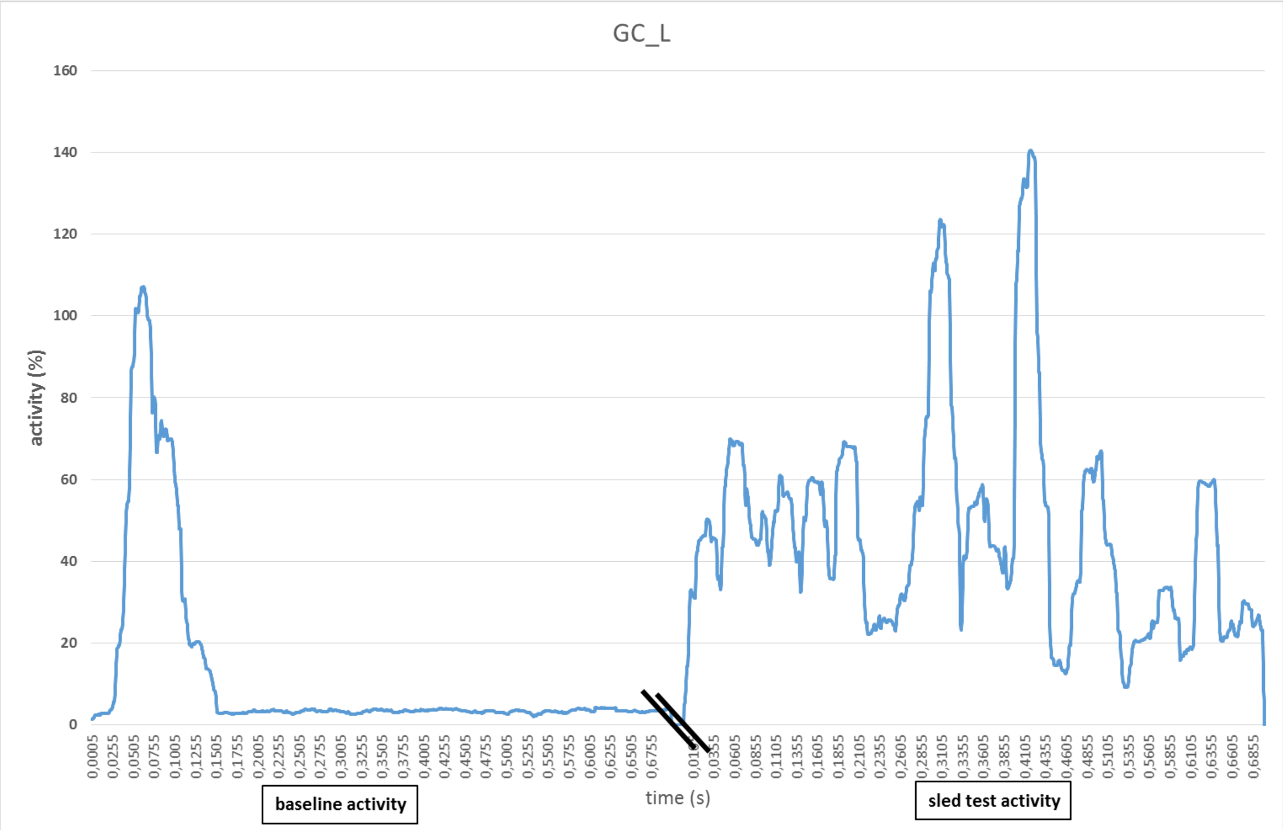

RF_R
activity (%)
time (s)
baseline activity
sled test activity


RF_L
activity (%)
time (s)
baseline activity
sled test activity


BF_R
activity (%)
time (s)
baseline activity
sled test activity


BF_L
activity (%)
time (s)
baseline activity
sled test activity


GC_R
activity (%)
25
20
15
10
5
0
time (s)
baseline activity
sled test activity


GC_L
activity (%)
160
140
120
100
80
60
40
20
0
time (s)
baseline activity
sled test activity

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