Additional Information
vHIT
EyeSeeCam

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1 Introduction

1.1   Preface

It is the purpose of this manual to provide users of the Interacoustics EyeSeeCam module with all the information required to carry out safe and reliable measurements.

In the past, a variety of techniques have been developed for measuring horizontal and vertical (that is, two dimensional) eye movements. These include Electro-Oculography (EOG), Scleral Search Coil (SCC) and photoelectric techniques. All of these techniques have been used in clinical and research applications.

EOG, using surface electrodes is limited in its application by an accuracy factor of around 2 degrees. It is further limited by its sensitivity to contamination by other electro-physiological artifacts and electromagnetic sources in the environment. Signal drift impairs measurement of absolute eye position and vertical eye position is highly non-linear. Photoelectric techniques have provided a higher degree of accuracy than EOG (down to 0.25 degrees). However, these techniques are often limited only to the measurement of the horizontal eye movement component.

Oculometric measurement with photoelectric techniques was first reported approximately fifty years ago. These early experiments involved manual photographic techniques to measure horizontal and vertical eye movement. Later, moving image techniques were employed to improve temporal resolution of the recordings.

With the establishment of electronic techniques for image scanning and reproduction, the image processing approach to oculometric measurement was introduced. With the development of the video market, small, high-resolution FireWire and USB cameras have become available.

These systems enable an accurate (0.1 to 0.5 degrees), contact free recording of eye movements. They can provide data on absolute eye position, and they are easy to handle.

Dizziness is a frequent symptom in ENT, Neurology, and General Medicine. Part of the clinical examination of dizzy patients is based on the head impulse test (HIT) of the vestibulo-ocular reflex (VOR). Head impulses are movements with small positional amplitude (10-20 degrees) but high acceleration (3.000-6.000 degrees/s2) and high velocity (150-300 degrees/s). When performed clinically with no quantitative analysis, the test only detects the presence of a corrective saccade as an indirect sign of a VOR deficit.

The EyeSeeCam can easily be conducted at the bedside, but it has only a moderate sensitivity (63% in experts and 72% in non-experts). Its specificity is 78% in experts and 64% in non-experts. Sensitivity, however, can be improved to up to 100% when quantitative data of the VOR are obtained during the head impulse. In patients with an acute unilateral vestibular deficit the quantitative HIT is as reliable as the caloric irrigation test. Chronic patients, however, show a pathological caloric result in only 64% of the cases but they were reliably identified by quantitative HIT. Hence, in the acute phase of a vestibular deficit either of these tests is sufficient, but in the chronic phase, which is typical for a vertigo and dizziness outpatient unit, the quantitative HIT is better.

HIT with its lightweight goggles and the integrated inertial measurement unit (IMU) provides a measurement device for an objective and quantifiable HIT. The mobile setup with a battery-driven laptop ensures that the HIT can be applied at the patient's bedside and in the emergency room. With it, a doctor can objectively and reliably assess peripheral vestibular function in a few minutes and differentiate peripheral from central vertigo. This video-based HIT is a novel, time-saving and low-cost tool that can be readily applied in all clinical setups, such as in vertigo outpatient units or in emergency rooms.

2 Working with VHIT (detailed) data capture and analysis

2.1   Data artifacts due to image problems

There is a rule that is of emminent importance for every eye tracking device:

The pupil must be completely and well visible throughout the impulsive head movement.

The less the pupil is visible the more noise and artifacts will be in the data. This can be due to a ptosis, eyelashes, blur, a deadjusted camera, etc. It might well be that the pupil touches the edges of the image somewhere during the head movement. In such a case the camera needs to be readjusted, i.e., the pupil needs to be re-centered.

Sometimes repeatable bursts of aphyisiolgic activity in the eye movement trace for head impulses might appear. In the video monitor this might be accompanied by the brief jump of a small circle inside the larger circle around the detected pupil. This happens when the camera is saturated by the reflection from the LED close to the pupil edge (see Figure 2.1 left). The circle around the pupil is the result of an ellipse fit to the pupil edge. Sometimes, the reflections can disturb this fit. Then the circle jumps.

To avoid these artifacts, the subject's head needs to be repositioned in pitch in such a way that the reflections are far below the pupil (see Figure 5.1 right). The head needs to be rotated into a more pitched down orientation until the distance between the two reflections and the pupil is increased.
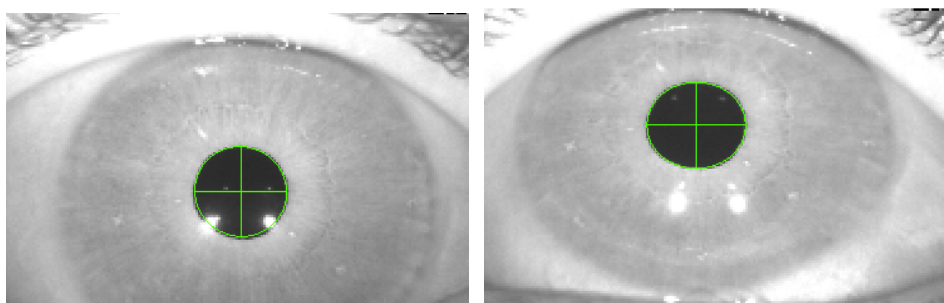

Figure 2-1 LED reflections located on the pupil edge (left) and far below the pupil (right). The reflections on the pupil edge interfere with the ellipse fit. On the left, the resulting ellipse is not perfectly aligned with the pupil edge. After re-orienting the head slightly downwards in pitch, the reflections are well below the pupil yielding an ellipse that nicely fits the pupil edge.

Another advantage of such a head orientation is that during the head impulse test the lateral canals become better aligned with the plane of stimulation. It might also help to switch off the ellipse fit on the Settings tab. But then only a less accurate center of mass calculation is performed on the dark pupil pixels. Another solution might be to try to increase pupil size by dimming the light in the lab. This way, the reflections might always remain inside the pupil without crossing the pupil edge. This also has the advantage that there is less noise in the eye movement data, due to the fact that more pixels enter the pupil center estimation.

2.2   Calibration

Pupil positions are originally detected and described in the coordinate system of the camera image in units of pixels. During the calibration procedure the examined subject needs to fixate luminous dots that are projected by a head-fixed laser at predefined agles of 8.5°.

The examiner must first select *Calibration* from the *Test* list and then press the *Prepare* pushbutton. This will switch on the laser. Then, the participating subject needs to be instructed to repeatedly fixate the 5 brightest laser dots, each for a duration of about 1 second or less. The sequence can be arbitrary. The patient can start with this procedure as soon as the examiner presses the *Start* pushbutton.
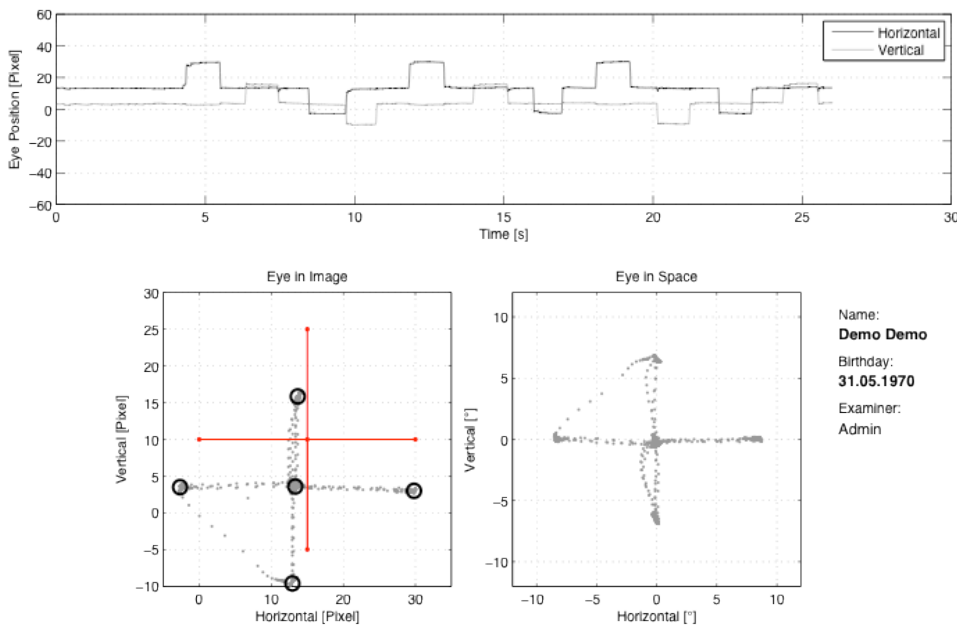

Figure 2-2 Exemplary data presentation after a successful calibration.

The recording is either stopped automatically after a predefined time or it can be aborted by a press on the *Stop* button. Instead, the keyboard space key can be used both for starting and for stopping the recording. After the recording was stopped the calibration analysis will automatically show a window with the fixation data displayed as raw points. The calibration fixations are detected by a clustering algorithm and the results are marked with circles.

2.2.1 **Re-Calibration**

Recorded calibrations can be used at any time later for both calibrating the realtime part of the system again and for (re-) calibrating the measurements that have been previously recorded from a patient in a certain session. This can be achieved by selecting the desired calibration file from the test trials table and by subsequently pressing the Full Report button. After the Full Report window with the calibration data is closed, a dialog box will be displayd asking whether you want to use this calibration.
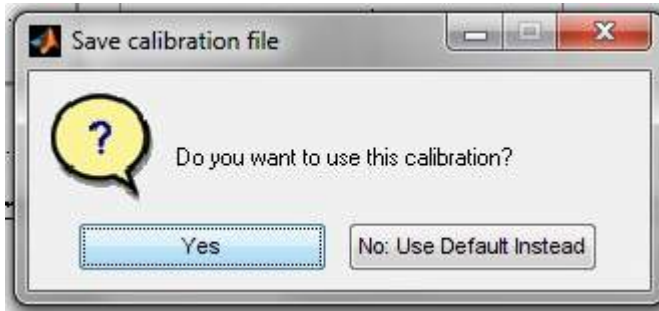

Figure 2-3 Re-Calibrating with previously recorded calibration data.

Selecting Yes will store this calibration data with the patient file. Instead, one can either cancel re-calibration by selecting No: Use Previous or use the default calibration by selecting No: Use Default Instead.

At any time a recorded calibration can be defined as the default calibration. This can be achieved by selecting the desired calibration file from the test trials table and by subsequently pressing the Full Report button. In the full report menu this function can be selected with Calibration / Save as Default Calibration.
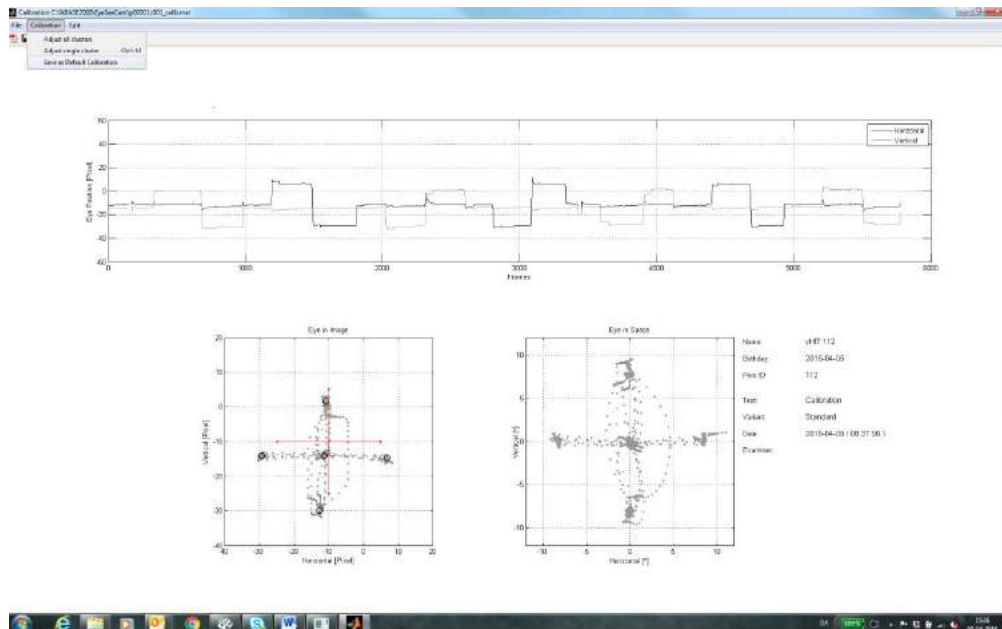

Figure 2-4 Save a calibration file as the default calibration.

2.2.2 Calibration failures

Calibrations can fail if, for example, patients are not able to fixate the calibration targets. This can have many reasons: attentional deficits (in childeren), spontaneous and fixational nystagmus, gaze palsies, ptosis in elderly, etc. Even healthy subjects might fail to successfully complete the calibration routine if not instructed correctly, if their pupils are partially covered by the eye lids, or if the pupils are not detected correctly throughout the measurement.
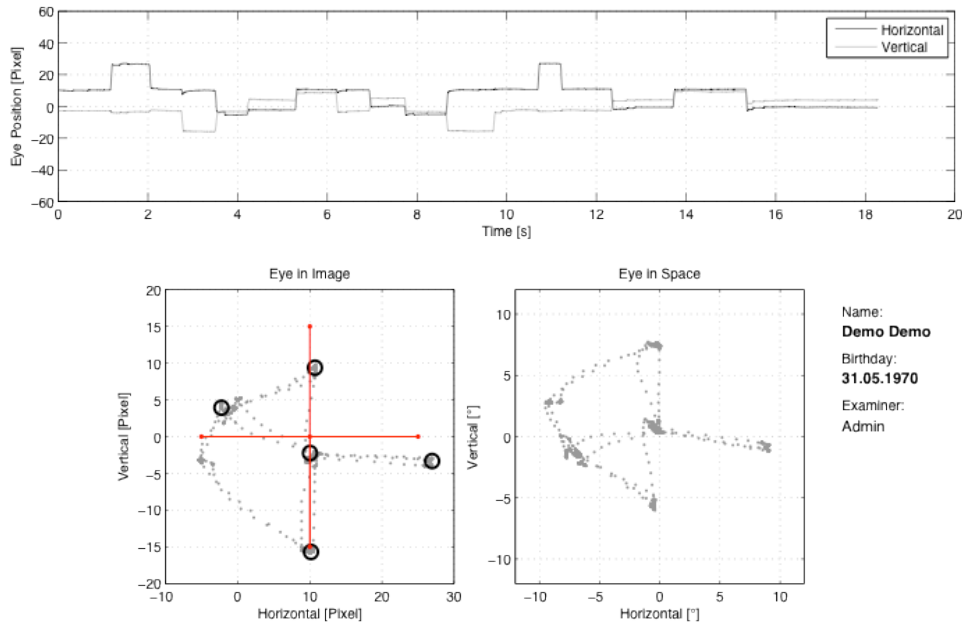

Figure 2-5 Example of a failed calibration. The patient fixated six instead of five dots.

If an error message is diplayed or if the fixation data is not displayed correctly as in the example of Figure 2-5 the automatic cluster analysis of the calibration measurement has failed. In such a case the user has the following options:

• Repeat the calibration
• Manually mark the fixation points
• Use a predefined default

If the automatic fixation detection algorithm has failed, the examiner can manually mark fixation points. The Calibration menu provides the functions Adjust single cluster and Adjust all clusters for manually adjusting either one fixation point or all five fixations, respectively.
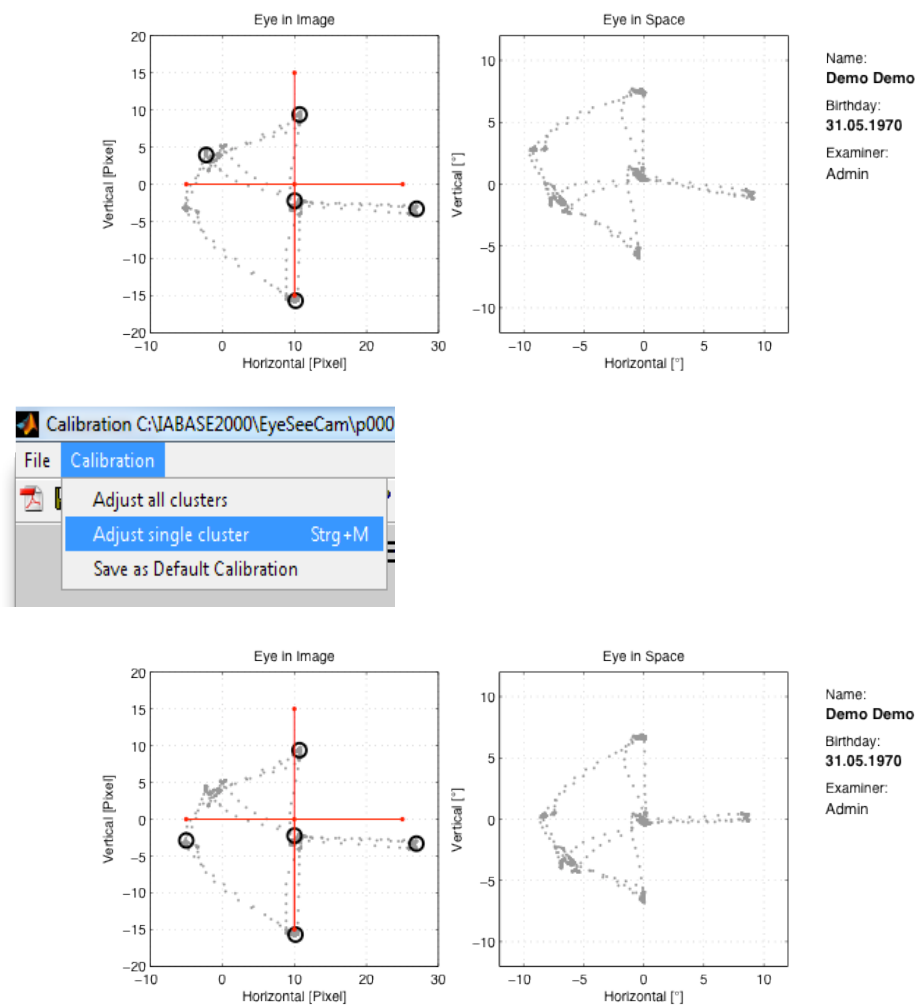
Figure 2-6 Manual marking of fixation points. After selecting Adjust single cluster from the Calibration menu, one of the circles denoting a detected fixation can be manually moved with the mouse to a new position. The Eye in Space data in the right plot are recalculated according to the newly defined fixation.

2.3   Performing the head impulse test

Before a HIT can be applied the system needs to be calibrated as described in the Calibration section. After calibration *Head Impulse / Lateral* needs to be selected from the *Test* list.

The HIT plot displays both the horizontal head velocity (grey), as measured by the angular rate sensor of the integrated inertial measurement unit, and the horizontal eye velocity (black), as determined from numerical differentiation of the horizontal pupil position. The realtime display of this eye and head rotation data provides immediate feedback to the examiner about the quality of the performed head impulse.

With sufficient experience the examiner can assess vestibular function by visual inspection of the realtime plot after just a few head impulses in each direction.

As soon as the *Start* button is pressed the recording is started. During the recording the examiner should apply at least six valid head impulses into each direction. Since some of the head impulses will probably be invalid due to small velocities and small accelerations or due to, e.g., a closed eye lid, a minimum of about 10 applications per head rotation direction should be considered.

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After the examiner has applied a sufficient number of valid head impulses she can stop the recording and display the results of the test with a click on the *Stop* button.

A press on the *Stop* button stops the recording and automatically displays the Full Report. After pressing the *Stop* button the test table is updated with a new entry containing the name of the test and the time of recording. The results of previous recordings can similarly be analyzed and displayed by selecting the desired data file from the test table and by a subsequent click on the *Full Report* button.

2.3.1 Head movement

Whether or not a head impulse is correctly analyzed by the system depends on many factors. Examiner training and experience is a major factor. The examiner needs to learn:

- how to grab the patient's head
- how to apply high-velocity and high-acceleration head rotations
- how to avoid moving the patient skin in order to minimize goggle slippage
- how to inspect proper fit of the goggles

Subjects need to be seated at least 1.5 m away from a fixation target at eye level on the wall in front of them. Before formal testing, the examiner needs to ensure that the subjects have an adequate range of unrestricted and painless angular head rotation. vHIT goggles need to be fitted firmly to the subject's head ensuring a tight fit so as to reduce goggle slippage. The camera needs to be adjusted and focussed on their eye while the subject fixate on the target.

The system then needs to be calibrated with the subject altering fixation around 5 dots projected onto the wall in front of them. This process is described in the Calibatrion section. The fixation sequence can be arbitrary and subjects need to be instructed to spend no more than 1 second fixating on each dot.

The testing method needs to be outlined to the subject and important testing guidelines have to be made clear. This includes:

- That the subject should clench their teeth during head impulse testing to reduce jaw movement and facilitate a more direct force transfer to the head. This is to reduce movement artifact
- To maintain relaxed neck musculature and not to anticipate or aid in head movements as their assistance with rotations could affect results
- Not to move the goggles once calibration was completed
- To keep their eyes open wide and try to minimize blinking. This would allow the EyeSeeCam vHIT software to keep track of pupil movements more easily

Eye and head rotations are then measured during the HIT while the examiner manually applies rapid unpredictable (in direction and time) angular head rotations (peak head velocity 150 °/s to 300 °/s.

In order to avoid interference between consecutive head impulses, the examiner should introduce breaks of unpredictable durations on the order of at least 2 s in between individual head movements. Instantaneous gains are recorded by the EyeSeeCam vHIT software at 40, 60 and 80ms. Head accelerations need to be manually controlled so that peak head velocity occurs within about 80 ms into each rotation. This can be achieved with angular head displacements of small amplitude (6° - 12°) with rapid rotation.

Rotation of the subjects head can be performed with the examiner standing behind the seated subject. A sequence of ten valid unpredictable head rotations in both directions is required in the assessment of the HIT.

Figure 2-7 Application of proper head impulses with the examiner in the back of the patient. The examiner is holding the mandible with his fingers while the patient clenches her teeth.

Proper head rotations are achieved by the examiner firmly holding the mandible with the fingers as shown in Figure 2–7. This reduces skin movement and thus goggle slippage, decreasing the amount of artefact. Care has to be taken to avoid touching the goggles strap during head rotation.

2.3.2 Head impulse test diagrams

The head impulse test diagrams are displayed on different time axes. In the head impulse test the following measurement graphs are available.

• Right side head impulses and corresponding eye velocities plotted over time
• Right side head impulse gains plotted over time
• Left side head impulses and corresponding eye velocities plotted over time
• Left side head impulse gains plotted over time
• Instantaneous gains at 60 ms for right and left side plotted over head velocity
• Phase diagram with left and right side eye velocities plotted over head velocity, yielding velocity regression slopes which represent average VOR gains
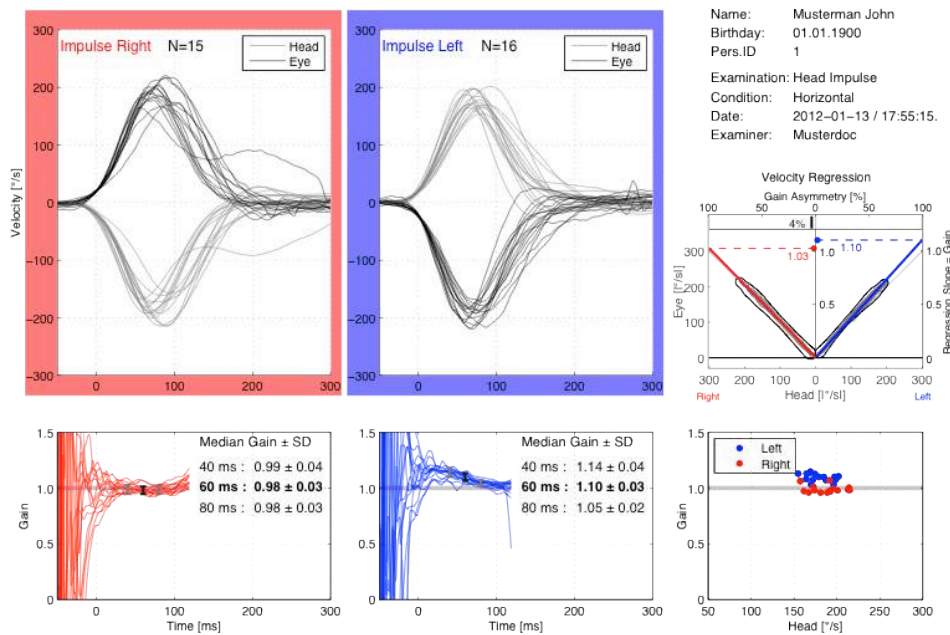
Figure 2-8 Head impulse test results in a healthy subject. In the upper two left diagrams the eye (black) and head (gray) velocity trajectories for all valid head impulses are separately overlaid for head rotations to the right and left. The time course of the instantaneous gain (defined as the ratio of eye and head velocity) is displayed in the bottom two left diagrams. For all pairs of eye and head velocity trajectories, corresponding gain trajectories are calculated and overlaid in these bottom graphs. Median values of instantaneous gains are calculated at 40, 60, and 80 ms in windows of ±10 ms and listed in the tables at the right of the respective gain diagram. The gains at 60 ms are highlighted by bold typesetting and they are displayed over head velocity for all valid head impulses in the bottom right diagram. In addition to the instantaneous gains, the upper right Velocity Regression diagram plots the absolute values of eye velocity over head velocity. Regression slopes for right (red line) and left (blue line) head impulses are fitted to all eye and head velocity data pairs. The resulting regression slope values for right and left are displayed in red and blue, respectively.

In Figure 2-7, impulsive head rotations to both the left and the right cause perfectly compensatory eye movements to the right and the left, repectively, with normal gains on the order of 1.0. Eye velocity trajectories in the upper two left plots resemble a mirror image of the head velocity trajectories. In these plots the eye (black) and head (gray) velocity trajectories are separately overlaid for all valid head impulses to the right and left.

In Figure 2–9 a patient with a right unilateral vestibular deficit (UVD) is shown.
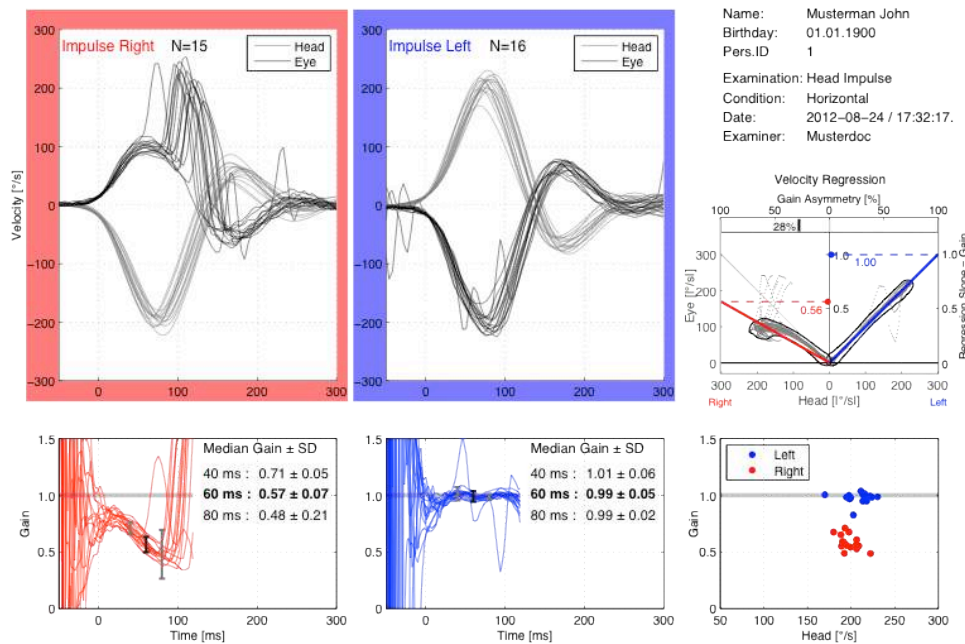
Figure 2-9 Head impulse test results with a right unilateral vestibular deficit (UVD). The UVD is clearly visible for head rotations to the Right. In the upper plot of Right head impulses, the slow phase eye movements do not compensate for the head rotation. Instead, covert corrective saddades are triggered with a short latency. The time course of the instantaneous gain for Right movements shows a continuous decay from values around 1.0 to values on the order of 0.5. The right-sided UVD is reflected in the below-normal gain of 0.62 at 60 ms and in the covert catch-up saccades that compensate for this deficit. The UVD is also reflected in the Velocity Regression diagram both the right slope of 0.57 and in the gain asymmetry of 27%.

2.3.3 Automatic detection algorithm

There are several methods to calculate the VOR gain. The analysis part of the EyeSeeCam software calculates three instantaneous gains as median values in windows of ±10 ms at 40, 60, and 80 ms after head movement initiation. This method is based on an algorithm that was validated for search coil recordings.

Head impulses are automatically detected from the data according to a combination of several criteria:

- Peak angular head velocity has to be reached within the first 150 milliseconds after onset of head impulse and has to exceed 70 °/s
- Head acceleration has to exceed 1,000 °/s^2
- Head velocity 50 milliseconds before onset of the impulse does not exceed 20 °/s
- The relevant component of head velocity does not change sign during the impulse
- The maximum difference between eye and head velocity before onset of the head impulse does not exceed 20 °/s
- The direction of the rotation axis of the head at maximal velocity has to lie within $\pm45°$ of the intended direction
- Head impulses with a maximum head velocity outside 1.5-fold the inter-quartile range are rejected as outliers

The onset of the head impulse is defined as the time when head velocity exceeds 20°/s. In patients with nystagmus, the additional slow-phase drift of the patients is computed as the median eye velocity vector of all data points when the head is stable in space. This eye velocity offset is subtracted from the eye velocity data before computing the gain values. This algorithm ensures that head impulse testing can also be performed in acute patients presenting with spontaneous nystagmus. Quick phases erratically occuring during individual head impulses are ignored by the median-based gain calculation.

2.3.4 Editing

If automatic elimination of badly performed head impulses should fail, outlier trials can be eliminated manually by using the menu *Edit / Selection.*.

The functions in this menu are useful for deleting head impulses with artifacts from the recordings.

2.3.4.1 Select multiple

Select Multiple allows you to click and select several waveforms to be edited at the same time.
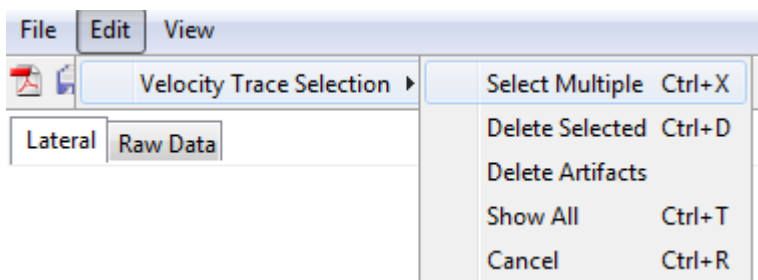

Figure 2-10 Edit menu, select multiple waveforms

In Figure 2–10, for example, there is one very early covert saccade in a head impulse to the right affecting the standard deviation (SD) at 80 ms. With a value of 0.23 this SD is considerably increased as compared to the values of 0.05 and 0.06 at 40 ms and 60 ms, respectively. In addition, for head impulses to the left there are some non-physiological measurement artifacts. These unwanted head impulses can all be removed by selecting all artifactual waveforms from the head impulses diagrams and by finally clicking *Delete Selected* from the menu. Figure 2–10 illustrates this selection process.
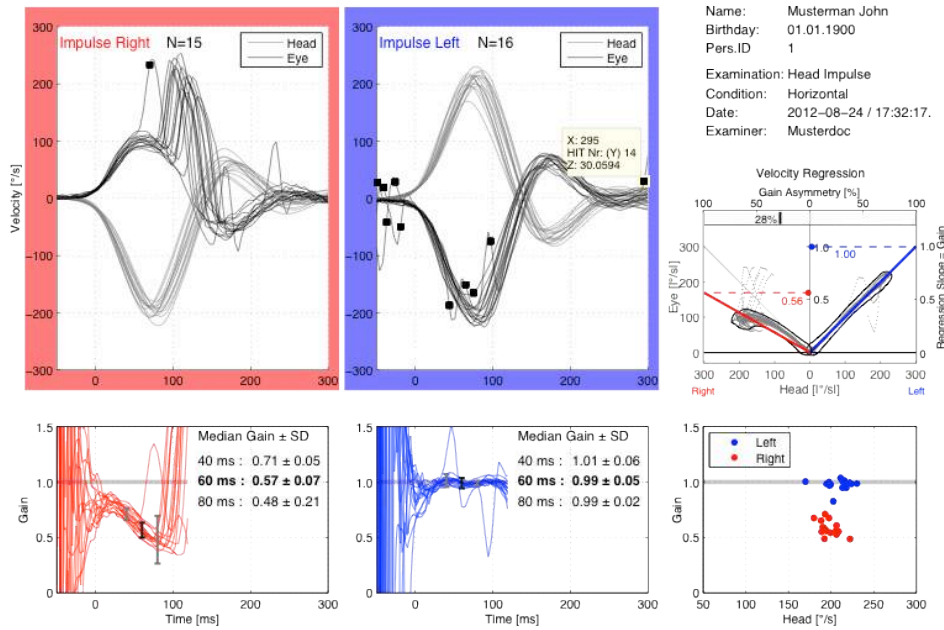
Figure 2-11 Head impulse traces with artifacts that are selected for removal. The selected traces are denoted with black markers. The last selected marker always shows a data tip containing the coordinates of its click.

2.3.4.2 Delete selected

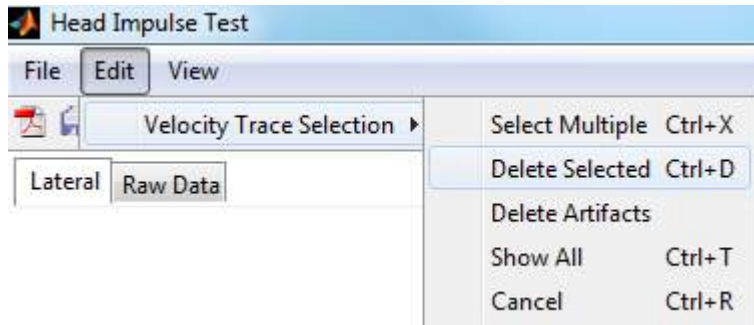Delete selected allows you to delete all the selected waveforms at one time.

Figure 2-12 Edit menu, delete selected

After all unwanted traces have been selected, as shown in Figure 2–12, the menu *Edit / Selection >/ Delete Selected* needs to be clicked in order to finally delete the selected traces. The final report and the gain calculations are automatically updated without the unwanted impulses.
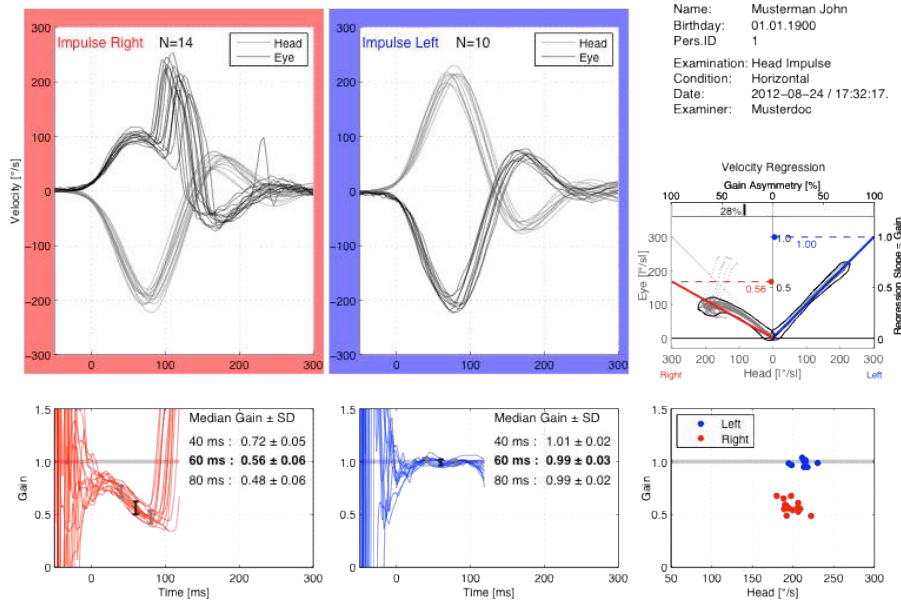
Figure 2-13 Head impulse traces with removed artifacts. As compared with the original data of Figure 5–9 the affected right SD at 80 ms and left SD at 40 ms both decreased after artifact removal from 0.23 to 0.06 and from 0.06 to 0.03, respectively. The instantaneous gains, however, do not change because these are based on a median calculation that is robust against artifacts and outliers. The regression slope, however, changed from 0.58 to 0.56 for impulses to the right.

2.3.4.3 Delete Artifacts

Delete Artifacts allows you to apply a filter that will delete data presumed to be artefacts. By default, this filter is applied automatically. However, after Show All is selected all recorded traces are shown again, including those previously removed with both the artifact filter and with manual selection. The artifacts filter can be applied again in order to remove the artifact traces again.
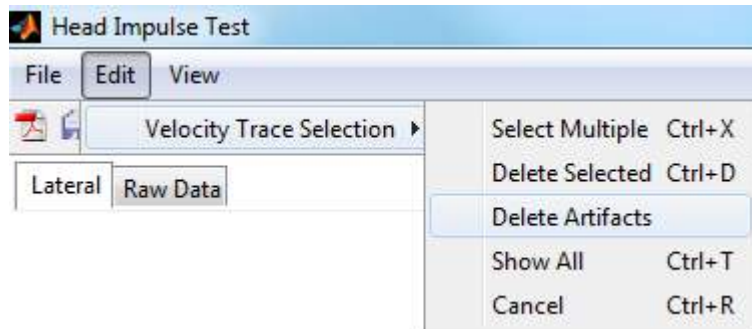

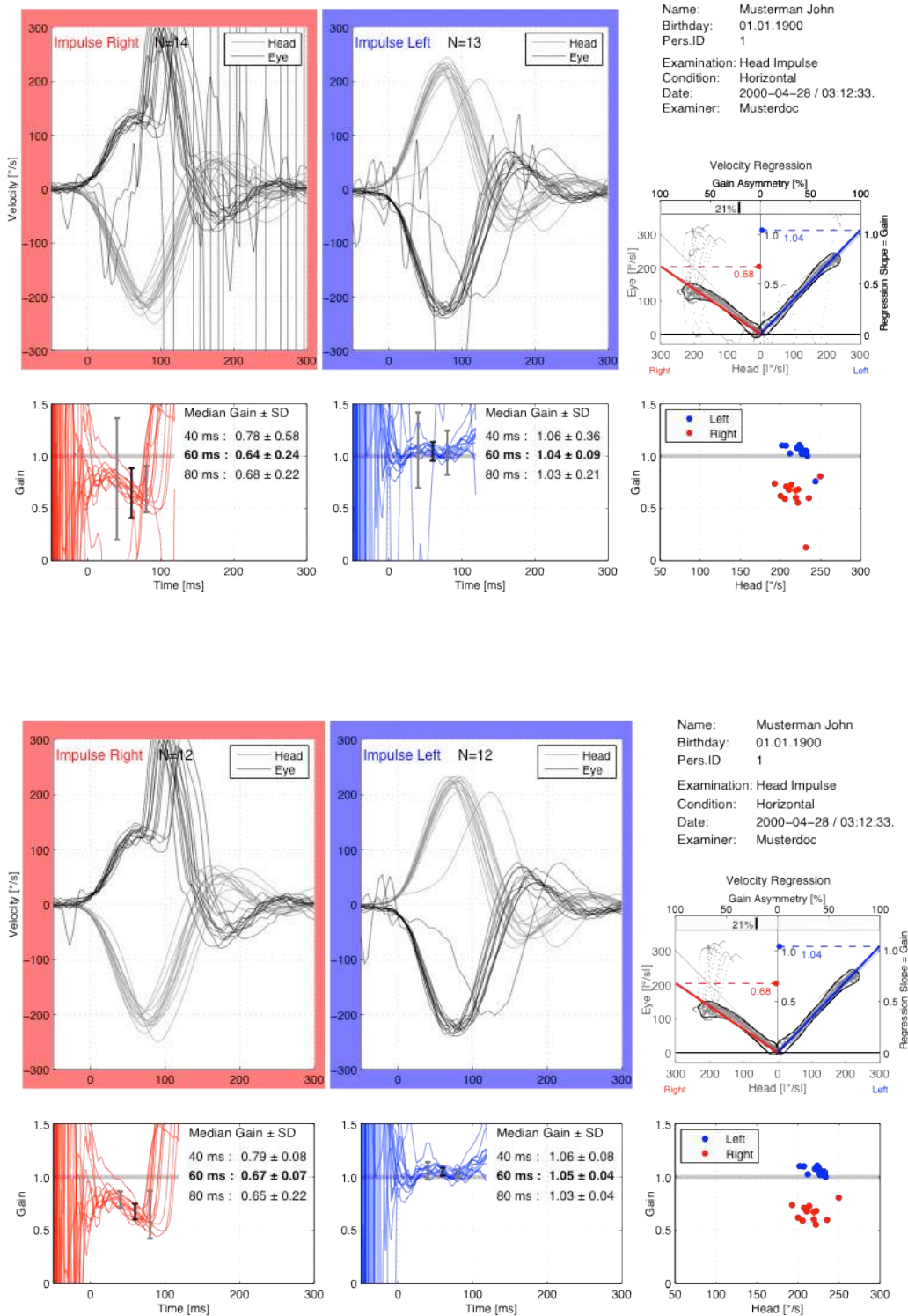*Figure 2-14 Edit menu, delete artefacts*

Figure 2-15 Exemplary traces with artifacts (top) and removal of artifacts by applying the artifact filter (bottom). Please note that due to the robust median-based calculation of gains there is no considerable change in the gain values before and after artifact removal. Only the standard deviations are changed.

2.3.4.4 Show all

Show all allows you to show all tracings including those previously removed with both the artifact filter and with manual selection.
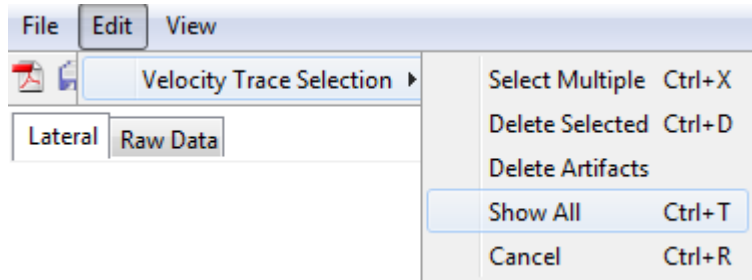

Figure 2-15 Edit menu, show all

Removal of unwanted traces can be undone by clicking the menu *Edit / Selection >/ Show All*. In addition to displaying the contents of Figure 2–15 again, this function would also display other artifactual head impulse traces which have been automatically removed with a variance-based outlier-detecting filter. This filter is applied per default to every recorded file. A click on the menu *Edit / Selection >/ Delete Artifacts* starts this filter manually.

The parameters of the algorithms that are described in this Automatic Detection Algorithm section are contained in the xml-file eyeseemat_settings.xml which is located in the .eyeseecam (note the dot!) directory in the user folder.

2.3.4.5 View display

The View Display menu gives you several choices for displaying your results.

2.3.4.5.1 Color/monochrome/3D wave

You can use color or monochrome black/grey. Monochrome can be used for WYSIWIG printing on a cost-efficient black and white laser printer.
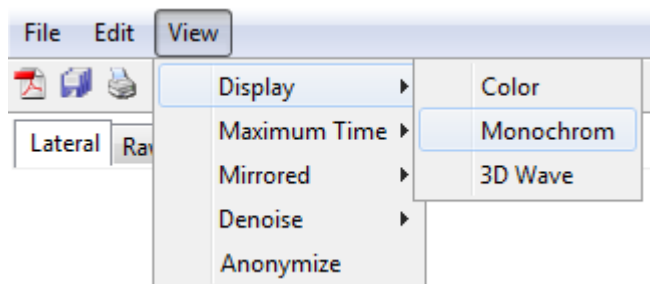

Figure 2-16 Edit Menu, display color

2.3.4.5.2   Maximum Time

You can change the maximum displayed time.

2.3.4.5.3   View Mirrored

You can view the data in a mirrored image where the eye and the head movements are displayed in the same direction.
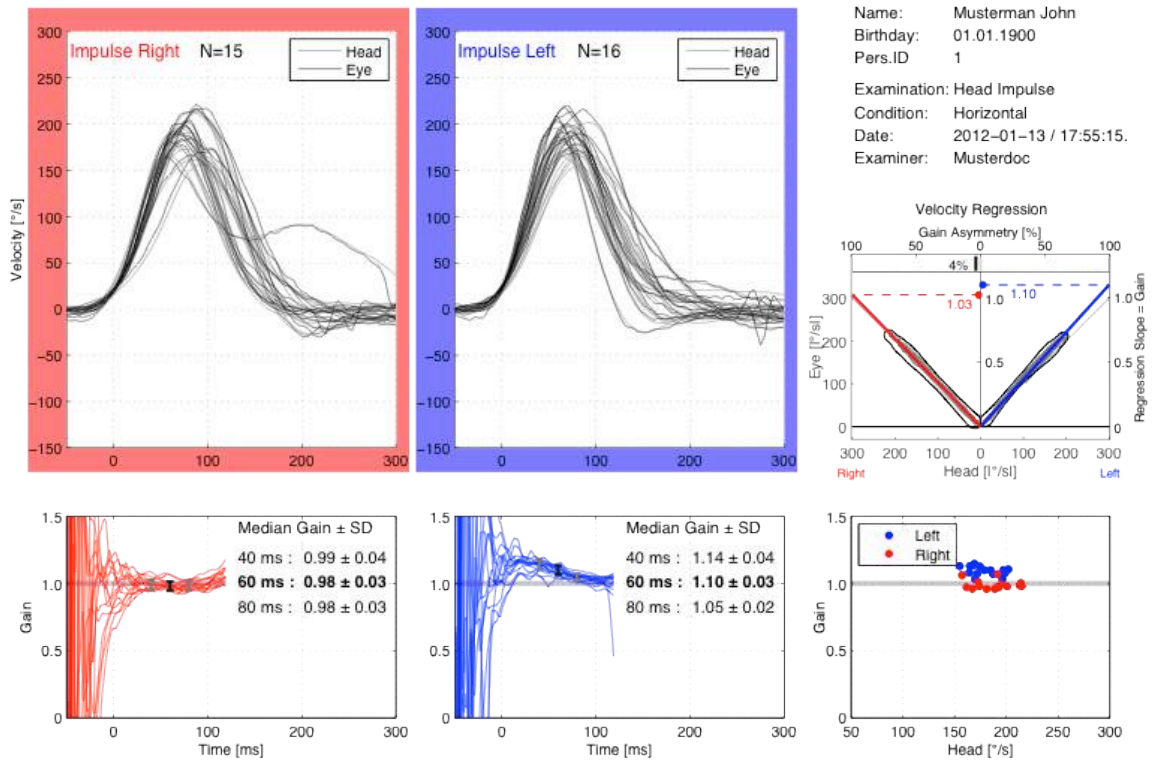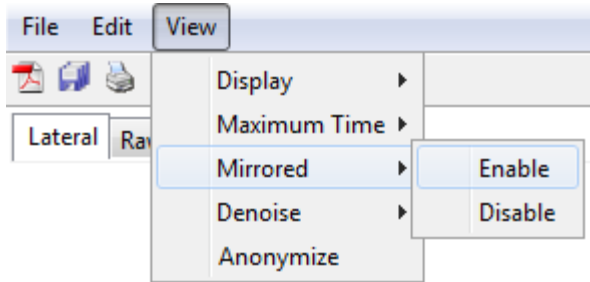

Figure 2-17 Mirrored display of the data

2.3.5 Statistical Data

In the statistical data fields of the gain diagrams, statistical data for leftward and rightward head impulses are shown.

For every head impulse and every time window a median value is calculated. Then for each of the three time windows medians over all head impulses are calculated. The use of the median instead of the mean ensures that outliers are ignored. Such outliers can result from badly perfomed head impulses or from artifacts, e.g., due to blinking. For these reasons at least six valid head impulses for each side should appear in the analysis plot.

2.3.5.1 Velocity Regression Analysis

As an additional measure of VOR gain the regression slope between eye and head velocity can be calculated. The result of this calculation is displayed in the upper right Velocity Regression graph of Figures 2–9 to 2–11. Ideally, instantaneous eye velocity should match instantaneous head velocity, thereby yielding a regression slope of 1.0 on the diagonal of the Velocity Regression graph. If eye and head velocity do not match, the slope is less than 1.0, and hence, below the diagonal. The UVD example in shows both cases. There is a nice match for head movements to the left, yielding a slope and a gain of close to 1.0. For movements to the right, however, the slope, and hence, the gain is less than 0.5.

In addition, the Velocity Regression graph displays a value for the gain asymmetry that is calculated according to Jongkees formula as:

$$Asym = gainLeft\ \text{-}gainRight/gainLeft + gainRight \times 100\%$$

The normative range of the gain asymmetry as measured by a reference search coil system is $\pm5.6\%$. Since head impulse testing by video-oculography (vHIT) and search coil (cHIT) have been shown to provide similar results, the normative range of gain asymmetry is also expected to be similar in both cHIT and vHIT.

2.3.5.2 Gain-based Classification

Automatic classification of normal and pathological observations is an often expressed wish. Such a classifier might compare the calculated gains, for example, with normative data in order to generate a simple semaphore-like test outcome as positive, negative, or unsure.

The example in Figures 2–9 to 2–11 demonstrates the problems that such an automatic classification would have. The gain traces for the head movements to the right do not remain constant over time. The gain starts at an almost normal value around unity and then it drops to less than 0.5. The evolution of the gain over time is not constant but it underlies a certain dynamic. During the covert saccades the gain at 80 ms even exceeds the normal range.

It is unclear which gain at which point in time shall be used. The earlier the gain is calculated, the more nomal it will appear in such a patient. An average gain calculated for the time interval between, e.g., 30 ms and 90 ms might correctly detect a dysfunction as the one shown in Figure 3, however, only if no covert saccedes enter this averaging calculation. In essence, the regression method used in the upper right plot of Figure Figures 5–9 to 5–11 corresponds to such an average. Therefore, a desaccadation method is applied to the data before the regression analysis is performed in order to prevent early quick eye movements like covert saccades from affecting gain calculation.

The drawback of a method that averages gain values over longer periods of time (tens of ms) is that the information about the dynamics of the gain evolution of a case like that in Figures 5–9 to 5–11 is lost. It has been shown that patients with a peripheral loss have gain dynamics like the one shown in Figures 5–9 to 5–11, while cerebellar patients have a constant gain over time. In future software versions this dynamics might possibly be used to classify and

differentiate between different types of patients. Also, the scientific literature does not yet conclusively answer the question of which gain to use. For these reasons the EyeSeeCam data analysis displays both instantaneous gains at different points in time and a gain value that is the result of a regression analysis.

The regression slope is calculated in the time range from 0 ms to 100 ms. After 100 ms not only the vestibulo-ocular reflex (VOR) but also the visual system starts contributing with smooth pursuit and optokinetic eye movements. Since the scientific literature is conclusive about the requirement to avoid any eye movements beyond 100 ms in VOR gain calculation, the regression analysis ignores later data points.

2.3.6 Troubleshooting

There are cases in which the data quality does not allow for a reliable assessment of the head impulse examination. Such cases can be avoided by repeating an unsuccessful examination after readjusting both software and hardware parameters of the device. Since the device provides immediate feedback on the success of each single head impulse, an examiner is assisted in his decision of whether or not to repeat perform more head impulses or to repeat a complete examniation on the basis of the displayed data plots.

2.3.6.1 Eye velocity artifacts

If there are artifacts in the eye velocity traces, this can have many reasons. One of the reasons can be that the pupil edge crosses the illumination reflections. Another reason can be that the pupil hits the image boundaries during head impulses.

These problems are discussed in Chapter Data Artifacts and counter-measures are provided.

In subjects with a narrow palpebral fissure, the eyelid can obscure the pupil and affect the ellipse fit. In such a case the skin beneath the lower eyelid can be pulled down and held in place by the lower rim of the goggles to ensure adequate pupil tracking. Similarly, subjects with long eye lashes can have their eyelids held open with the rim of the goggles.

2.3.6.2 Increased VOR gain

In some subjects the VOR gain during the head impulses can appear to be increased to superunity values. There can be three technical reasons and one physiological reason for this kind of apparently over-compensating VOR gain

1. Goggle slippage due to skin movement, which can be avoided by applying head impulses.

2. Inappropriate calibration, maybe due to systematically incorrect fixations

3. A fixation target at a distance of less than 0.7 m can be a physiological reason for superunity gain since vergence enhances the VOR

4. Magnifying spectacles for presbyopia in elderly can be another physiological reason for superunity gain

2.3.6.3 Goggle slippage

Goggle slippage can cause severe artifacts such as eye movements leading or lagging the head movements. Normally, eye movements should be perfectly synchronous with head movements, apart from the VOR latency during movement initiation. Goggle slippage can also cause bump artifacts. Eye movements leading head movements are usually a sign for skin movement due to force application to the skin in the proximity of the goggles. This can be avoided by applying the force to the lower jaw while subjects clench their teeth (see Figure 2–7).

When eye movements lag head movements or when bump artifacts are visible during movement initiation, this can indicate that the goggles are not firmly attached to the nose. This is often the case with the small noses of Asian faces. If the nose is too small a few layers of sticking plaster or tape can be used to artificially increase the nose until the goggle rim firmly touches the outer plaster layer.

2.3.6.4 Movement direction-dependent offset

A head movement direction-dependent velocity offset before movement onset can be observed if head impulses are performed too quickly in a row with alternating, i.e., predictable directions. This leads to a systematic interference of the previous head impulse with the current one. Therefore, examiners need to introduce breaks of unpredictable durations on the order of about 1 s in between the individual head impulses. The sequence of head impulse directions also needs to be unpredictable.

3 Appendix

3.1   Settings menu

Under the settings menu you have the following options:
- Training Guide
- Display Laser during HIT
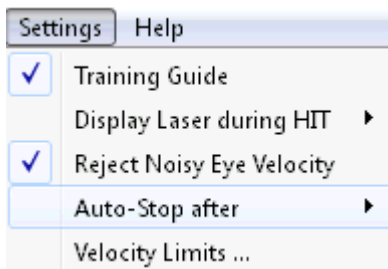- Reject Noise Eye Velocity
- Auto-Stop after
- Velocity Limits

Figure 3.1 shows the five features are available from the Settings menu.

3.1.1 Training guide

The shaded area is used as a guide for the new user to practice their technique. If your head impulse peaks in the shaded area you will get a green check mark, otherwise you will get a red 'X'. In this menu option you can choose to turn the guide off, which will disable the green checks and red "X's" from appearing but the shading will still be visible.
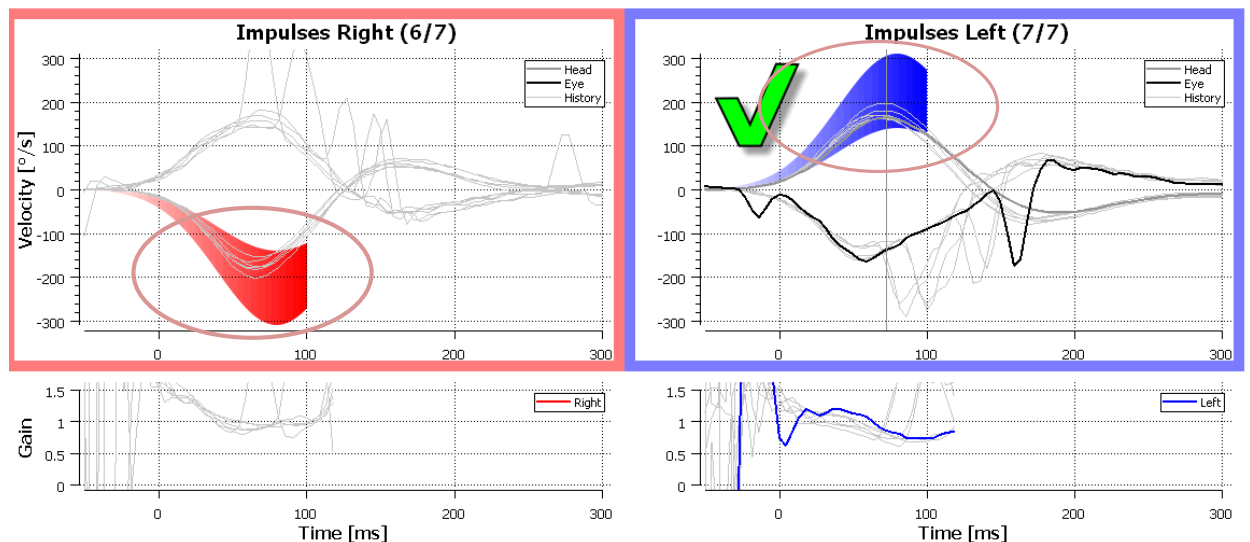
Figure 3.2 shows the shaded areas for training new users and the thrust count showing the accepted number of impulses compared to the total number of impulses needed to stop the test.

3.1.2 Display laser during HIT

This option allows you three choices:
(1)   To turn the laser off during head movements.
(2)   To always have the lasers off during impulses.
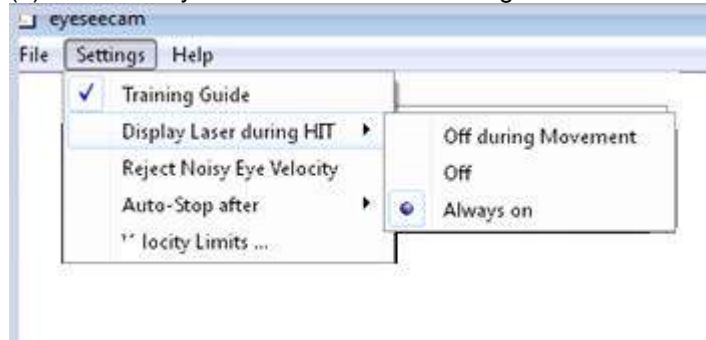(3)   To always have the lasers on during head movement.

Figure 3.3 Menu options available for goggle mounted laser illuminations

3.1.3 Reject noisy eye velocity

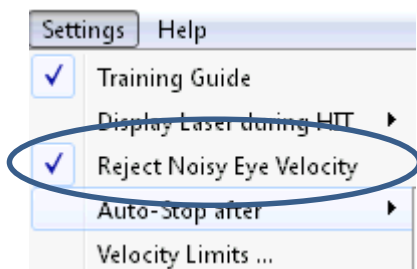When "Reject Noisy Eye Velocity" is checked the software will only accept an impulse if the eye velocity creates a spike-free waveform.

Figure 3.4 Checking the Reject Noisy Eye Velocity which will remove some noisy tracings from your final report.

3.1.4 Auto-stop after

Auto-stop allows the test to be completed and the report to be generated after a certain number of impulses are reached. You can choose to stop after 7 or 15 impulses or you can choose Never and then you will have to manually the stop the test.
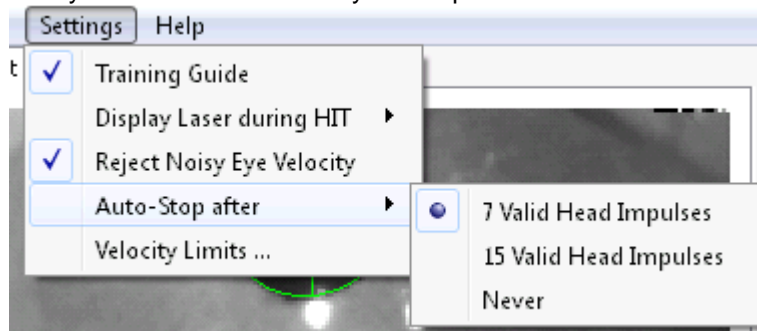

Figure 3.5 the options to select Auto-stop after a pre-defined number or impulses.

3.1.5 **Set velocity limits**

The velocity limits the values that used to generate the shading in the impulse training guide. The default limits are 150 to 310 ⬚/sec but you can override these values by typing new values into the table.
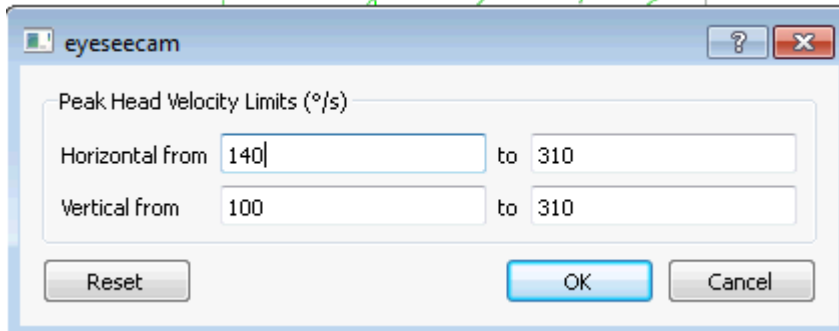

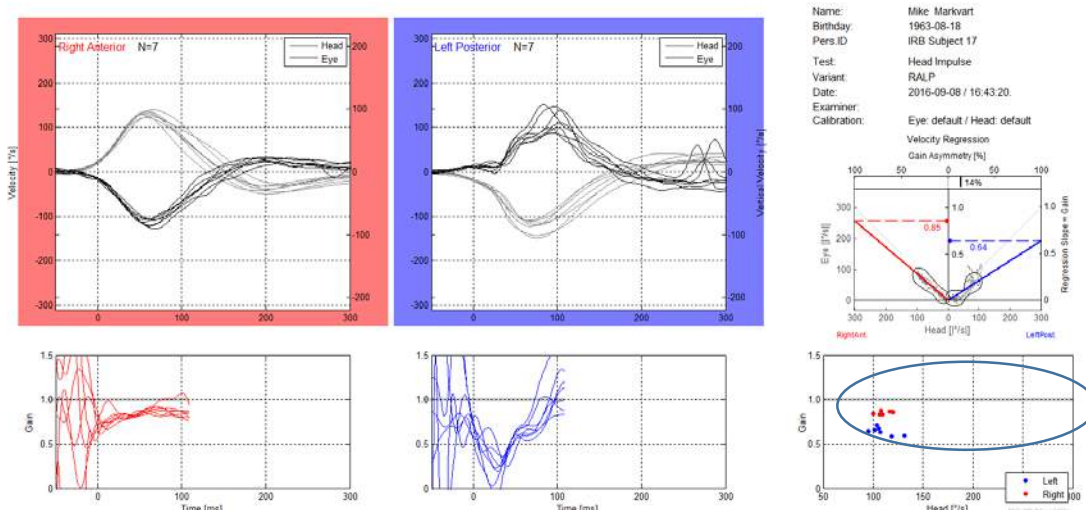*Figure 3.6 shows the table for entering used-defined peak head velocity limits.*

Figure 3.7 shows the lower limit of accepted head velocity in this case is set to 100 degrees per second or faster.

3.2   Edit menu

3.2.1   Velocity trace selection (renamed)

In the edit menu you will find a submenu for Velocity Trace Selection, in this submenu you can select the option to choose one or more impulses to be deleted or you can delete all artifacts or show all impulses.
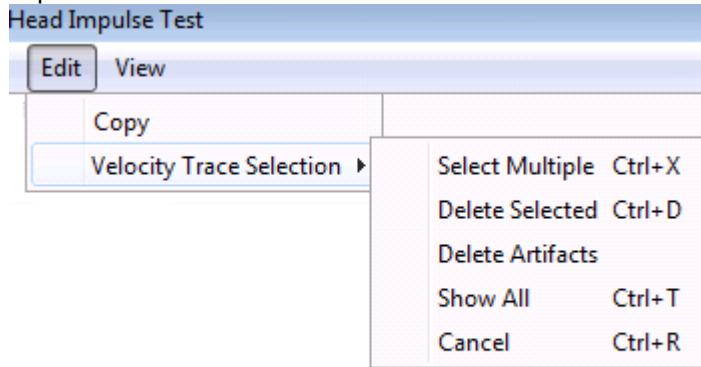

Figure 3.8 shows the velocity trace selection options

3.3   Median gain calculation

An additional calculation for gain is added to the Median Gain table. In contrast to the instantaneous gain values at 40, 60, and 80 ms, this new gain value is calculated from each head impulse as the ratio of median eye velocity to median head velocity sampled from the onset of each head impulse at 0 ms to 100 ms.
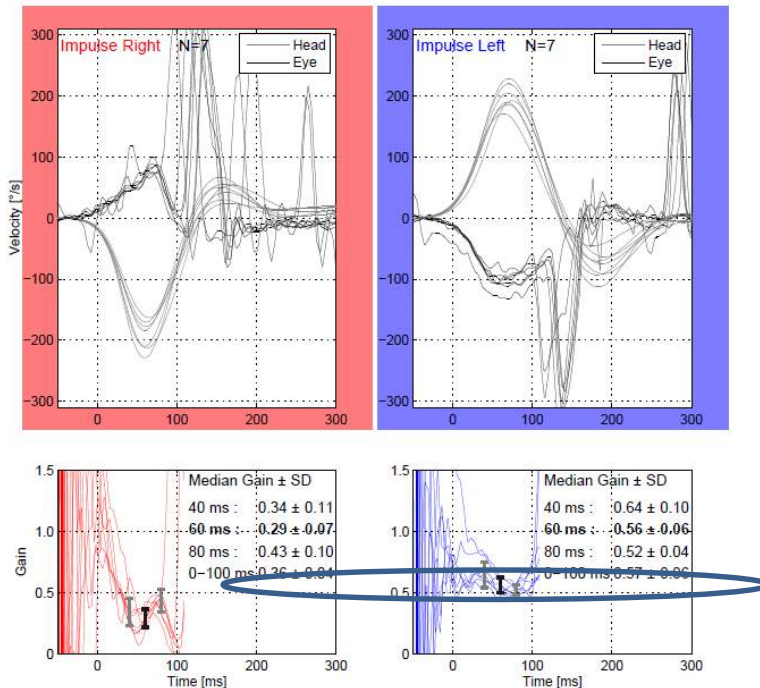

Figure 3.9 shows the new median gain 0-100 ms calculation

3.4   Improved nystagmus detection algorithm

Easy identification of slow phases of nystagmus

Slow Phase Velocities are plotted for horizontal and vertical Spontaneous Nystagmus in degrees per second.

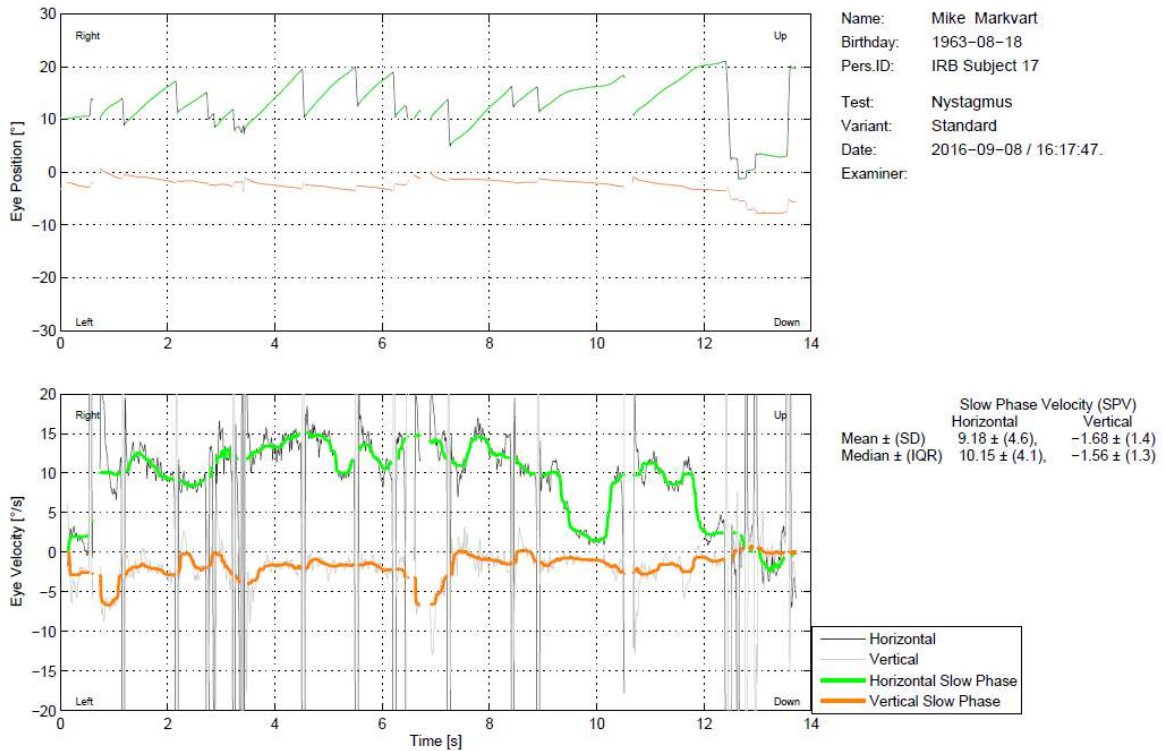The measured horizontal SPVs are interconnected by a green line, and the vertical SPVs are connected by a red line.

Figure 3.10 Example of a left beating spontaneous nystagmus