NeurOne EEG <> Siemens Prisma Compatibility Test, 2nd Feb 2015

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Introduction

The aim of these measurements was to establish if the NeurOne Tesla MR EEG amplifier manufactured by Mega Electronics Ltd. (Kuopio, Finland) is fully compatible with the new Siemens Prisma 3T MR scanner and particularly with its enhanced strength XR gradient system when running the scanner at its full capacity with respect to a combination of slice time, flip angle and band width.

To this end, two measurements were performed in the Prisma system at the BION (Bender Institute of NeuroImaging) institute in Giessen, Germany.

MR Scanning Parameters

The BION is a registered Siemens research site and thus has access to the newest "Work in Progress" sequence packages, which is a prerequisite to being able to establish compatibility of the NeurOne EEG system with the Prisma, since the current stock EPI sequences show timing jitter that would make any attempt to record science quality EEG in the scanner futile. The ID of the WIP EPI sequence in use at the BION center was "N4_VD13D_PHYSIOLOGGING_BECKTH7I_WIP_883A".

The two measurements were both taken with this sequence and with the same scanning parameters, were TR=2500ms, TE=30, FA=90°, Slices=39 with the interslice time being 63.58ms and with a gap of approx. 20.38 ms between Volumes.

A PDF with the full set of MR recording parameters can be provided upon request.

EEG Recording Parameters

All EEG data was recorded with 20 kHz and with a bandwith of 5 kHz, without any further digital filtering being done before MR gradient artifact correction. The EEG was recorded with a 64 channel EasyCap MR with a standard 10-10 layout. The setup also included three bipolar channels used to record ECG, VEOG and HEOG.

ECG was recorded from a position lumbar position slightly off the spine to the right against a position between the shoulder blades. Both electrodes were placed on the back of the subject to avoid creating a loop across the myocard.

VEOG and HEOG were both recorded according to current standards with electrodes being placed above and below the left eye (VEOG) and on the left and right outer canthii of the eyes with both pairs being placed perpendicularly to each other to avoid receiving mixed horizontal and vertical eye movement activity with each electrode pair.

EEG/MR Acquisition Paradigms

Two paradigms were used to record EEG data. The first was simple Eyes Open vs. Eyes Closed paradigm aimed at showing topographically and conditionally clear Alpha induction/suppression with closed and open eyes.

The second paradigm was a very straightforward and standard "face processing" ERP. The subject was asked to actively view (and thus process) the face stimuli but there was no further discrimination or deviant/oddball style task attached to the paradigm. For this task we expected to see a topographically correct P1/N170 complex, i.e. a clear sequence of a visual P1 at around 90-100ms post stimulus at posterior/occipital electrode sites followed by a clear N170 component peaking at around 170ms post stimulus and with a clear occipito-parietal maximum.

MR Gradient Artifact Correction

The recorded EEG/MR data was corrected for gradient artifact activity and for cardioballistic artifact activity using a very standard sequence of analysis and correction steps, which have been proven effective over the last decade.

All data analysis and artifact correction steps were performed with BrainVision Analyzer (Version 1.05.0005) and minimal variations to the established and by now “run of the mill” sequence of analysis and correction steps were made necessary by differences between the NeurOne recordings and the recordings using BrainAmp MR amplifiers. The reason for this is that the NeurOne amplifiers are 24 bit amplifiers while the BrainAmp MR amplifiers are 16 bit only. This means that the BrainAmps must be run with a severely limited bandwidth of 250 Hz to not risk saturation and the resulting gradient artifacts in the EEG data must not and cannot exceed 16.384mVpp. The NeurOne amplifiers are true 24 bit amps and can therefore be run with any bandwidth (depending on sample rate) and were used with a bandwidth of 5 kHz in this case.

This means that the gradient amplitudes in the NeurOne EEG data are +/-70mV and that the resultant EEG data will show a much more “true” record of the actual gradient activity, but obviously also along with much more potential to pick up gradient and other ambient “noise”.

The figure below shows a stretch of 10 seconds at the beginning of the first paradigm, i.e. before scanning commenced.

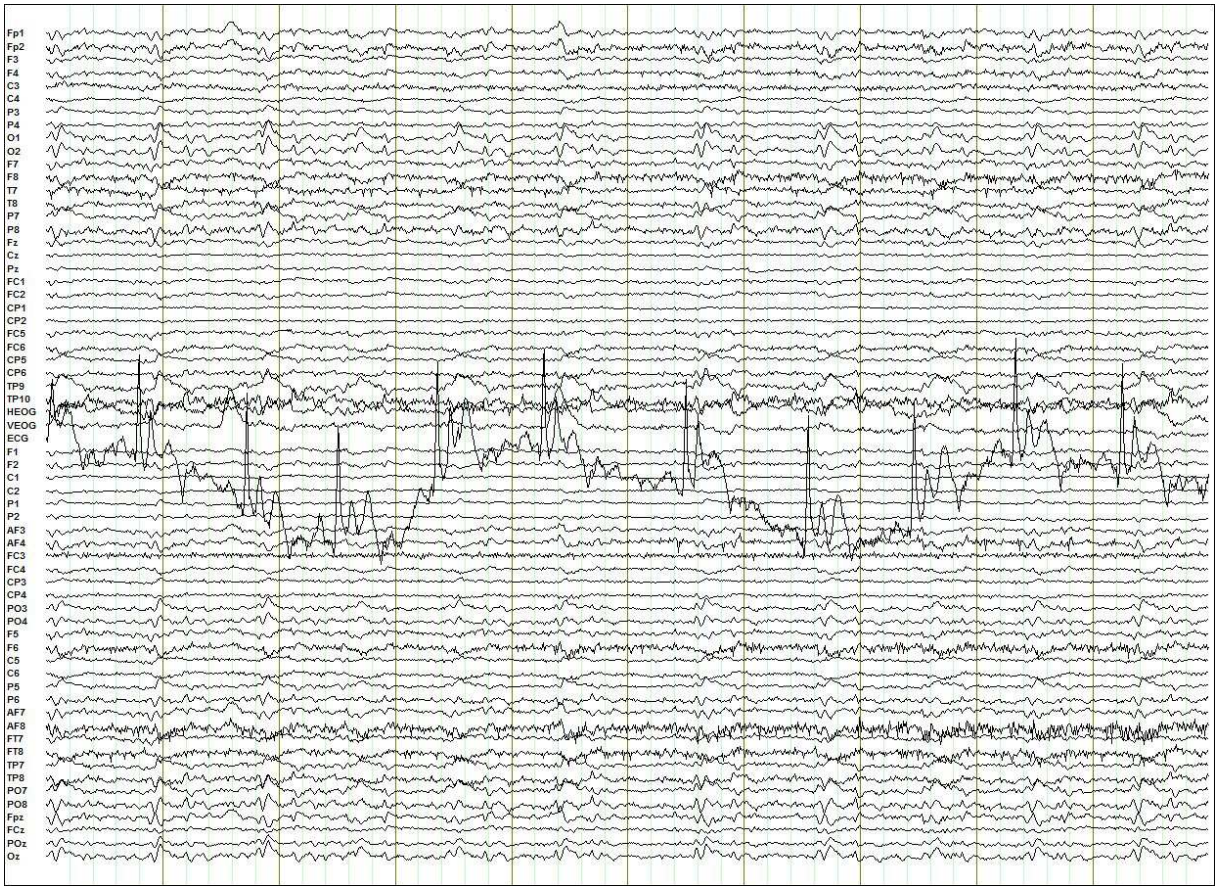

Fig. 1: 10 second stretch of Raw EEG Data before MR scanning commenced, showing unfiltered data.

From the above figure it can easily be seen that the EEG data does not contain extraneous amounts of “extra noise” due to it being recorded with a 5 kHz bandwidth. Also, the BCG artifact can clearly be discerned in nearly all EEG channels and the temporal correspondence with the time signature of the

ECG channel can clearly be seen. The ECG channel shows a slow rhythmic fluctuation due to the respiratory cycle. This effect will later be removed with a selective 2Hz@24dB/Octave HighPass imposed only on the ECG channel before cardioballistic artifact detection and subsequent correction is done.

The sequence of MR gradient artifact correction steps performed was as follows…

1. Check for MR volume trigger timing invariance.
2. Selective Averaging of short stretch of GAC data to check for linearity of SD time course.
3. Upsampling and statistical realignment of raw data.
4. MR Gradient Artifact Correction with timing parameters previously established.

1. Check for MR volume trigger timing invariance

This initial test is typically done to establish the level of synchrony between the EEG and the MR system. However, in this case, the test was done to check if the WIP sequence indeed corrected the ill timing of the stock EPI sequence to the point of being compatible with EEG even at 20 kHz.

This test promptly failed. The NeurOne EEG system was correctly and reliably synchronized to the Siemens Prisma 4 Mhz clock available on daughter board D70. However, the timing analysis at 20 kHz showed that there still is a certain amount of timing jitter present in the MR sequence or rather inter-slice timing of the scanner. This shows up in the marker timing diagram as a periodic shift of the marker timing by exactly one data point (i.e. 0.05ms jitter).

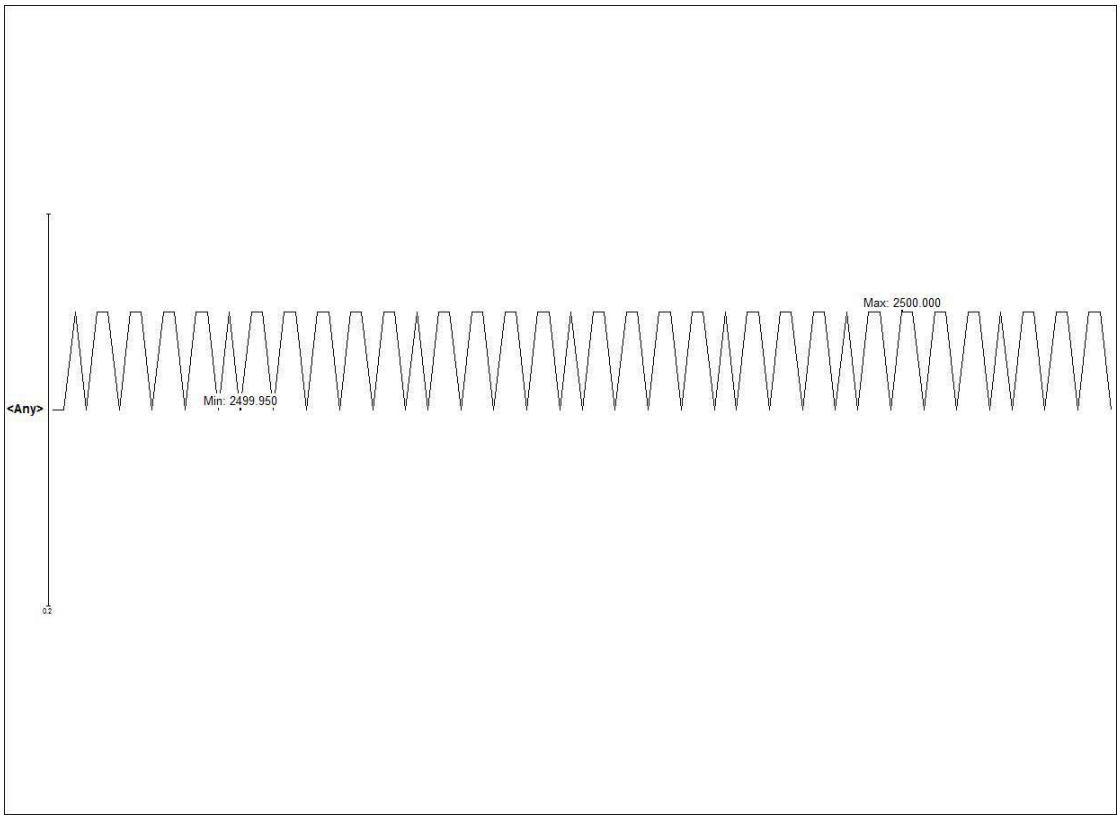

Fig. 2: Marker timing analysis

The true jitter is difficult to ascertain, since the recording was done at 20 kHz “only”, but the 2:1 rhythmicity shown in the below figure indicates that the shift will be on the order of around 17µs.

At this time it is difficult to say if this effect might be due to the particular WIP sequence version installed at the BION center not being perfect in its timing or if this is simply not the latest Siemens

effort in the regard. Clearly, the full timing quality of the Prisma EPI sequence will only be ascertainable when Siemens releases their efforts in form of a new “stock” EPI sequence.

2. Selective Averaging of short stretch of GAC data to check for linearity of SD time course.

With the sequence timing still not being 100% correct, it has to be expected that there will still be a certain amount of standard deviation inflation at the slopes of each (larger) gradient peak. This was tested by segmenting a very short stretch of data around the MR Volume markers, -3 to 10 ms in this case. This data was then averaged with the standard deviation being computed. If timing synchrony is perfect, the time course of the standard deviation should be practically flat and any deviation can be attributed to gradient activity and temporal jitter.

The two figures below show this effect at different scales.

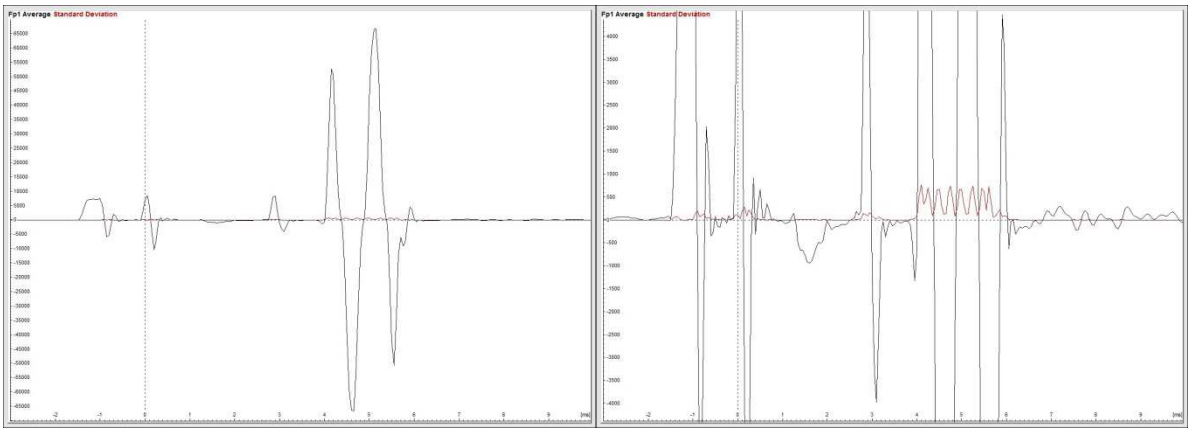

Fig. 3: Standard Deviation time course with inflated SD at points of highest slew rate on right.

The figure on the left shows the actual magnitude of this effect in relation to the amplitude of the gradients and the figure on the right shows this effect at a higher magnification. The highest SD values are around 750µV in size while the gradient amplitudes are on the order of 67000µV, making this a 1.1% effect, which has to be seen as sizeable and requires offline synchronization and statistical alignment of the data, which is described in the next step performed.

3. Upsampling and statistical realignment of raw data.

Much of the reason for this imperfection in scanner timing to show up in the recorded data is due to these recordings being done at 20 kHz and with a very large bandwidth of 5 kHz. It therefore has to be said that this effect could have been minimized or avoided by recording the data at 5 kHz as in the BrainAmp systems, but still with a useable bandwidth of 1250 Hz and with a vertical resolution of 51nV, 10x higher than with the BrainAmps.

However, since the data is as it is and since the residual slice time jitter in the Prisma at least for now is a reality, the remainder of this document will aim at showing that even under these adverse conditions it is easily possible to obtain fully science grade data with the NeurOne amplifiers, while – as was already stated above – tapping into its superior vertical resolution.

To this end, the data recorded was upsampled from 20 kHz to 100 kHz using a fast cardinal spline approach implemented in BrainVision Analyzer. The data was then statistically realigned using the Analyzer Solution “Slice Volume Align”. The figure below shows the realignment effect:

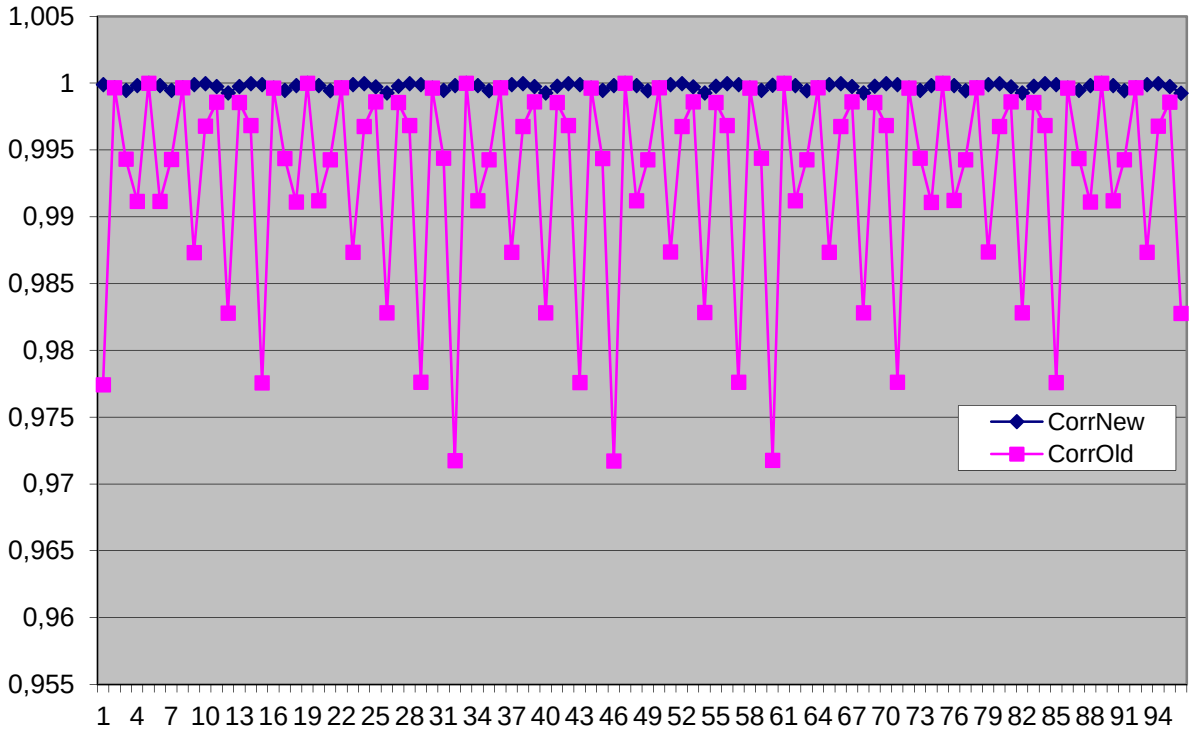

Fig. 4: MR Volume intercorrelation before (pink) and after upsampling and statistical alignment.

As can clearly be seen above, the MR volume intercorrelation is improved dramatically by the statistical alignment. The table below gives the changes in the minimum, maximum and average intercorrelations with realignment:

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Minimum cross correlation before alignment:   0.97174
Maximum cross correlation before alignment:   1.00000
Average cross correlation before alignment:   0.99770

Minimum cross correlation after alignment:    0.99926
Maximum cross correlation after alignment:    1.00000
Average cross correlation after alignment:    0.99986
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These data also show the profound improvement in MR Volume intercorrelation and the figures below show this effect at the data level.

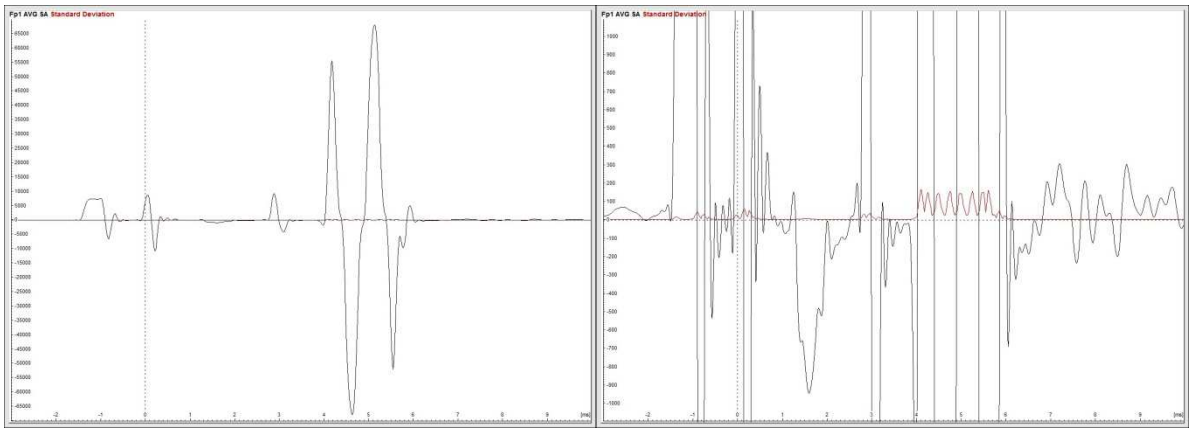

Fig. 5: Standard Deviation time course with much reduced SD at points of highest slew rate on right.

The resulting maximum standard deviations at the points of highest slew rate are around 150µV in size, which indicates a 5-fold increase in template quality and a reduction of the net effect to 0.22% of the gradient amplitude. Also, it has to be noted that at 20 kHz, these timing jitter based SD increases amount to cutting an extremely fast moving gradient slope with a slightly imperfect

correction template. In essence, the template is slightly broader and slightly smeared compared to the individually crisp, but temporally jittered gradient slopes. The artifacts induced by this effect will be of the magnitude shown above, but will all reside at very high frequencies, clearly within Nyquist, but also clearly beyond the useful and desired EEG band for these measurements! This effect is therefore not entirely, but to a very large extent irrelevant to the data recorded and practically completely irrelevant to the paradigms used in these measurements.

4. MR Gradient Artifact Correction with timing parameters previously established.

Consequently, all further processing steps and notably also the MR gradient artifact correction were done with no further attention needing to be paid to the slightly imperfect timing.

Gradient artifact time range was established to be from -14 to 2486ms relative to the Volume marker and all MR volumes were entered into the analysis, since the realignment correlation chart shown in figure 5 above clearly showed that no secondary effects such as subject movement, etc. which might deteriorate the template quality were present in the data.

The figure below show a data stretch of 10 seconds from the middle of the recording and after standard MR gradient artifact correction had been performed. The markers “SA” at the bottom of the screen are the time points of the MR volume markers and the lack of visible MR gradient residuals shows that the artifact correction worked extremely well despite the remaining timing jitter.

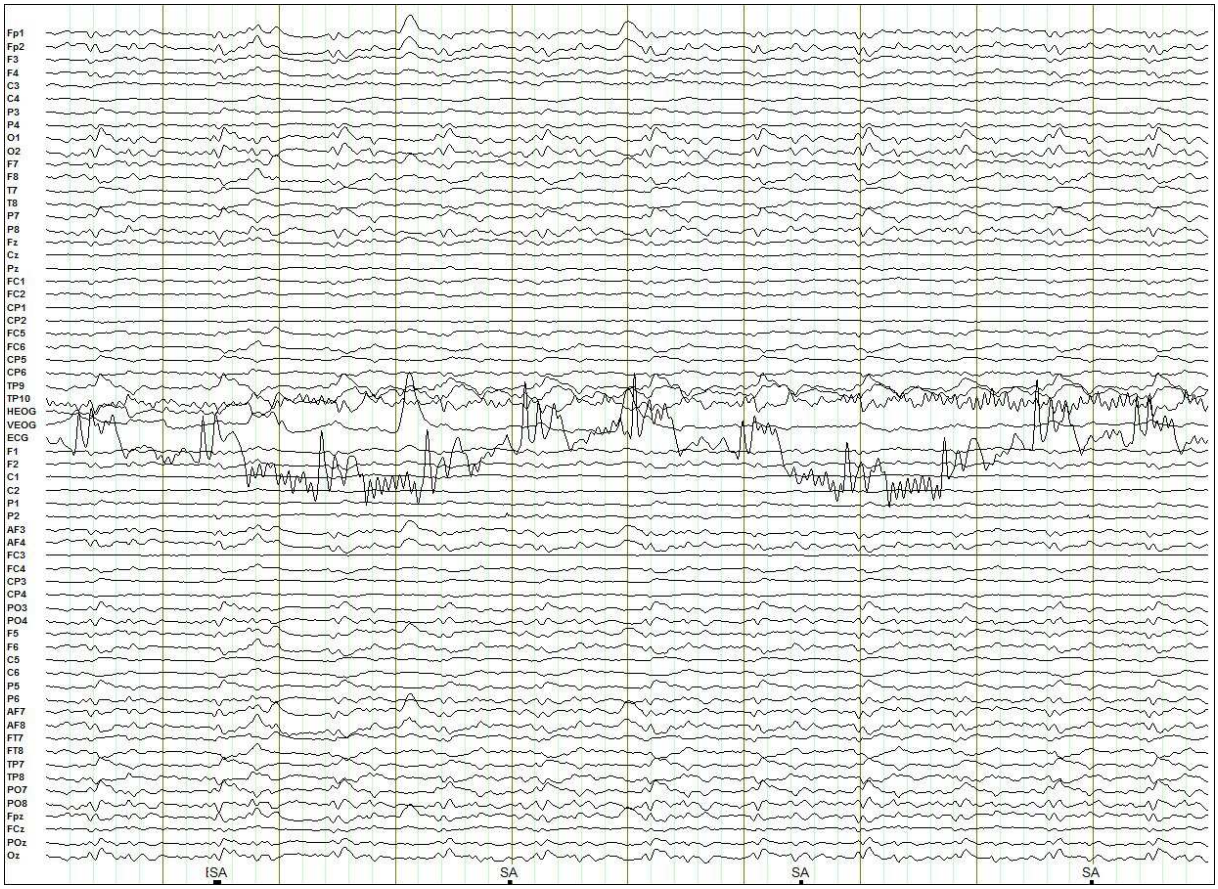

Fig. 6: Data stretch of 10 seconds with gradient artifact corrected data, VEOG activity clearly visible.

The further sequence of MR correction and data analysis steps performed were as follows

5. Cardioballistic Artifact Detection and Correction.
6. ICA Based removal of Eye Movement potentials.
7. Paradigm 1: EEG data analysis for Eyes Open/Closed based on FFT averaging.

8. Paradigm 2: ERP data analysis for N170 “face processing”.

5. Cardioballistic Artifact Detection and Correction.

As could be seen in figure 1 showing a raw initial data stretch, the ECG channel showed a respiration induced slow shift. This was corrected with a 2Hz High Pass filter (24 dB/Octave). The figure below shows a typical screen from the subsequent Cardioballistic Artifact Detection step.

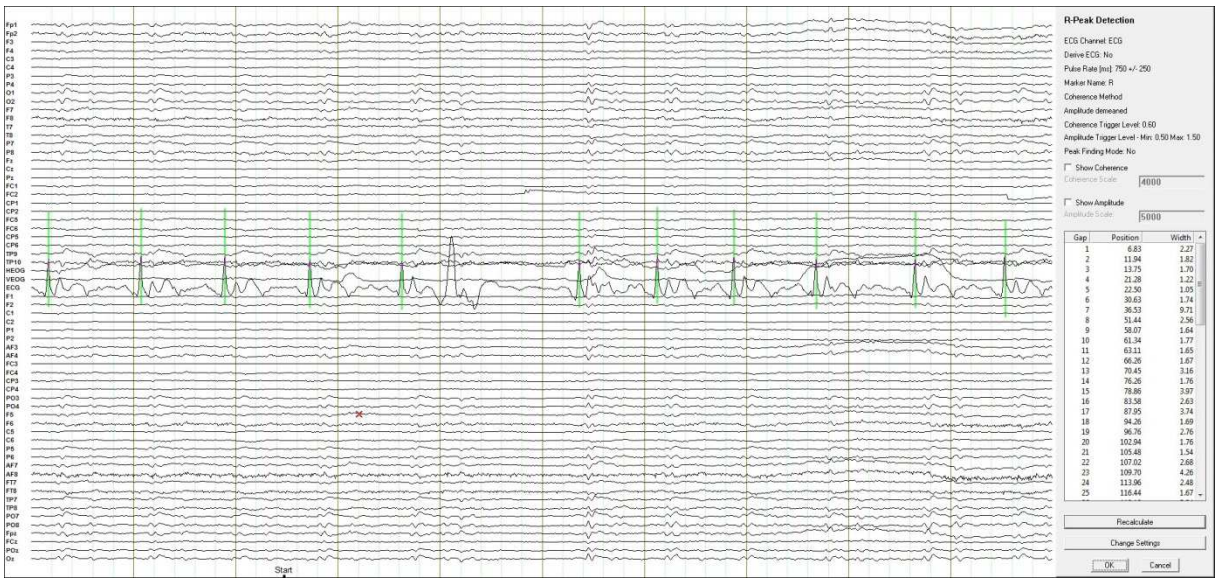

Fig. 7: Data stretch of 10 seconds with semiautomatic ECG episode detection in progress.

From the above figure it can clearly be seen that the bipolar ECG derivation results in a clearly discernible ECG pattern with a clear R-Wave. There is one episode in the 4th second with an ECG abnormality leading to an inflated RR period for this beat.

This type of event reoccurs around once to twice per 10 seconds throughout the recording, which can also be seen in the “gap list” on the right, which shows a fairly large number of extra-long ECG episodes that require special attention during detection. Nearly all of these are such ECG artifacts.

However, since the strong deflection after the T-Wave has no observable effect on the EEG data, these episodes are marked as valid ECG episodes for the purpose of correcting the EEG channel data.

The figure below shows the effect of the subsequent cardioballistic artifact.

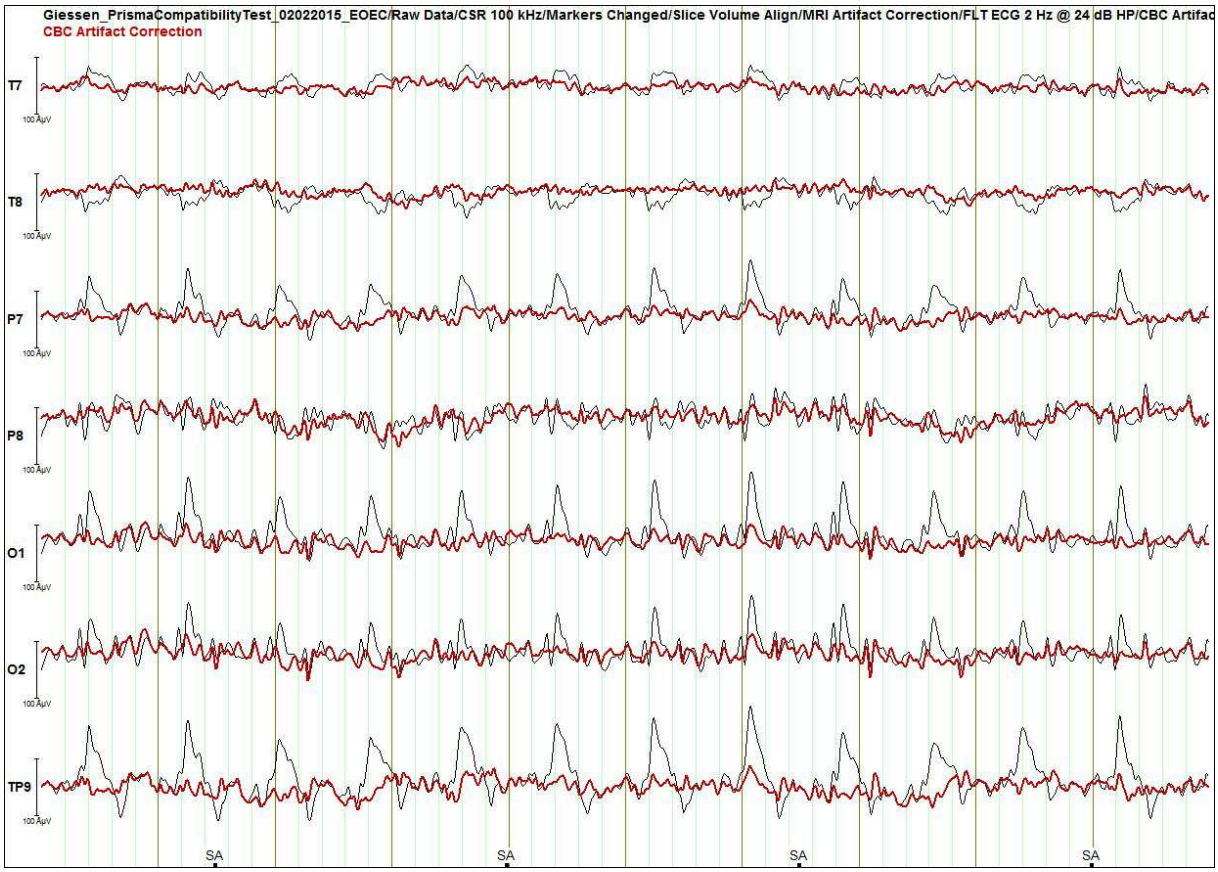

Fig. 8: Data stretch of 10 seconds with CBC artifact corrected vs. noncorrected EEG data.

The effect of the cardioballistic artifact correction shown above is profound and nearly all of the existing BCG artifact is removed with this method. Typically, secondary ICA analysis shows one or two ICs with a slight amount of residual BCG activity, but also typically, removal of these residuals does not improve the resultant EEG data to any meaningful extent. This was therefore omitted here.

6. ICA Based removal of Eye Movement potentials.

Due to the relatively high quality of the data recorded with the bipolar vertical and horizontal eye channels, detection and subsequent removal of eye related components was very straightforward and a total of 4 independent components were removed.

Removal of eye potentials with ICA concludes the data preprocessing steps and the following two steps describe the analysis of the resulting fully MR and eye movement corrected EEG data with respect to the two paradigms employed. The data from both paradigms was exported to new datasets at this time and these datasets can be provided upon request.

7. Paradigm 1: EEG data analysis for Eyes Open/Closed based on FFT averaging.

The further processing of the data from the Eyes Open/Closed paradigm consisted of …

- A manual artifact detection step to remove any remaining data artifacts before FFT.
- A segmentation of all time frames belonging to the Eyes Open and Eyes Closed periods into 2 second segments with a 1 second overlap.
- Baseline correction for the full period to remove the A0 spectral content (DC Offset).
- Calculation of the average Power Spectrum with a Hanning window of 20% duration and with a spectral resolution of 0.488 Hz.

The figure below shows a comparison of the power spectra for eyes open vs. eyes closed for a selection of channels from frontal to occipital and with the topographic map showing the topography at the maximum Alpha frequency.

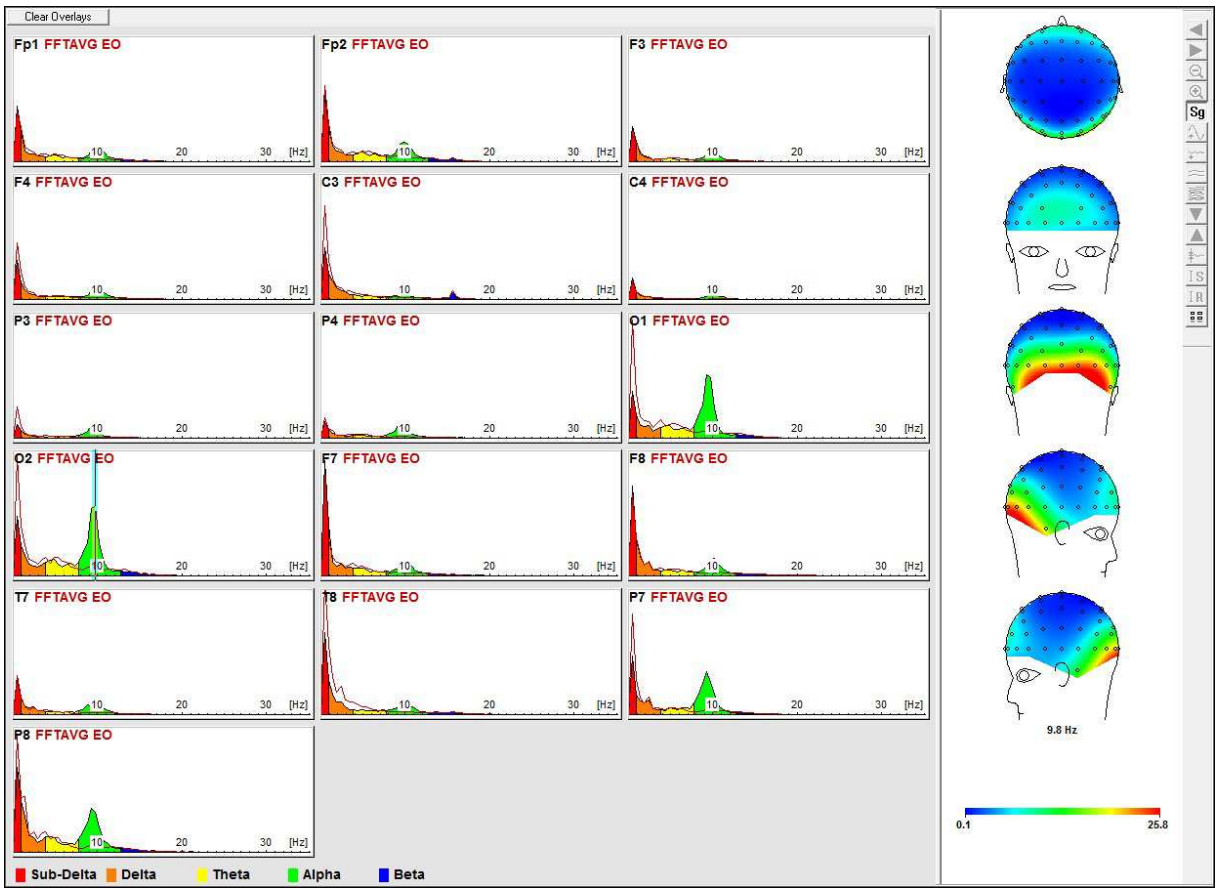

Fig. 9: Comparison of eyes open vs. eyes closed across the scalp. Alpha topography on the right.

The strong difference in the spectra for eyes open and eyes closed conditions only with respect to the Alpha magnitude is clearly visible as is the very typical occipito-parietal distribution of Alpha and the slight "alpha mirroring" at frontopolar electrode sites.

The figure below shows this effect for channel O1 exclusively and in this figure it becomes very clear that this effect is very clean and very profound at a difference in Alpha magnitude between eyes closed and eyes open of more than 20µV².

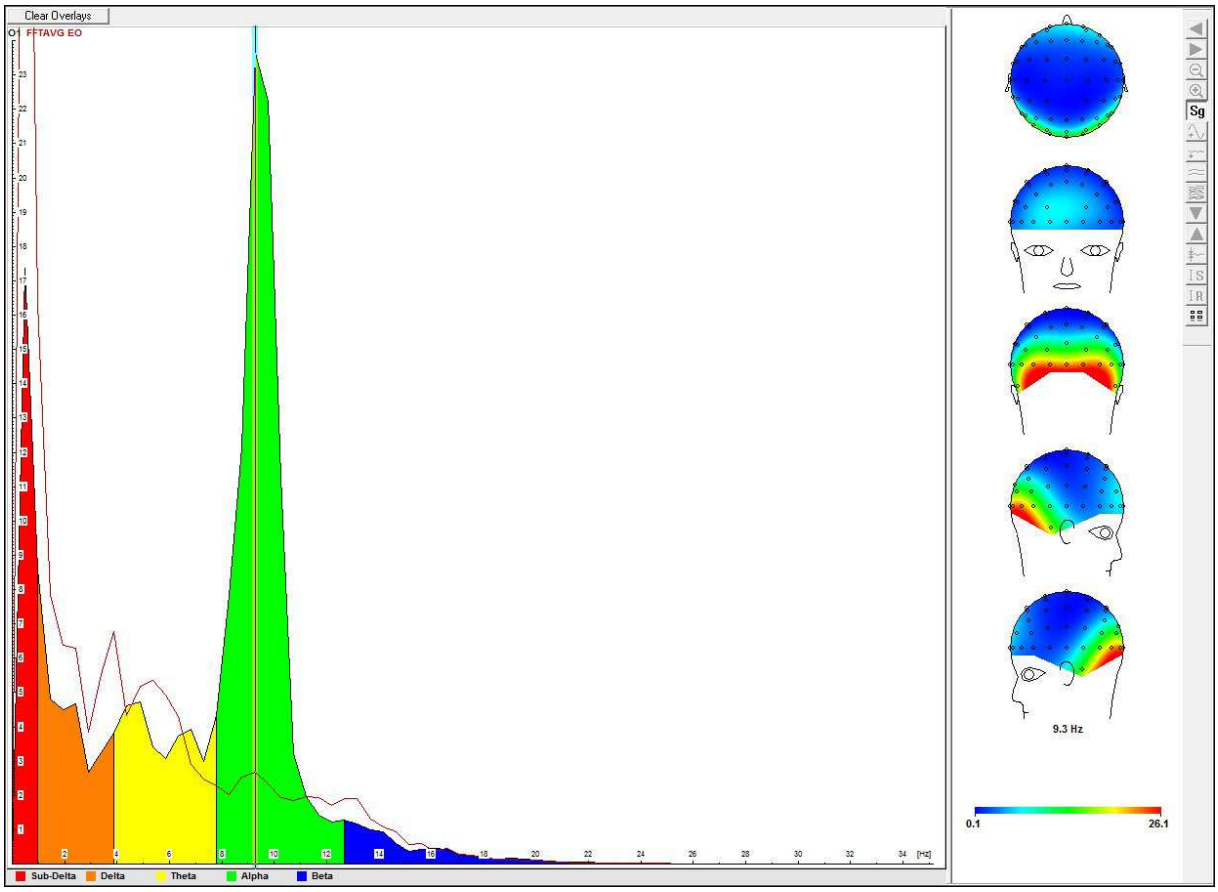

Fig. 10: Comparison of eyes open vs. eyes closed for channel O1 only. Alpha topography on the right.

8. Paradigm 2: ERP data analysis for N170 "face processing".

The further processing of the data from the N170 Face Processing paradigm consisted of …

- Filtering the data with a band pass from 1 to 15 Hz @ 24 dB/Octave.
- Segmenting the data into segments from -200 to 600 ms around the stimulus markers.
- Subtracting the baseline from -200 to 0 ms.
- Averaging the 156 face stimulus based segments to obtain a stable face processing average.

The figure below shows the distribution of the face processing ERPs across the topography of the entire scalp and the topography of the N170 component on the right.

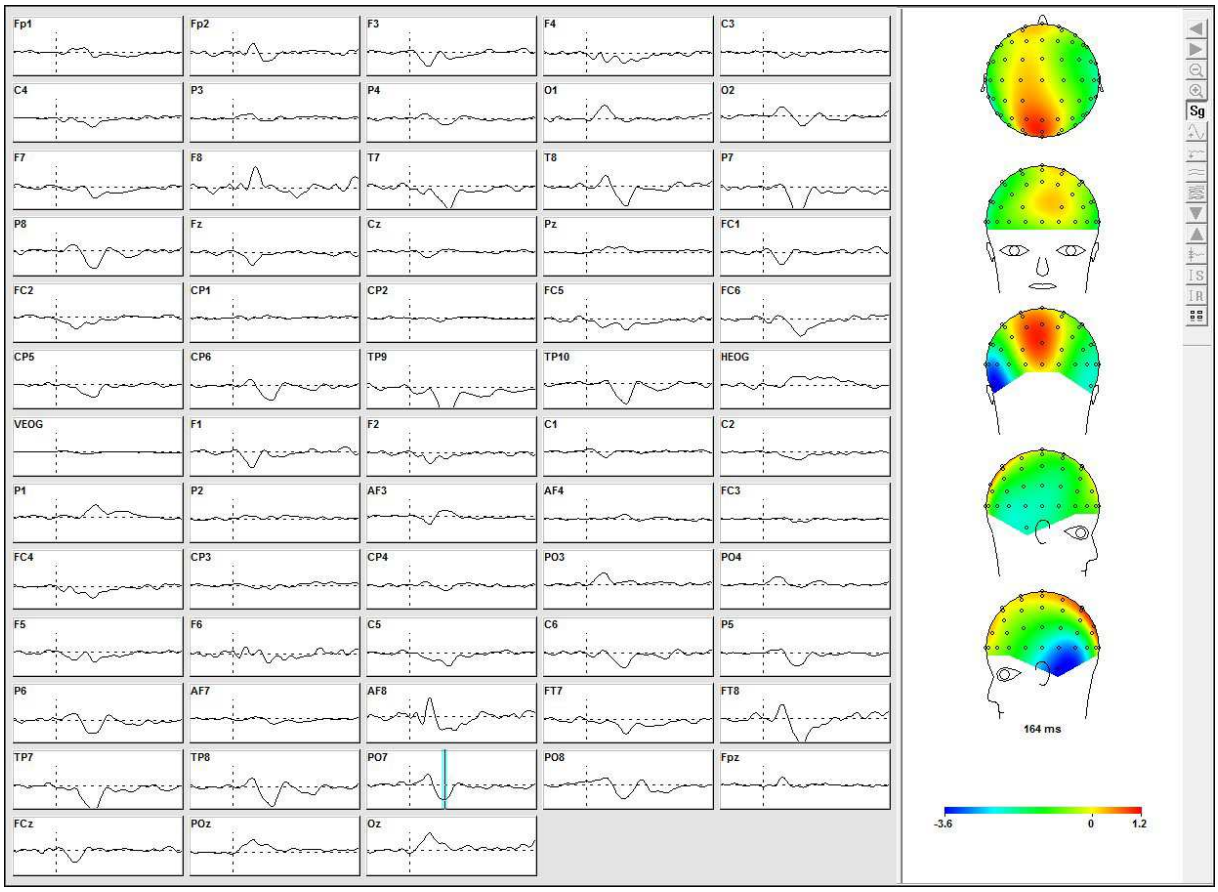

Fig. 11: Topography of face processing ERP data, Topography of N170 at PO7 maximum on the right.

The negativity on the parieto-occipital plane can easily be seen in the ERP data and also in the topography plots on the right. The figures below detail this effect both for the visual P1 and for the N170 at PO7 only.

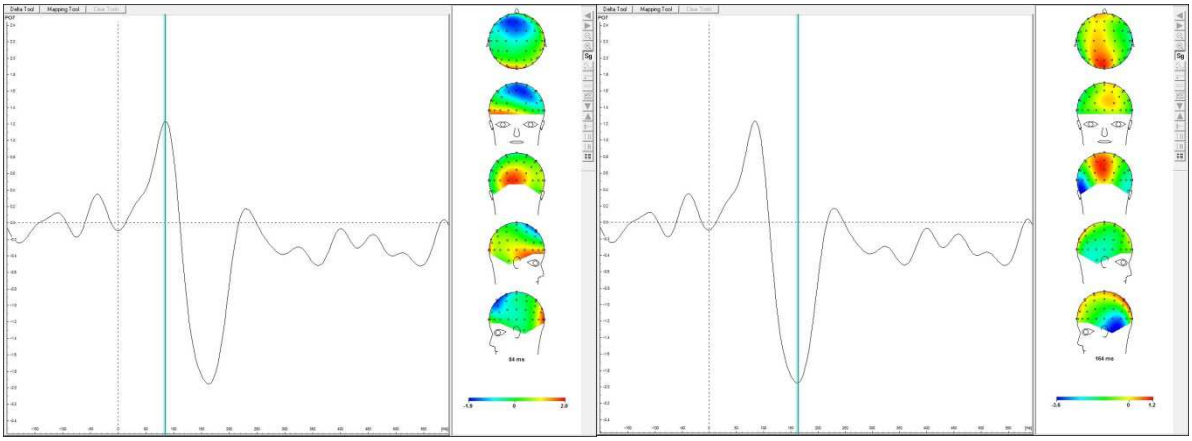

Fig. 12: Topography of face processing based ERP data, P1 and N170 at PO7, Topography on right.

As can be seen from the figures above, the N170 negativity effect is somewhat stronger in the left hemisphere. However, it has to be noted that this is a single subject “study” performed in the MR while recording fMRI at very aggressive EPI scan settings. Taking this into consideration, the already strikingly clear and truly science grade face processing results gain even more weight and credibility.

Summary and Outlook

As it seems, the slice time variability noted in the Siemens Prisma stock EPI sequence has not been completely abolished at least in the WIP EPI sequence currently installed at the BION MR center in Giessen, Germany.

At the same time, the measurements performed here explicitly were aimed at testing this and the clarity and high quality of the FFT and ERP results clearly show that the NeurOne EEG amplifier is capable of performing flawlessly even with very “sharp” scanning being performed and under adverse conditions, such as those encountered here with the slight lacking in slice timing.

The NeurOne amplifier has a vertical resolution that is 10x (AC mode) to 100x (DC mode) more finely grained than that of the BrainAmp MR family. And being a 24 bit amplifier it has an enormous dynamic range of +/-430 mV @ those 51 nV/bit compared to only +/-8.192mV @ a 10x lower resolution of 500 nV for the BrainAmp MR family.

But most importantly, the BrainAmp MR family can only reliably be run in the scanner with a band width of 250 Hz, which may be enough for most but not all EEG paradigms and clearly not for measuring other biosignals, such as facial EMG, which has its main spectral content in the frequency range up to ~3 kHz.

It remains to be seen how stable and “perfect” the timing of the ultimately released Siemens Prisma “stock” EPI sequence will be. Should it return to Siemens’ prior timing perfection, which should be achievable, then the NeurOne amplifier can be run in the Prisma at any of its available speeds and with the respective full bandwidth, to achieve even the most ambitious measurement paradigms. However, should a slight amount of slice time jitter remain, then it would be advisable to reduce the sample speed and/or the band width of the NeurOne to a band width below 5 kHz to avoid having to perform the above upsampling/alignment step to achieve the truly obtainable data quality.