

# qEEG-Pro Manual



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# 1. Standardized Artifact Rejection Algorithm (S.A.R.A)

In section 1 of the QEEG-Pro report, the results of the automatic artifact rejection algorithm (S.A.R.A) are depicted. S.A.R.A. works in four steps: Epileptiform episode detection, Filtering, Detection/Rejection/Interpolation of noisy channels and Detection/Rejection of EEG-segments containing artifacts. For a detailed description of the procedures that were used, the reader is referred to Appendix 1.

## 1.1 Epileptiform Episode Detection

The Epileptiform Episode Detection algorithm searches for high-amplitude, low-frequency segments in the raw data. When such episodes are detected, the start point and duration of the episode will be reported in the S.A.R.A results page and it is recommended that the original recording is inspected. When these episodes are possibly of neural origin, it is recommended to consult a certified neurologist.

## 1.2 Filtering

The EEG-data is filtered with a high-pass filter of 1 Hz and a notch filter of 50Hz or 60Hz, depending of the power line alternating current frequency of the country where the EEG was recorded.

## 1.3 Noisy channels

Noisy channels are defined as channels that contain a disproportional amount of high-frequency power due to muscle artifacts. Noisy channels are not removed from the EEG data but are marked red in the SARA report. When more than 5 channels need to be discarded, the analysis is terminated.

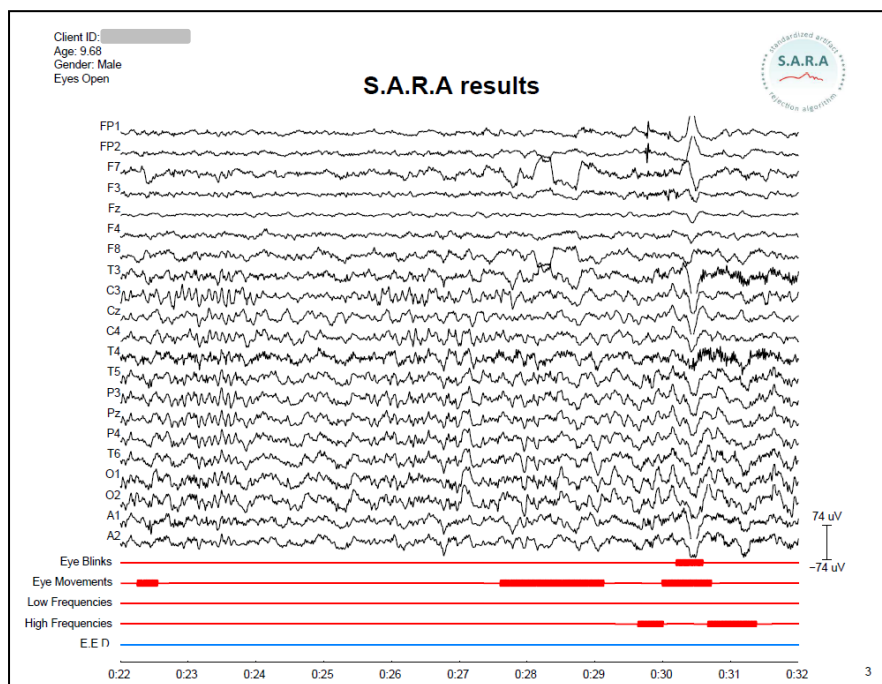
## 1.4 EEG-segments containing artifacts

A number of calculations are done in succession before the detection of segments containing artifacts starts. Separate algorithms are used to detect eye-blinks, horizontal eye-movements, low-frequency artifacts and high-frequency artifacts.

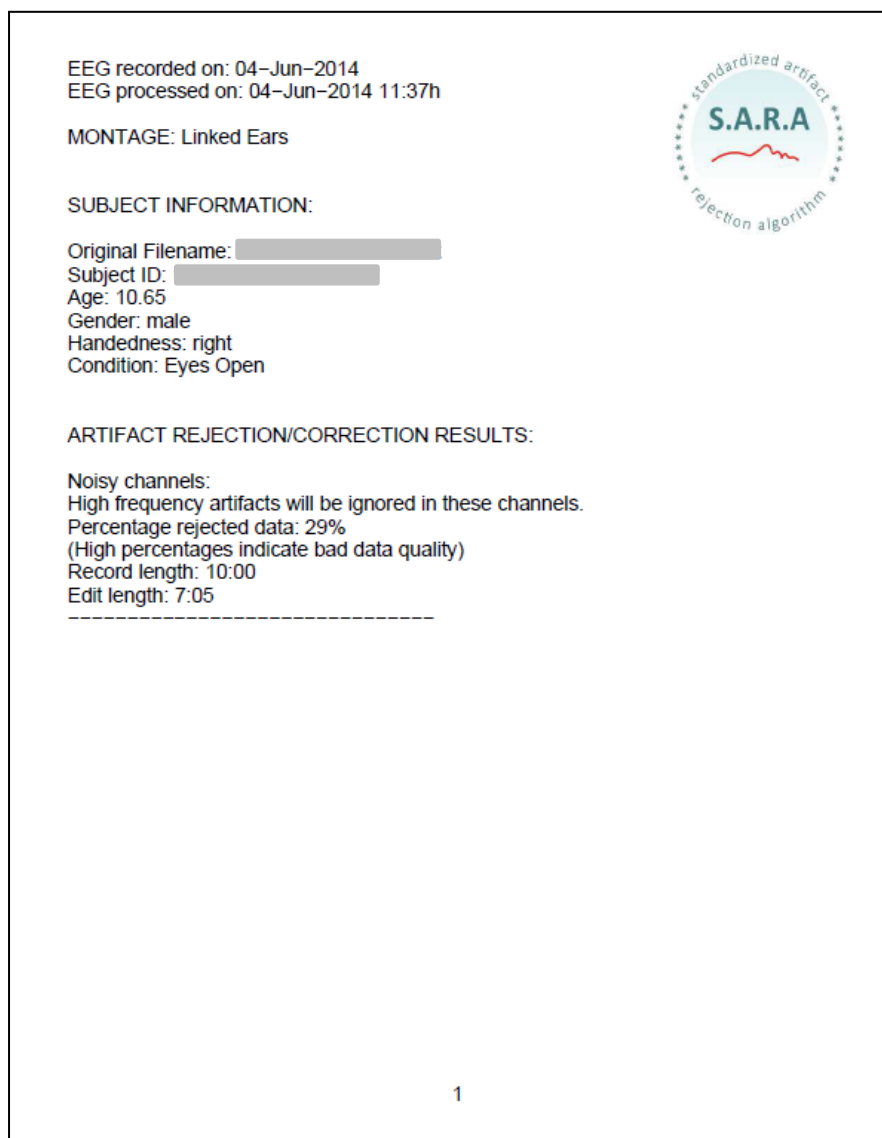
Moreover, an algorithm was developed to minimize the introduction of 'slicing' artifacts (sudden changes in amplitude resulting from the removal of segments containing artifacts).

Artifacts in noisy channels are ignored.

For a detailed description of the calculations underlying section 2-10 of the QEEG-Pro report, the reader is referred to Appendix 2.



**Figure 1.** Example of one EEG segment in a SARA report.

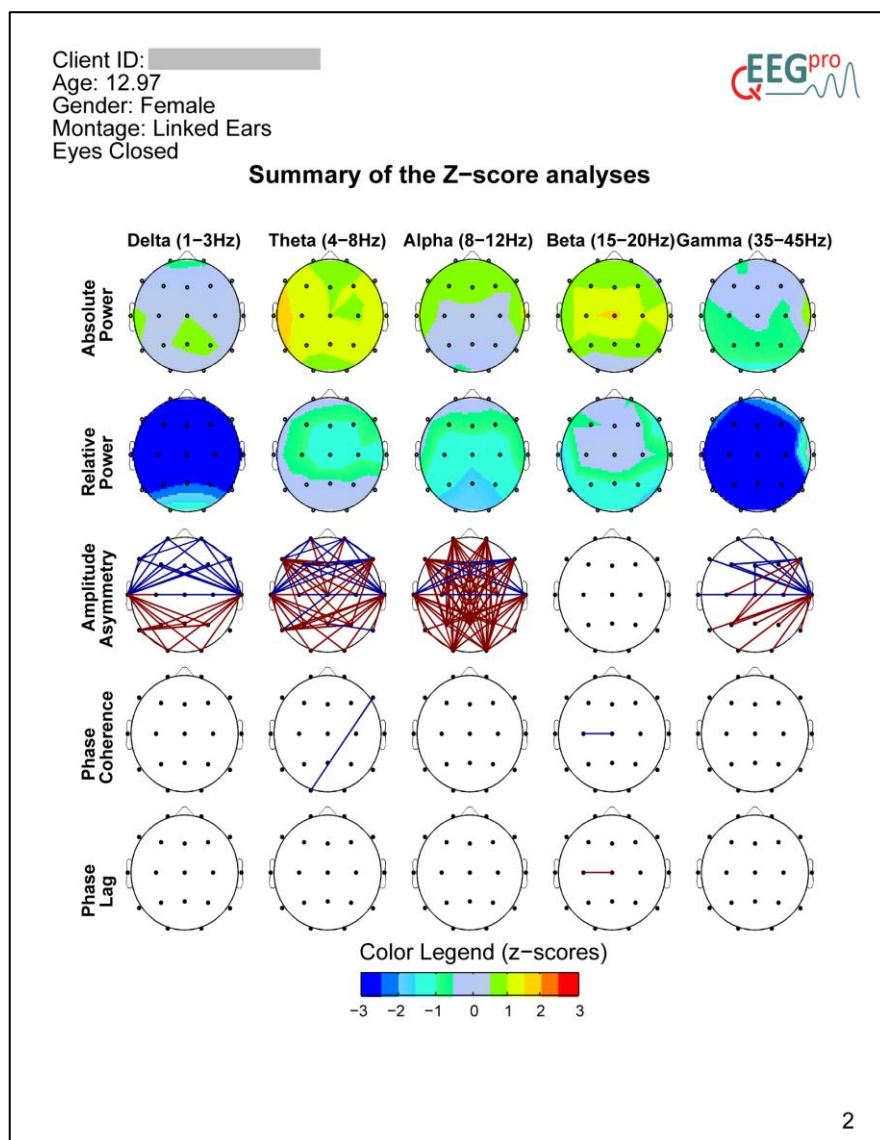


**Figure 2.** Example of the SARA report summary.

## 2. Summary

In section 2 of the qEEG-Pro report, a summary of the Z-scored results is depicted. topoplots of the following analyses are depicted for the Delta, Theta, Alpha, Beta and Gamma band:

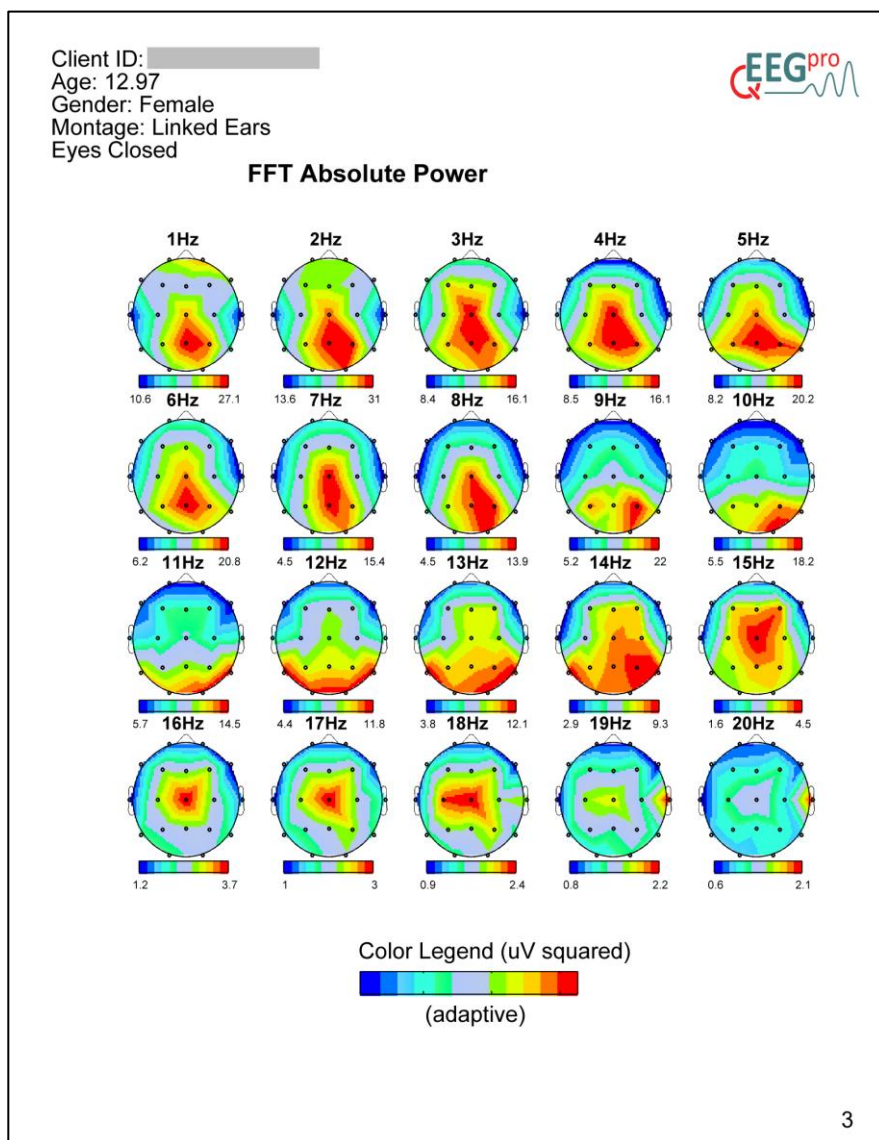
- Absolute Power
- Relative Power
- Amplitude Asymmetry
- Phase Coherence
- Phase Lag



**Figure 3.** Example of the Z-scored FFT Absolute Power analysis.

### 3. FFT Absolute Power

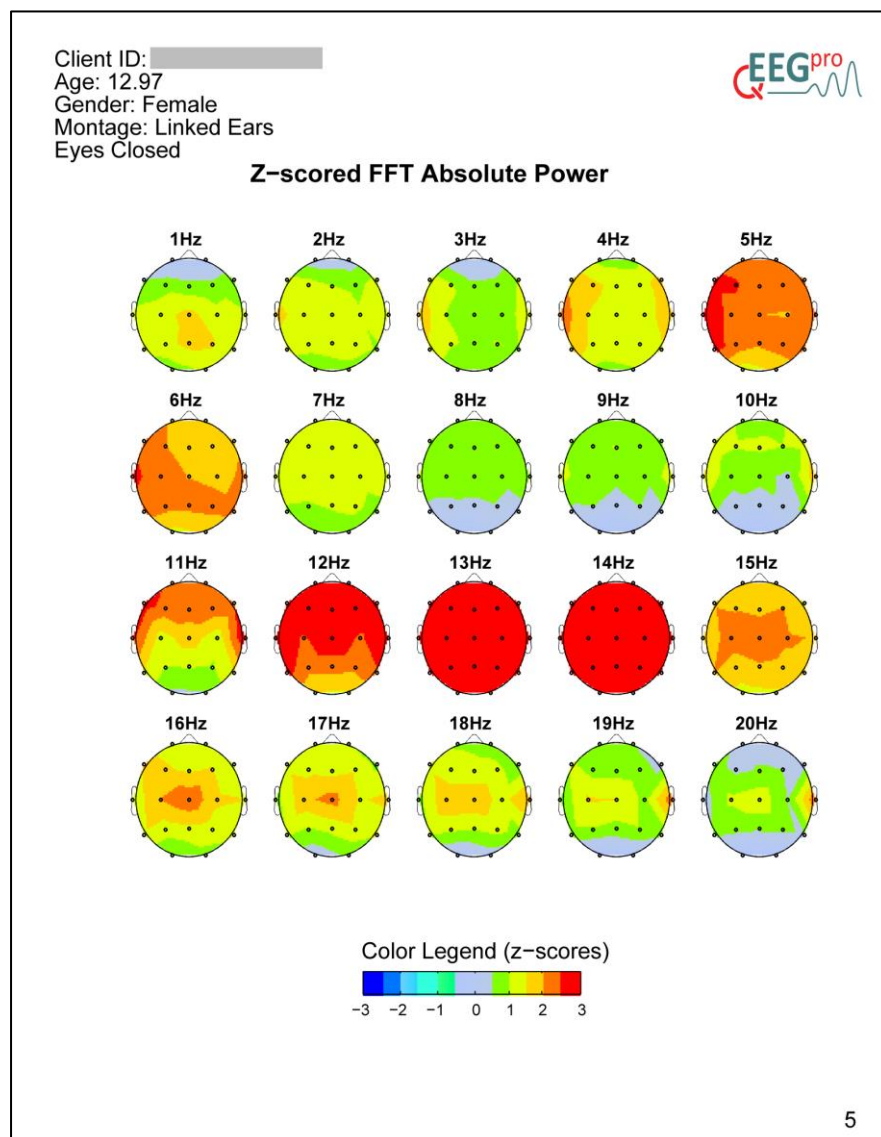
In section 3 of the qEEG-Pro report, topoplots of the absolute power (in microvolts squared) are depicted for each 1 Hz frequency bin, starting with 1 Hz and ending with 40 Hz. Each frequency bin ranges from  $\pm 0.5$  Hz. For example: The 12 Hz bin ranges from 11.5 to 12.5 Hz.



**Figure 4.** Example of the FFT Absolute Power analysis.

## 4. Z-scored FFT Absolute Power

In section 3 of the qEEG-Pro report, topoplots of the Z-scored absolute power are depicted for each 1 Hz frequency bin, starting with 1 Hz and ending with 40 Hz. The sample of the normative database consists of 200 subjects that have the lowest age difference compared with the age of the client, with an 'age resolution' of 6 months.



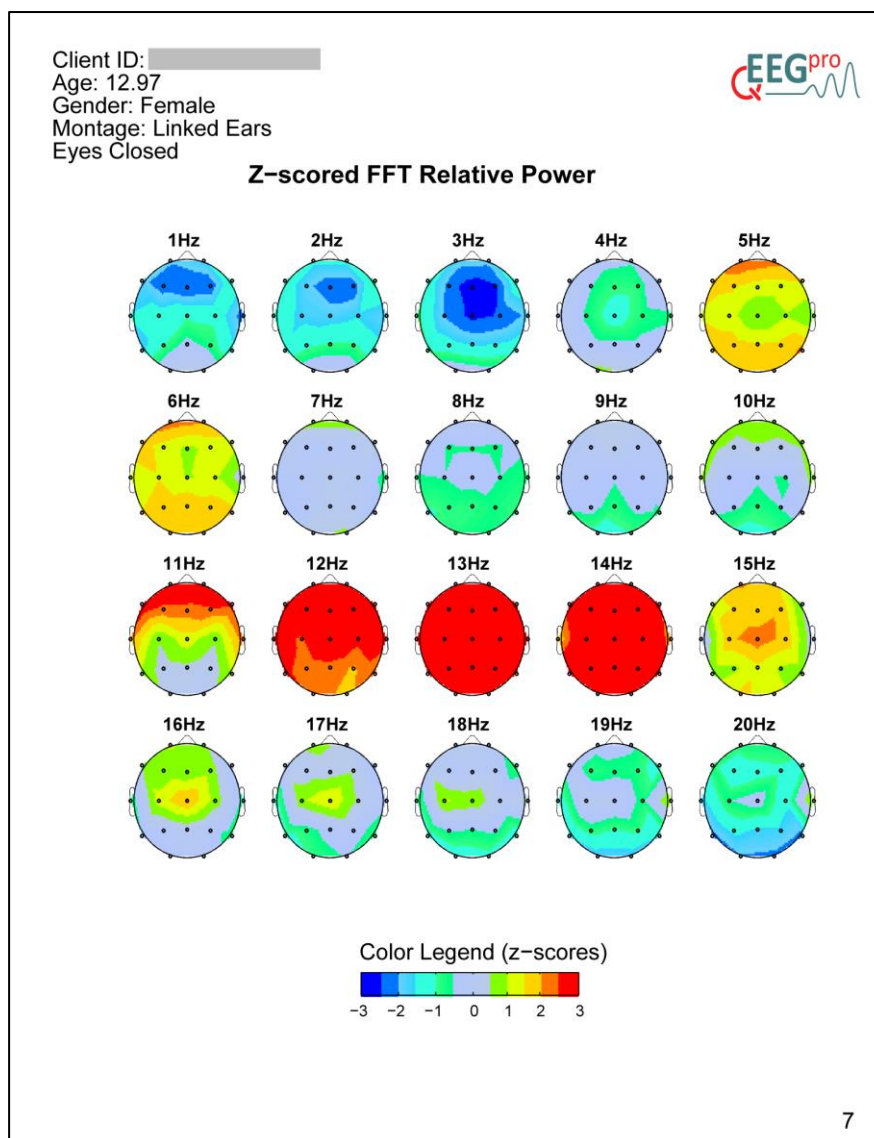
**Figure 5.** Example of the Z-scored FFT Absolute Power analysis.



## 5. Z-scored FFT Relative Power

In section 4 of the qEEG-Pro report, topoplots of the Z-scored relative power are depicted for each 1 Hz frequency bin, starting with 1 Hz and ending with 40 Hz. Relative power is calculated with the following formula, where RP is Relative Power, AP is Absolute Power and f is frequency.

$$RP(f_1) = \frac{AP(f_1)}{\sum_{f_2=1}^{45} AP_{f_2}} * 100$$



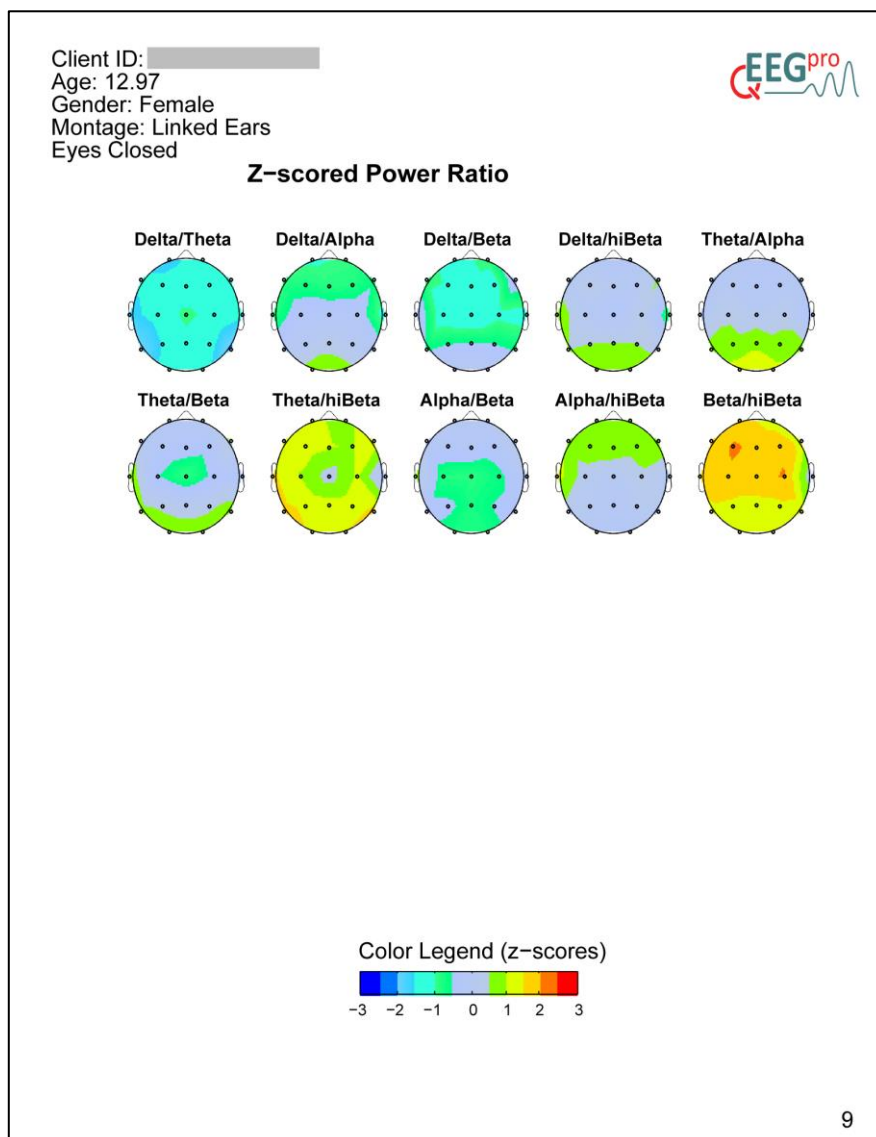
**Figure 6.** Example of the Z-scored FFT Relative Power analysis.



## 6. Z-scored Power Ratio

In section 5 of the qEEG-Pro report, topoplots of the following Z-scored Power Ratios are depicted:

- Delta/Theta
- Delta/Alpha
- Delta/Beta
- Delta/hiBeta
- Theta/Alpha
- Theta/Beta
- Theta/hiBeta
- Alpha/Beta
- Alpha/hiBeta
- Beta/hiBeta

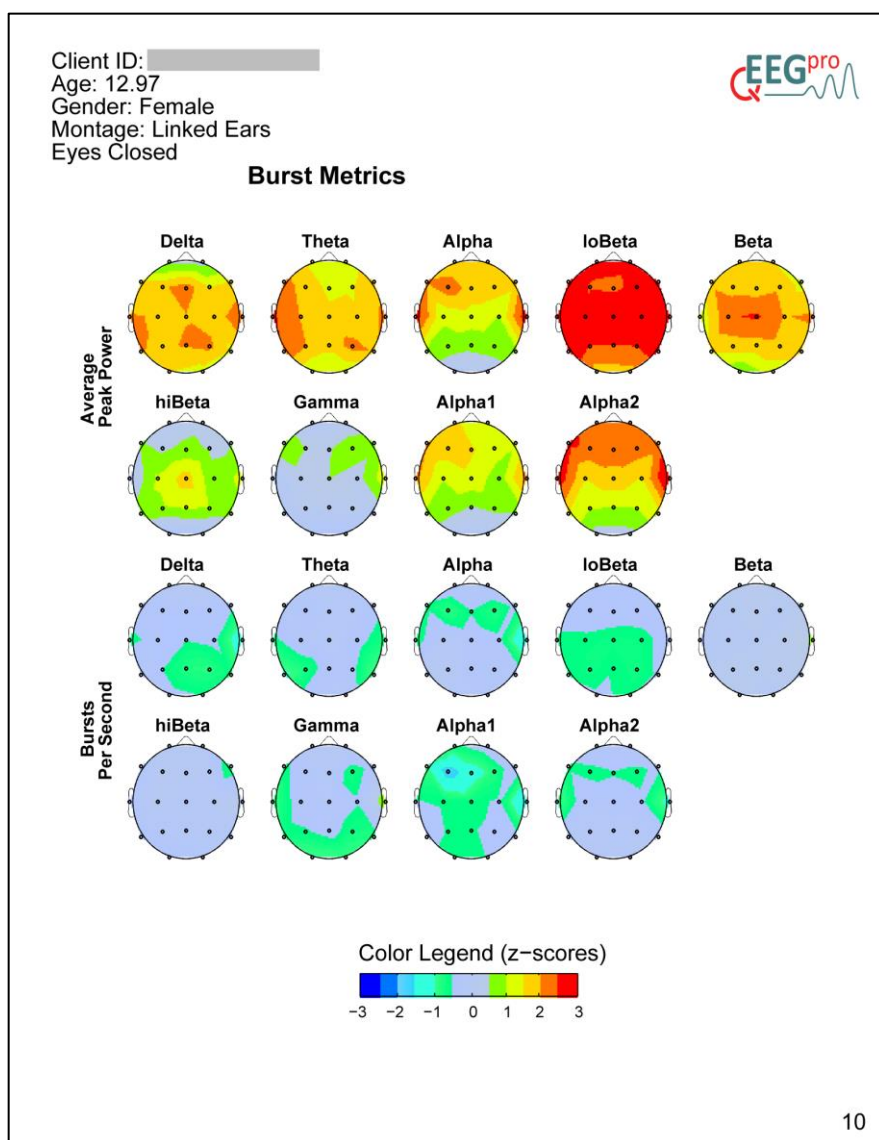


**Figure 7.** Example of the Z-scored Power Ratio analysis.

## 7. Burst Metrics

In section 6 of the qEEG-Pro report, the Z-scored Burst Metrics are depicted. The analysis of Burst activity is calculated in several steps. First, the second derivative of the power in 9 frequency bands was calculated. In this time series, peaks in power are defined by the points in time in which the value of the second derivative turns from positive to negative. After the peak power detection, bursts were identified by the evaluation of two criteria. The first criterion evaluates the duration of the full-width half-maximum (FWHM) around a peak in the power within a frequency band of interest. When the FWHM is larger than  $2^*$  and smaller than  $10^*$  the average cycle duration of the center frequency within a frequency band of interest, the first criterion is met. The second criterion evaluates the difference between the power at the start of the burst period and the peak power of the burst period. When this difference exceeds the median band power +  $1^*$  the standard deviation, the second criterion is met. The following metrics are derived from the periods in which both criteria are met:

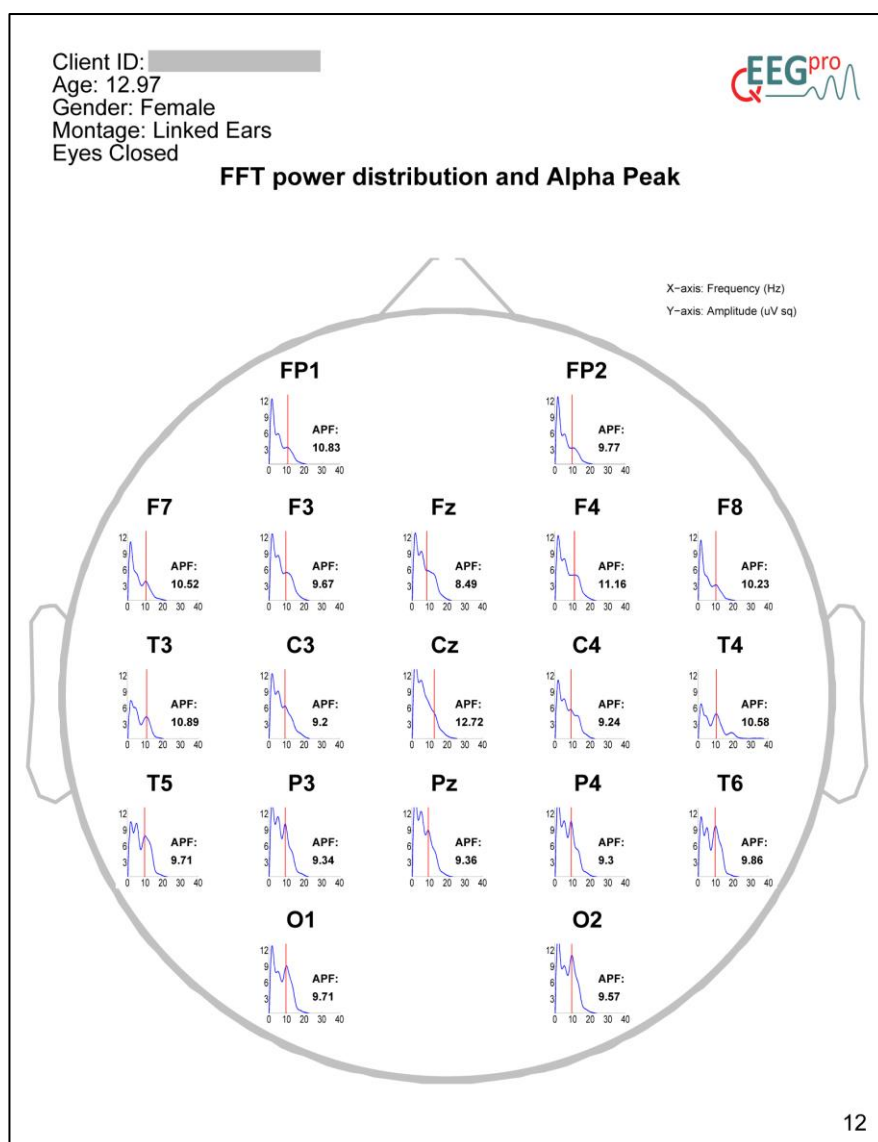
- Average Peak Power
- Bursts per second (number of burst periods divided by the duration of the recording in seconds)
- Full Width Half Maximum (average FWHM of the burst periods)
- Inter Burst Interval (average duration between burst periods)



**Figure 8.** Example of the Z-scored Burst Metrics analysis.

## 8. FFT power distribution and Alpha peak frequency

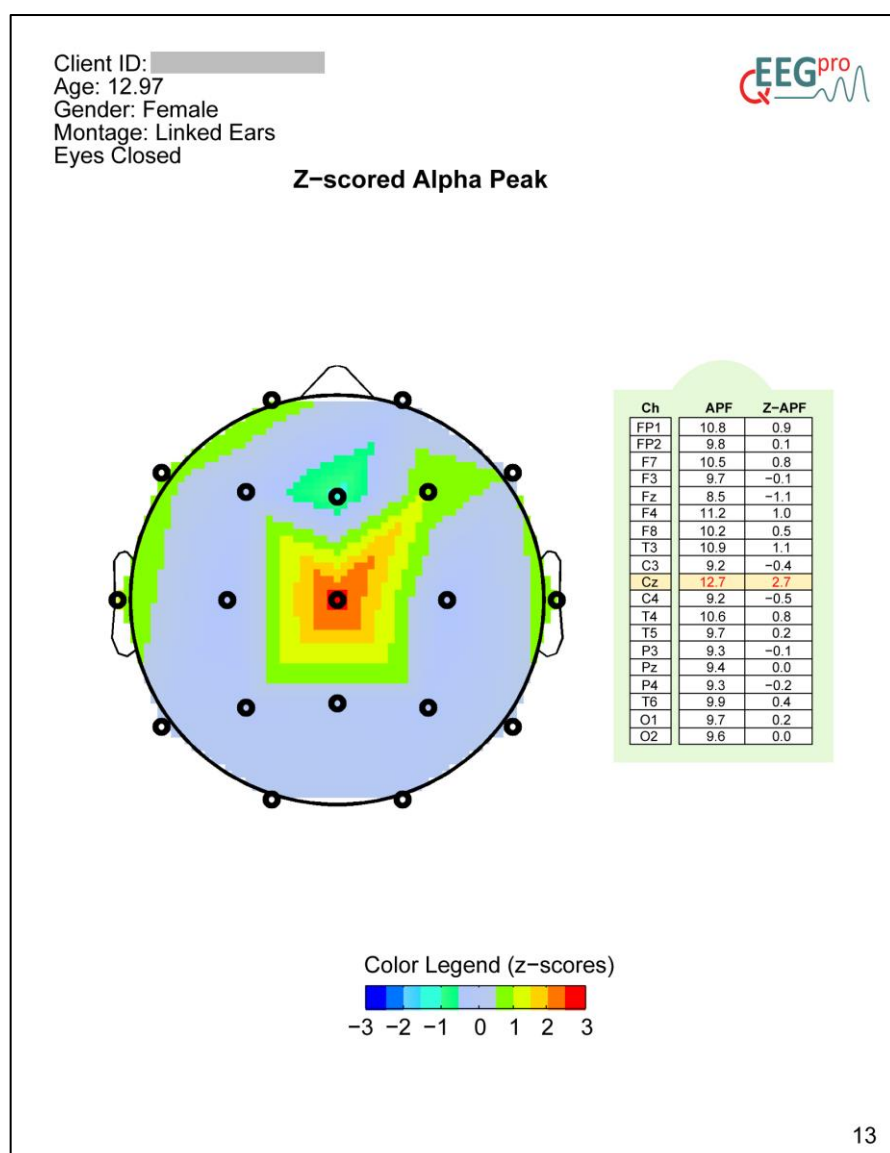
In section 7 of the qEEG-Pro report, a topoplot is depicted, showing the FFT results for each channel. A red, vertical line represents the frequency at which the Alpha peak frequency (APF) was detected. The exact Alpha peak frequency is shown on the right of this line.



**Figure 9.** Example of the Alpha peak analysis

## 9. Z-scored Alpha peak

In section 8 of the qEEG-Pro report, a topoplot is depicted, showing the z-scores of the APF. A positive z-score reflects a higher APF and a negative z-score reflects a lower APF, relative to the norm group. The table next to the topoplot shows the channel, APF and Z-scored APF (Z-APF) is shown. Deviant z-scores ( $>2.3$  or  $<-2.3$ ) are marked in color. The alpha peak detection algorithm uses the first derivative to detect whether the slope of the FFT power distribution is positive or negative in the range of 7 to 13 Hz. The power of the peak frequency of the frequency ranges that exhibit a rising slope are compared and the peak frequency exhibiting the maximum power is considered the alpha peak frequency.



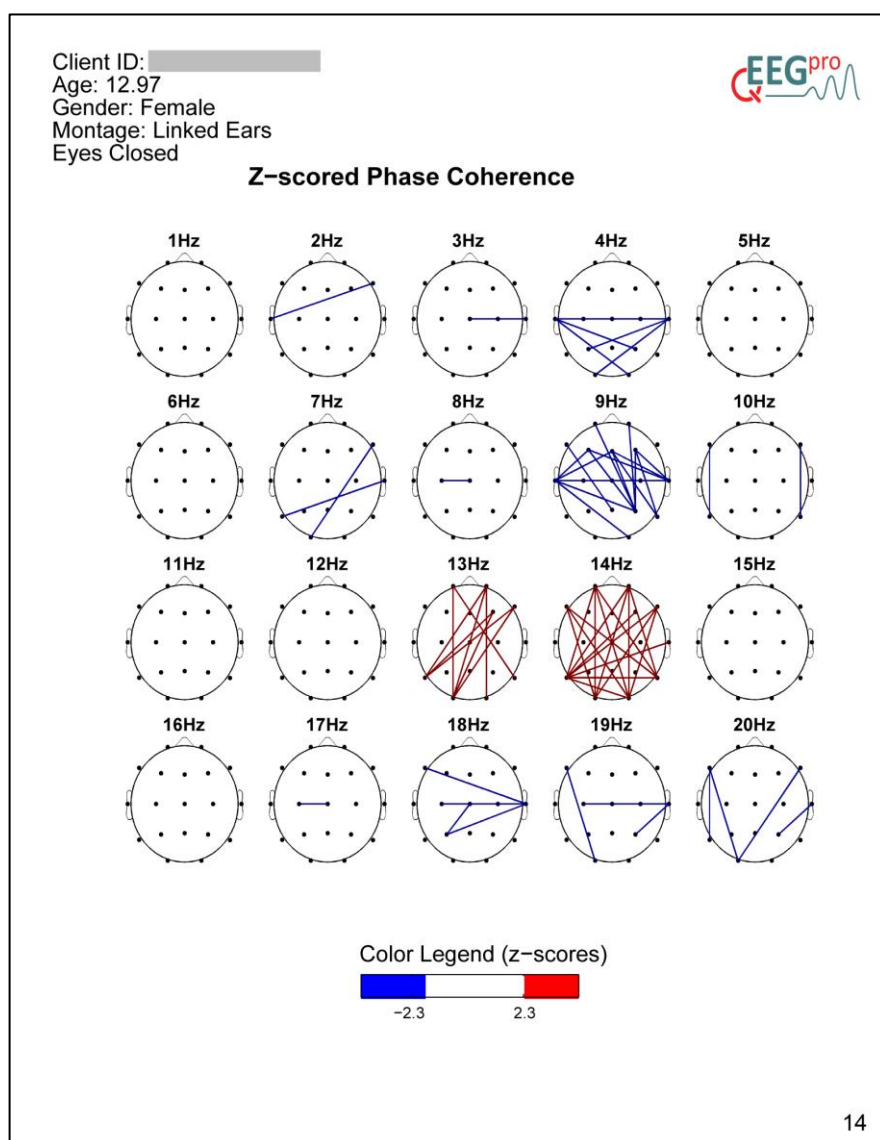
**Figure 10.** Example of the Z-scored Alpha Peak analysis.

## 10. Z-scored Phase Coherence

In section 9 of the qEEG-Pro report, plots of the Z-scored phase coherence are depicted for each 1 Hz frequency bin. Blue and red lines represent z-scores below and above a z-score of -2.3 and 2.3, respectively.

Phase coherence is calculated using the following formula, where PH is phase coherence, x and y are the EEG signals from two electrodes, f is frequency and P is (cross) power spectral density.

$$PH_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$



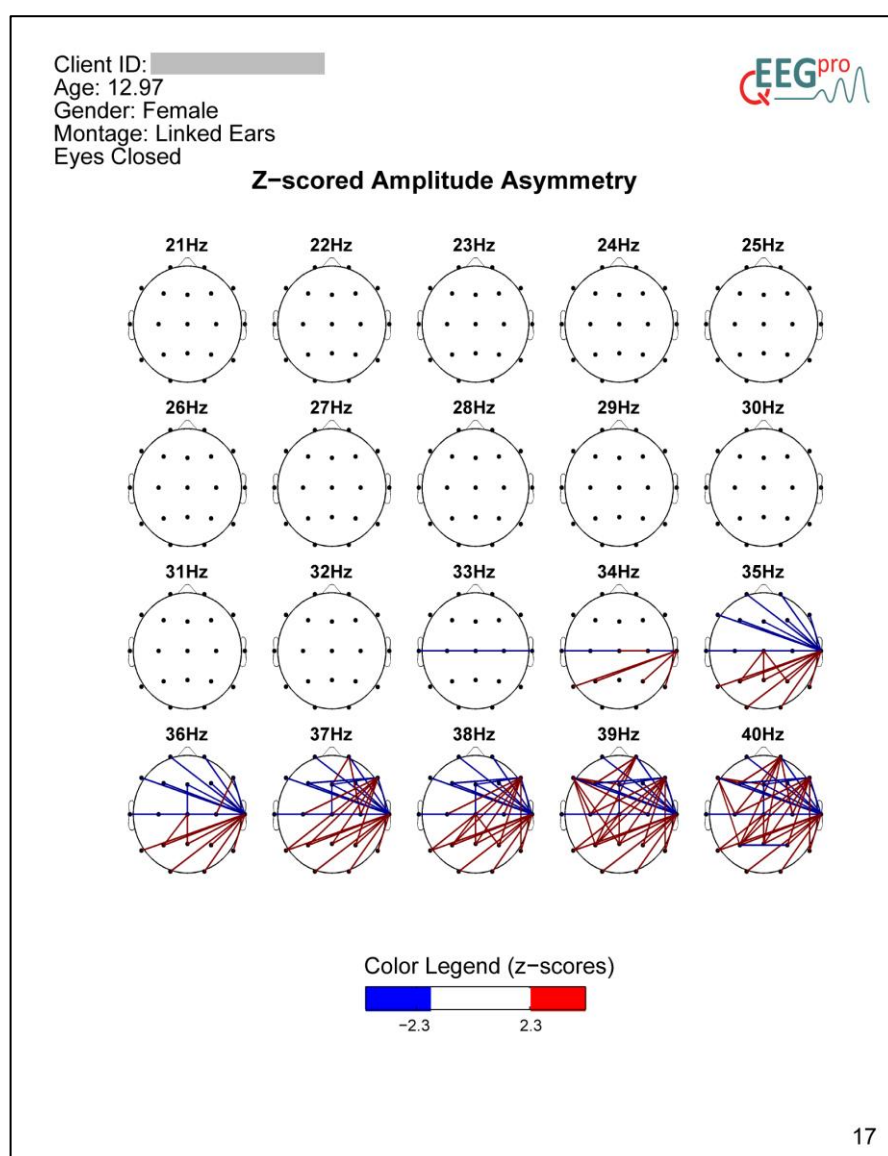
**Figure 11.** Example of the Z-scored Phase Coherence analysis.

## 11. Z-scored Amplitude Asymmetry

In section 10 of the qEEG-Pro report, plots of the amplitude asymmetry z-scores are depicted for each 1 Hz frequency bin. Blue and red lines represent z-scores below and above a z-score of -2.3 and 2.3, respectively.

Amplitude asymmetry is calculated using the following formula, where AA is amplitude asymmetry, ax and ay are the amplitudes of the EEG signals from two electrodes and f is frequency. Adding 100 is to ensure the amplitude asymmetry is a positive value, which is necessary for applying the log-transform.

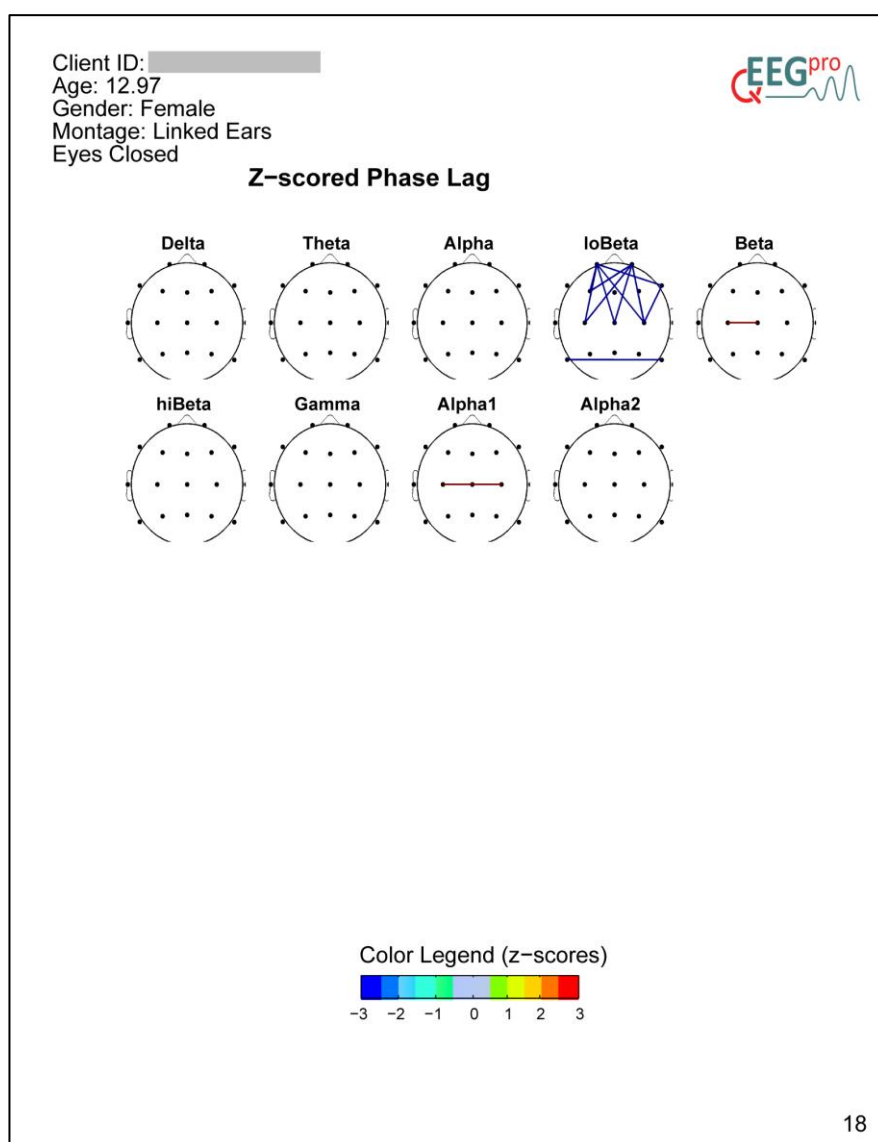
$$AA_{axay}(f) = \frac{ax(f) - ay(f)}{ay(f) - ax(f)} + 100$$



**Figure 12.** Example of the Z-scored Amplitude Asymmetry analyses.

## 12. Z-scored Phase Lag

In section 4 of the qEEG-Pro report, plots of the Phase Lag z-scores are depicted for 9 frequency bands. Phase lag is calculated in several steps. First, band pass filtering is applied to the EEG signal which filters out the frequencies around the frequency band of interest. Next, new EEG signals are created by summing the filtered EEG signals for all possible electrode combinations. Phase lag is calculated by calculating the exponential of the ratio between the sum of the power of the EEG signal of two channels of interest and the power of the summed signal of these two channels. For a detailed description of the rationale behind this approach, see 'Technical Foundations of Neurofeedback' by Thomas F. Collura (2013).



**Figure 13.** Example of the Z-scored Phase Lag analyses.

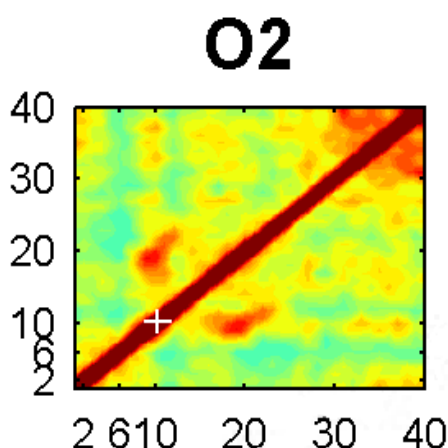


### 13. Comodulation (Cross-frequency power correlations)

Section 12 of the qEEG-Pro report contains the individual comodulation analysis (also called Cross-frequency power correlations). Power fluctuations within the recording of each 1 Hz bin are correlated with the whole frequency spectrum (1-40 Hz). The resulting heatplot represents the correlations between all 40 X 40 possibilities. The red diagonal line that is present in all of these heatplots represents the correlations between identical power bins, which are always 1. As a reference, the Alpha Peak Frequency is marked with a white cross (Eyes Closed condition only).

The frequency autocorrelations analysis can be used to identify harmonics or functionally coupled frequency bands. For example, when the z-score analyses reveals that there is both an excess of 10 Hz and 20 Hz power on occipital sites, one may hypothesize that the excess of 20 Hz power can be explained by harmonics. Looking at the frequency autocorrelations at occipital sites can confirm this hypothesis when there is a high positive correlation between 10 Hz and 20 Hz.

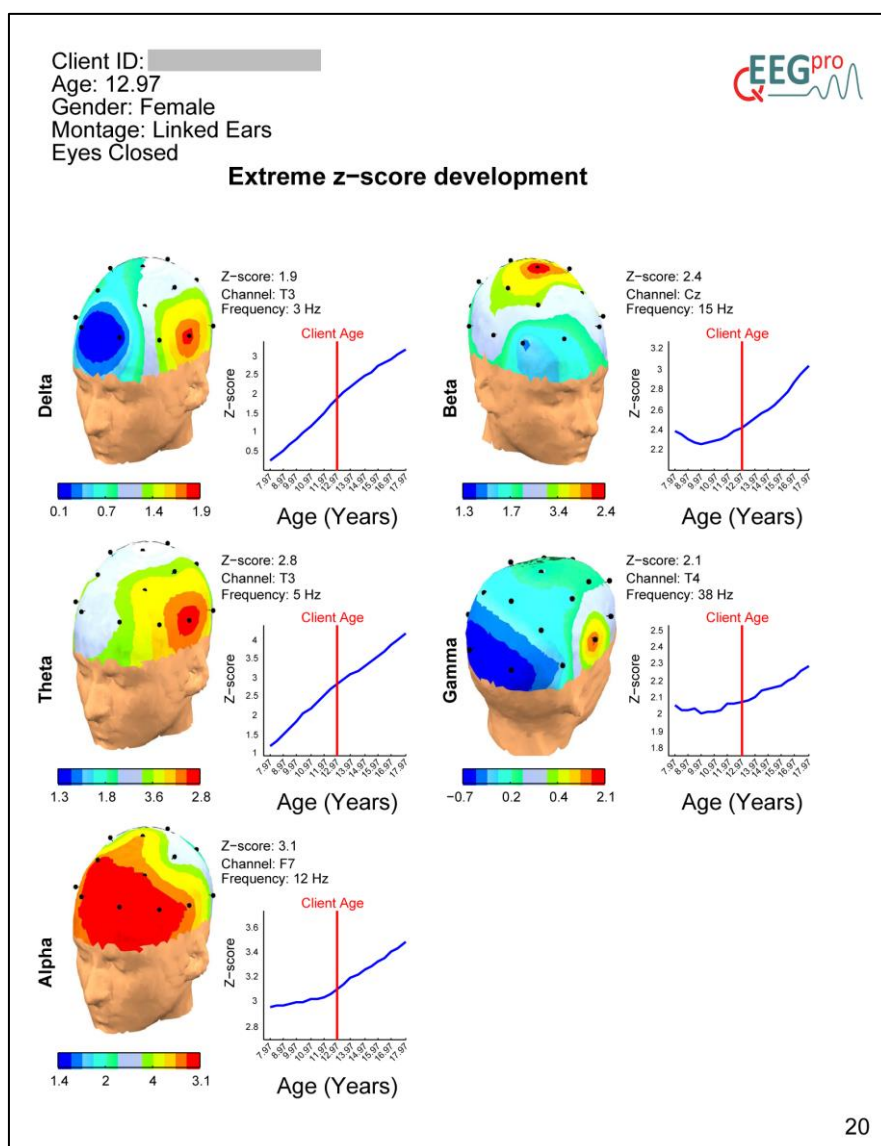
Furthermore, this analysis can be used to determine the width of a frequency band that will be used for Neurofeedback training. For example, if there is an excess of 13-14 Hz and the frequency autocorrelations analysis reveals that the frequencies between 12 and 18 Hz show a high positive correlation, one may safely decide to set the frequency bandwidth for Neurofeedback training between 12 and 18 Hz. On the other hand, a theta-beta Neurofeedback protocol in which the theta band is down-trained and the beta band is up-trained is not recommended when these frequencies are highly positively correlated.



**Figure 14.** Example of the Comodulation analysis. In this example, the alpha peak (marked with the white cross) shows a high positive correlation with 20 Hz. This is most likely a result of harmonics.

## 14. Extreme Z-score Development

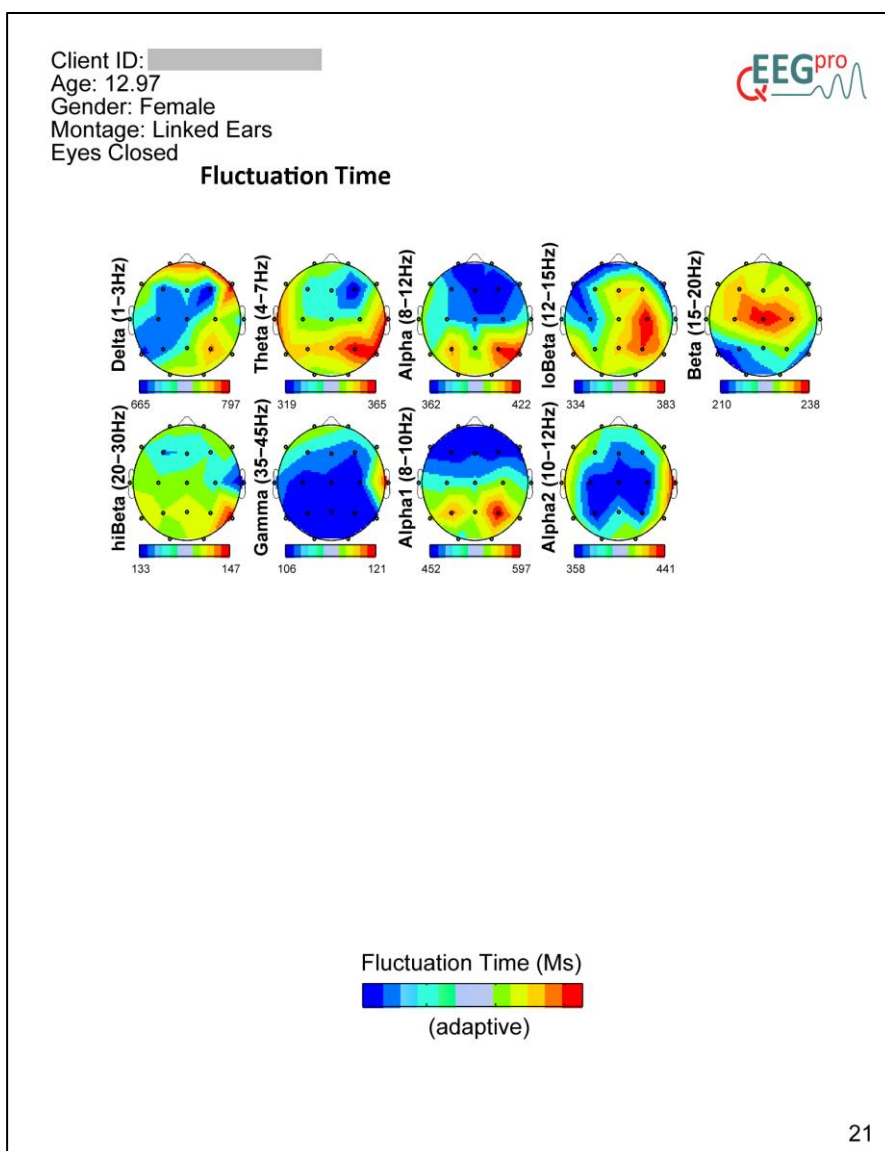
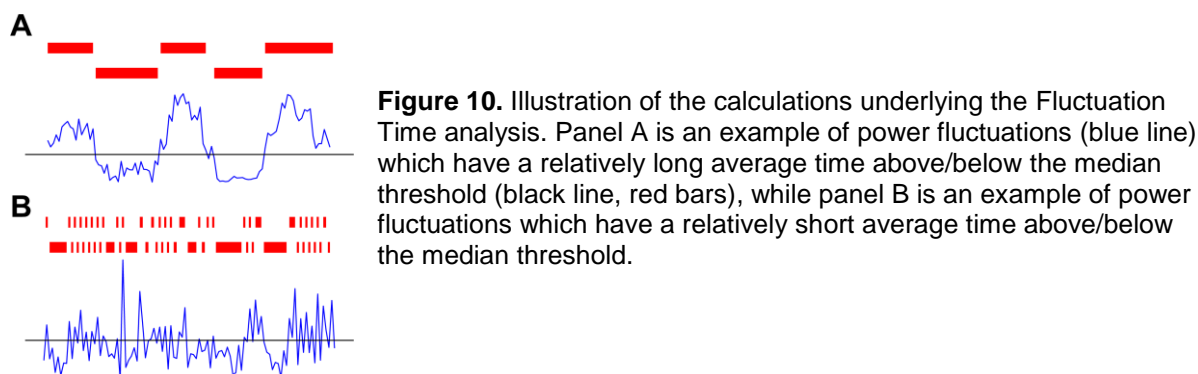
Section 13 of the qEEG-Pro report contains the results of the extreme z-score development analysis. For 9 frequency bands the frequency is analyzed in which the most extreme z-score is found. The left panels show headplots which are scaled to the maximum and minimum z-score within that frequency. The right panels show the result of the age simulation analysis. The x-axes of these graphs represent the actual age of the client, marked with a red vertical line, and the simulated ages, ranging from -5 years to +5 years in .5 year increments, respective to the actual age. The blue lines indicate the change in z-score when the age of the client is artificially changed. This analysis indicates whether the severity of deviant activity that a client shows increases or decreases when the client ages and the EEG stays the same. For example, when a client shows an excess of frontal theta activity at the age of 10 years old, and the Extreme Z-score Development analysis shows that this activity would be less deviant at a younger age and more deviant at an older age, one may conclude that this deviant activity is the result of a ‘maturation lag’.



**Figure 15.** Example of the Extreme Z-score Development analyses.

## 15. Fluctuation Time

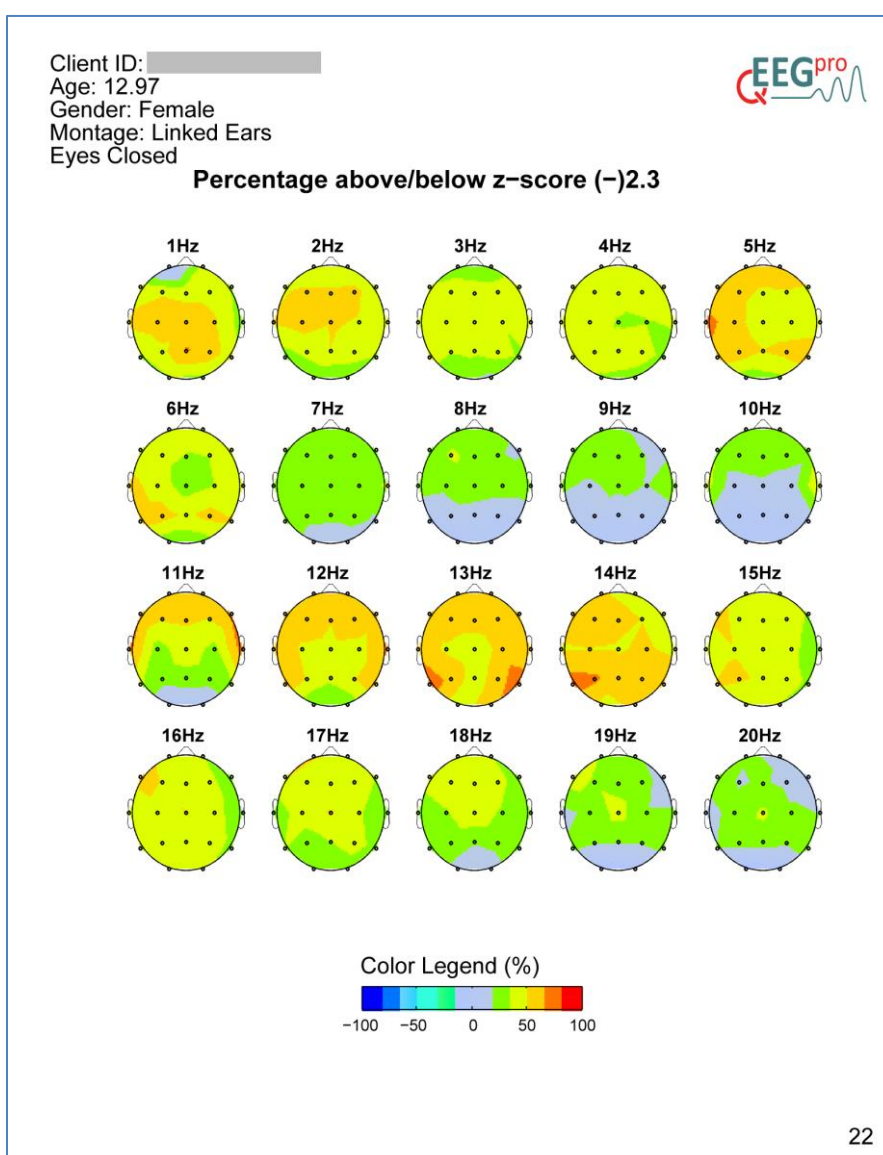
Section 14 of the qEEG-Pro report contains the results of the Fluctuation Time analysis. In this analysis, power fluctuations relative to the median power is calculated in 9 frequency bands. Next, the average duration between two crossings of the median is calculated. By definition, the average duration above the median threshold is identical to the average duration below the median threshold. This analysis can be used to study the variability of the power for a frequency bin of interest and may function as a guide for setting the time above or below threshold criterion in Neurofeedback protocols.



**Figure 16.** Example of the Fluctuation Time analysis.

## 16. Percentage Deviant Activity

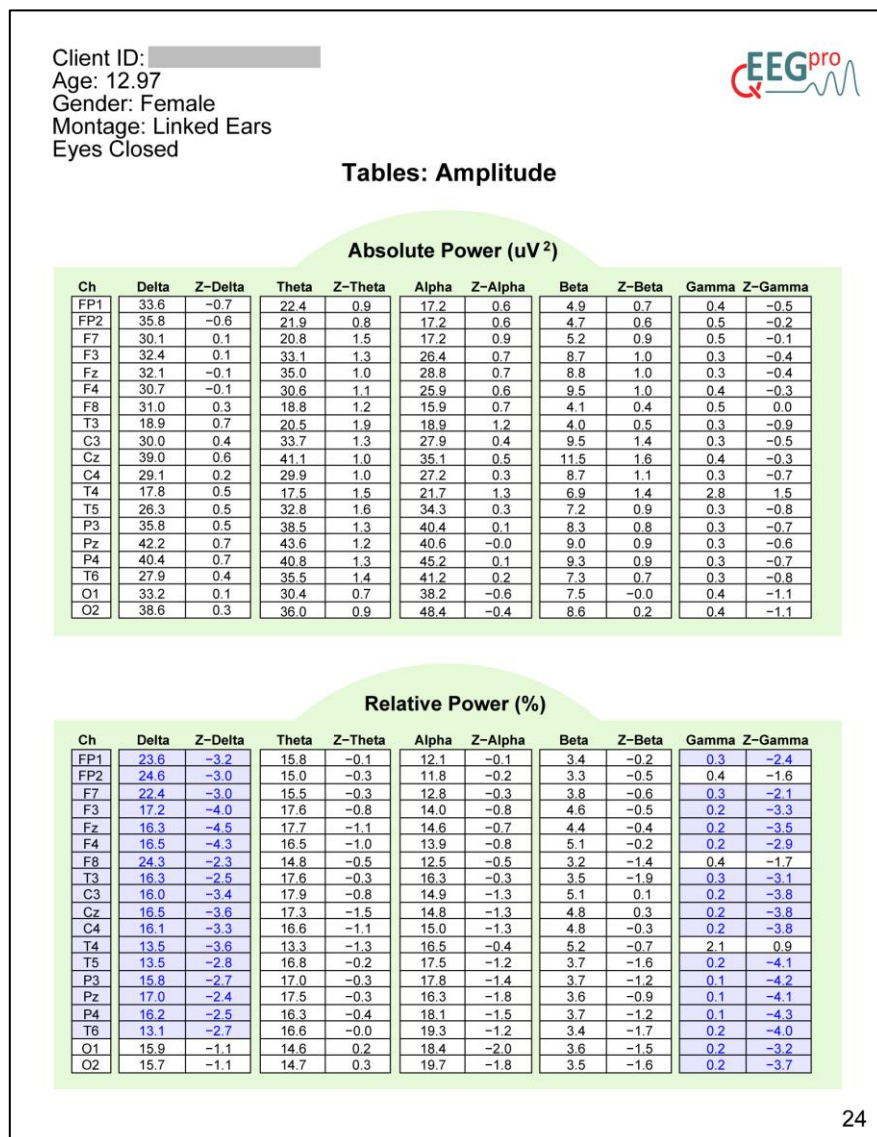
Section 15 of the qEEG-Pro report contains the results of the Percentage Deviant Activity analysis. In this analysis, the power fluctuations are compared with the normative database. The percentage of the time in which the z-score is above or below 2.3 is calculated. When the z-score analyses for an electrode site and frequency bin depicted on page 2 and 3 is positive, the percentage from 0 up to 100 percent is scaled from green to red (0 up to 100 percent). When the z-score analyses for an electrode site and frequency bin depicted on page 2 and 3 is negative, the percentage from 0-100 percent is scaled from green to blue (0 down to -100 percent). The reason a z-score cutoff value of 2.3 was chosen is that this z-score value corresponds with a p-value of .001, which is a commonly used threshold for comparisons that are uncorrected for multiple comparisons in neuroscience literature.



**Figure 17.** Example of the Percentage Deviant Activity analysis. Note that the color scale ranges from -100 percent to 100 percent (see text for clarification).

## 17. Tables: Amplitude

Section 16 of the qEEG-Pro report shows two tables containing the Absolute Power and the Relative Power data as well as the Z-scored Absolute Power and Relative Power data respectively. Deviant z-scores ( $>2.3$  or  $<-2.3$ ) are marked in color.



**Figure 18.** Example of the Tables: Amplitude section.

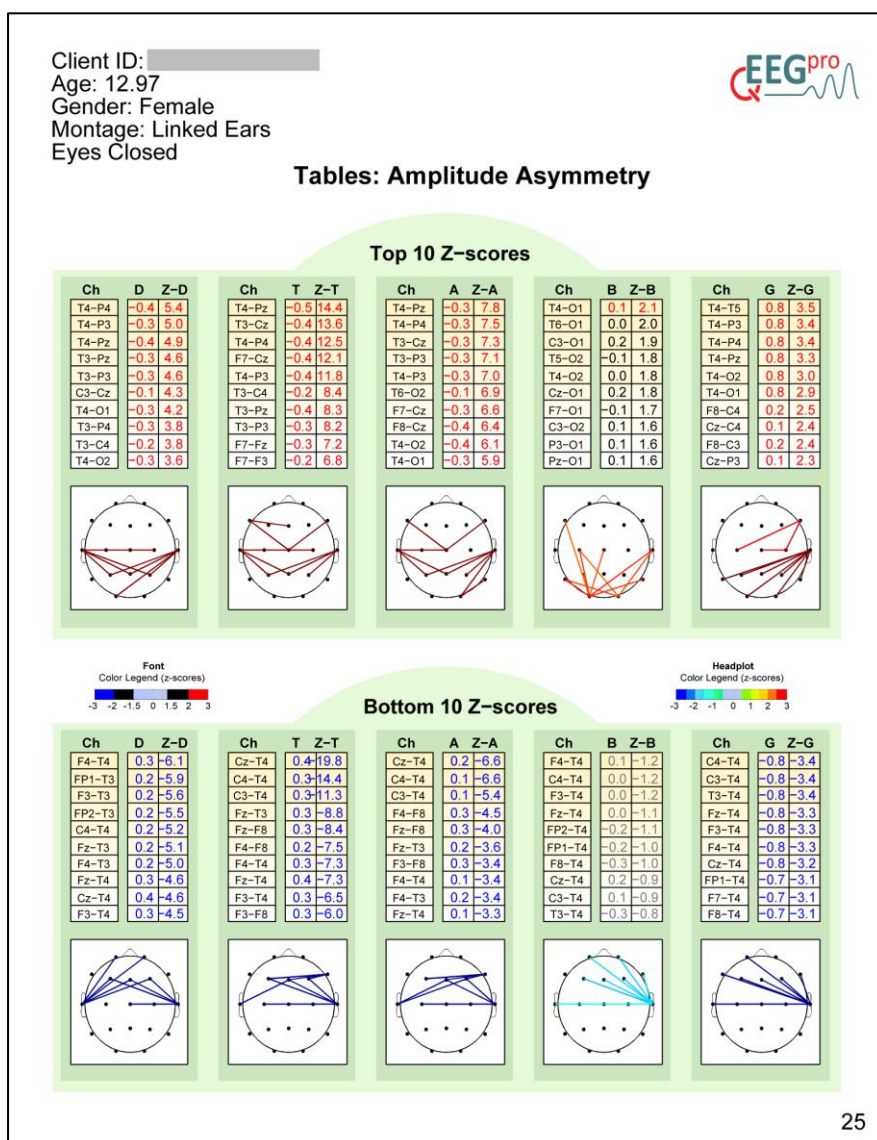


## 18. Tables: Amplitude Asymmetry

Section 17 of the qEEG-Pro report shows two tables containing the top and bottom 10 Amplitude Asymmetry data and the z-scored Amplitude Asymmetry, for 4 frequency bands:

- Delta (1:3Hz)
- Theta (4:8Hz)
- Alpha (8:12Hz)
- Beta (15:20Hz)
- Gamma (35-45Hz)

Deviant z-scores ( $>2.3$  or  $<-2.3$ ) are marked in color. The top and bottom 10 Amplitude Asymmetry z-scores are shown in topoplots.



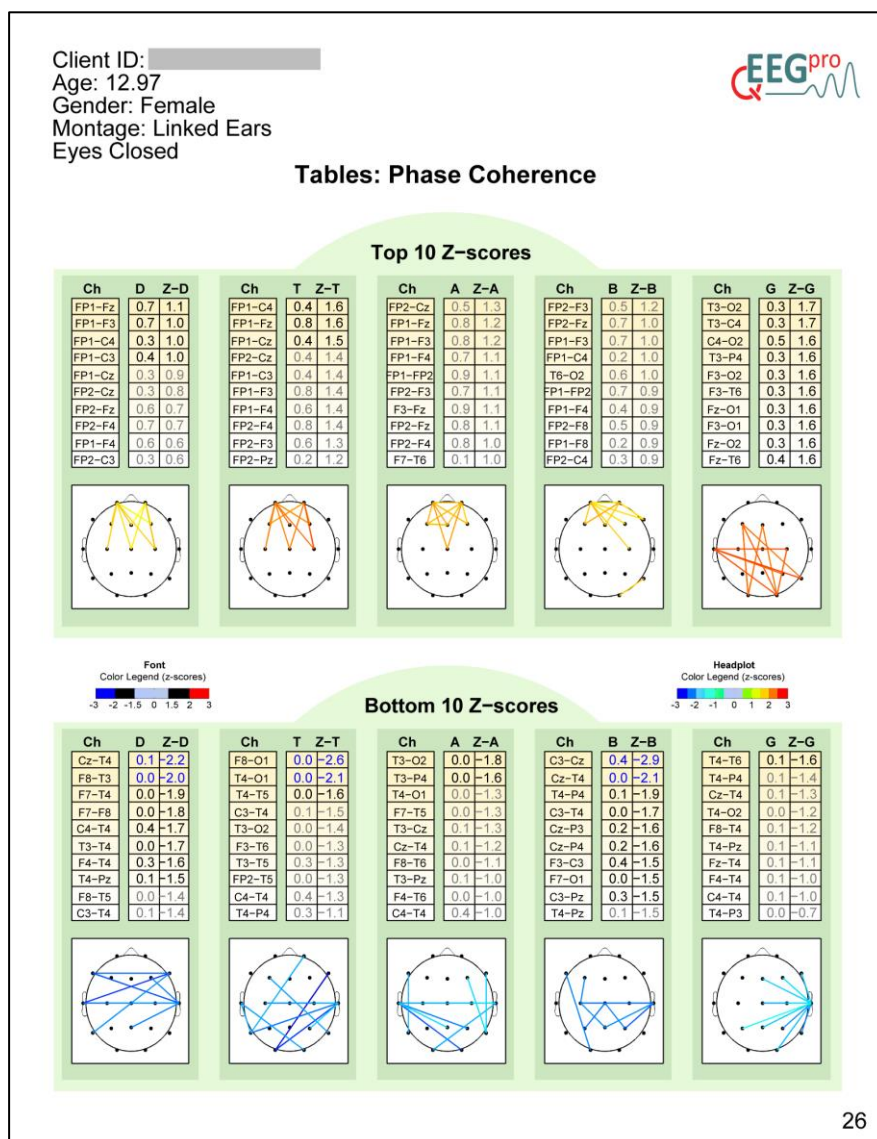
**Figure 19.** Example of the Tables: Amplitude Asymmetry.

## 19. Tables: Phase Coherence

Section 18 of the qEEG-Pro report shows two tables containing the top and bottom 10 Phase Coherence data and the z-scored Phase Coherence, for 4 frequency bands:

- Delta (1:3Hz)
- Theta (4:8Hz)
- Alpha (8:12Hz)
- Beta (15:20Hz)
- Gamma (35-45Hz)

Deviant z-scores ( $>2.3$  or  $<-2.3$ ) are marked in color. The top and bottom 10 Amplitude Asymmetry z-scores are shown in topoplots.



**Figure 20.** Example of the Tables: Phase Coherence.

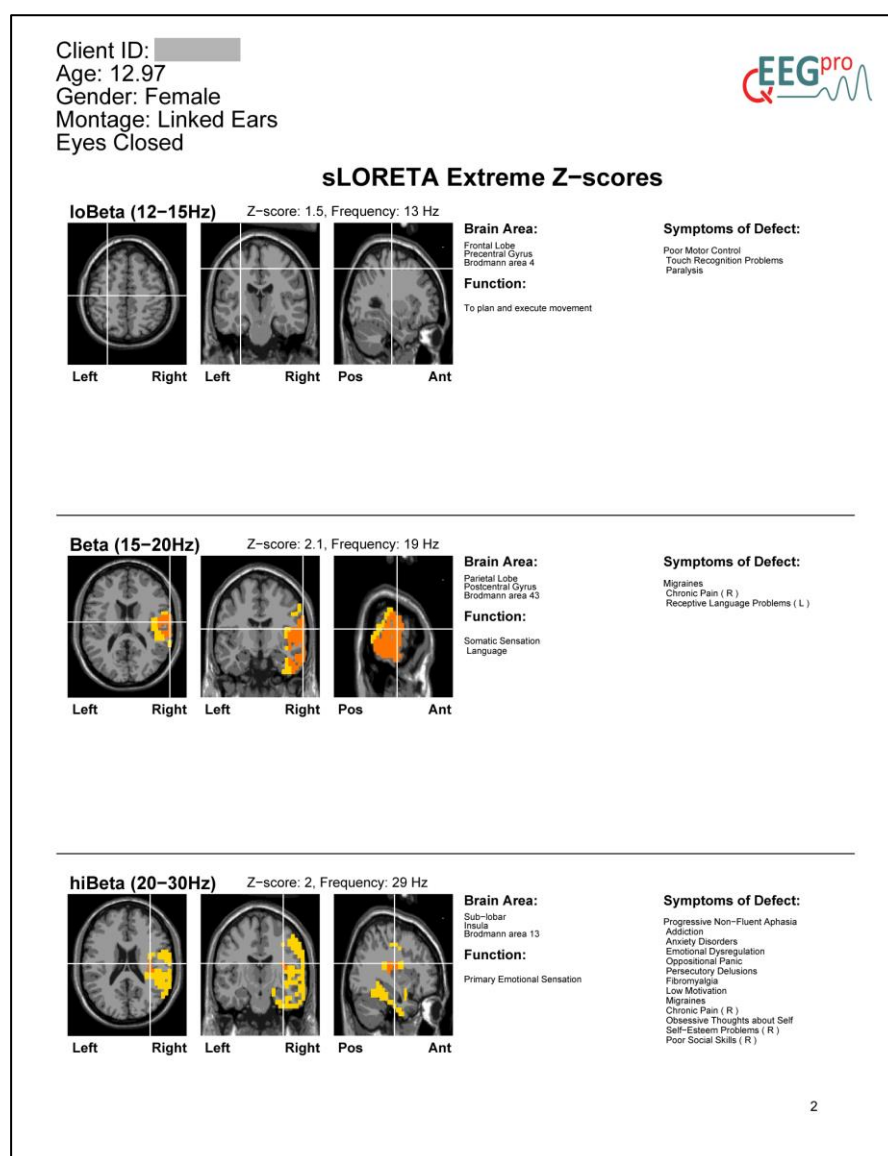


## 20. sLORETA reports

Source reconstructions for all discrete frequencies between 1 and 45 Hz for all EEGs in the qEEG-Pro database were performed using standardized low resolution brain electromagnetic tomography (Pascual-Marqui, 2002). For each EEG, two sLORETA reports are generated.

### Report 1: Summary / Extreme Z-score Analysis

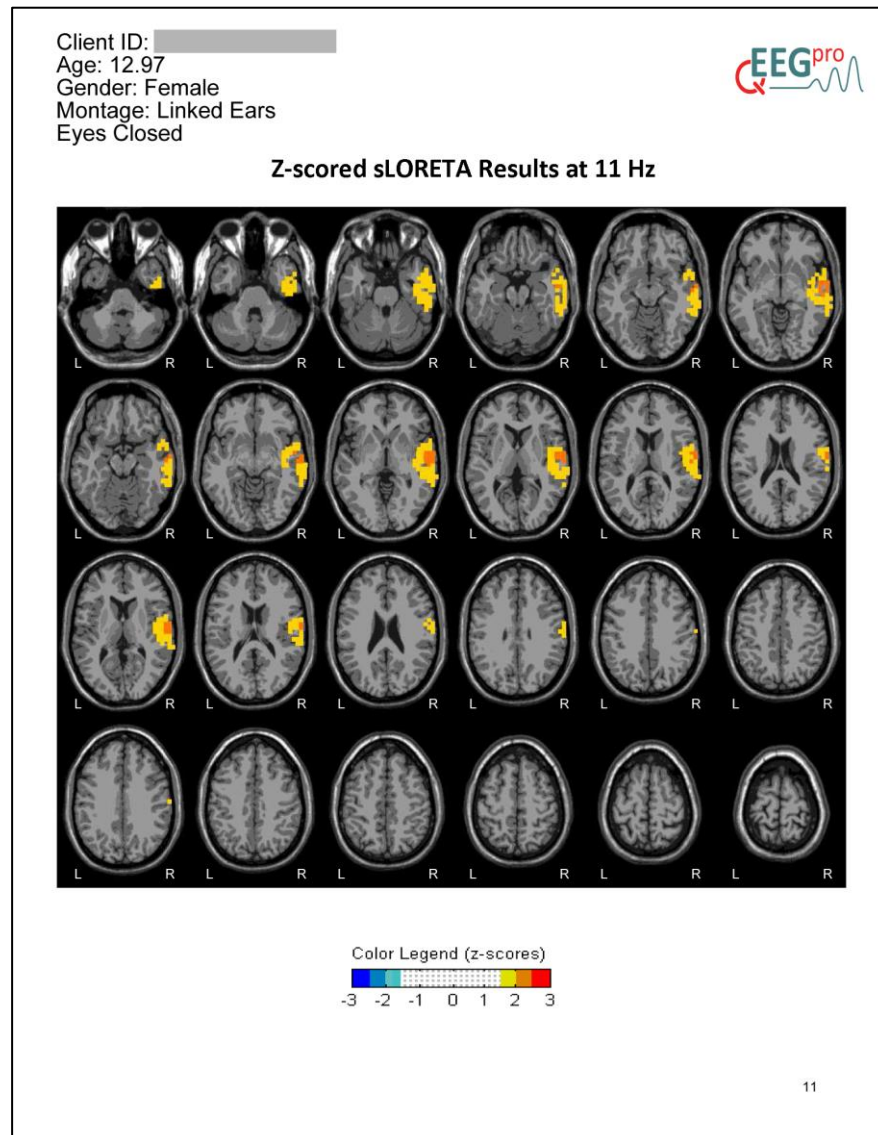
Report 1 contains the results of the Extreme Z-score Analysis. For 9 frequency bands the frequency is shown in which the most extreme z-score is found. The left panels show the transverse, coronal and sagittal slices (from left to right) of the MNI template in which the most extreme z-score is found. The voxel that shows the most extreme z-score is marked with a crosshair. On the right of each frequency band, the brain area and Brodmann area is depicted of the voxel that shows the most extreme z-score. Moreover, the functions and symptoms of deficit which are associated with that brain area are shown.



**Figure 16.** Example of the sLORETA extreme z-scores analysis.

## Report 2: Discrete Frequencies

Report 2 contains the z-scored sLORETA results for each discrete frequency between 1 and 45 Hz. Each page shows the results for a selection of slices in the transverse plane of the MNI template brain.



## Appendix 1. S.A.R.A calculation details

The calculations and report generation was done using the Matlab<sup>®</sup> ([www.mathworks.nl](http://www.mathworks.nl)) programming environment. In order to filter the EEG signal, the FIR filtering functions of the EEGLab (Delorme and Makeig, 2004, <http://sccn.ucsd.edu/eeGLab/>) Matlab<sup>®</sup> plugin were used.

### 1. Epileptiform episode detection

The raw data is copied and low-pass filtered with a cutoff value of 6 Hz. The maximum amplitude difference within a moving window (1 second duration, 50 percent overlap) is compared with a predefined threshold. When the maximum difference surpasses the predefined threshold, the segment is marked as containing epileptiform activity.

### 2. Filtering

The EEG-data is filtered with a high-pass filter of 1 Hz and a notch filter of 50Hz or 60Hz, depending of the power line alternating current frequency of the country where the EEG was recorded.

### 3. Noisy channels

The raw EEG data is copied and band-pass filtered leaving only high frequencies above 25 Hz and below 40 Hz. When the median high-frequency power of a channel is higher than the median high-frequency power of all channels plus 2 times the standard deviation and the median high-frequency power exceeds a predefined threshold, the channel is ignored for further artifact rejection processes and it is marked in the SARA report.

### 4. EEG-segments containing artifacts

Detection of eye-blinks is done by constructing a new signal which represents the sum of channels Fp1 and Fp2. A moving window of 1/4 seconds (3.1 percent overlap) then compares the average amplitude of the window with a predefined threshold. Whenever the average amplitude surpasses the predefined threshold, the segment is removed from the raw data of all channels.

Detection of horizontal eye movements is done by constructing a new signal which represents the difference between channels F7 and F8. A moving window of 1/8 second (6.2 percent overlap) then compares the average amplitude of the window with a predefined threshold. Whenever the average amplitude surpasses the predefined threshold, the segment is removed from the raw data of all channels.

Detection of low-frequency artifacts other than eye-related artifacts is done by applying a low-pass filter to the raw data of all channels ( $< 3$  Hz). A moving window of 1/2 seconds (50 percent overlap) then compares the average amplitude of the window with a predefined threshold. Whenever the average amplitude surpasses the predefined threshold in a certain channel, the segment is removed from the raw data of all channels.

Finally, high-frequency artifacts are detected by applying a high-pass filter to the raw data of all channels ( $> 22$  Hz). A moving window of 1/20 seconds (15.5 percent overlap) then compares the average amplitude of the window with a predefined threshold. Whenever the

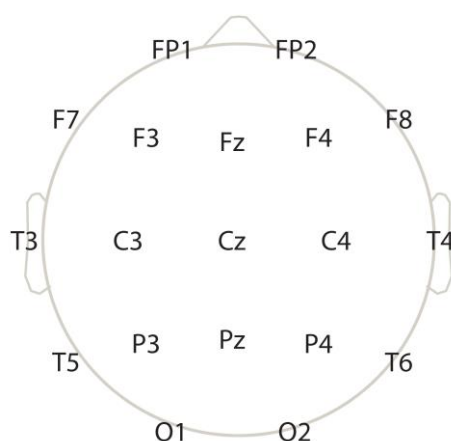
average amplitude surpasses the predefined threshold in a certain channel, the segment is removed from the raw data of all channels.

To minimize the introduction of 'slicing' artifacts (sudden changes in amplitude resulting from the removal of segments containing artifacts), an algorithm was developed that searches for the minimal difference between the start and end of a segment containing artifact in a 1/4 second window preceding and following that segment.

## Appendix 2. qEEG-Pro calculation details

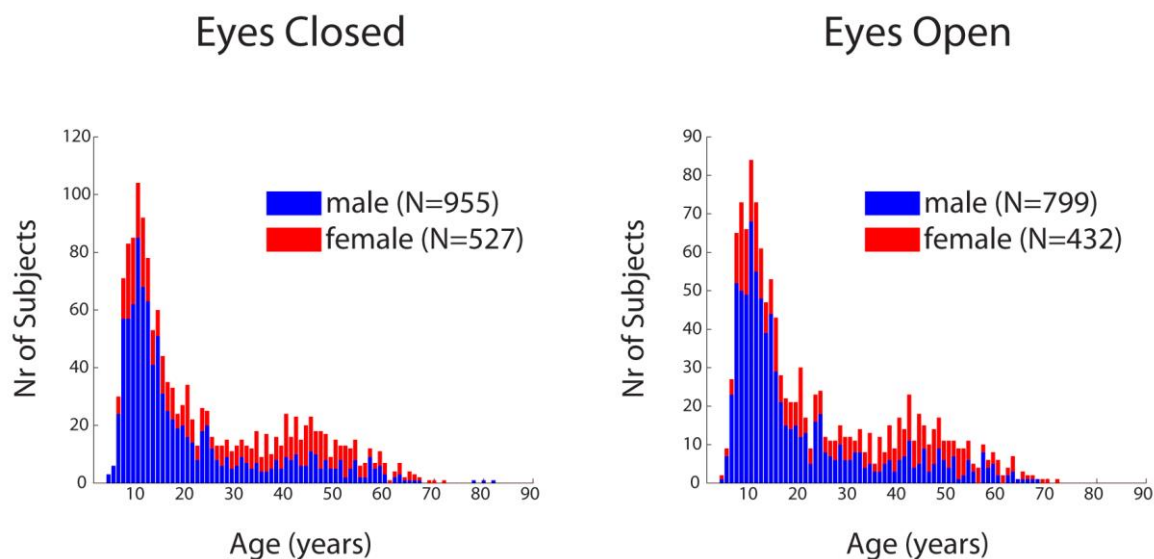
### 12.1 qEEG-Pro normative database data collection

The qEEG-Pro normative database was constructed by using the resting-state EEG and questionnaire data of clients that visited the Neurofeedback Institute Netherlands (NIN) between 2004 and 2013 in one of the 10 different Dutch cities the NIN is located (Neurofeedback.nl). The EEG recording and questionnaire was done in order to guide subsequent Neurofeedback treatment. All clients signed an informed consent form, which stated that their anonymous EEG and questionnaire data may be used for research purposes. The questionnaire consisted of 292 questions (each rated from 0 to 8) that were directly based on the criteria of 46 DSM psychopathologies (CNC1020<sup>®</sup>; [www.EEG-Professionals.nl/en/cnc-1020/](http://www.EEG-Professionals.nl/en/cnc-1020/)). The recordings were done using the 19-channel Deymed TruScan<sup>™</sup> EEG amplifier ([www.deymed.com](http://www.deymed.com)). The electrode sites were positioned according to the international 10-20 system (see figure 13).



**Figure 13.** Electrode positions and labels used for the resting-state EEG recordings of the qEEG-Pro database.

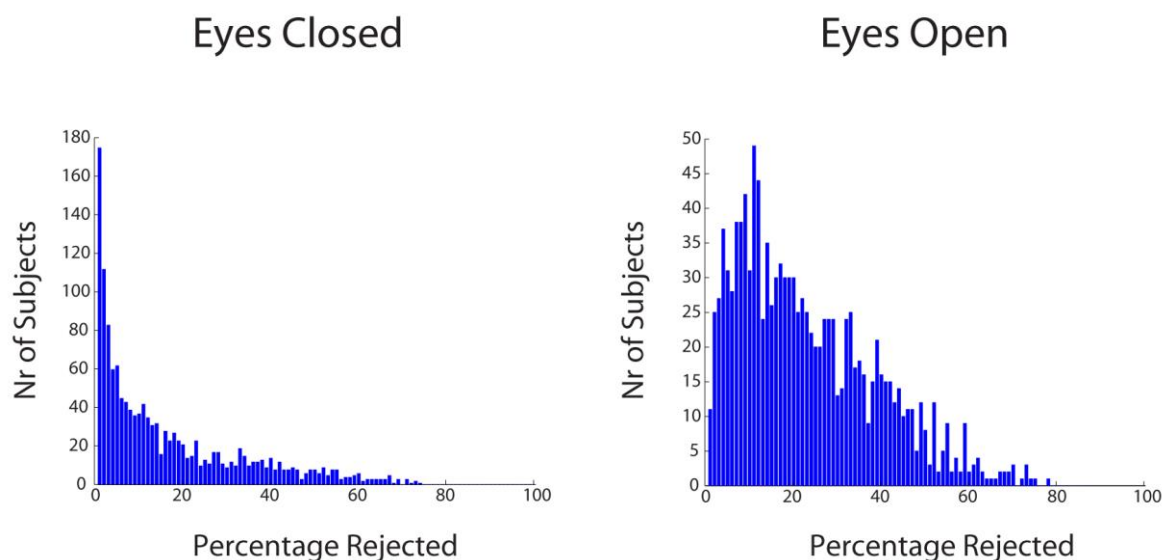
Sampling frequencies of 128 Hz and 256 Hz were used (8% and 92% of the subjects, respectively). The EEG recording session consisted of an 'Eyes Closed' condition (EC) and an 'Eyes Open' condition (EO). In the both conditions, the clients sat in an upright position for a total of 10 minutes. The clients were instructed to keep their neck and facial muscles relaxed and refrain from making an excess of eye movements or eye blinks in the EO condition. A total of 1696 clients completed the questionnaire and the EC EEG recording. A total of 1364 clients completed the questionnaire and the EO EEG recording. 88(EC) and 21(EO) clients showed epileptiform activity in their EEG recording according to the epileptiform episode detection algorithm and were excluded from the qEEG-Pro database. The duration of the de-artifacted EEG of 126 (EC) and 112 (EO) clients was less than 1 minute and were therefore excluded from the qEEG-Pro database. So to summarize, the EEGs of 1482 (EC) and 1231 clients were included in the qEEG-Pro. Clients ranged from 4 to 82 years of age. Figure 14 shows the age and gender distribution for both the EC and the EO condition.



**Figure 14.** Age and gender distribution of the qEEG-Pro normative database.

## 12.2 qEEG-Pro EEG preprocessing

The raw EEG data was de-artifacted using S.A.R.A (see Chapter 1 and Appendix 1). An average of 17% and 24% of the raw EEG data was rejected in EC and EO conditions, respectively (see figure 15). 121 and 133 clients had one or more noisy channels (average number of noisy channels, EC: 1.3, EO: 1.3) removed in the EC and EO condition, respectively. The data from these channels were not included in the calculation of the group means and standard deviations.



**Figure 15.** Distribution of the percentage of rejected EEG data using S.A.R.A.

### 12.3 qEEG-Pro EEG data analysis

All metrics that are described in detail above were applied to the qEEG-Pro database. A total of 150 subgroups (ages 1-75,5 years, 6 months resolution) were created by selecting 200 subjects that had a minimum age difference with the age bin of interest. A regression analysis was performed for all (log-transformed) metrics, using the log-transformed data from the 47 psychopathologies categories in the questionnaire. The residuals of the regression model represent the variance in the EEG data that cannot be explained by any of the 47 psychopathologies. These residuals are then used to calculate the means and standard deviations for all metrics.



## Appendix 3. Practical guide for uploading raw EEG

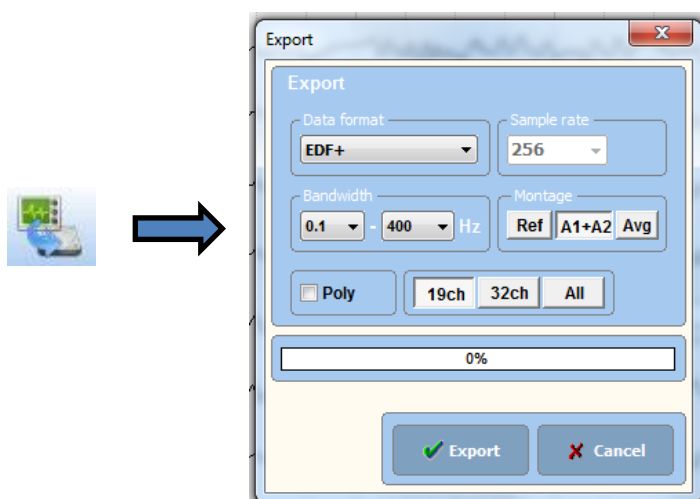
Follow the steps below to start using the qEEG-Pro report service.

1. Locate the .edf file containing your client's EEG on your computer.

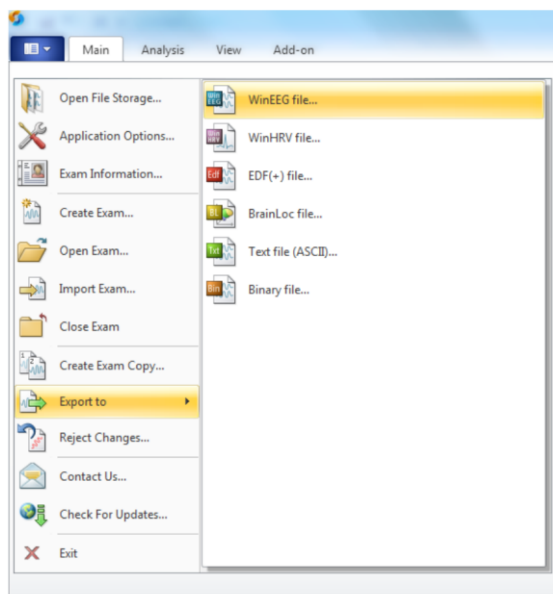
For **BrainMaster Discovery** users: The .edf file is automatically generated by the BrainMaster software.

For **Deymed TruScan** users: Generate an .edf file in **TruScan Explorer** by clicking on the 'export file' button.

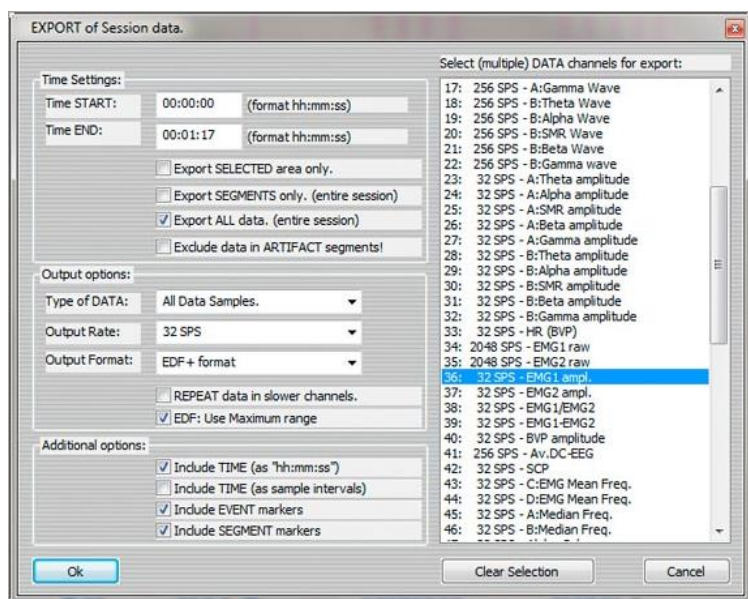
An options dialog will pop up. Select EDF+ and use the same settings as depicted in the image below.



For **Mitsar** users: Go to the main drop-down menu in **EEGStudio** and select 'Export to' -> 'EDF (+) file' (see below).



For **MindMedia Nexus** users: Go to 'File' -> 'Export Session Data' in **Polyman Viewer** with the 'Output Format' set to 'EDF+ format'.




2. After you have logged into the user environment, click on the 'Clients' tab and fill out the form.

3. Click on the 'EEG' tab and then on 'Add EEG'.


4. Select the appropriate client, fill out the form and upload the raw EEG.

The age of the client can easily be selected by using the calendar tool. Left click on the upper panel in the calendar tool to switch from 'days' to 'months' and 'years' (see below).

 **Clients**

**Client Code** Do not use client name! \*


**Client Birthdate** \*





**Client Gender** \*

**Client Handedness** \*

**Client Email**







5. After the upload is complete, you can safely log out of the system by clicking on the 'Logout' tab. The estimated processing time for QEEG-Pro reports is 30 minutes, after which the SARA reports and QEEG-Pro reports can be downloaded to your computer.

### Client sensitive information and Data security

- The qEEG-Pro report service assures that no client sensitive information that may accompany your uploaded EEG files will be accessible to third parties.
  
- The raw and processed EEG files and the QEEG reports will be stored on the qEEG-Pro report service servers but the qEEG-Pro report service cannot be held responsible for situations in which the raw data or the reports are no longer accessible for the user. The user is recommended to back up their EEG files and qEEG reports on a (hard)disk or backup server/webservice.

## References

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