# QEEG AS A BASE FOR NEUROFEEDBACK TREATMENT: IS IT RELIABLE ENOUGH?

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**Abstract**

In the last two decades, qEEG has turned from a purely research tool into an important, basic part of the work of many neurofeedback clinicians. The analysis of EEG samples requires extensive knowledge and experience, which up until a decade ago were the province of a few experts in the neurofeedback community. Unlike the deep knowledge that is required in order to analyze raw EEG, performing an FFT analysis and creating qEEG maps and graphs is computerized and relatively straight forward. This article presents examples that explain the importance of surveying the raw EEG before starting the qEEG analysis, and combining raw EGG analysis with a close reading of the qEEG report in order to perform a reliable analysisof the information and to make proper decisions regarding the treatment protocol. In this article, we will use a few different softwares and technologies, and try to illustrate the common factors and common ideas that underlie each of these technologies.



*Keywords:* qEEG; neurofeedback; EEG biofeedback; EEG; EEG artifacts; automated qEEG reports

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## 1. Introduction

EEG was invented in 1924 by Hans Berger, however it was only inspected visually when computers became available to scientists in the late 1960's. The new developments in technology made it possible to apply spectral analysis (Fast Fourier Transform; FFT) on the recorded EEG data in order to define the frequency content of the signal.

This has eventually led to the appearance of graphs and brain maps, as we know them today. As that change was taking place, scientists and therapists began to collect normative data on the EEG and began to analyze the EEG quantitatively by comparing test results to a control group or normative database.

This quantitative EEG (or qEEG) has since been scientifically researched in more recent years to try and determine whether certain characteristic of the EEG be used as biomarkers of neuropsychiatric conditions. Since the 1990's, the neurofeedback community accepted the use of 19 channel qEEG as a comprehensive, scientific, objective assessment tool for deciding on a treatment protocol and as an objective way of looking at the outcomes of treatment (by making pre- and post-training comparisons).

There have been more publications of peer-reviewed research-studies that showed the effectiveness of qEEG guided neurofeedback versus training based on quantitative evaluations of the EEG at only a limited number of electrode sites (miniQ's) or on protocols derived from symptoms, solely from clinical experience (Bounias et al., 2001; Hammond, 2003; Hoffman et al., 1996; Thornton 2000, 2002).

In 2004, a position paper on the standards of use of qEEG in neurofeedback was published by a group of leading therapists in the field (Hammond et al., 2004). This position paper was accepted by the ISNR board as an official position paper of the ISNR.

The following is a quote from that position paper:

"The committee reached the following conclusions:

1. Although clinical research indicates that a full 19 channel QEEG does not appear necessary for conducting successful neurofeedback training, an increasing number of clinicians are using comprehensive QEEG evaluations to guide their neurofeedback training.
2. An impressive body of peer reviewed scientific literature attests to the utility of the QEEG in providing a scientifically objective and clinically practical assessment of a wide range of psychiatric, psychological and medical conditions.
3. Many of the significant contributions to the field of QEEG have come from psychologists, and the Board of Professional Affairs of the American Psychological Association has concluded that QEEG is within the scope of practice of psychologists trained in this specialty.
4. Unlike neurology and psychiatry, where QEEG is principally used for purposes of diagnosing medical pathology, neurotherapists who use QEEG primarily do so to guide EEG biofeedback training.
5. It is not necessary for a physician to screen raw EEG data as part of a QEEG evaluation for neurofeedback training."

The attitude which the committee displays in this position paper, according to which there is no need to specialize in inspecting the raw EEG in order to reach a decision about a neurofeedback treatment protocol, made the necessary expertise needed to read the EEG redundant, and provided an opening for a wide use of automatic qEEG report generators, which have become accessible and available to all neurofeedback clinicians.

## 2. Purpose and aim:

This paper will review examples of raw EEG and compare them with the qEEG graphs and maps to show the importance of screening and understanding the raw EEG as a part of qEEG evaluation for neurofeedback training.

This paper will discuss the following topics:

- The ease of automatic reports: fast, but are the outcomes reliable?
- Artefacts and automatic artefact detectors
- The importance of looking at the morphology of brainwaves
- Epileptic discharges and qEEG

**The ease of automatic reports: Fast, but are the outcomes reliable?**

Z-Score maps serve many clinicians not just to decide on a treatment protocol, but also to perform a follow-up of treatment results and to show their clients the significant change in their brain function with a scientific, objective tool. The colourful maps show the differences visually even to those who do not know how to read them, and websites of many clinics present them in order to show the efficiency of neurofeedback treatment. However, these maps do not always represent reality accurately. We will present a few examples here, to demonstrate this point:

*Example 1:*

This example is taken from a neurofeedback clinic ad, showing the pre- and post-training of a 15-year-old autistic boy. The Z-Score FFT maps were produced by an automatic report generator, and show some incredible outcomes attributed to neurofeedback training.

Pre-Training Post-Training

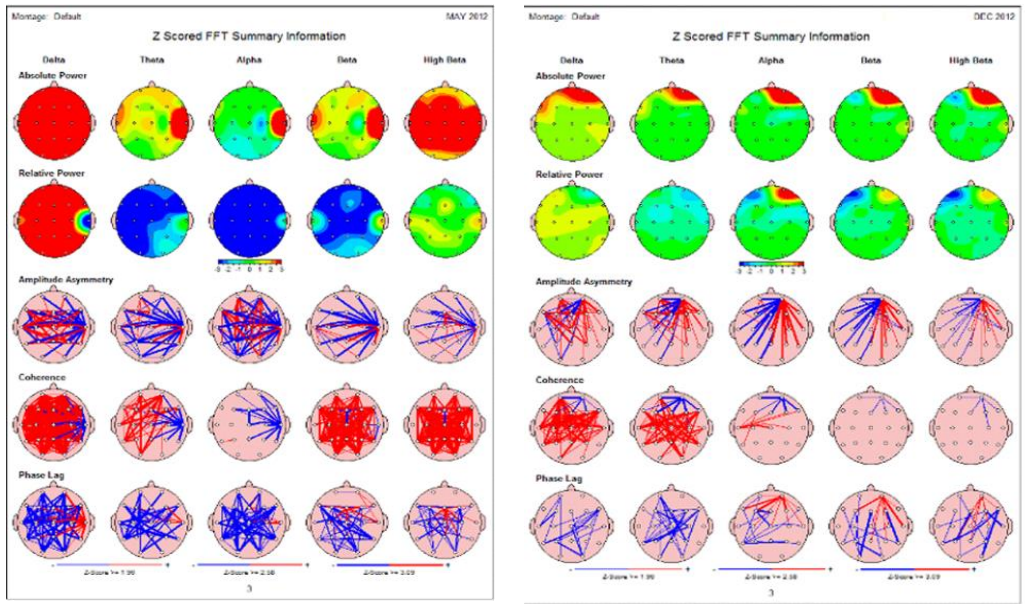


Fig. 1. A Z-Score FFT map of a 15-year-old autistic boy, (a) Pre and (b) Post neurofeedback training.

The pre-training map reveals an excess of Delta waves and an excess of high Beta waves in all cortical areas, as well as hyper-coherence of Delta, Beta and high Beta in intra- and inter-hemispheric connectivity. The post-training map reveals a frontal excess of Delta, Theta, Alpha and high Beta, but still, it is an incredible improvement from the pre-training map.

A Delta wave is a high amplitude wave with a frequency of oscillation between 0.5–4 Hz. Delta waves are usually associated with the deep stage 3 of NREM sleep. Delta-waves are also the predominant wave-form of infants. Analysis of the waking EEG of a newborn infant indicates that Delta wave activity is predominant in that age, and still appears in the waking EEG of five-year-old children.

Delta wave disruptions may present as a result of physiological damage, changes in nutrient metabolism, chemical alteration, or may also be idiopathic. Disruptions in Delta activity are seen in adults during states of intoxication or delirium and in those diagnosed with various neurological disorders such as dementia, schizophrenia or TBI.

A trained practitioner will know that although studies of qEEG in autism show generally increased Delta-Theta activity in the frontal region of the brain (Pop-Jordanova et al., 2010), the excessive Delta in all areas of the cortex, as shown in the pre- training map, cannot appear in the waking EEG of a 15-year-old boy.

Automated report generators should be used only on a clean, artifact removed, raw EEG. Automated report generators are simply not able to distinguish between artifacts and actual brain waves. The excess of Delta and high Beta activity all over the brain, as presented in the pre-training maps, are the outcomes of artifacts. The hyper-coherence of Delta, Beta and high Beta shown in the

pre-training maps are also the outcome of artifacts. As for the post-training map, the excess of Delta, Theta, Alpha, Beta and high Beta waves on the exact same area indicates that the source is an artifact.

## Artifacts and Automatic Artifact Detectors

The EEG data are typically contaminated with artifacts such as those generated by eyeblinks, eye movements, muscle activity, ECG and pulse artifacts, as well as electrode artifacts. The elimination of artifacts from the raw EEG is of substantial importance for analyzing the EEG correctly and obtaining clinical information related to pathology.

Some automated qEEG report generators use artifact removal algorithms, combining a few research methods. The most common methods are based on Independent Component Analysis (ICA) that separates EEG data into neural activity and artifacts. Most ICA methods are performed using theoretic learning algorithms, and different software tools use different variants of the learning algorithms, such as Jade and FastICA. Once identified, artifactual components can be .deleted from the data.

In the following exampels I used the WinEEG software with the HBI database. The first step was using the ICA algorithm. The ICA algorithm can be used to separate neural activity from muscle and blink artifacts in spontaneous EEG data. The basic assumption of ICA applying to EEG artifact removal is that the time courses of the EEG activity and artifacts are statistically independent. However, some real EEG activity might be correlated temporally with particular artifacts and will also be removed from the raw EEG.

The next step was applying the search and rejection artifacts option, using the default parameters of the database.

Example 2 and 3 below will demonstrate the problem that occurs when clinicians rely on the automatic artifact removal tools to distinguish between artifacts and actual brain wave activity.

*Example 2:* A 24-year-old student with symptoms of ADHD:

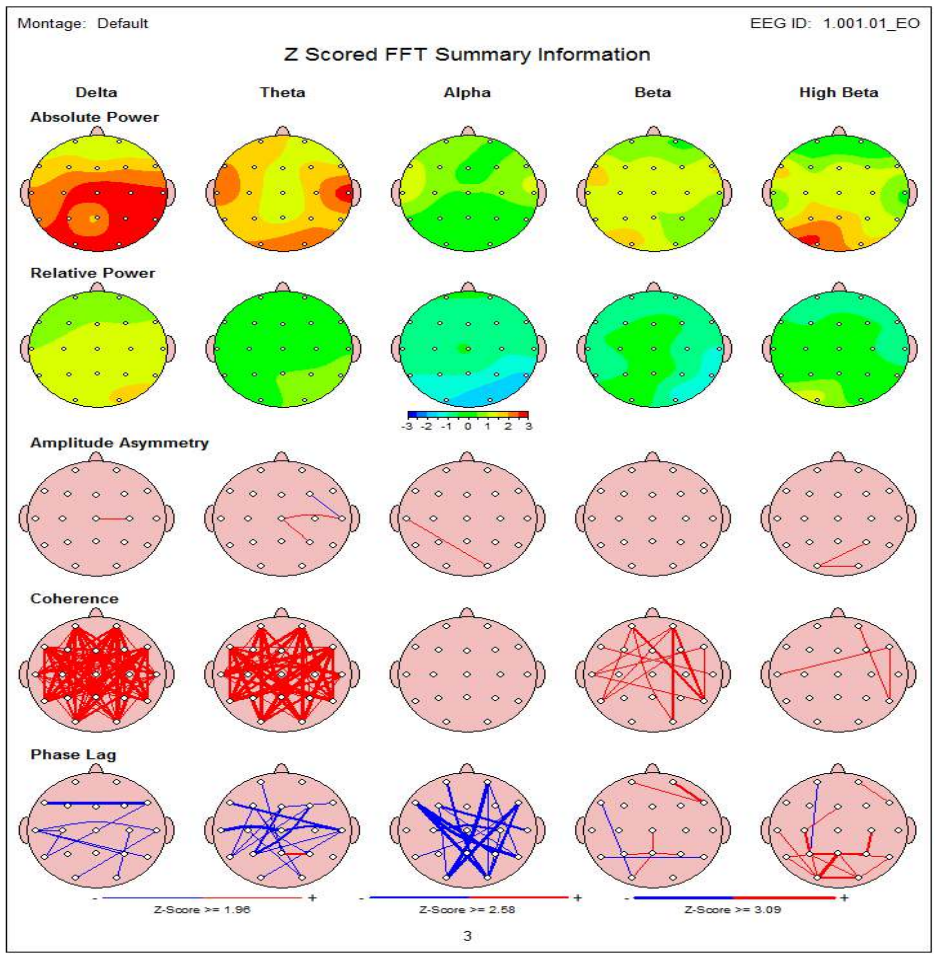


Fig. 2: A Z-Score FFT map of a 24-year-old student with symptoms of ADHD (example 2)

The map presented in Fig. 2 above reveals an excess of Delta and Theta wave activity in the central, parietal and occipital areas, and hyper-coherence of Delta and Theta in intra- and inter-hemispheric connectivity.

Looking at the raw EEG presented in Fig. 3 below, we can see that the recording contains many artifacts. I used an automatic artifact detector software to identify and mark the artifacts. The artifacts that were identified are marked in a blue underline.

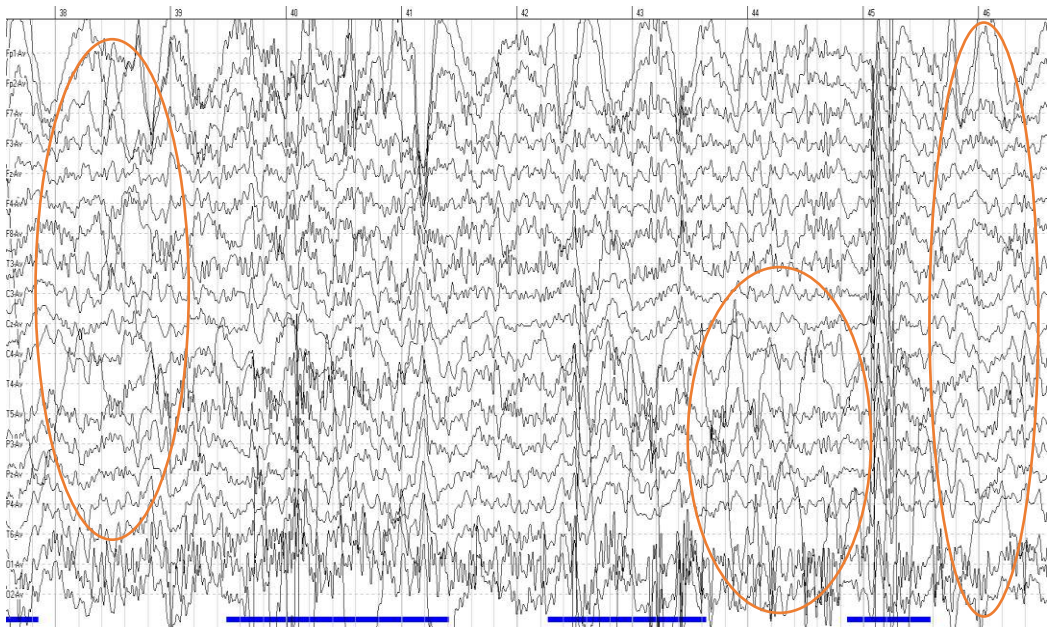

Fig. 3: The raw EEG of the 24-year old-student (example 2). The artifacts that were detected by the software are underlined in blue. The electrode artifact (circled) was not detected by the software.

Only a part of the artifacts were recognized by the software. The artifacts that were not recognized by the software are marked with red circles. These artifacts will be mistaken as an abnormally slow Delta and Theta brain waves and will be visible in the topographic maps as such.

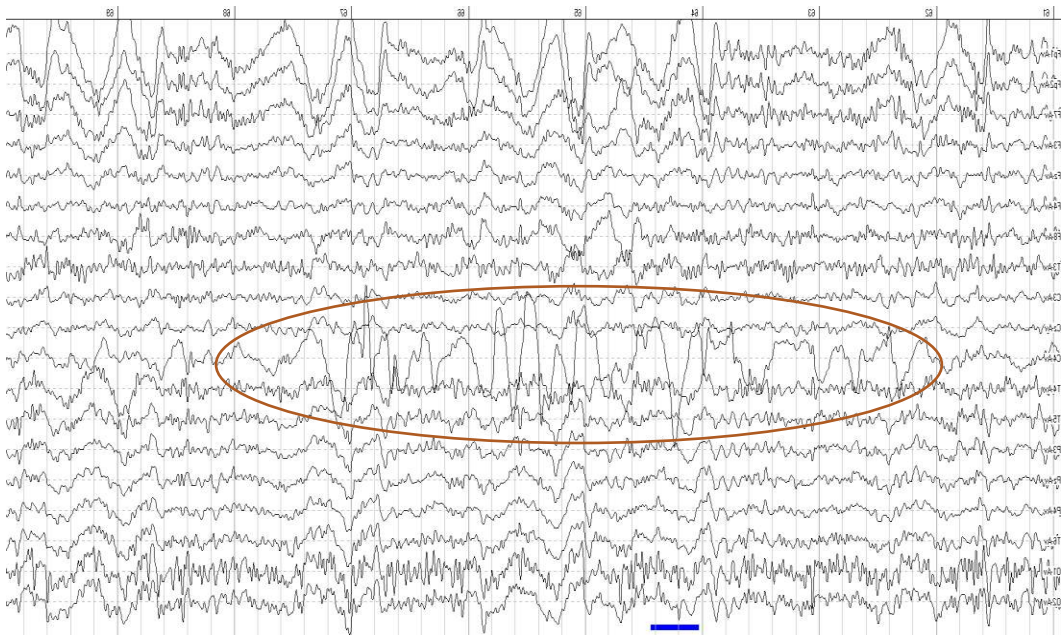

Fig. 4: The raw EEG of a 24-year-old student (example 2). The electrode artifact (circled), was not detected by the software.

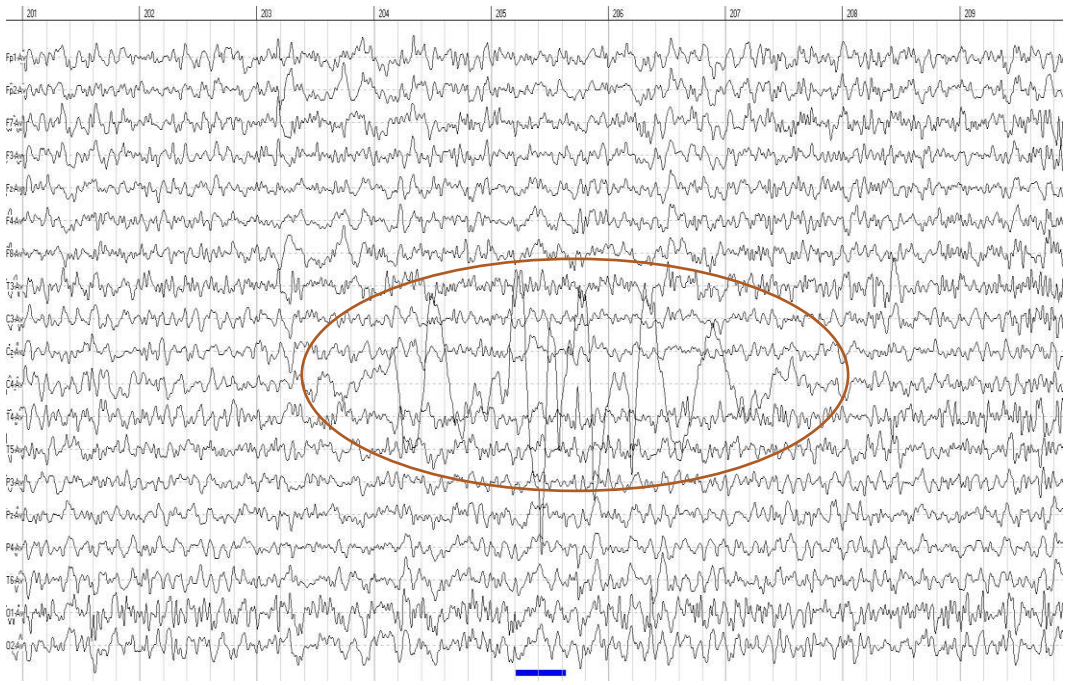


Fig. 5: The raw EEG of a 24-year-old student (example 2). The electrode artifact (circled), was not detected by the software.

Fig. 4 and Fig. 5 above present more shots from the same raw EEG. Again the automatic artifact detector software identified just a small part of the electrode artifact in C4. The artifacts that were identified are marked in blue.

*Example 3:* An 11-year-old with symptoms of ADHD:

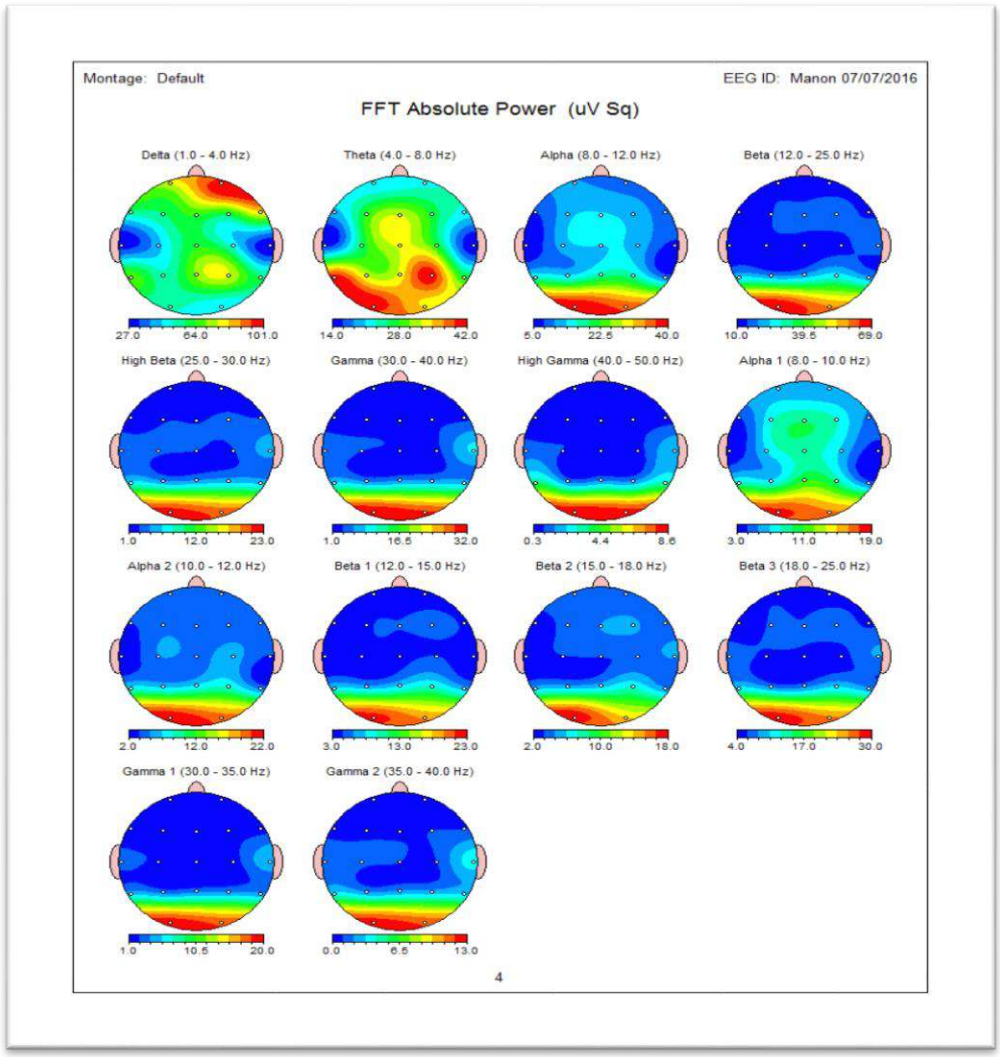


Fig. 6: Spectral analysis (Fast Fourier Transform) of an 11-year-old with symptoms of ADHD (example 3). The map shows Delta activity and a focal slow activity in the Theta range in the parietal-tempotal right side (P4/T6).

The spectral map in Fig. 6 above shows a focal slow activity in P4/T6.

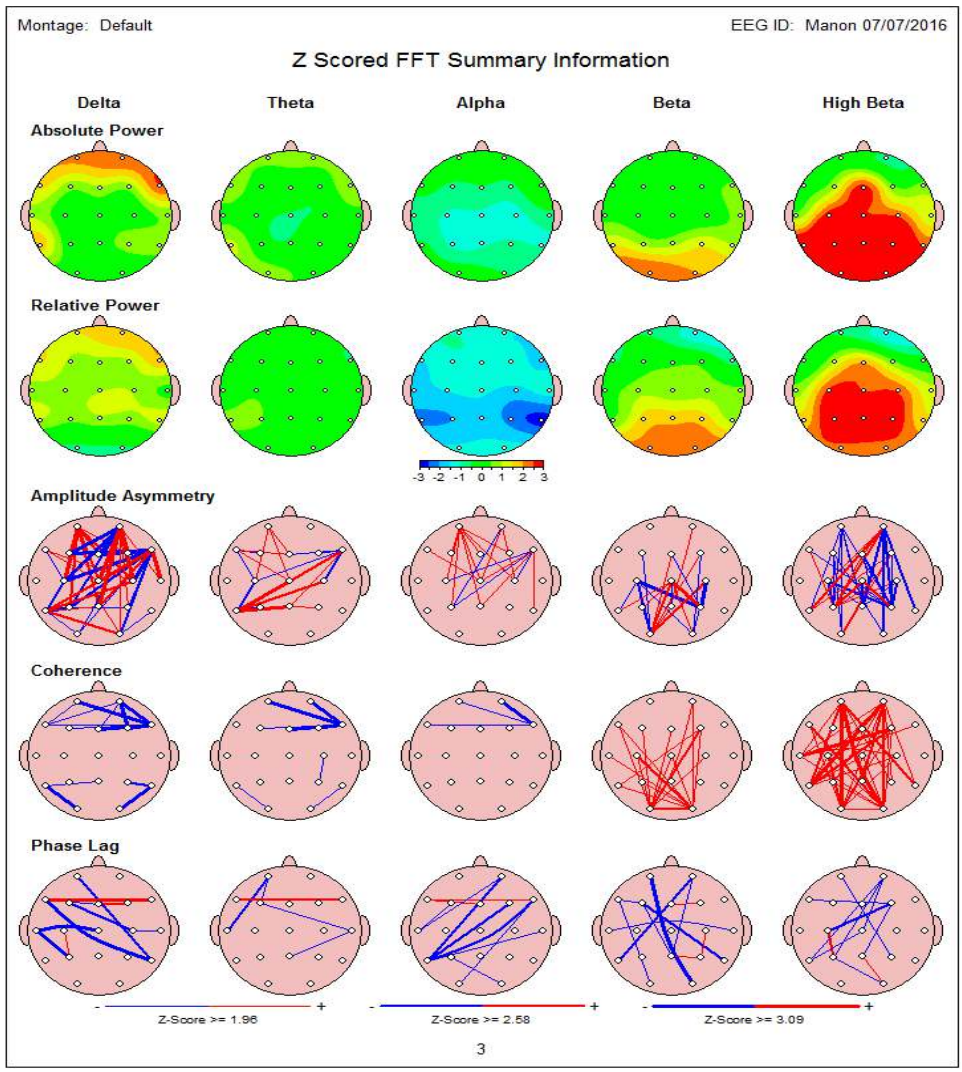


Fig. 7: A Z-Score FFT map of a 15-year-old with symptoms of ADHD (example 3). The maps show an excess of frontal Delta and an excess of Beta activity in the occipital head region in addition to excesses of high Beta in the central, parietal and occipital brain regions. There is hipercoherene in the Beta and high Beta range.

The map in Fig. 7 above reveals an excess of frontal Delta and an excess of Beta activity in the occipital head region in addition to excesses of high Beta in the central, parietal and occipital brain regions. Please note that the focal slow activity in P4/T6 that was shown in the spectral map in Fig. 6 left no trace in the Z-Score map shown in Fig. 7.

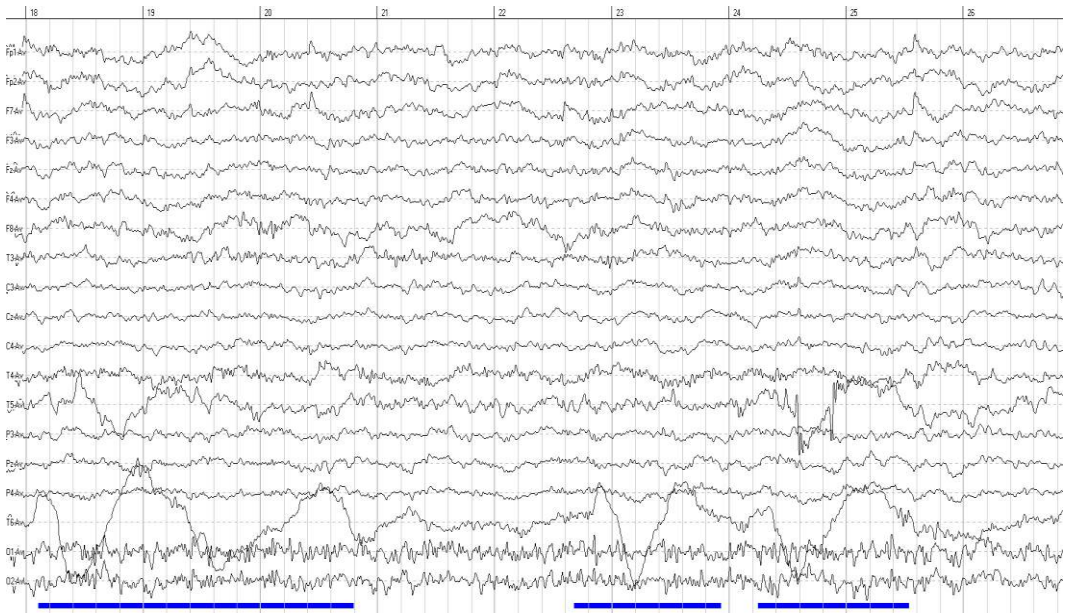

Fig. 8: The raw EEG of a 15-year-old (example 3). The artifacts that were detected by the software are underlined in blue. The electrode artifacs on T5, T6 were detected by the software. .

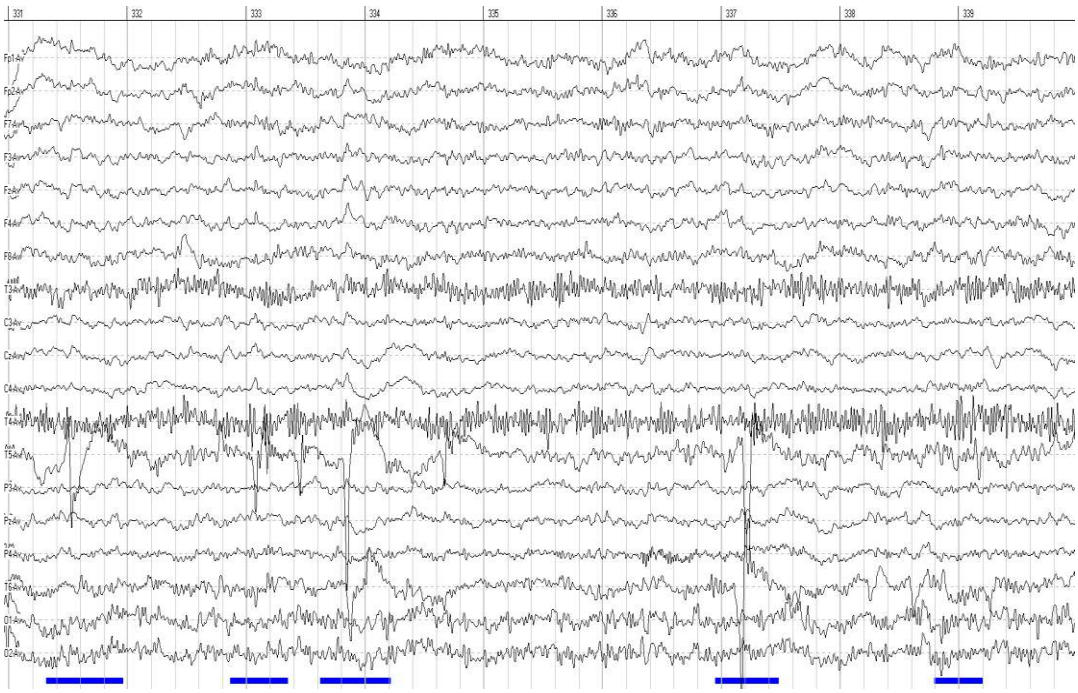

Fig. 9: The raw EEG of a 15-year-old (example 3). The artifacts that were wrongly detected by the software (underlined in blue) are epileptiform discharges.

Fig. 8 and Fig. 9 above show the raw EEG of the 15-year-old patient. We used an automatic artifact detector software to identify and mark the artifacts. The artifacts that were identified are marked in blue underline. Fig. 8 shows an electrode artifact in T6 that was identified by the artifact detector. In Fig. 9 we can see that the artifact detector marked the spike-and-wave discharges shown in T5 and T6 as artifacts. These spike-and-wave discharges are the source of the focal slow activity on T6,that was shown in the FFT map in Fig. 6. The Spectral Analysis in Fig. 7 is compared with norms. Since the spikes were excluded as artifacts in the raw EEG and in the Z-Score compared with norms, we cannot see the abnormal activity in this map.

*Example 4:* The raw EEG of a 21-year-old epileptic patient with generalized seizures.

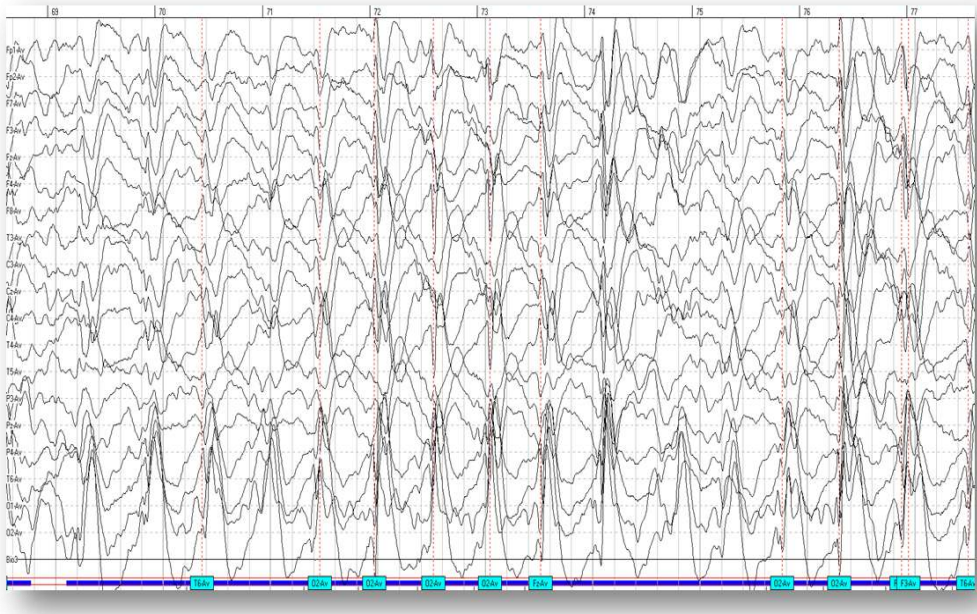

Fig. 10: The raw EEG of an epileptic patient (example 4). The EEG backround high amplitude activity was wrongly recognized as artifacts.

Patients who have a generalized seizure disorder frequently have higher amplitude background rhythms, as demonstrated in Fig. 10.above. The automatic artifact detector recognized the high amplitude activity as an artifact and marked it with a blue underline. The marked parts will not be included in the qEEG that will be calculated from this raw EEG, and the critical pathological information will be lost.

As demonstrated in examples 3 and 4, the ability to distinguish artifact from pathological epileptiform discharges requires an EEG professional expert that is to provide the essential identification of an abnormal EEG.

## The importance of looking at the morphology of brainwaves

Raw EEG provides us with information of amplitude versus time. When we mathematically convert the raw information to qEEG, we lose relevant information about changes over time and the morphology of the brainwaves. The qEEG maps divide the brainwave bands according to predefined band widths, but the frequency of any of the brainwave bands varies from person to person. In order to correctly recognize pathological states, we must know the type of the brainwave, its frequency, its morphology, and its location on the scalp. *Example 5:*

Fig. 11 and Fig. 12 below (courtesy of Dr. Ron Swatzyna) show the qEEG maps and graphs of a 55-year-old woman who suffers from a significant reduction in her language skills: she forgets words, is unable to express herself coherently (confused discourse), and has difficulty understanding things that are being said to her.

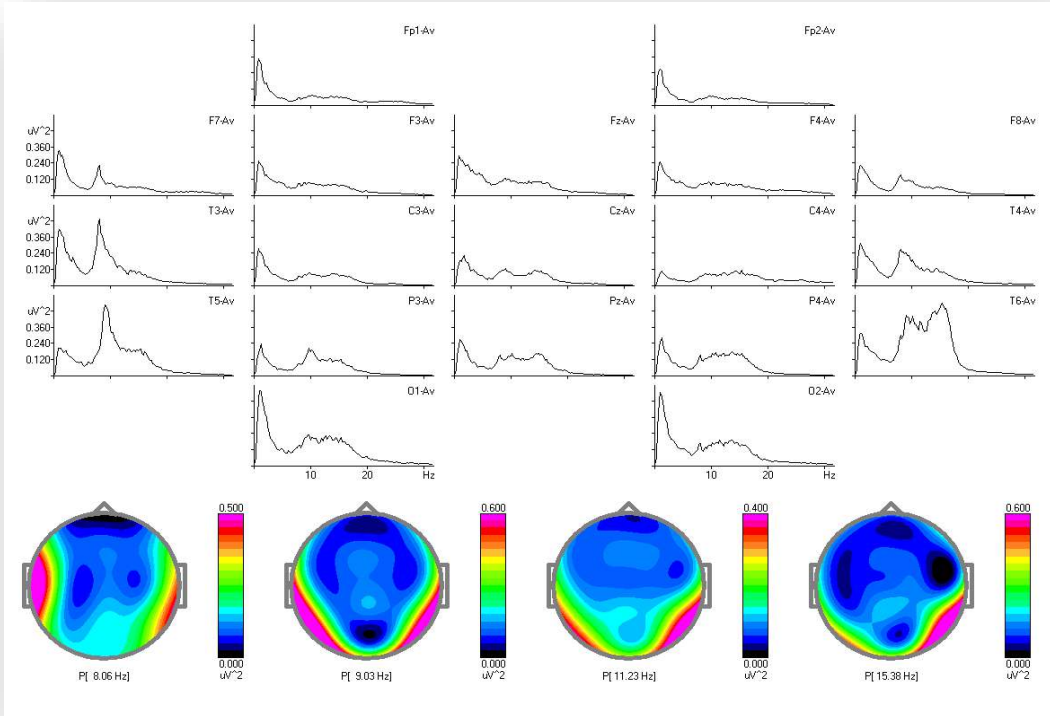


Fig. 11: Spectral Analysis (Fast Fourier Transform; example 5, courtesy of Dr. Ron Swatzyna)

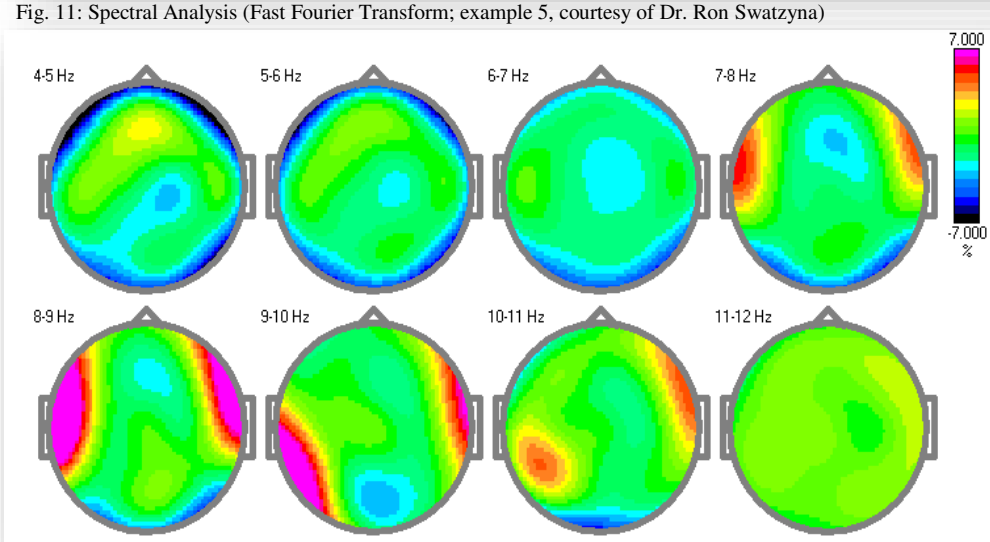


Fig. 12: Z-Score FFT map (spectral analysis compared with norms; example 5, courtesy of Dr. Ron Swatzyna)

The maps in Fig. 11 and Fig. 12 above reveal a slow activity 7-9 Hz on the left temporal lobe.

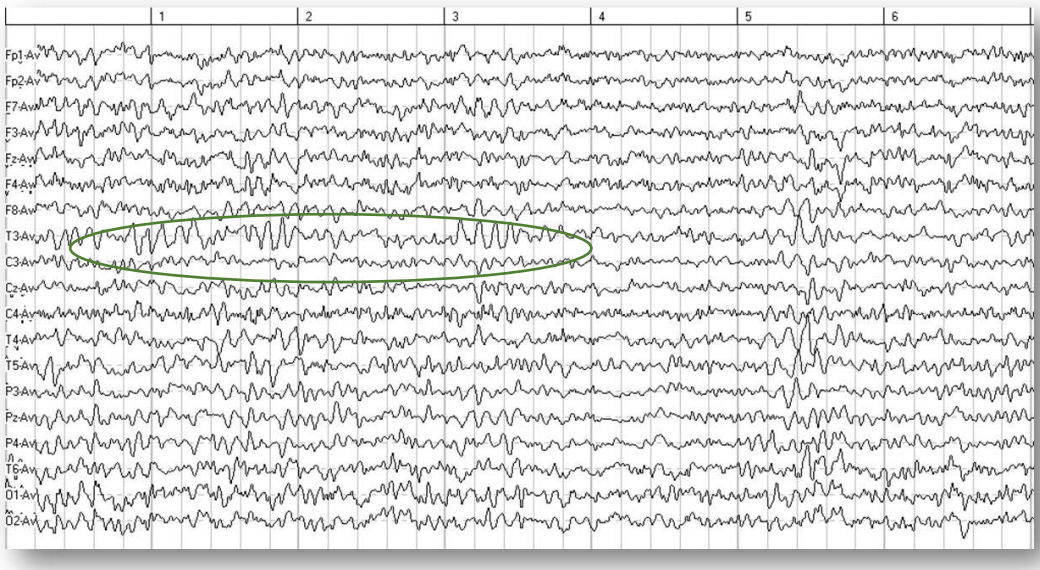


Fig. 13: Raw EEG for example 5 (courtesy of Dr. Ron Swatzyna)

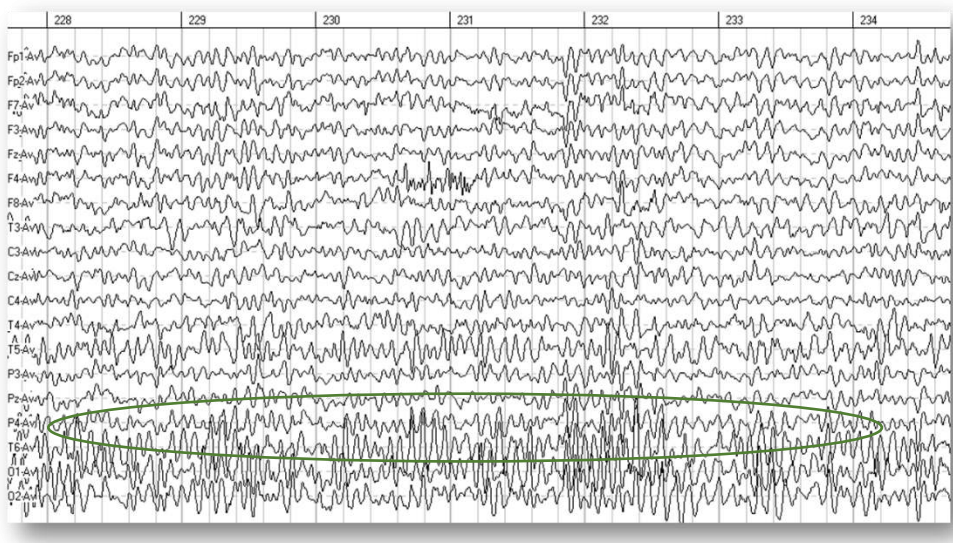


Fig. 14: Raw EEG for example 5 (courtesy of Dr. Ron Swatzyna)

Looking at the raw EEG of this woman in Fig. 13 and Fig. 14, we can see the background Alpha is at 9-11 Hz posteriorly, with excessive slower Alpha content at 7-9 Hz seen left-temporally. The slower Alpha on the left suggests low activity of this cortical area, such as seen in cases of brain trauma, tumor and cerebral vascular issues. In this case MRA identified a 7mm aneurysm on her left internal carotid artery. This example demonstrates the importance of identifying the brainwave type by looking at its morphology.

**Epileptic discharges and QEEG**

Neurofeedback, from its inception, has dealt with epilepsy, and there are numerous articles that testify to the efficacy of this treatment (Sterman and Egner, 2006; Cott et al., 1979; Kaplan, 1975; Finley et al., 1975; Lantz and Sterman, 1988; Tan et al., 2009; Sela and Shaked-Toledano, 2014). The question is whether in cases of epilepsy, we should trust the qEEG alone to lead us to the right protocol decision. In some cases, the qEEG may give us information that is insufficient (and sometimes even confusing) in order to make a proper treatment protocol decision. Nevertheless, it may help us follow-up on the treatment results.

The examples below will show spectral graphs and maps of Z-Score spectra. The graphs show the difference from normality for each channel. The horizontal (X) axis presents the frequency, the vertical (Y) axis shows the amplitude, and the small vertical bars show the confidence level of deviation from normality (starting from p=0.05).

In the maps of the Z-Score spectra, the frequencies are defined by the peak of the EEG spectra. Please note that the graphs and maps give us a different point of view.

*Example 6:* Rolandic epilepsy is a benign epilepsy with central temporal spikes and is a localized form of epilepsy. The Raw EEG in Fig. 15 below reveals spike-and-wave discharges located at T6 and T4.

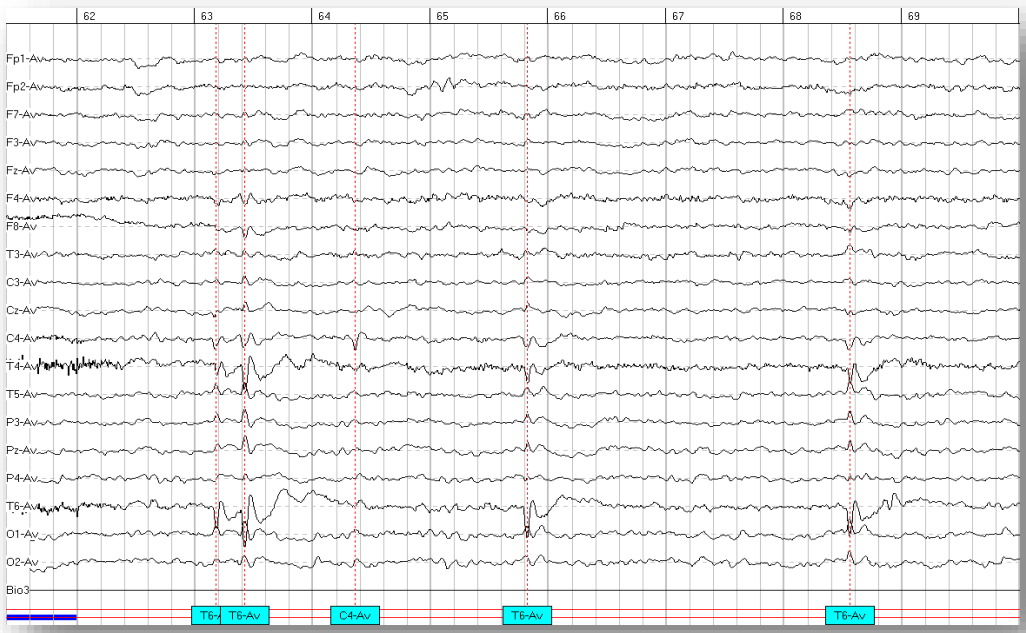


Fig. 15: Raw EEG characteristic of Rolandic epilepsy (example 6

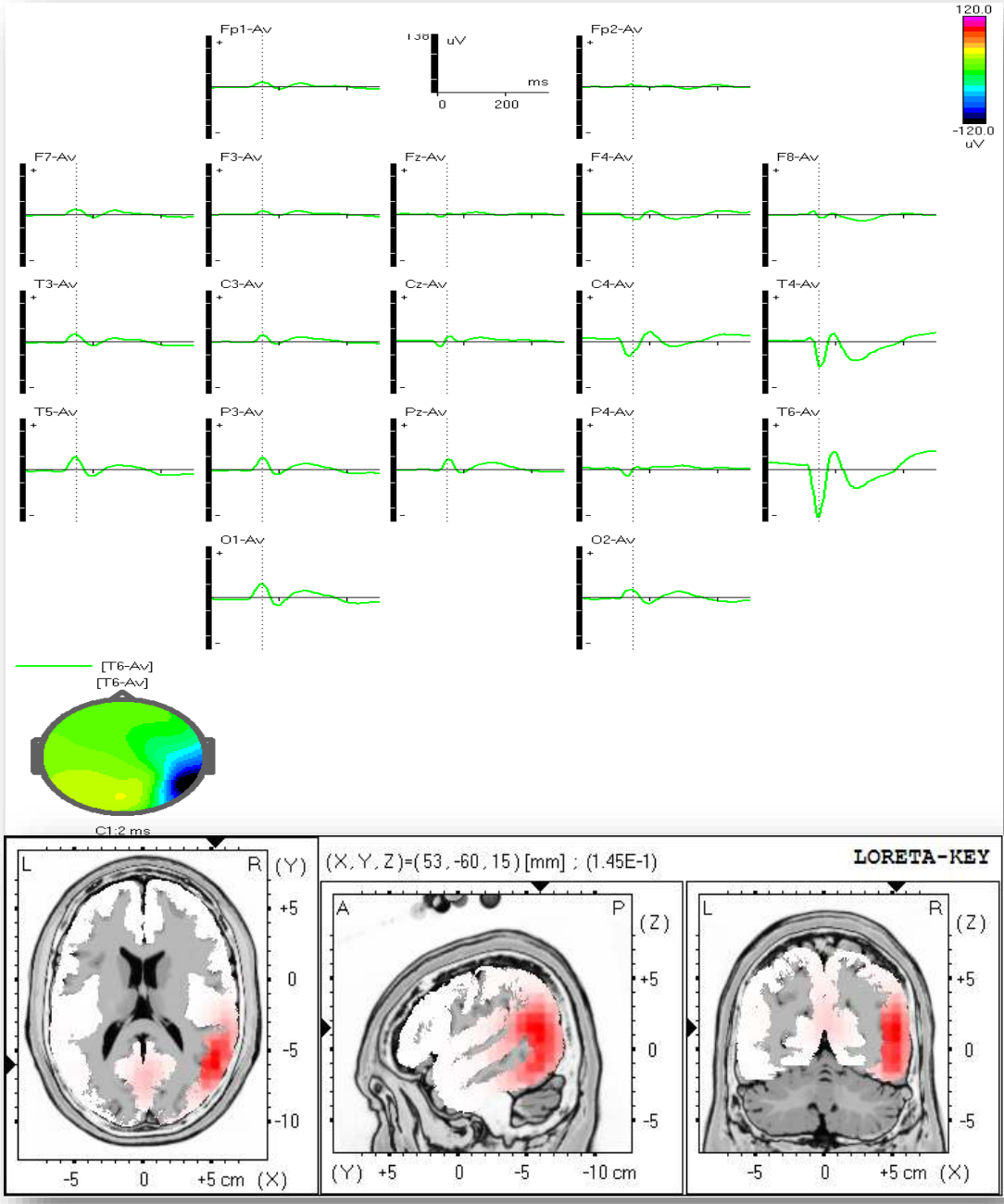


Fig. 16: Spike averaging (a) and source distribution (b) - example 6

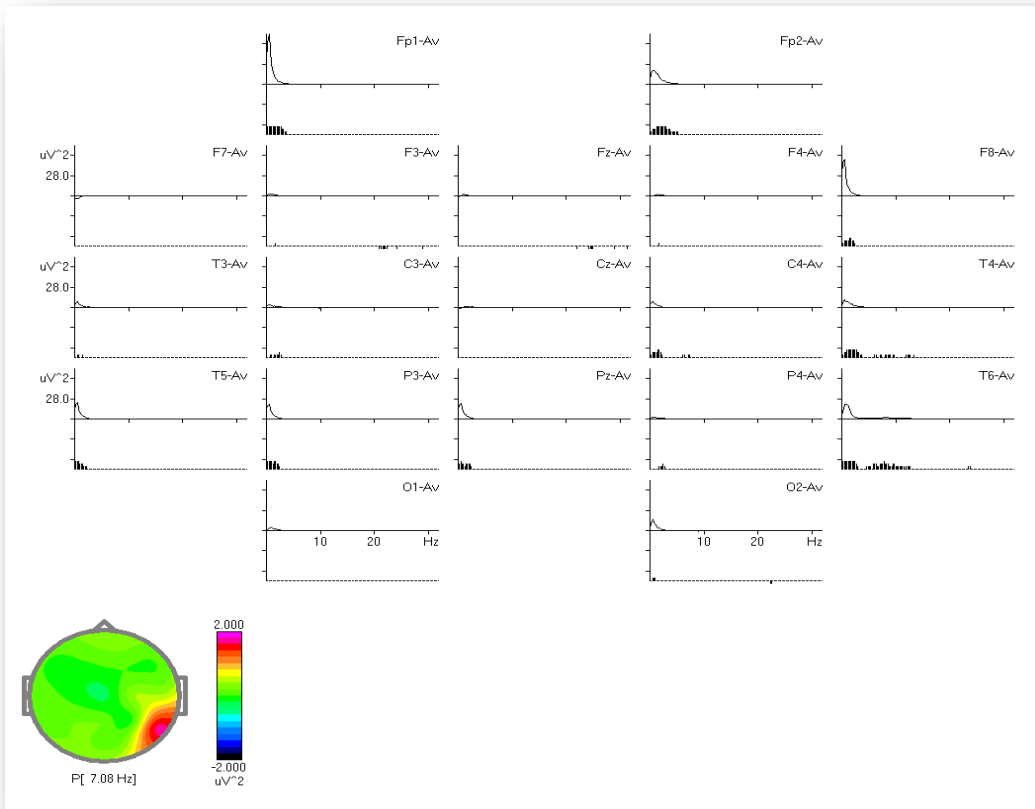


Fig. 17: Z-Score spectra (example 6)

The spectra compared with norms (Fig. 17) reveals increased activity in all frequency bands at the site of the focus (T4/T6). The information that the qEEG gives us in this case can be helpful at least for deciding on the electrode placements for the treatment protocol.

*Example 7:*

Epileptic patient who suffers from generalized epilepsy.

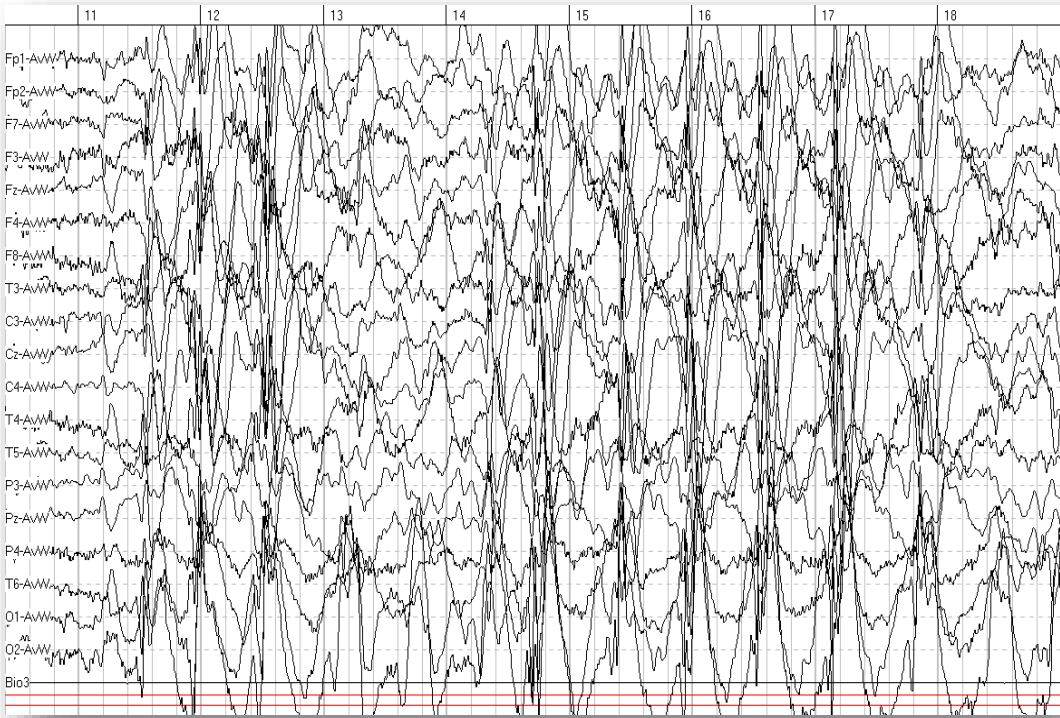


Fig. 18: Raw EEG of a patient who suffers from generalized seizures (example 7)

The Raw EEG in Fig. 18 above reveals epileptic discharges with higher amplitude background rhythms.

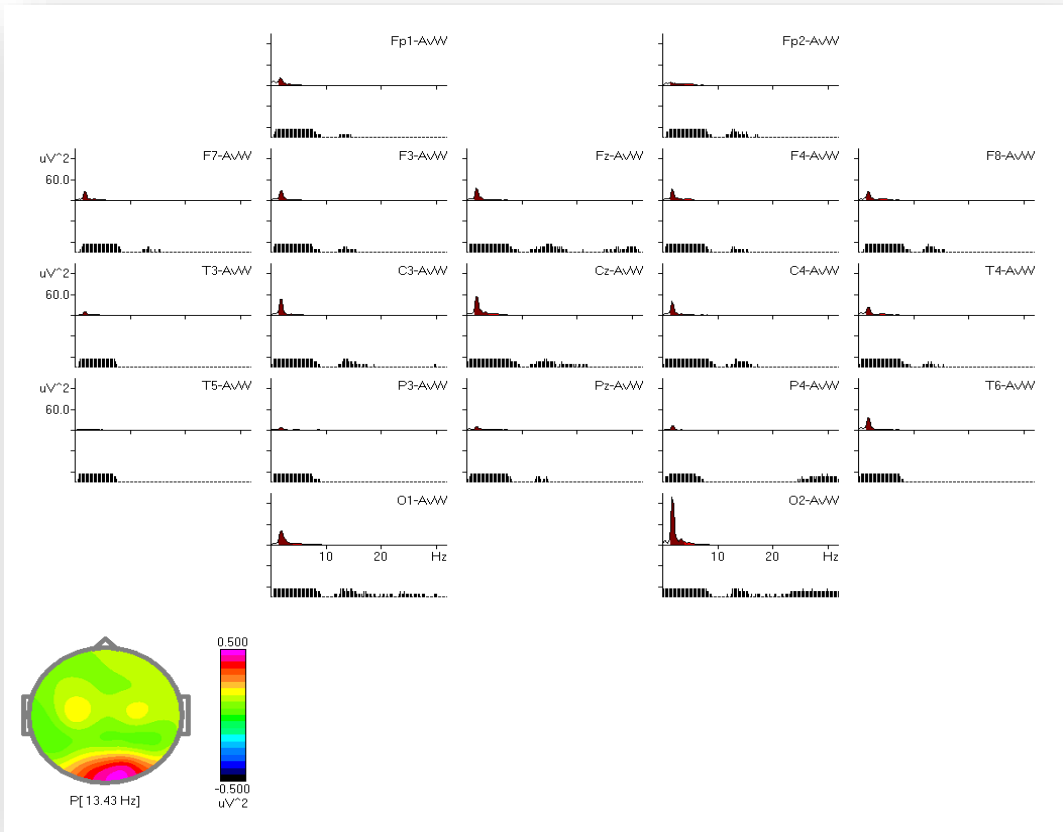


Fig. 19: Z-Score spectra (example 7)

In Fig. 19 above, which shows the FFT compared with norms, we can see that the higher amplitude background rhythms obscure additional focal changes. In this case the information that the qEEG gives us is insufficient and confusing and does not assist in guiding us in the protocol decision.

*Example 8:*

Epileptic patient who suffers from generalized epilepsy.

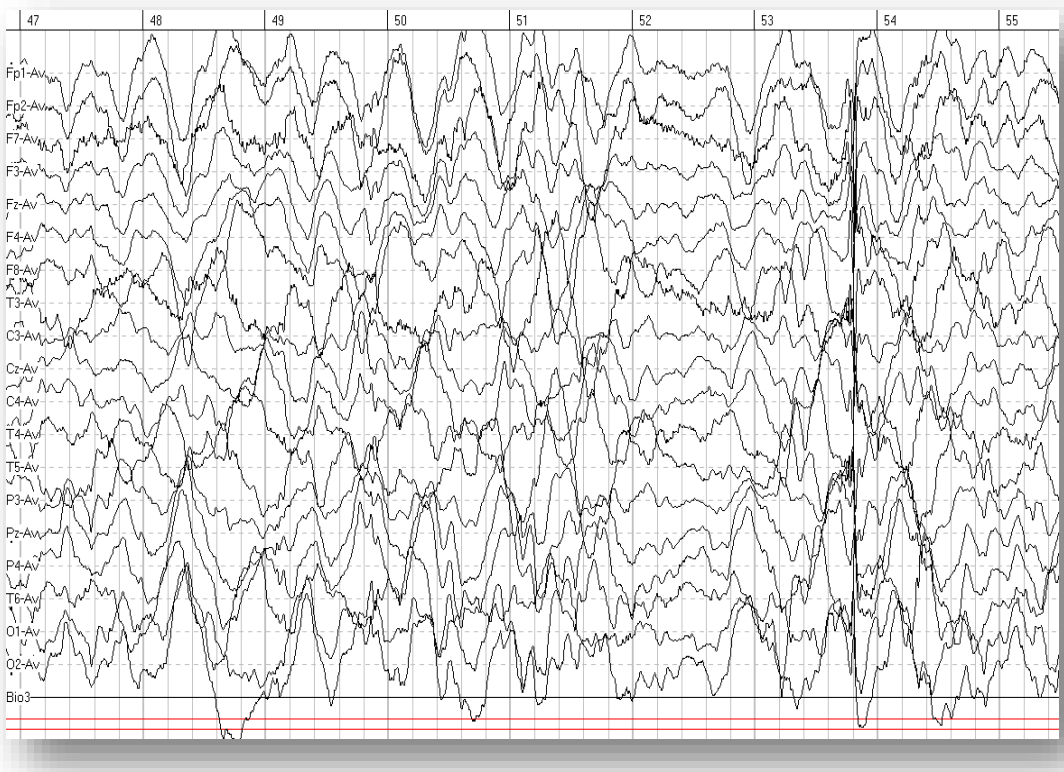


Fig. 20: EEG of an epileptic patient (example 8)

Looking at the raw EEG in Fig. 20 above, we see abnormal slow activity on the right side of the brain followed by a spike-and-wave pattern on the left side.

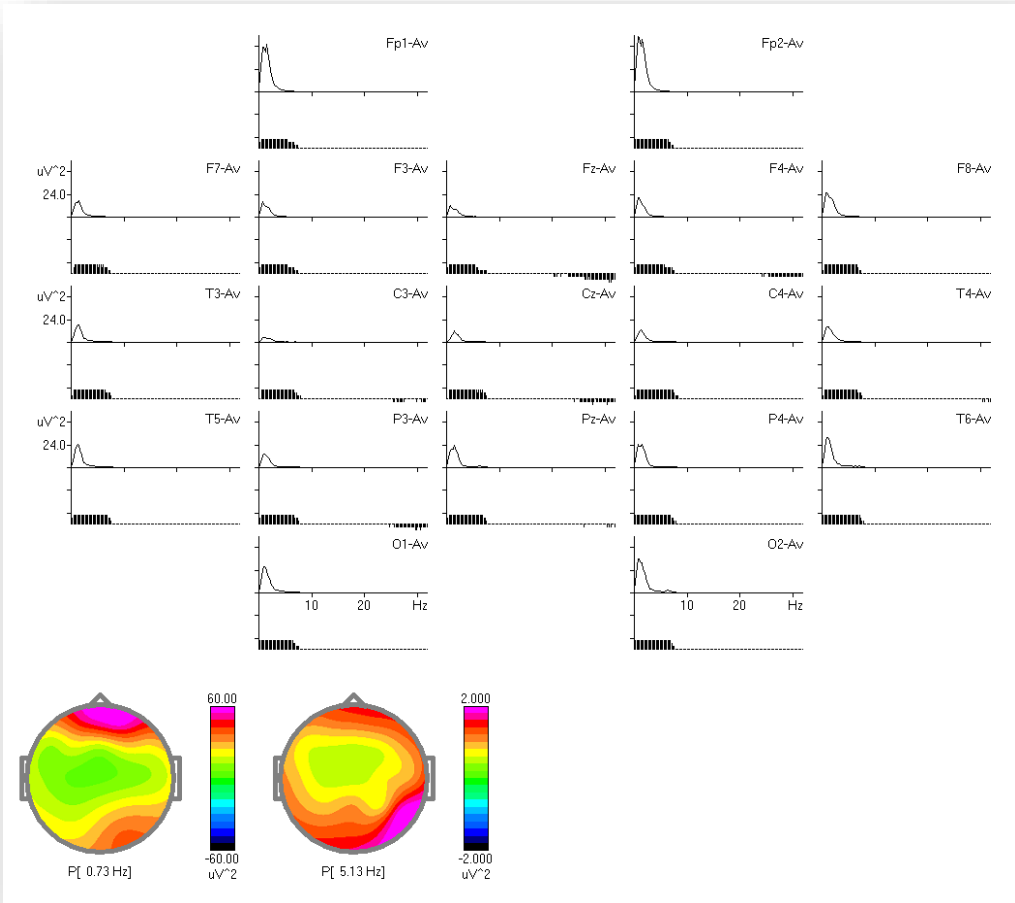


Fig. 21: Z-Score FFT of the epileptic patient (example 8)

In Fig. 21 above, which shows the FFT compared with norms, we can see the slow wave activity in all recording sites. In this case the information that the qEEG gives us does not help in guiding us in the protocol decision.

*Example 9:*

In Fig. 22 below we see the raw EEG of another epileptic patient, and in it we see a spike-and-wave pattern that occur relatively rarely (only 2 events over a 20 minute recording).

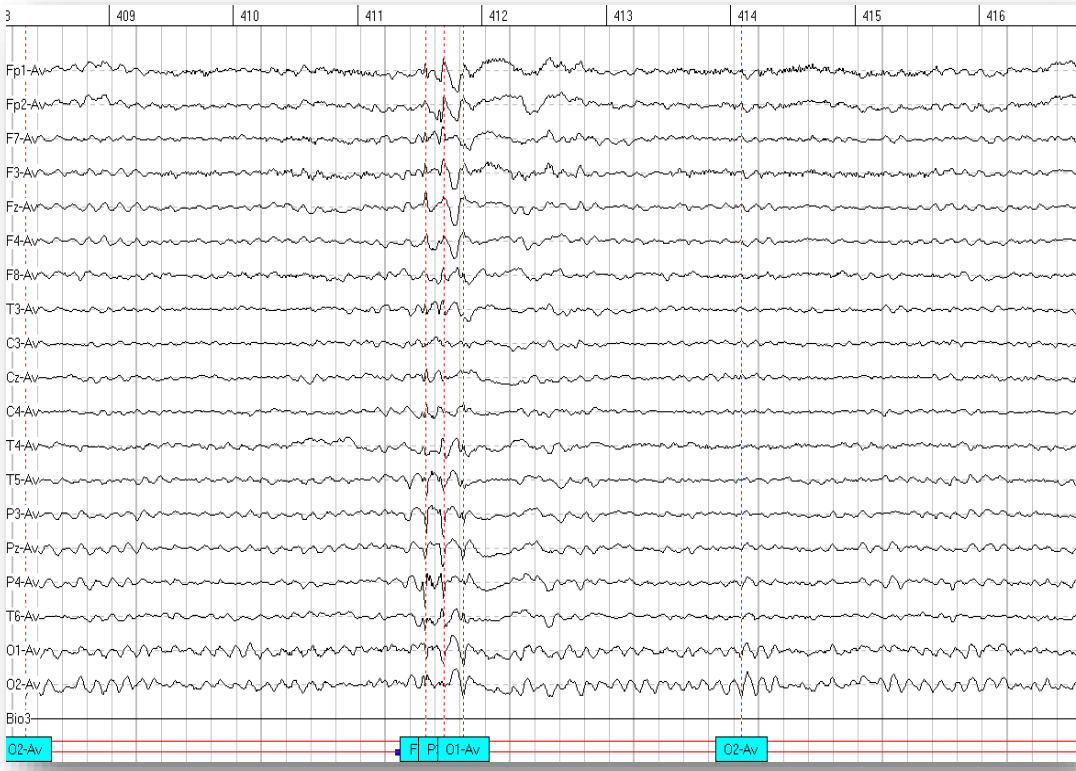


Fig. 22: EEG of an epileptic patient (example 9)

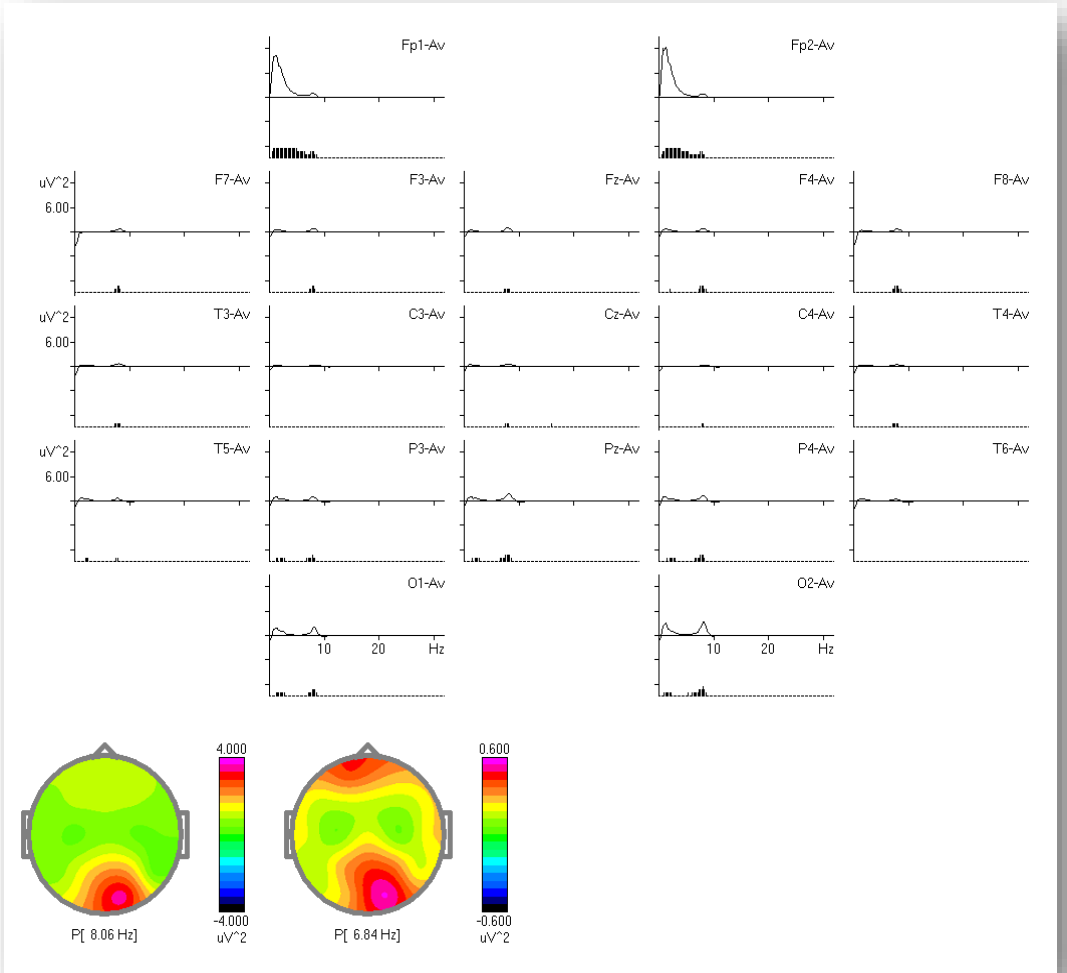


Fig. 23: Z-Score FFT of epileptic patient (example 9)

The Z-Score FFT in Fig. 23 (above) reveals slow activity in all electrode placements. In this case, when the discharges occur relatively rarely, the focus of the discharge is not indicated by the qEEG, and therefore the qEEG is not particularly helpful in deciding on the electrode-placements for the treatment protocol.

## 3. Discussion:

Brainwaves are generally classified according to their frequency, amplitude, and morphology. The FFT divides the raw EEG into brainwave bands according to frequency**,** and even thaen only by fixed frequencies that were pre-defined in the software (Delta, Theta, Alpha, Beta, High Beta,

and Gamma). Other waveforms can be identified only by visual inspection of the raw EEG by shape, some by shape and location on the scalp and some by shape and state at recording: These include K complexes, Vertex (V) waves, lambda waves, and positive occipital sharp transients of sleep (POSTS), spindles, mu rhythm, spikes, and sharp waves. These waveforms that can only be seen in the raw EEG are crucial for the diagnosis of abnormalities.

There are many different types of artifacts: eye blinks, eye movements, muscle activity, ECG and pulse, as well as electrode artifacts. Artifacts can only be identified by examining the raw EEG.

Automatic artifact detection technologies are still limited in their abilities to distinguish special wave forms from artifacts. Often, artifact rejection algorithms require a human element to review and confirm their accuracy. Analyzing data that contain artifacts may lead to a wrong treatment protocol decision.

A trained Therapist can benefit from using advanced algorithms such **as** ICA in the process of cleaning artifacts from the raw EEG. The ICA can be used to separate neural activity from muscle and blink artifacts in spontaneous EEG data. But in using this option, one should keep in mind that:

- The basic assumption of ICA applying to EEG artifact removal is that the time courses of the EEG activity and artifacts are statistically independent. However, some real EEG activity might be correlated temporally with particular artifacts and will therefore also be removed from the raw EEG.
- The correction of the data can change the phase and that will affect the coherence analysis.

Artifacts that accompany epileptic spikes are a regular occurrence and are usually seen with the same polarity in many electrodes. Also, patients who have a generalized seizure disorder frequently have higher amplitude background rhythms, which may be wrongly detected as artifacts by the automatic artifact detection technologies.

In cases of epilepsy, the QEEG is not particularly helpful in deciding on a treatment protocol, for the following reasons:

- When the recorded EEG shows frequent spikes, the QEEG will present a picture of increased activity in all frequency bands in the location of the focus.
- In cases of abnormal slow activity, or a higher-amplitude background activity, the QEEG will present a picture of slow wave activity in all recording sites.
- If the recorded EEG shows rarely occurring epileptiform discharges, the QEEG will not present a picture of increased activity in the location of the focus.

The main point of this paper is that neurofeedback therapists that are using QEEG should have the training and knowelege in interpretation of raw EEG. Reading the raw EEG data in addition to looking at QEEG brain maps and the information obtained in the clinical intake will lead to a good decision regarding neurofeedback treatment protocols.

No software, as sophisticated as it may be, is able to recognize all artifacts and abnormalities. Our suggestion for therapists that want to benefit from the automatic reports is to first learn to scan and interpret raw EEG. For beginners who just started using QEEG, it is strongly recommended to work under the supervision of a QEEG specialist until they feel comfortable in scanning the raw EEG by themselves.

## 4. Conclusions:

QEEG analysis techniques can provide additional measurements of EEG, including: graphic displays of frequency and voltage, statistical comparisons to normative databases, evoked potentials and coherence.

The QEEG alone as a source for making treatment protocol decisions is insufficient. Consulting the QEEG requires clinicians to also perform at the same a thorough examination of the raw EEG. We, as clinicians, cannot and should not reach any conclusions based on the QEEG alone without referring to its source, the raw EEG. The raw EEG is a source of important information that can be lost in the averaging process. Studying the raw EEG must be done by a qualified expert. The automated tools, sophisticated as they may be, are still incapable of recognizing pathologies like a skilled professional.

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