Biofeedback Primer

This documentation is supplied by Durham Systems Management Limited
for use alongside the Vilistus system

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Introduction

This paper aims to briefly introduce some of the concepts and benefits of biometric monitoring and feedback, but first, let us define some terms:

Biometrics - "is the recording and analysis of signals from the body used for diagnostic, research or "Convincing"

Biofeedback - "A technique for making us conscious of involuntary bodily processes (such as heartbeats or peripheral skin temperature) perceptible to the senses (as by the use of an oscilloscope) in order to manipulate them by conscious mental control.

Neurofeedback - "Neurofeedback is a type of biofeedback that uses electroencephalography (EEG) to provide a signal that can be used by a person to receive feedback about brain activity".

The Awareness Model

The awareness model is central to how biofeedback and neurofeedback operate. The model is:

Awareness – to discern a physiological change

Control – The discerned change

Generalise – Do anywhere

The aim of biofeedback training is to make us aware of what we are doing in order to allow us to control the activity and finally, to provide sufficient structure to allow us to replicate the new behaviour anywhere.

In short, the objective of biofeedback (and neurofeedback) is to help people develop greater awareness and voluntary control over their physiological processes that are otherwise outside their awareness and/or unless less voluntary control.

The Autonomic Nervous System (ANS)

The autonomic nervous system acts as a control system functioning largely below the level of consciousness, and controls visceral functions.

The ANS affects heart rate, digestion, respiratory rate, salivation, perspiration, pupillary dilation, urination, and sexual arousal.

Whereas most of its actions are involuntary, some, such as breathing, work in tandem with the conscious mind. The ANS is located in the medulla oblongata which is then divided into the respiratory control centre (RCC) the cardiac control centre (CCC) and the vasomotor centre. These then subdivide into other areas of which, for biofeedback purposes, the most important are the *parasympathetic nervous system* (PSNS) and the *sympathetic nervous system* (SNS).

- The **Parasympathetic Nervous System** is responsible for the unconscious regulation of the internal organs

- The **Sympathetic Nervous system** is the basis of the "fight of flight" response but also, at a more basic level is active to maintain homeostasis. The SNS is what we attempt to manipulate using biofeedback and neurofeedback techniques.

Imagine that the total amount of stress possible in a system is equated to a glass of water and, for the purposes of this analogy, the water represents an increase in the level of stress – or the action of the Sympathetic Nervous System.

As we become more stressed – as more water is tipped into the glass – our level of stress, our level or arousal, increases. Once the danger – or stimulus – is over, the water is drained from the glass just like the level of adrenalin is reduced in the body.

The problem comes when the glass overfills - we reach a level of stress where we respond instinctively and emotionally rather than with thought and clarity.

What happens at this point is that we tend to respond disproportionally to the stimulus presented, however trivial it may be.

Biofeedback can help to reduce the level of arousal – the level of stress – using techniques such as monitoring Galvanic Skin Response which we will discuss in more detail later but it is also important to note that you should not attempt to adjust behaviour if the level of arousal is too high as you may not get the results you intend!

A couple of minutes of rhythmic breathing may be enough to reduce the level of stress to a point where it is appropriate to begin a neurofeedback training session.

So, What are Biofeedback and Neurofeedback?

There are many brain training modalities but, in essence, they come down to two basic types, feed-forward and feed-back.

Feed-forward products attempt to entrain the brain using specific frequencies without recourse to understanding the internal state of the subject. Thus, to entrain a client to, say 10Hz, "Audio/Visual Entrainment" (AVE) Products will flash lights and emit sounds at 10Hz and, after a period, the subjects dominant brain wave activity will (*maybe*) be near to the entrainment frequency. Within Feed-forward products there are three aspects which can be used together or separately.

- **Visual Stimulation** – Flashing (usually LED) lights held close to closed eyes
- **Audio Stimulation** – Stereo (or mono) sounds of pulsed waves at particular frequencies
- **Binaural Beats** – As popularised by the Monroe Institute, it you play two frequencies, one to the left ear and one to the right, the brain automatically subtracts the smaller frequency from the larger and creates a third "beat" frequency.

According to various research projects, the entrainment from feed forward technologies does not last long after the end of the session; they are designed to elicit a particular brain state for a given period whether for performance, relaxation or meditation. The duration of active entrainment is completely dependent on the context of the session.

Further, research shows that the effectiveness of the various feed-forward modalities is in the order listed above and the visual stimulation is by far the most effective of the three.

It has been shown through a number of studies that feed-back modalities tend to have a longer lasting effect on the brain/body, although there is some indication that "top-up's" may be needed at regular intervals to maintain performance.

Feed-back technologies fall into two categories:

- **Biofeedback**, which is concerned with monitoring external manifestations of "state" such as stress, heart rate or skin temperature
- **Neurofeedback** which is concerned specifically with affecting brain state.

It is, of course, obvious that biofeedback alters brain state (Galvanic Skin Response, for example, is an excellent way of reducing stress) but Neurofeedback (or EEG Neurofeedback to give it its full title) is the only modality to directly monitor and manipulate brain waves.

This paper concentrates on using Electroencephalography (EEG) as a method for investigating brain state and providing interventions to increase desired states and reduce those less helpful.

The Vilistus range of biometric monitoring equipment will be used for all examples.

A brief introduction to Biofeedback

Generally speaking, the standard sensors in biofeedback are: Peripheral Skin Temperature, Pulse rate (taken either from a Blood Volume Pulse sensor or an ECG), Skin Conductance / Galvanic Skin Response and Respiration. There are other more specialised sensors that are used for specific purposes and training such as those for pelvic floor exercises.

As an example, the Vilistus Skin Conductance / Galvanic Skin Response sensor is a simple way to measure the level of stress in a subject, and to provide a mechanism for reducing what is termed “the level of arousal”.

Galvanic Skin Response sensors are normally placed on the fingertips:

where changes in sweat gland activity are most pronounced. Other sites for the sensors include the palms of the hand and the soles of the feet.

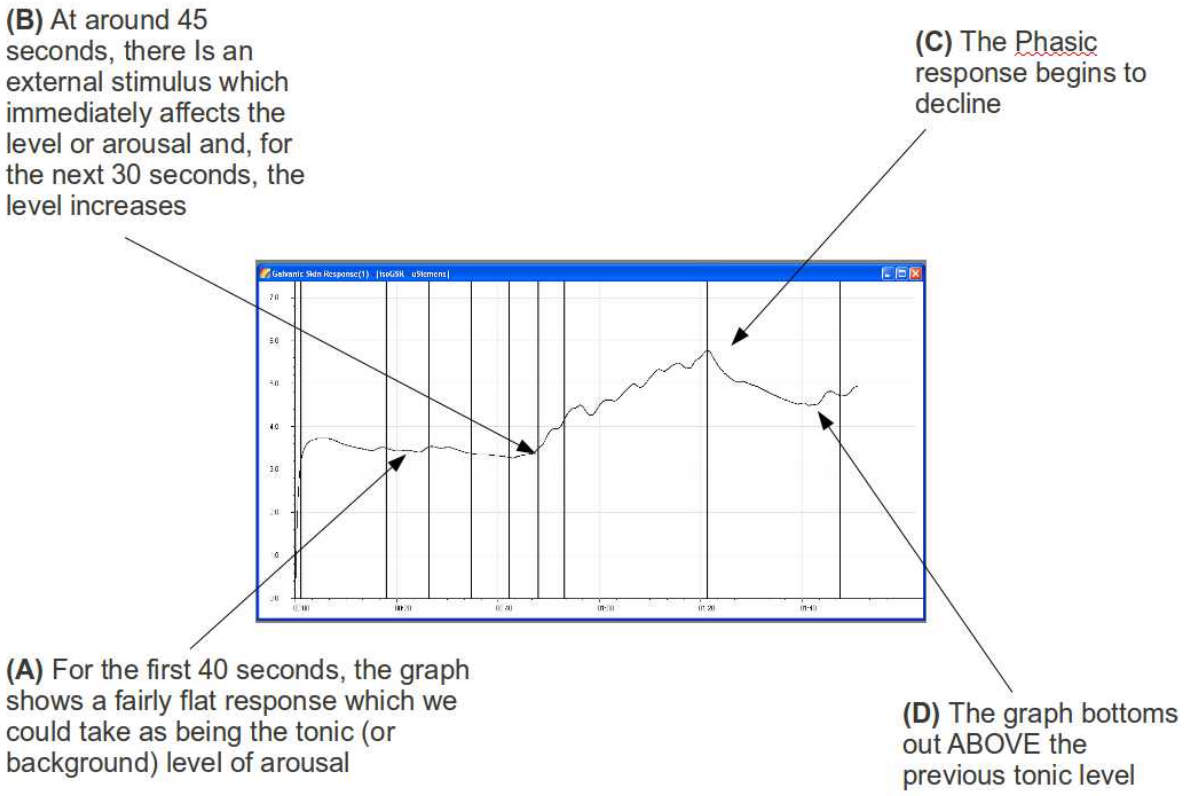
Within a reading of SC/GSR there are two components: The Tonic (or Basal) Level and the Phasic Reponse.

The **Tonic Level** can be seen as the background level of arousal. The tonic level varies minute by minute as we respond to external stimuli which leads on to one of the most important aspects of biofeedback:

Biofeedback is the *relative* measurement of the current state of the Autonomic Nervous System. There are very few absolute figures in biofeedback and a session on one day may elicit vastly different results from the next. We are therefore – apart from very specific modalities - looking for a general trend to monitor performance over a period rather than comparing absolute readings from one session to the next.

The **Phasic response** can be seen as the response to an external (or internal) stimulus. It is intuitively obvious that the tonic and phasic levels interact and that prolonged exposure to stimuli will result in an increase in the tonic – or background – level of stress.

As an example, the following graph shows a Galvanic Skin Response session that contains both a fairly constant "tonic" level and illustrates what happens when the ANS responds to an external stimulus:



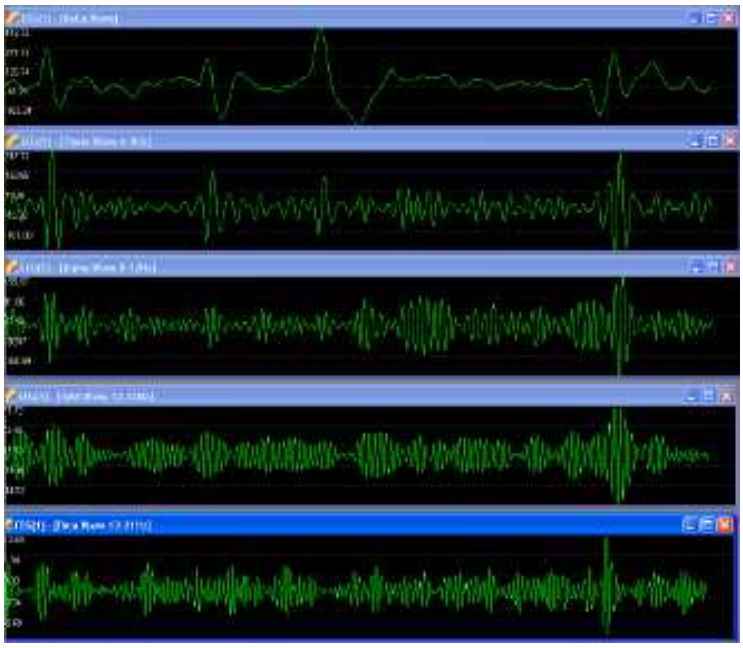
In part, these changes in the ANS are due to the bodies responses to external stimulus. The phasic response is an external indication of a change in the ANS (usually the parasympathetic nervous system) which, while the level of adrenalin may decline quickly, leaves a residual level of stress that take time to reduce.

It is therefore important that time is taken before a biofeedback session to "ground" oneself and to reduce the tonic level of stress by using simple structured breathing exercises and, of course, SC/GSR to reduce the level of stress. Remember the glass of water!

An Introduction to Neurofeedback

Neurofeedback consists of monitoring brain waves through attaching electrodes to the scalp. Generally, we monitor the following waves (although there is some slight disagreement about wave boundaries, the following are *generally* accepted):

- **Delta Waves : (1-3Hz)** - A state of deep relaxation. We won't be dealing with Delta in this document
- **Theta Waves : (4-8Hz**) – Creativity, insight, deep states
- **Alpha (8-12Hz)** – Alertness, peacefulness, readiness, meditation
- **SMR (12-15Hz)** – Mental Alertness, Physical Relaxation
- **Beta (13-21hz)** – Thinking, focussing, sustained attention
- **High Beta (22-36Hz)** – Intensity, hyper alertness, anxiety
- **Gamma (35-45Hz)** – Cognitive processing, learning

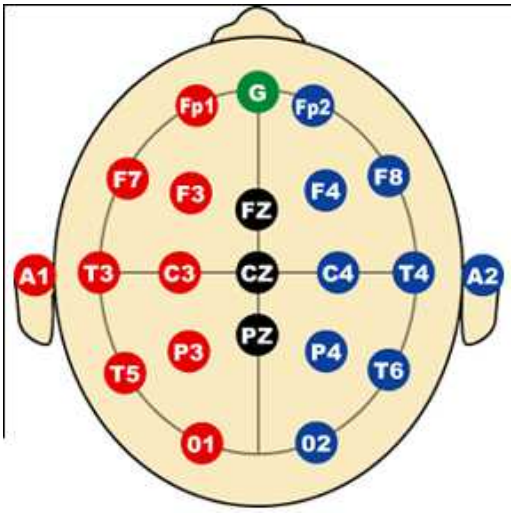


We are interested in both the waves and the amplitudes (which is calculated as being the Root Mean Square (RMS) of the filtered waveform and averaged over, usually, 32 samples a second).

Note that for the purposes of neurofeedback, we use the Amplitude of the wave and NOT the power (the amplitude squared). Power readings should never be used for baselines for EEG training as they have more applicability in showing the energy across specific bands of waves over a period of time (known as an epoch).

Electrode Placement

The placement of the electrodes have been standardised into what is called the “International 10/20 system (see below):



Thus, we may choose to use an electrode on Fp1 (in essence, above the left eye as close to the hair line as possible) or cZ, equidistant between the ears and the nose and occipital bone. This paper focusses on using Fp1 and Fp2 although other protocols use many of the other sites.

Suggested Placement of electrodes

The Vilistus EEG sensor is a differential sensor which means that the electronics automatically determine the brain waves by subtracting the results from one electrode with the results from the other. This means, of course, that it is important that the “negative” electrode should be placed on an area where there is little electrical activity.

We suggest that the “positive” electrode should be placed at Fp1 and the negative either on the earlobe (A1 in the diagram above) or on the mastoid bone behind the left ear. For consistency, always use the same location.

There are two kinds of Vilistus EEG sensors; 2-wire and 3-wire. The 2-wire sensors require an external ground line which should be plugged into the GND socket to the left of the Vilistus face plate. The 3-wire EEG, which is used for multi-person readings has its own ground line.

As you can see from the diagram on the previous page, the ground line, whether integral to the EEG sensor or plugged in to the GND socket, should – for consistency - be placed in the centre of the forehead although it can be placed anywhere on the body.

For the purposes of high performance training, we are most interested in the Theta, Alpha and Beta brain waves and their relationship to each other.

Positioning and cleaning electrodes

Generally speaking, there are two kinds of electrodes, single and multiple use. With single use electrodes, which are pre-gelled, you should prepare the skin throughly and stick the electrodes down making sure that (a) the the electrode is flat and (b) that no hair is caught either under the gel or the electrode.

The reason for ensuring that hairs are not caught is that if they are under the electrode it will decrease the effectiveness and if under the gel, well, it gets difficult to remove with taking hair with it.

Multi-use electrodes, such as the blue 2RT3 electrodes:

come in two varieties, pre-gelled and no gel. The pre-gelled ones will act just like the single use electrodes but can be cleaned afterwords, the clean electrodes require either a direct connection to the scalp (i.e. where there is no hair) and fixed with either a head band or a BraiNet 10-20 template or used with Ten20 electrode Paste.

Single use electrodes should be discarded after use. Multi-use electrodes can be cleaned using a simple alcohol swab to carefully clean off any conductive paste.

Analysis Protocols using the 10/20 System

The following investigation protocol utilises two well known diagnostic aids within Neurofeedback. For the purposes of these protocols, we assume that we are looking for symmetry between the left and right hemisphere and the ability to concentrate (as displayed by data taken from the pre-frontal cortex). Please note that this protocol should be undertaken with the client in a relaxed state free from the effects of alcohol or drugs (whether prescriptive or recreational).

This information is taken in part from "Getting Started with Neurofeedback" by John Demos (available from http://www.vilistus.com/books.shtml)

Ratios

Lubar, Swartwood, Swartwood and Timmermann (1995) studied Theta to Beta ratios. Their investigation was to compare a control group of adults with various children and young adults diagnosed with ADHD. The control group themselves (adults 16-55) had no such diagnosis.

The conclusions drawn from this study were:

- Theta-to-beta ratios decrease with age
- Largest Theta-to-beta ratios are found at Cz or Fz
- Smallest Theta-to-beta ratios are found at the temporal lobes
- Adult Controls had lower ratios than those found in the ADHD population
- Adult Controls had the highest theta-to-beta ratio at Fz (2:1)

Demos says that a theta-to-beta ratio of greater than 3:1 constitutes a slow-wave disorder. This ratio applies to dorsal sites such as Cz, C3, C4 and Fz. Demos also says that high theta-to-beta ratios in the pre-frontal lobes signal a problem with attention and other executive functions. He points out that the ratios are best observed when the client is involved in the task rather than at rest.

The Vilistus software provides a "Theta/Beta ratio" filter for EEG. It can be graphed using any of the instruments but can be most effectively seen on the "*Horizontal Graph*" instrument.

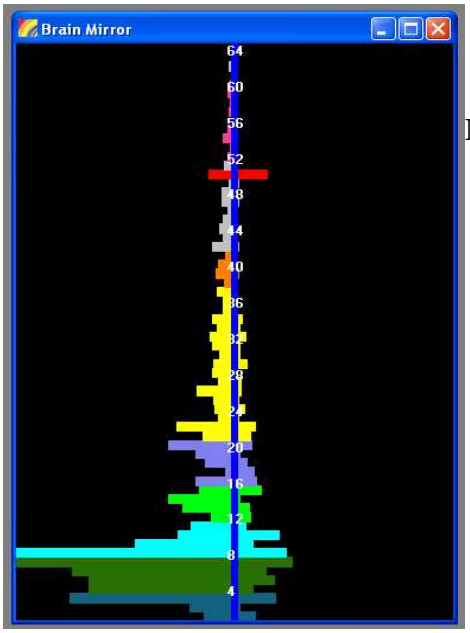
For practical purposes, the application of the theta-to-beta ratio in Clay Angel / Vilistus would seem to be that at points Fp1 and Fp2 (the pre-frontal cortex) and we are looking for a ratio of 1.5 – 2.

Asymmetry

Asymmetry is defined, for the purposes of Neurofeedback, as being an examination or comparison between different parts of the brain.

Demos points out that while Ratios compare the distribution of frequency bandwidths at a specific site (say Fp1), abnormality can only be seen by comparing the scalp from side to side (i.e. using Fp1/Fp2 or C3/C4 etc).

We generally compare the left and right hemispheres of the brain but sometimes check between back and front. In order to clinically assess a client, a full QEEG would be required to show asymmetry. For the purposes of training, however, we would expect to see similar levels of amplitude/power at opposing sites (although it's unlikely to be identical). For our purposes, a margin of error of 20% would be acceptable.



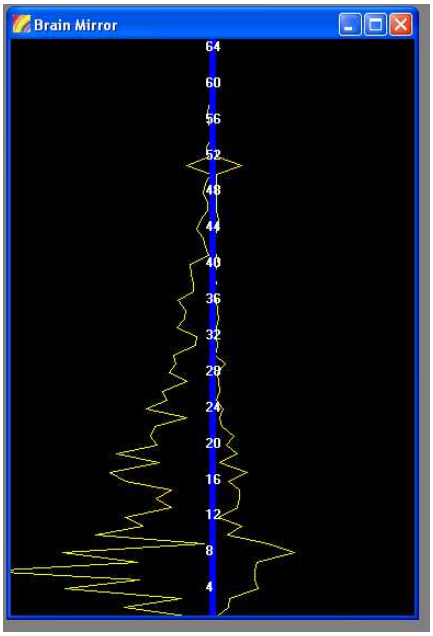
Note that the various bands are colour coded:

- Delta – grey
- Theta - dark green
- Alpha – light blue
- SMR – light green
- Beta – Purple
- High Beta – Yellow
- Gamma – Orange
- 50 Hz – Red

Using the Vilistus software, the best instrument to monitor Asymmetry would be the *Brain Mirror.* It shows all the relevant frequencies (3-60 Hz) in a stacked bar graph (as can been to the left). Two things can be noticed immediately from this particular example:

- There appears to be far more processing on the left hemisphere than the right, particularly at low frequencies (those at the bottom of the graph).
- There is significant 50Hz interference (the red bar)

The brain mirror can also be seen as a line chart rather than as bar chart which provides, we think, a better overview but obviously less detail:



It is obviously possible to combine the ratio and asymmetry investigations using the Brain Mirror instrument. In this case, we would be looking for a shape similar to that of a double bass where the theta activity is approximately double to that of the beta activity.

Eyes Open / Eyes Closed

Generally speaking, we aim to check brain waves with both the eyes open and the eyes closed although, obviously, it's not possible to have your client “on task” when his/her eyes are closed.

(*This part of the protocol would be used for more in-depth analysis of client brain state and would be used as a precursor to a training activity*).

The reason that we test both eyes open and closed is that, when closed, the eyes produce less sEMG artifact and is therefore, generally, a more reliable indicator. You can use both the ratio and asymmetry tests in both. We recommend:

1. **30 Seconds of relaxation**. This can be extended so that the client begins to produce “reasonable” EEG (which you can detect from either a *time series* instrument or from the *brain mirror*). The aim here is to ensure that the client is in a neutral state

2. **30 seconds of Eyes-open.** This is the “control”; it is the standard state of processing. The client should be asked to observe something nearby passively

3. **30 seconds of Eyes-closed**. With the eyes closed and less distraction, you would expect to see better EEG from sites around the pre-frontal cortex (Fp1/Fp2) although it must be remembered that ALPHA AMPLITUDE increases in a kind of rolling wave from the neocortex when the eyes are closed. An increase in Alpha is therefore to be expected.
4. Repeat (2) but this time perform a mental task such as counting back from 100 in 4's
5. repeat (4) but with eyes closed.
6. Repeat (1) as a further control.

It is possible to use the Vilistus MiniQ script to run this automatically and get the data you need to analyse performance.

Here are some sample statistics:

Segment #2 (30 Seconds)

Channel	Filter	Minimum	Maximum	Average	Variance	Std. devn
0	EEG - [Alpha Amp.]	0.00	56.51	4.34	324.44	18.01
1	EEG - [Alpha Amp.]	0.00	46.87	1.56	45.44	6.74

Segment #3 (37 Seconds)

Channel	Filter	Minimum	Maximum	Average	Variance	Std. devn
0	EEG - [Alpha Amp.]	0.00	89.83	9.65	198.43	14.09
1	EEG - [Alpha Amp.]	0.00	56.51	3.74	27.16	5.21

Segment #4 (32 Seconds)

Channel	Filter	Minimum	Maximum	Average	Variance	Std. devn
0	EEG - [Alpha Amp.]	0.00	74.03	4.78	311.76	17.66
1	EEG - [Alpha Amp.]	0.00	38.81	1.72	43.80	6.62

In this case, we have 2x eyes-open (Segment 2 and 4) and one eyes-closed. The statistics show the alpha amplitude at Fp1 and Fp2 over the three segments and, other than the asymmetry between the two hemispheres, the important thing to note is the significant increase in alpha amplitude in segment 3 (eyes-closed) - Basically double (9.65uV to 4.5uV).

The purpose of using the above protocol is to assess the level of asymmetry and hemispheric balance with a view to constructing a training protocol for the client. This is covered in the next section.

What is very important, however, is to clearly document the findings of the protocols both before, during and after the neurofeedback intervention to see exactly what has changed as a result. One of the most powerful "convincers" is being able to quantify the amount of change rather than using merely qualitative measures. The statistics function within the Vilistus product will enable you to keep records of progress and provide valuable feedback and encouragement to your clients by showing them exactly the progress they are making.

A quick explanation of Vilistus statistics

Vilistus displays basic statistics from a session, it is assumed that for more detailed analysis, more sophisticated software such as MS Excel, SPSS, Matlab or “R” would be used.

A Vilistus statistics session shows the following:

1. Minimum
2. Maximum
3. Mean (average)
4. Variance
5. Standard Deviation

To be frank, depending on the quality of the hookup, the Minimum and Maximum are not that useful. The mean shows the average reading for the session so, to take an example from the report above:

0	EEG - [Alpha Amp.]	0.00	89.83	9.65	198.43	14.09

The 0.00 and 89.83 can safely be ignored, the highlighted column shows the mean and to the far right, 14.09 shows the standard deviation. The Standard Deviation is a figure generated from the data showing the amount of fluctuation of readings from the mean or average. Thus, in this case, the data for the alpha amplitude is 9.65 +/- (Plus or minus) 14.09. Which means that approx. 68% of the data was in the range 0 – 23.74.

In neurofeedback sessions where the aim is to increase the amplitude of, say, alpha amplitude, we would seek to increase the mean or average and, if possible, decrease the standard deviation.

In other words, we want to increase alpha amplitude in a controlled fashion with the majority of the readings as close as possible to the mean.

Neurofeedback training

Neurofeedback training should only be undertaken by trained therapists.

There are obviously many (perhaps infinite) different situations identified by the Vilistus hardware and software. In itself, the trace is meaningless; there are many reasons why a client was, perhaps not focussed sufficiently on the task at hand. It is, however, the combination of a series of tasks that begins to show a developing pattern.

A combination of the ratio/asymmetry protocols mentioned above can identify potential issues that can be addressed using the neurofeedback functions of Vilistus. The following paragraphs detail how Vilistus can be used to increase brain synchrony and keep the theta-to-beta ratio within the boundaries mentioned above. You will be aware, of course, that there may be many reasons why certain values are displayed:

- Brain injury
- Attention disorders
- Medication
- Recreational Drugs including Alcohol

It is therefore vital to understand both the circumstances of the client and to ensure that, when the tests are taken, the client is "clean". It should further be recognised that performance at a high level is a combination of having the optimum mental and physical performance AND being able to activate the right state of mind for competition.

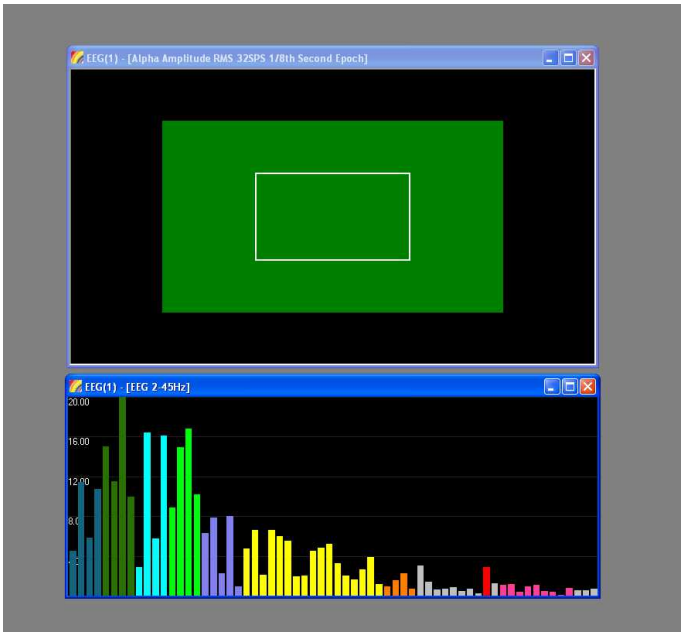
These two aspects are co-dependent but they should not be confused; neurofeedback training can make a client more focussed and balanced but the extra stress involved in real-life situations means that they must be able to access the "training" state at will. The latter usually involves using psychotherapy tools such as anchoring, visualisation and accessing optimal states. An analogy would be that neurofeedback is like tuning the racing car; the mental regime of psychotherapy gives the driver the ability to drive the race successfully.

There are therefore, in our opinion, three aspects to high performance brain training:

- **Neurofeedback** – to re-educate the brain into more effective brain states. This can also include biofeedback modalities such as breathing, heart rate variability (HRV), Galvanic Skin Response and Skin temperature – all of which are outside the scope of this document.
- **AV Entrainment** – to elicit short term brain states
- **Anchoring / Visualisation** – Used in psychotherapy to elicit brain state

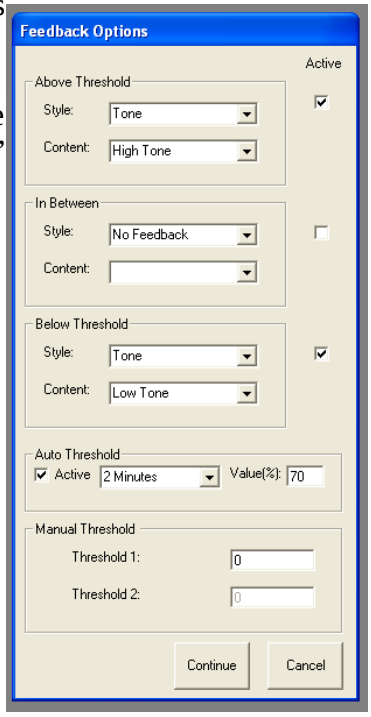
All three aspects, when used together, can provide the client with a powerful focus for his or her occupation whether business, sport or academia and give the extra 20% of performance over and above technical ability. AV entrainment and anchoring/visualisation are outside the scope of this document although we can provide information, training and equipment for these aspects.

What follows is an example of a neurofeedback training using the “Zoomer”, an accessory available within the Vilistus/PC software that you can use to either maximise a given brain wave or ratio. For the purposes of these instructions, we will use the Zoomer to increase the amount of alpha.



The Zoomer is typically used with a single electrode and a particular amplitude of the a given brain wave frequency (alpha, beta, theta etc).The image shows both the Zoomer instrument and an FFT showing a breakdown of all brain frequencies between 1 and 60.

The basic idea is to make the green square as large as possible and certainly bigger than the white box which indicates the threshold between what has been set as “acceptable” and what isn't.



The parameters for the feedback are set in the feedback dialog and the key things to notice are the “above threshold” and “below threshold” boxes and the “auto threshold” option.

We recommend that the parameters are set as in this image:

Above threshold
- Style = Tone
- Content = High Tone

Below Threshold
- Style = Tone
- Content = Low Low

Auto Threshold
- Active = Yes
- Time = 30 minutes
- threshold = 70%

Make sure the “active” boxes are ticked to the right of the “above” and “below” threshold options.

This instrument is typically used to increase Alpha amplitude, but it can also be used to reduce high beta or theta. In order to use the zoomer in reverse, you should set the “above” threshold option to “low tone” and the Below threshold option to “high tone”. You should also set the Value in the active threshold to 30%.

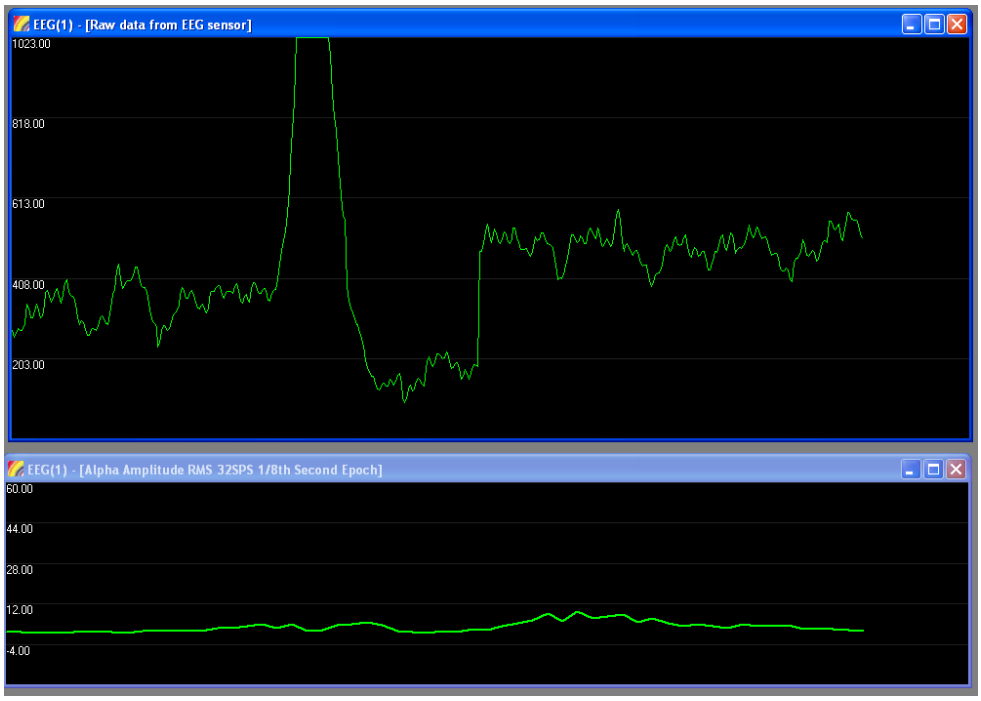
The “Auto threshold” option allows the software to automatically set an optimum training threshold (in the case of Alpha training, we recommend 70% - meaning that the software will ensure that you are over threshold around 70% of the time; and in the case of theta training, you would set a threshold of 30% to ensure you are rewarded for being under threshold for 70% of the time.

When you start the neurofeedback session (with, say, a single electrode on Fp1, the ground reference in the middle of the forehead and the other EEG electrode on the mastoid bone behind the ear) you will see the green and white boxes expand and contract as the Vilistus analyses the data.

Signal Quality and Artifact

It is important to get as good a signal from the EEG sensors as possible. Thre are, however, a number of ways in which the signal can be degraded and artifact induced into the raw data. There are two main causes of artifact:

1. **Surface EMG**. The electrical energy in muscles is roughly ten time stronger that the electrical energy that comes from true EEG signals. Therefore any muscle movement close to a sensor electrode is likely to induce a “spike” in the the EEG trace as in the picture below. Note that although the eye blink is obvious from the raw EEG trace, it is pretty much invisible on the Alpha Amplitude trace. You should therefore always look at the raw trace and if the graph goes either to 0 or 1023 make sure that the electrodes are sited correctly and that you are in a position where you can minimise muscle movement.



2. **Signal Quality**. This is generally due to to either the proximity of radio devices (mobile phones etc.) or the quality of the connection between scalp and electrode. In the former, make sure that there are no mobile telephones in the area and, for the latter, it is important to both prepare the skin properly using with NuPrep or Alcohol swabs AND use a good conductive paste such as Ten20. There is an EEG filter in Vilistus called “Signal Quality” which you can use to check the link; 1 means perfect, anything less should be investigated.