In cooperation with Erwin Hartsuiker of Mind Media Netherlands, I received an advanced copy of the new NeXus-10 / BioTrace+ system in January of 2004. I was quite impressed by the quality of the hardware and software but I was immediately drawn to a new feature with which I was completely unfamiliar. The system utilized a sophisticated DC amplifier that was capable of displaying a wide frequency range from 0 Hz up to about 1000 Hz. I was of course accustomed to AC amplifiers that blocked the DC portion of bio-potential signal, leaving only the AC or alternating current EEG pattern that fluctuated in a positive to negative wavelike pattern above and below the zero line.

With the benefit of this new amplifier and software, I was able to see not only the AC information but also a general fluctuation in the overall electrical properties of the cortex that I was later to learn represented a measure of the excitability characteristics of that cortex from moment to moment. I now had access to a measure known as slow cortical potential (SCP), but what to do with it?

Erwin suggested a search of the literature for information about SCP and recommended publications by Niels Birbaumer and colleagues at the University of Tübingen in Germany. They had been working with slow cortical potentials for quite some time and had shown some positive results when working with clients with seizure disorders. They had noted that the SCP gradient became more negative prior to the onset of seizure activity. It appeared from their published work that they found training an individual to have voluntary control of this electrical gradient could give them the ability to prevent or minimize seizure activity and their results appeared to demonstrate this quite nicely.

At this point a discussion of what this electrical gradient represents and how it is measured is needed. In 1875, Richard Caton identified what may have been the first evidence of slow cortical potentials (SCP) in an article in the British Medical Journal, titled The Electric Currents of the Brain. He stated “The cortex’s Direct Current baseline waxes negative whenever it is more active. Gradients of 150-200 µV/mm are noted.” He later noted "when any part of the gray matter is in a state of functional activity, its electric current usually exhibits negative variation." Some later researchers suggested that this signaled the
discovery of the "steady potential" or the DC potential of the brain, though others have noted the possibility of equipment based artifacts in his recordings (Niedermeyer, 1999).

This characteristic of cortical activity identified by Canton has been subsequently verified in animal and human subjects research. To put it simply, when the cortex is active and engaged, it becomes more electrically positive and this change in electrical gradient can be measured at the scalp with appropriate devices. When the cortex becomes less active we observe a corresponding movement toward greater positivity in the electrical gradient.

Birbaumer and others have used this characteristic feature of SCP to train individuals with a variety of conditions, including migraine headaches and ADHD, in addition to those with seizure disorders. The thinking seems to be that when you have an individual with a significant degree of under arousal, which you might find in an ADHD client with a finding of excess frontal slowing, you would train for control of the SCP signal with an emphasis on encouraging greater negativity, which we have noted above corresponds with more activation of the cortex. For an individual with excess activation, which might include a migraine headache sufferer, the same protocol could be used with an emphasis on encouraging greater positivity and hence a decrease in overall cortical activation.

This was certainly an intriguing possibility. Here we have a single measure, easily accessible with a DC amplifier and appropriate software that could be trained in one direction or another to resolve a wide variety of presenting conditions. Significant research had already been done by reputable individuals and this information had been published and had also been presented in a variety of professional meetings, including the ISNR annual conference.

As I continued to pursue this line of inquiry, I had a discussion with an electrical engineer who informed me that to be able to manage the high voltages of the DC signal it would be necessary to have a high resolution analog to digital (A/D) converter. I then found that the NeXus amplifiers have very high resolution, 24-bit analog to digital converters (more than one million steps of resolution), which gives them ample "headroom" to handle DC offset voltages. Most AC amplifiers with a lower A/D converter value would find their input stages overwhelmed if they didn't block these voltages with capacitors and hardware-based high pass filters. The NeXus 10 amplifier that I was using had four channels with this high resolution capacity.

This amplifier and the corresponding BioTrace+ software allowed me to view a single electrophysiological signal that included slow cortical potentials, EOG (electrooculargram), ECG (electrocardiogram), EEG (electroencephalograph) and EMG (electromyograph), depending on sensor placement and filter settings. I didn't need separate sensors, pre-amplifiers or other devices to visualize each of the signals. They were all available as a result of the design of the amplifier and software. Finally, access to SCP also opened up the potential for monitoring and assessing event related potentials (ERP).

Another issue addressed by the new technology was the elimination of the customary alteration of the EEG signal by the use of various filtering approaches. Erwin explains this as follows:
Artifacts and the classical (old style) EEG Amplifier

The typical classical AC based EEG amplifier cannot measure slow cortical potentials and uses all kinds of filters to eliminate “unwanted” signals (external and physiological artifacts). Such amplifiers typically use 3 filters to accomplish this:

1) A high pass filter set at 0.5 to 1 Hz. (filtering out DC activity and SCP)
2) A low pass filter set at, for instance, 35Hz, 40Hz or 70Hz. (suppress EMG)
3) A notch filter to suppress 50/60Hz mains interference.

The ‘bad news’ is that all these filters actually alter the signal and the phase of the waves. In other words: they alter the shape of the EEG waves. There is even a risk that a bad source signal may look quite reasonable after intensive filtering. Bio-medical engineers know the principle of: “garbage in – garbage out”. In EEG terms this means: if you put a noisy signal, full of EMG, 50/60Hz, movement artifact and other garbage, into a classical EEG amplifier, run it through some heavy duty filtering, you may end up with something that looks quite acceptable. But of course it is not. Garbage is garbage.

The image below shows such a ‘poor’ source signal. It contains movement artifact, EMG and 50/60Hz. By the way, this ‘EEG’ signal was not measured on the head, but from the foot! Beneath it, the same signal is shown after filtering. It does look somewhat like EEG, does it not? This should perhaps make us wonder what it really is we are monitoring and using for EEG training. How much artifact does a typical EEG really contain?

The following list is not complete by far, but some of the typical problems with classical EEG amplifiers and electrode cables are:
1) Movement artifact may show up as Delta or Theta waves. (try swinging your EEG cables on your system and observe what happens)
2) Low level EMG artifact may appear to be SMR, Beta or Gamma activity
3) 50/60Hz (even when suppressed by a notch filter) may impact Beta and Gamma and distort the EEG signals.
4) High electrode impedance (poor contact to the skin) above 10Kohm may cause noise and increase 50/60Hz interference.

5) We have to realize that any filtering that is used to removing artifacts (whether it is digital or analog) is really something that alters the signals and data. But then, is there a way to use less filtering to condition the signals? Is there way to see the source signal as it is (wide band) and get signals with less artifact?

One of the main design considerations in the development of NeXus and the BioTrace software was to address these questions. One surprise, the NeXus wideband DC amplifier does not have any of the typical filters found in most classical EEG amplifiers. There are no high pass filters around 1 Hz, no low pass filters around 35-70Hz, nor are there any notch filters. From DC to way over 200 Hz, the frequency response is flat.

The graph below illustrates this flat response and compares it with the frequency response of a typical classical EEG amplifier.

As you can see, NeXus monitors the entire EEG signal from DC (slow cortical potentials) up to high EMG frequencies around 1000 Hz. This allows us to see a much broader picture. The graph below shows the filtered classical EEG (1-40Hz) and the entire wide band signal without any filters. Notice the DC offset in the source signal.
This approach has some real advantages to researchers and clinicians. From a single set of electrodes, say a standard referential placement with positive on Cz and negative and ground on the earlobes, we can simultaneously monitor both the DC (SCP) activity, Delta, Theta, Alpha, Beta to Gamma and observe EMG artifact up to 500 Hz or more. So now we can check whether our Beta and Gamma activity is real or whether it is actually a ‘side effect’ of high frequency EMG. After all, Neurofeedback is about training the brain and not muscle activity.

**NeXus active Noise Cancelation Technology**

In order to get a cleaner source signal, the NeXus uses special carbon cables with active shielding technology, also called active noise cancelation. The net effect of this is that 50/60Hz artifact is very low (without any notch) and movement artifact is virtually absent. Normally, even swinging the cables does not create movement artifact! With most classical EEG systems, movement artifact is a problem.

By the way, it should be noted here that active noise cancelation does not work like a filter, rather it shields the signals from external interference, so some of the ‘garbage’ does not enter the amplifier to begin with. This is particularly important at the lower end of the spectrum where we find Theta, Delta and slow cortical potentials. Most classical EEG amplifiers use copper wire for electrode cables. Moving that cable will generally produce slow wave like activity with amplitudes that can be as low as a few microvolts (difficult to recognize) or over 100 microvolts. (easy to recognize).

Anyone with EEG equipment can try this out and see how much artifact moving the cable actually causes. So why is movement artifact a concern? Well, we all know that some ADHD kids (and adults) have a hard time sitting perfectly still. When slow wave activity is used for feedback training, it would be nice to know it is not caused by (subtle) cable movement.
What is DC-EEG and how do we measure SCP’s with NeXus?

Slow cortical potentials can only be measured with a DC-EEG amplifier. The DC amplifier not only measures the alternating current (AC) signal but also the absolute DC levels. The largest DC component of the DC-EEG signal is composed of the electrode-offset or ‘battery effect’ of the electrode. The combination of electrode paste and gel, the electrode material and the skin (sweat) works like a miniature battery. Then on top of that are the actual, rather small bio-potentials generated by the brain. The electrode-offset is usually fairly large. With Ag/AgCl based electrodes it can be as high as 25,000 microvolts. Silver and Gold produce even higher offsets and are therefore not recommended for DC-EEG or SCP recordings.

Being able to measure this DC electrode offset in real time has a nice side effect; the offset correlates with electrode impedance! That means if electrode impedance is higher the offset will also be higher. So indirectly this is a good alternative method to check the electrode-skin contact, with the advantage that a session does not need to be stopped as with most classical impedance tests.

All this great technical capability was nice to have, and yet I was on the trail of training slow cortical potentials and wanted to further explore this method. I began experimenting with SCP training according to the Tübingen approach as implemented by the BioTrace software.

SCP training and clinical protocols with NeXus

The BioTrace software of the NeXus uses a dual monitor approach where the client screen is shown on a second monitor. (see the picture below, which shows a NeXus-10 and two 22 inch monitors)
In a semi random fashion, the client is instructed to make their brain potentials more negative (cortical activation) or positive (reduced activation), so the emphasis is on training control. The actual amplitude of the shift is secondary. Each trial is about 8 to 10 seconds. During each trial the success of the training (time over threshold) is fed back with a tone, reward counter (score) and visual graphic animation.

With this protocol already built into the software, I was able to practice this technique and develop fairly good control of the signal, as evidenced by the separation of the tracings in the image below representing the averaged negativity (red) and positivity (blue) responses during a session.

During this self training, I experienced changes that appeared to be attributable to greater control of the slow cortical potential gradient. When the emphasis was on increasing negativity (more negativity trials) I experienced an increase in activation, at times leading to difficulties with sleep and an increase in muscle tension. Training that emphasized greater positivity (more trials encouraging the positive shift) tended to leave me feeling somewhat sluggish and tired. All of these training sessions were done with the dual (two channel) active sensor at Cz and a reference on each mastoid, following the Tübingen approach.

After this period of self training and following further study of the published literature, I was ready to work with a few select clients. The first was an 18-year-old male with significant frontal slowing and a diagnosis of ADHD inattentive type. His initial SCP training session showed little ability to control the direction of his electrical gradient in response to the trial stimuli (see the image below).
Later sessions showed much greater control and corresponded with self-reports of improved attention and better grades in school (see graph).
Other clients showed similar results when the goal was increased activation. However, clients with a need for decreasing activation had more difficulty and did not experience the same positive effects.

There appeared to be a need for an alternative training approach for these clients. With this in mind, a protocol was devised to gradually reward an increase in positivity in the SCP signal over the course of a 30-40 minute training session. Participants reclined in a comfortable chair with their feet up and listened to variable volume music feedback or variable volume natural sounds such as a recording of ocean waves. The volume was set to increase as the SCP gradient became more positive and decrease as it became more negative. The sound of birds chirping was linked to a delta frequency (1-4 Hz) feedback instrument to alert the client if they became drowsy (delta amplitude exceeds a preset threshold) as this has been a reliable indicator of the onset of sleep in alpha/theta training protocols.

Figure 1 shows the composite session results for an individual undergoing this training protocol. It is clear that the individual has demonstrated a steady trend toward the positivity condition and that this trend corresponds with several other changes in both AC EEG and in the peripheral biofeedback measures of finger temperature and GSR.

Figure 1: This review screen shows changes in peripheral measures: basal skin resistance (BSR), a measure of galvanic skin response and finger temperature – higher values of both measures reflect
decreased arousal. Slow cortical potential gradients show positivity as up with the zero line indicated. Alpha and theta line graph indicates the classic “crossover” state common to a/t training. A 13-36 Hz. bar graph shows decreased cortical activity and possibly decreased motor output. 7 Hz. bar graph shows increased activity in the 5.5-8.5 Hz. band, again associated with the so called crossover state.

The post-session self-report of this individual described a profound level of relaxation and a sense of peace not experienced prior to this session. This individual was an experienced meditator and had participated in a number (>20) of traditional alpha/theta training sessions.

Figures 2, 3 and 4 show another individual utilizing the same training paradigm. Figure 2 shows the initial eyes closed segment for this individual indicating a high degree of 8-11 Hz. activity. Figure 3 shows the activity later in the session indicating a generalized decrease in overall activity. Figure 4 indicates the average SCP change for the entire session. Note the time indicator of figure 3 corresponds to the period of greatest SCP positivity.

Figure 2: This figure shows four compressed spectral array graphs representing approximately 10 seconds of data at approximately 5 minutes into the session. The top two graphs represent channel A and B activity while the bottom graphs show the sum of the two channels (left) and the difference between the two channels (right). Note the high amplitude 10 Hz. activity that appears to be quite synchronous.
Figure 3: This figure shows the same view as in figure 2, at approx. 22 minutes, using the same y-scale values. Note the generally decreased levels of cortical activity displayed here compared to Figure 2.

Figure 4: This figure shows the SCP gradient as 1 minute mean value bars indicating that the greatest positivity values corresponded with the same time point (between 22 and 23 minutes) displayed by the graphs in Figure 3.
In conclusion, based on the scientific research that has been published up to date, we believe training slow cortical potentials is certainly something that may be of interest to many clinicians and researchers. We believe the potential of SCP training is not so much that it will replace classical EEG feedback training, but we do expect it will establish itself as another method to train the brain.

It is clear that there are many opportunities for additional experimentation. These possibilities could include active sensor placements in areas that are specific to a client’s presenting disorder and/or findings on a quantitative EEG assessment, rather than simply using a Cz placement. Additionally, other training protocols could develop that might be more efficacious when working with clients needing to increase either positivity or negativity.

For more information on NeXus physiological monitoring and feedback technology:  [www.mindmedia.info](http://www.mindmedia.info)