Practicing with Multichannel EEG, DC, and Slow Cortical Potentials

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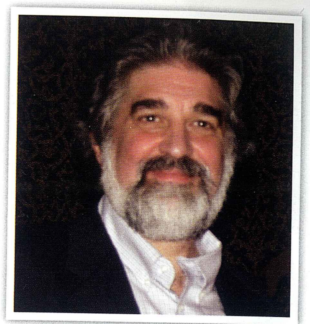

In the Atlantis series of EEG devices, BrainMaster has implemented hardware and software capable of recording and training DC (Direct Current) and SCP (Slow Cortical Potentials). This provides the ability to record the DC or "standing" offset potential of the EEG channels down to zero Hz, and to train using the DC information, and/or using SCP. The Atlantis hardware includes 2 or 4 high-quality DC-sensitive EEG amplifiers, and all EEG recordings have always been taken internally with DC coupling. However, until recently, the PC software has only had access to the "conventional" EEG information. The new software (and firmware) now makes it possible for the PC to have access to the DC EEG data, and to use it for research in DC/SCP EEG monitoring and training. In addition to providing DC measurements down to zero Hz, this capability also provides extended bandwidth for standard protocol-based EEG training (0.01 – 120.0 Hz), and simultaneous SCP data.

The DC potential is the actual "standing" or "zero hertz" component of the EEG. Unlike the other components which all have a defined frequency range (e.g. 8.0-10.0 Hz for alpha), DC potentials are recorded with a low-frequency cutoff of 0.00000 Hz. That is, if the sensor is "sitting" at a steady offset of, say, 150 microvolts, then that signal can be recorded and trained. This capability allows the system to monitor the slow, graded changes in the brain potential, which has traditionally been very costly and difficult to achieve. The SCP potential is defined as the DC offset, but with a very slow adaptive baseline correction factor, that eliminates the need to "zero" the amplifiers. Rockstroh et. al. (1989) provide a very complete and thorough review of applications of DC and SCP signals in research and in clinical practice. The recent article in NeuroConnections by Hartsuiker and Anderson (2008) also provides important background and practical data.

The Atlantis (2 and 4-channel) and Discovery (24-channel) EEG encoders employ DC amplifiers that provide measurable signals all the way down to 0.000 Hz. Combined with the 24-bit digitizers, the devices are capable of resolving EEG signals with an accuracy of less than 0.02 microvolts, and a dynamic range of 200 millivolts. The entire signal is digitized, then processed into two signals, the first being an EEG channel with a working bandwidth of 0.100 to 100 Hz, and a DC channel with a working bandwidth from 0.000 up to more than 5 Hz. While the EEG channel is filtered using conventional frequency bands, e.g. 0.1 to 2.0 Hz, etc., the DC data is managed by using a "damping factor" that applies a time-constant to the data. There is a direct inverse relationship between frequency and time-constant. For example, a time-constant of 8 seconds corresponds to a cutoff frequency of 0.16 Hz. The low-frequency cutoff of the DC channel is always 0.000 Hz, so it is typically some nonzero number, e.g. "175.0 microvolts," so would typically "be off the graph". By subtracting off a damped baseline, it is possible to create the SCP data, which have an average value of zero, hence always return to the center of the graph.

The DC signal contains all forms of offset voltage including metal-to-electrolyte junctions, skin potential, and other offsets. In and of itself, it is of limited use because it includes so many sources of voltage, and it is very difficult to achieve stable recordings. High quality DC sensors made of silver chloride must be used, and the physical connection must be very robust. More useful is the Slow Cortical Potential which is derived by removing the nearly constant standing offset, and allowing only the slow changes to be measured. In order to do this, the bandwidth of the SCP is typically taken with a "time constant" of about 10 seconds, which corresponds to a low frequency cut-off of about 0.05 Hz, and a high frequency cutoff of a few Hz. Most practical EEG training is done with the SCP potential. The raw DC offset is, however, particularly useful for monitoring and assessing the quality of the sensor contacts. It is thus useful for detecting poor or intermittent sensor connections, and is a useful sensor quality monitor.

The DC and SCP potentials are generated by several physiological mechanisms. One of these is the slow graded post-synaptic potentials of giant pyramidal cells in the cerebral cortex. However, these potentials typically do not extend down in frequency much below 0.5 Hz, and are primarily "oscillatory" signals. The predominant source of the slowest cortical potentials is the population of glial cells which support and regulate the neurons, as part of the global brain system. Glial brain cells have been found to be closely related to overall brain activation, and are also connected with brain stability. There are almost 10 times as many glial cells as neurons, and they are known to be related to general cortical arousal, intention, and are also very relevant to epilepsy and other abnormal processes. The training of slow cortical potentials has been pioneered primarily in Germany, by a group at Tubingen headed by Dr. Neils Birbaumer. This group has published results with brain-controlled interfaces (BCI), as well as working with epilepsy and ADD/ADHD using biofeedback training of slow cortical potentials.

DC/SCP training is generally done in a monopolar fashion. In this way, the system is monitoring the shifting of the brain potential levels relative to a standard reference. This makes it possible to specifically train the potential up or down, depending on the protocol. Unlike with regular EEG rhythms, the polarity of the training is important, as it dictates whether the brain potentials will be trained in an activating, or in a de-activating fashion. This is the approach used by the Tubingen group, and is the most precise and accurate form of DC or SCP EEG. With the use of the BrainMaster's Event Wizard, specifically directional DC and SCP protocols can be designed with 1, 2, or 4 channels. The entire DC signal, with 0.0000 Hz as the low end, can be recorded using this approach.

It is also very likely that recent use of very low frequencies in bihemispheric training is in fact working with slow cortical potentials. In this work, if, for example, T3 and T4 are used, the trainee is learning the effects of increasing the difference between the sensors, at low frequencies, hence

Continued on page 36

Some Speculative/Theroretical/Elucidation Considerations

If glial cells outnumber pyramidal cells by 10 X and they control general cortical arousal, intention, and epilepsy mechanisms; they can hardly be regarded as functionally silent supporting connective tissue as medical students were taught long ago. In fact current studies suggest they may play an integral role in all brain activity. Do glial cells act en masse to condition the whole brain or could they act regionally, hemispherically, or locally? Could their influence affect cortical pyramidal cells only or could it affect relationships between the cortex and subcortical entities like the amygdala, medial bundle, reticular activating system, or caudate nuclei? Could glial cell cortical excitability-settings affect "conventional" EEG feedback training between 1 and 30 Hz? Those, and a host of other questions, await elucidation and the Atlantis (and soon the Discovery) hardware/software systems can play a role in that elucidation. Is it time to train the entire measurable spectrum of brain activity? Is it time to consider dynamic brain function as a mélange of the known, and yet unknown, local micro functions as well as global interactive activity?

Let's take depression as an example entity we might use to begin answering some questions posed above. Depression is the most common of all human afflictions; it pervades all human cultures; and it is easily diagnosed with an interview lasting just a few minutes; the Beck Depression Inventory; or other more extensive measures. It causes significant, possibly huge, economic effects that affect all societies worldwide. Expensive psychotherapy may help and drugs are used widely to combat it but neither approach leads to reliable, long-lasting, or side-effect-free results. Effective neurotherapy will attract favorable attention to our field of endeavor and governments as well as insurance companies will be willing to consider a neurotherapy alternative to very expensive, lifelong drug and psychiatric therapy, both with their expensively treated ripple side effects.

Further, let's take advantage of some very special technical aspects inherent in the ratio and interval scaling made possible by using full spectrum data available with combined elegant DC amplification for 0-1 Hz data and z-score data for measuring 1-40 Hz spectral brain activity in local, regional, or hemispheric brain spaces. Those information-rich measurements will enable us to test well-conceived hypotheses relevant to dynamic brain functioning, including cortical-subcortical relationships, with small enough sample sizes to make clinical studies conducted by clinically involved practitioners possible, scientifically rigorous, and convincing to super-critical criticism as well as our most important audience, our clients.

Then, let's apply a head-to-head clinical study design currently under consideration by the ISNR Clinical Studies Subcommittee as an appropriate research tool. This approach will use clinical skills and experience of seasoned and new neurotherapists working under scientifically rigorous protocols to test well-conceived hypotheses will indeed provide answers to many of the above-mentioned questions as well as other, elegantly-imagined questions put forward by experienced neurotherapists as well as serious neurotherapy critics. Because these proposed trials will be financially lean and have considerable economic importance, they will likely attract private funding.

By first comparing SCP-only training results head-to-head with conventional EEG feedback z-score training results, or any other conventional EEG training results, we can, for example, discern whether SCP-only training has an advantage over conventional EEG feedback, or amplitude EEG feedback training, or LENS training. Then, we can conduct further head-to-head trials to determine various combinations and exclusions that fair better over others. With each interative step in the comparisons we will get closer to an optimal clinical approach to depression. Further, because the trials will be conducted in real clinical settings in diverse geographic and sociologically different populations by diversely capable clinicians, any significant differences revealed will likely be robust in real neurotherapy settings. Isn't that the goal of all research?

For details regarding anything above please contact the authors. To join this clinical trial effort, go to: http://spreadsheets.google.com/ccc?key=pD1i6LBZw6tXMpVgV9dt-Ng&hl=e

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EEG, DC, Slow Cortical Potentials

CONTINUED FROM PAGE 35

is working with basic brain activation processes. One advantage of the Atlantis system is that it permits the exact recording of the precise offset between each channel and the reference, thus providing more information than a single difference channel. It is still possible to train differences, or sums, or other derived values, based on the DC and SCP data recorded for each channel.

This DC/SCP capability can also be used to provide extended EEG frequency range in connection with bihemispheric protocols, to provide training that rewards any shift in the slow potentials, whether up or down. In these applications, both the active and the reference sensor are placed on active sites (e.g. T3 and T4), and the difference between them is used as the training signal. When a wide-band EEG channel is used as for uptraining ("go"), then any shift in the potential will cause a training reward. Training down ("stop") in this context will train the potential to stay constant, and not to change. The most direct method to do such training is to use a standard EEG channel for the feedback, and use the BrainMaster built-in protocol processing software. This provides training using conventional protocol-based approaches, with a working bandwidth range of 0.01 to 120 Hz.

The firmware upgrade provides a number of significant improvements, incl[illegible]al types of DC and SCP re-[illegible]. When used in "Full Atlantis" [illegible]EG signals normally recorded f[illegible]standard EEG training will extend from the range of 0.01 to 120.0 Hz. The software and hardware filters can be used to limit this as desired. It becomes possible, in "Full Atlantis" mode, to design protocols that operate down to 0.01 Hz, and provide useful training data.

In addition to extending the range of the standard 2 or 4 channels of EEG, this upgrade provides the ability, via the "Event Wizard," to access the DC and SCP data directly. This facilitates a variety of protocol approaches including automatic baseline correction, directional training, and complex protocols involving all 4 channels. Protocols can combine conventional EEG training including alpha synchrony, peak-performance protocols, z-score training, or LENS training, with the use of DC or Slow Cortical Potential data.

The Atlantis system does not require any additional hardware modules or special cables in order to record these potentials. It is, as is customary, important to use silver chloride sensors, in order to achieve a valid and stable DC recording. This is because only silver chloride provides a "reversible" ionic interface with the skin and electrolyte, allowing DC signals to pass. Other sensor materials such as gold, silver, and tin, are all "capacitive" and will block DC signals due to the ion layer they build up with the electrolyte (paste or gel).

Many types of silver chloride sensors are generally available, including disposable stick-on EKG sensors and low-cost disposable or re-usable plastic retainers with embedded silver chloride disks, generally held on with a headband or measuring cap. Any of these are usable with the Atlantis equipment. With the use of proper sensors, DC and SCP data are immediately available, without having to resort to using EEG channels for "special" connectors or interface devices to access DC/SCP data. This allows users to learn about DC potentials as they are doing their customary work using any other EEG protocols. This avoids the need to "jump in" to DC work, but rather, it is possible to add DC/SCP monitoring and training without abandoning existing capabilities or familiar procedures. Each EEG channel thus provides both the standard EEG data, as well as the DC/SCP information, on each channel. In addition, in the "Full Atlantis" mode, the EEG channel bandwidth is extended to a range of from 0.1 to 100 Hz, facilitating wide-band EEG work, in addition to the use of DC and SCP data.

There is recent interest in "pushing" the capabilities of EEG systems to operate at low frequencies. Even a conventional EEG system with a low cutoff frequency of 0.5 Hz, has a finite gain at low frequencies. A signal with energy at 0.01 Hz, for instance, may be attenuated by 100 times or more by the EEG amplifier, yet still be measurable. For example, a 100 microvolt shift, when reduced by a factor of 100, still produces a 1 microvolt signal, at the input of a conventional EEG amplifier. However, it is preferable to employ EEG amplifiers that are designed to accurately record these slow potentials, and record them reliably, with valid quantitative results.

This DC/SCP capability operates simultaneously with the existing Atlantis capabilities, as shown in Figure 1. Therefore, in addition to the DC/SCP data, the complete EEG signal, with all of its component bands and protocol processing, are still operational. The built-in continuous impedance measurement is also operational. The new firmware additionally provides access to all of the impedance data

Continued on page 38

Figure 1 – Four-channel training display using ultralow Delta band (top traces), as well as DC and SCP data (bottom panels). The four DC/SCP channels 1, 2, 3, and 4 are recognizable as blue, yellow, green, and red, respectively. The Event Wizard text panel (bottom left) shows the DC and SCP values, while the Event Trend display (bottom right) shows the 4 components in real time, along with the reward indicator.

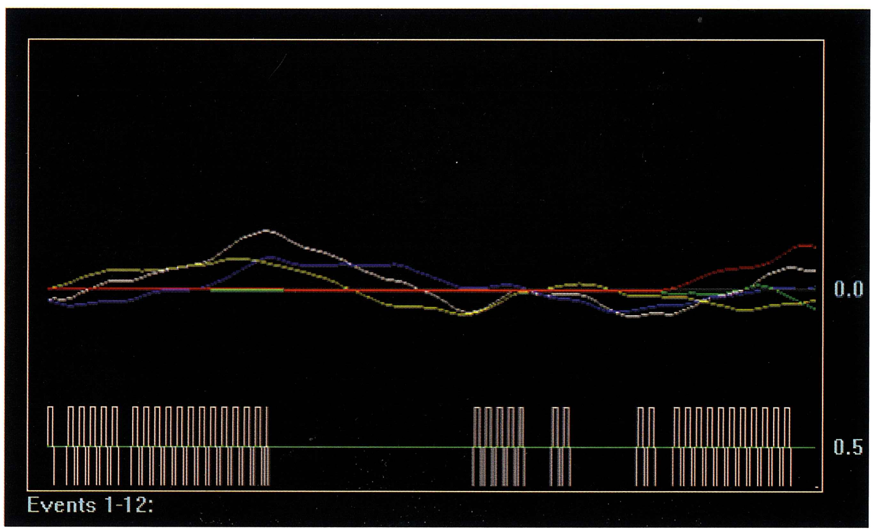

Figure 2. Detail of SCP training screen and reward method. SCP signals for F3, F4, P3, and P4 are shown in blue, yellow, green, and red respectively. Total SCP signal is in white. Rewards are earned when the total SCP potential is rising (bottom indicator).

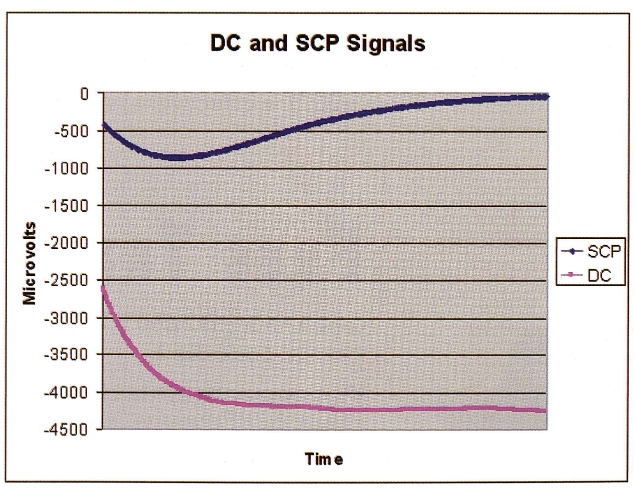

Figure 3. Comparison of SCP and DC signals for a 60-second epoch. The SCP signal (in blue) tends to stay near the baseline (zero value), while the DC signal stays at its full value, which exceeds -4000 microvolts. The SCP signal reflects the negative deflection of the DC signal (in pink), and returns to baseline after the DC signal has stabilized.

from within the PC software. This provides the sensor impedances for all leads, both active and reference on the PC display, and accessible via the Event Wizard. It is therefore possible to record DC/SCP potentials, conventional wideband EEG, and sensor impedances simultaneously, and monitor and train on any or all of these variables in real time. No other system to our knowledge provides simultaneous EEG, DC and SCP, and impedance monitoring on all channels at all times, moreover without additional hardware required.

The DC offsets of all channels are displayed in the status line above each of the raw EEG waveforms at all times, when the Full Atlantis mode is in use. This means that no special protocols or setups are required in order to view the DC data. All 8 frequency bands are also continuously monitored, and can be used for assessment and training, including live Z-Scores. In addition, the DC and SCP data are also available via the Event Wizard, regardless of the other training protocols or displays in use. Figure 2 shows 4 channels of SCP data displayed and trained using the Event Wizard. This approach makes it possible to incorporate DC and SCP work seamlessly into existing designs, without having to resort to special designs in order to access the data. All games, animations, DVD, CD, and other training screens may be controlled by DC/SCP signals. The combination of using standard leads and inputs, and having continual access to DC data, means that DC and SCP work can be incorporated at any time into any BrainMaster training protocols, so long as silver chloride sensors are in use.

With the 4-channel cable available with the Atlantis 4x4, it is possible to connect all 4 EEG channels with only 7 lead wires and a single cable to the user, eliminating confusion and excessive cables. It is hoped that this new capability will help to spread the use of DC and slow cortical potentials, by providing an economical, reliable, and accurate means of recording and training multiple channels, while retaining existing EEG capabilities.

The standard DC/SCP protocols provide a simple and well-defined use of lead wires to record 1, 2, or 4 channels. The standard use of color for 4 channels is the familiar blue / yellow / green / red color scheme, used to distinguish typical channel placements of, for example, F3/ F4/ P3/P4, or C3/C4/T3/T4. Using a standard placement, the 4-channel data are recognizable, as shown in the Figure 1. This design also provides a training feedback variable that is active when the combined shifts of all 4 channels is net positive (signals rising).

Both objectively and subjectively, DC and SCP potentials are a thing apart from conventional EEG rhythms. Figure 3 shows the relationship between SCP and DC signals, for a typical shift occurring over a period of 1 minute. Figure 4 shows an SCP signal simultaneous with the magnitude of a theta wave. An SCP signal does not resemble the magnitude of an alpha or SMR wave that waxes and wanes continually. When using conventional EEG magnitudes, the trainee must learn to let go and allow the feedback to lead the brain into a state that is often difficult to articulate. Some experienced peripheral biofeedback practitioners struggle when confronted with the apparent uncontrollability and relentless waxing and waning of EEG magnitudes. Slow cortical potentials, on the other hand, have a different "flavor." When using SCP signals, there appears to be more of a tendency for there to be essentially no response at all, until the brain decides to do something interesting. Monitoring 4 channels allows the simultaneous observation of all 4 brain quadrants.

When demonstrating 4-channel SCP monitoring and training, trainees may report that after a few minutes, they become aware of something to do with intention and the relationship to the environment, which shows up in SCP signal deflections. For example, when an interesting discussion begins, one or more of the traces may rise for many seconds, reflecting the change in regional brain activation. By observing the location and direction of the shift, it is possible to observe brain responses in real time that are not possible using conventional EEG rhythms. When using a standard F3/F4/P3/P4 montage, the responses may reflect regional hemispheric function, roughly corresponding to the following:

F3: Approach, engagement, interest

F4: Withdrawal, apprehension, disinterest

P3: Language processing, integration with self, logical reasoning and memory

P4: Image processing, integration with environment, spatial reasoning and memory

It is possible to observe correlations and relationships between DC and conventional EEG data using 1, 2, or 4 channels with the Atlantis, or up to 24 channels with the Discovery. It is also possible to simultaneously record, monitor, and train all 8 EEG components in the normal fashion, while DC/SCP data are also recorded and trained. Peripheral measures such as nIR and pIR HEG, Temperature, and HRV can also be monitored continually along with DC, SCP, and EEG signals. No special setup files are necessary for DC or SCP signals to be available for monitoring or training. In addition, live Z-Scores can also be monitored during DC and SCP training by specifying an age and eyes condition for the session, and enabling the Z-Score panel. Continuous impedance monitoring is also enabled when using the Full Atlantis mode.

Figure 5, for example, shows F3 and F4 SCP data over a period of 5 minutes. It is apparent that, at times, the entire frontal cortex is shifting in a similar fashion, demonstrating hemispheric co-ordination of activation patterns. At other times, however, they clearly behave separately, revealing differential hemispheric activity. Figure 6, similarly shows F3 and P3, demonstrating intra-hemispheric slow cortical potentials and their relationship.

DC and SCP potentials provide a valuable window into the brain and mind, and one that has historically been difficult and costly to obtain. With new technology, it is now possible to record and train DC and SCP brain signals in any clinical or research environment.

For further details and links regarding research and the use of DC and Slow cortical potentials, see the BrainMaster Technologies, Inc. Knowledge Base: http://www.brainm.com/kb/entry/302 /

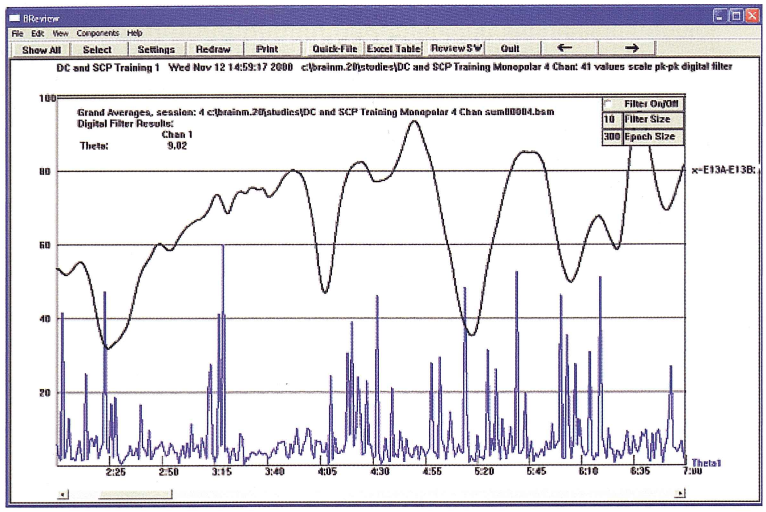

Figure 4. Simultaneous slow-cortical potential (SCP) (black), and filtered magnitude of theta wave (blue) for a 5-minute training epoch. Note that the SCP signals exhibit a characteristically different type of response, when compared to conventional magnitude-based training variables.

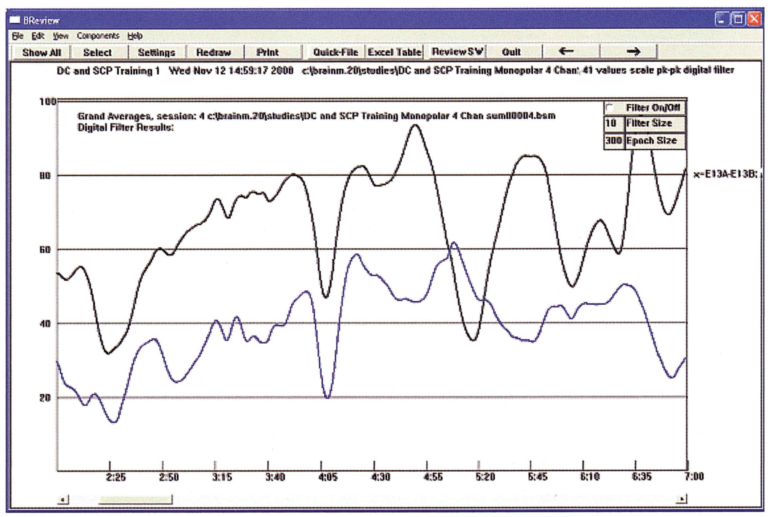

Figure 5. Comparison of F3 (black) and F4 (dark blue) SCP signals. The signals have periods of agreement, and also periods during which they are divergent, and even out of phase.

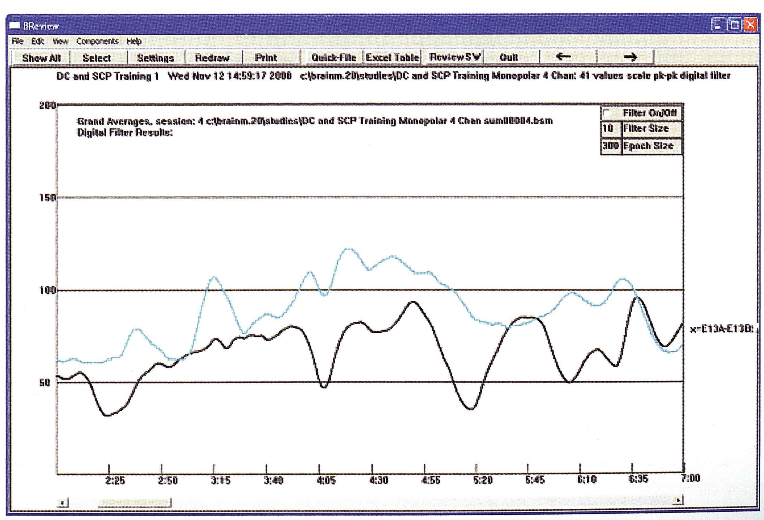

Figure 6. Comparison of F3 (black) and P3 (light blue) SCP signals.

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