

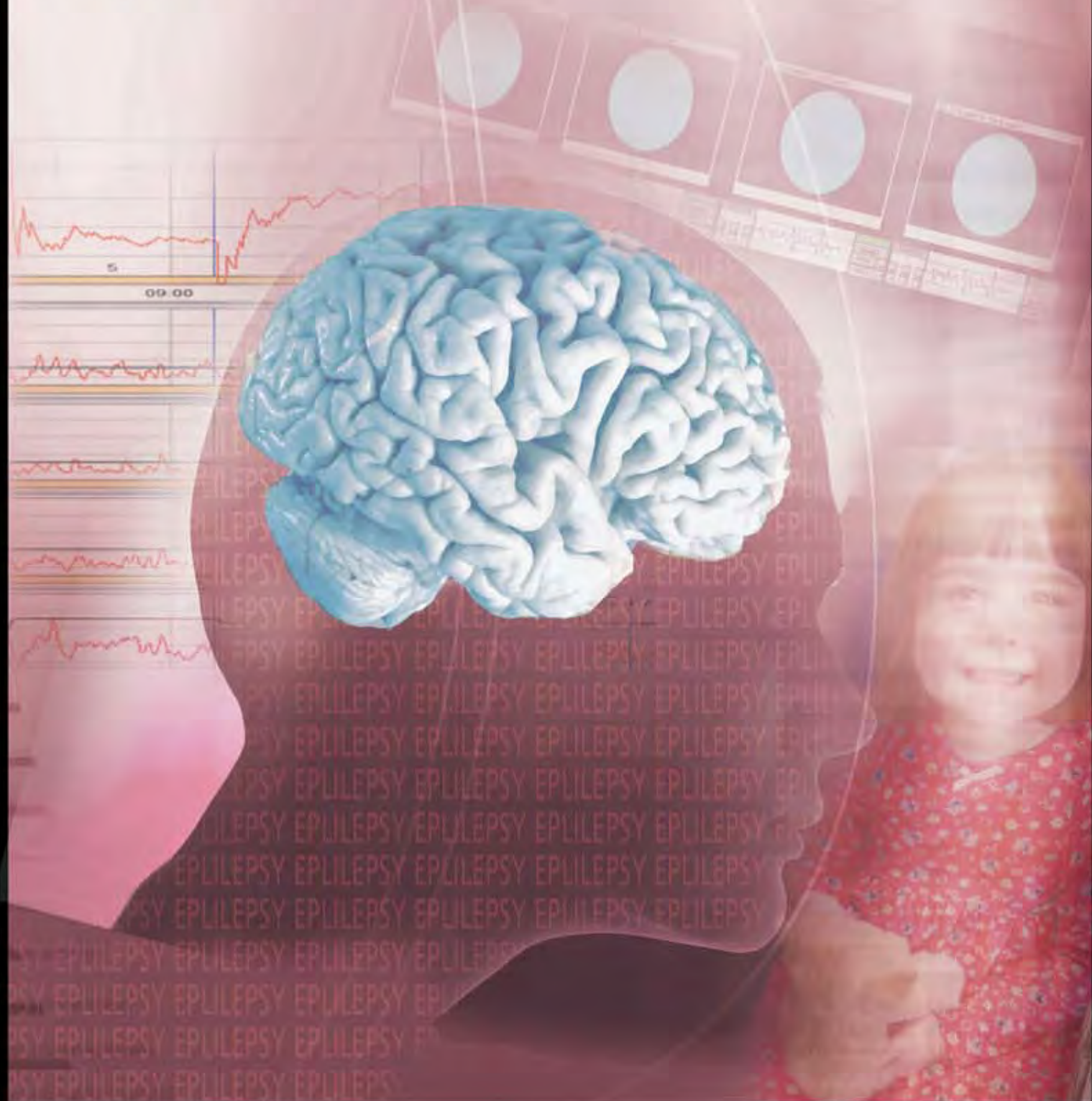


NEURO CONNECTIONS



Summer 2010 *Newsletter*

A joint newsletter from the  ISNER
& the  AAPB Neurofeedback Division



MAKING SENSE OF INFRA-LOW FREQUENCY NEUROFEEDBACK

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ABSTRACT

Infra-low Frequency (ILF) neurofeedback training is loosely defined as training EEG signals below 0.5 Hz. This is generally well understood in the context of slow cortical potentials (SCP), but poorly understood in cases where trainees' claim to discriminate between harmonics differing by hundredths of a Hertz in the 0.1 Hz EEG range (Othmer, 2010). We analyze signals of this frequency to explain what is happening when we train these EEG components. This training can affect both the SCP and long wavelength, rhythmic cortical activity.

BACKGROUND

Real harmonic functions of time take the form $A \cdot \sin(X)$, where $\sin(\)$ is the sine function of an argument given as X , and A is any real number that does not depend on the argument. To display its important structure, the argument X is written as $(wt+h)$ where w is the frequency, t the time, and h the phase.

Harmonic functions form a complete set. This means that any function of time that meets certain conditions can be expressed as a sum of a potentially infinite number of harmonic functions each with a different phase and frequency. For this to be the case a function must be continuous and all of its rates of change must be finite at every moment. Continuity requires that the function model a phenomena that is continuous in time, and "finite rates of change" mean that the phenomena varies smoothly, even if that smooth variation is apparent only at the highest magnification. In particular, even if a phenomenon appears to have an inflection point where it changes direction instantaneously, as discerned by the naked eye, as long as this change either is not literally instantaneous, or it can be modeled as something that is less than instantaneous, then it is completely amenable to being expressed as a sum of harmonic functions.

When a function of time is expressed as a sum of harmonic components it is said to be "decomposed into harmonics," resolved into its "frequency spectrum,"

or shown as a "spectral decomposition." These conditions are met by most measured quantities of natural systems, such as brain waves, and for that reason we can use the technique of spectral decomposition to describe the EEG.

The fact that such a decomposition can be done says little about the function being decomposed. Measuring some function of time and decomposing it into harmonics adds no information to the observation, but it might make some properties of the function more evident. In particular, decomposing the EEG signal makes various important structures of the signal more evident, and we are able to describe the signal more simply. And for the purposes of feedback, the decomposition enables a person to interact with specific aspects of the EEG signal over a period of time, rather than with the signal at an instant.

Harmonic decomposition is straightforward in theory, but the description given above contains assumptions about how natural phenomena can be modeled mathematically. The two major assumptions are that the phenomena being modeled is not truncated, which means that it has no start or end, and that its values are known at all times. In practice our observations do begin and end, and are intermittent. These practicalities violate the basic requirements of harmonic analysis but, because the underlying phenomena do satisfy the requirements, we can adopt looser rules that apply to our finite and intermittently observed EEG signal. As a result we get some "fine print" that goes under the name of Signal Analysis.

Neurofeedback practitioners learn the rudiments of harmonic analysis, understanding that the erratic EEG signal is composed of harmonic elements. Practitioners are unfamiliar with signal analysis and are unaware of the ambiguities that signal analysis introduces into the EEG spectrum. In particular, infra-low frequency neurofeedback is misunderstood.

ILF FEEDBACK

The longest spectral wavelength that can be extracted from a series of EEG measurements is equal to the time period over



which the EEG signal is sampled. This means that to resolve a frequency of 1/8 Hz, or a wave of 8 seconds duration, requires analyzing at least 8 seconds of EEG data. An observation over this time period, or epoch that samples at a typical rate of 256 values per second enables us to discriminate between spectral components roughly 0.1 Hz apart.

Let's suppose the feedback shown to the trainee is updated 16 times per second. With an 8 second epoch, and with each feedback event separated from the next by 1/16 of a second, each subsequent feedback event is highly correlated. If the amplifier is recording 256 EEG values per second, an 8 second window accumulates 2,048 EEG values. The 8-second windows for two feedback events that are 1/16 of a second apart share 2,032 of the same EEG measurements. That is to say only 16 of 2,048 EEG measurements contribute new information that is fed back to the trainee. As a result, the feedback is about 1/20th as responsive to changes in the trainee's EEG as it would be if an epoch of 1/2 second were used, which would only collect 128 EEG values.

Due to this sluggish feedback response we might expect the trainee to be unable to modify their EEG when training a frequency as low as 0.1 Hz. To better understand this we should ask how the trainee's short-term responses change the infra-low frequency components.

WHAT IS ILF TRAINING DOING TO THE EEG?

The EEG signal has its greatest effect on a specific spectral component when it changes in synch with that component. This says nothing more than to satisfy feedback criteria that reward alpha waves, for example, the trainee generates alpha waves. But over

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a short interval of time, an interval much shorter than the frequency of the ILF spectral component being trained, the trainee can only generate a small portion of ILF cycle. What sort of change in their EEG must the trainee accomplish in the short term in order to satisfy a feedback reward criteria based on an EEG component whose full period extends over a much longer time?

The change of a sine wave can be represented by a polynomial that is an infinite sum of terms each of which contains higher powers of the argument. This is called the Taylor Series expansion and for the sine wave it begins with a term that's linear, followed by a term that's proportional to the cube of the argument, and then the argument to the 5th power, and so on. It's important to note that these contributions alternate in sign, which means that when the value of the argument is less than 1, the contributions from these terms both get smaller and partially cancel each other out. When the argument is much less than 1 the higher order terms contribute proportionally little to the infinite sum and can be ignored at the expense of incurring a small error. The smaller the argument, the better the approximation one gets when ignoring the higher order terms.

The long wavelength components of the EEG have the smallest arguments, and when considered over a time interval short compared to their wavelength it's sufficient to compare them by comparing the effects of their leading terms in this power series. In the limit of extremely small arguments one can consider the sine function to look like a segment of a straight line. For example, if you looked at just a few inches of a long, smooth ocean wave, then in spite of the fact that its surface is described by a curved line, the few inches of profile that you could see would look like a straight line that was tilting back and forth like a seesaw. If you were to consider waves of increasingly shorter wavelength, then at some point you would start to see some curvature in this short line; the curvature would appear in phase with this seesaw motion curving up, going flat, and then curving down.

It's important to note that the contribution from a small portion of the full wave component, say 1/2-second of an 8-second waveform, is not symmetric in its

amplitude about zero. That is to say that if you were looking at a short straw floating on the surface of a long wave, then not only would the straw rock back and forth like a seesaw, but it would also rise and fall at the same time. What this means for feedback is that the trainee is rewarded for adding a component to their EEG signal that varies between being electrically net positive to net negative over the longer term. This is true whenever the feedback is being generated over a time period much shorter than the epoch over which the spectral components are measured. The difference in the trainee's response to rewards at different long wavelength components is that the longest components record the greatest contribution from the smoothest change in trainees EEG, which is to say a more linear change in the electrical signal over time, while positive contributions to the shorter wavelength reward components (though still much longer than the feedback interval) are generated by incrementally more rapid changes that continue to have a net positive or net negative contribution.

IS ILF FEEDBACK TRAINING THE SCP?

Slow cortical potentials (SCP) are discussed by Ute Strehl (2009) who shows them to have positive and negative electrical components. SCP changes persist over periods longer than 6 seconds, show a sharp cusp, a slow relaxation period, and are not periodic. Nevertheless, if 8 seconds of a SCP signal is decomposed into harmonics, then it will include long wavelength components. Its largest signature, however, will be at zero frequency as typical of a DC excursion away from electrical neutrality, but this component is automatically removed from the EEG spectra on that supposition that it represents an artifact in the phenomena of interest, which are presumed to be net neutral, periodic signals. The SCP long wavelength components might resemble the long wavelength components of sinusoidal cortical activity over the short time intervals to which the trainee is attending. If there is no way to discriminate the SCP from ILF sinusoidal activity, then there is no way to distinguish whether it's the SCP or ILF sinusoidal activity that is being rewarded.

Because the electrical signature of the SCP is neither smooth nor periodic it will have a complicated set of harmonics that we cannot assume to be dominated by low frequency components. Using the harmonics of the EEG to train SCP would re-

quire rewarding more than the frequencies in a narrow band, and would instead require rewarding a set of frequencies that, when added together, reproduce that aspect of the SCP that the trainee is to develop.

Tom Collura (January, 2009) contrasts the electrical behavior of low frequency harmonics with that of slow cortical potentials in his discussion of BrainMaster's Atlantis EEG amplifier. He points out three differences:

- Long wavelength periodic EEG signals display much weaker voltages than changes due to the SCP.
- Differences in the nature of the training, which partly reflects the different nature of the signals, and which leads to different subjective experiences for the trainee.
- The SCP is episodic by nature and so is less amenable to continuous forms of training, such as entrainment and threshold-based rewards.

Meaningful Signals?

A greater potential difference is that whereas the SCP is thought to originate in the action of the glial cells, the long wavelength EEG components may be nothing more than artifacts generated by transient shifts in the DC potential. That is to say they may be unimportant. This point of view seems to be held by some leaders in the field of neurofeedback, but since it has not been elucidated we're left to guess possible reasons behind it. Here are three possible arguments.

Objection: "EEG wavelengths longer than the EEG epoch don't exist."

Response: I'm unaware of anyone claiming to train such wavelengths.

Objection: "Long duration phenomena cannot effect, or be affected by short time-scale training."

Response: While it's true that 1/2-second changes in the EEG are an order of magnitude less powerful than the long wavelength signal itself, we commonly observe changes of this magnitude in signals as a response to feedback training. It's plausible that similar differences may be significant here.

Objection: "Long duration phenomena are unaffected by training in which the trainee's response occurs over a small fraction of such long duration phenomena."

Response: This objection may be based either on the idea that a slow, neural phenomenon cannot respond rapidly, or on

the assumption that slow and fast neural phenomena are not linked. While we lack knowledge of the generators of the EEG, it is common for nonlinear systems to couple at different frequencies, the slow rocking of a house fan due to an imbalance of the rapidly spinning blades being one example. In this case adjusting the motor's rheostat to make a small change in the speed of fan blades can immediately stop the fan's slow oscillations.

More relevant examples might be the long time-scale phenomenon of task planning that depends on the short time-scale phenomenon of mental focus, or the way a dancer improves the fluidity of his or her overall movement by focusing on such momentary phenomena such as the movements of joints, the shifting of their balance, and the mastery of their gestures. In both cases contributions over a 1/2 second interval affect the phenomena that exist over a 5 to 10 second interval. In both cases the brain must discern the small changes of which the larger phenomena are composed.

TRANSIENTS

There are two sources of transient phenomena in the EEG: episodic neurological events, such as the SCP, and the time relaxation of the amplifier's circuit due to an abrupt change in the signal. The origin of the first transient is in the brain, the origin of the second transient is in the amplifier.

In both cases the signal generates multiple harmonics, and in both cases training the originating event can be attempted using an AC or a DC amplifier.

Training with a DC amplifier aims to train base-line changes in the overall electrical potential and presumes the importance of this aspect of the phenomena. Training with an AC amplifier removes changes in the base-line and presents only harmonic components over the epoch that is observed. Training based on the signal's harmonics presumes these harmonics capture some mechanism of importance. The character and the duration of the displayed phenomena are different in each case.

A transient signal has both impulse and harmonic features. It can be fully represented as either a changing, instantaneous, DC potential, or as a complete set of harmonics measured over a period of time. Each approach has the potential to train different aspects of the signal. The two training approaches are complementary, each reflecting aspects of the transient signal missing from the other.

CONCLUSION

Assuming the SCP activity is sufficiently "loud" in low frequency harmonics, so as to enable the brain to distinguish it from other cortical activity, ILF training may impact some aspect of it. Transients also generate high frequency components ignored by ILF

feedback that play an important role in describing the signal, and may play an important role in training. Training the whole SCP would require the simultaneous reward of a mixture of many frequencies, not only the distinctive long-term DC polarity changes reflected in the zero frequency component of the EEG signal. If there are important cranial rhythms in the 0.1 Hz region, and if the slow harmonic components of the SCP are of importance, then these are best trained with a slow response AC amplifier.

The important point is that ILF training is mathematically plausible, may provide a window onto the training of SCP phenomena, and may also have repercussions for the training of slow, periodic cortical rhythms that may or may not be related to the SCP. Regardless of the signal's origin both DC and AC training can be conducted, and each training modality focuses on different aspects of the signal.

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REFERENCES

- Collura, T.F. (1995). Basic Electronics and Physics, p.1-10 in: Levin, K. and Luders, H. (eds.) Comprehensive Clinical Neurophysiology, Elsevier.
- Collura, T.F. (January 2009). Practicing with Multi-Channel EEG, DC, and Slow Cortical Potentials, *NeuroConnections*, 34.
- Othmer, S. & Othmer, S. (Spring 2010). Introduction to Intra-low Frequency Training, *NeuroConnections*, 14.
- Strehl, U. (2009) "Slow Cortical Potentials Neurofeedback," *Journal of Neurotherapy*, 13(2): 117.

DEAR ISNR MEMBERS—

The Public Relations Committee is in need of your assistance to vastly extend the range of their efforts in two simple ways:

1. Providing suggestions of media targets for the PR Committee and Board of Directors to address with letters and other types of contact. The working definition of "media target" would be
 - national television programs,
 - radio programs,
 - professional organizations,
 - patient or organizations concerned with neurofeedback potential disorders
 - continuing education organizations for various professional fields that should be knowledgeable about or referring for neurofeedback,
 - prominent individuals who have either written about a disorder that

- neurofeedback improves or
 - celebrities who themselves have gone public with a disorder or bothersome symptom that neurofeedback likely would successfully address
 - science or other journalists that might be interested in neurofeedback
- 2. Taking the initiative and a few minutes to send individual faxes, e-mails, or hard copy letters to media targets that are locally based or of particular interest to you as individual providers. As an assist, the Committee has written a form letter that you can tailor to your own style to fit specific situations of which

you become aware. Contact Grayce Stratton at DrGrayceStratton@aol.com for further assistance.

The Committee will compile a listing to be made available to the entire membership when complete.

THE PUBLIC RELATIONS COMMITTEE:

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