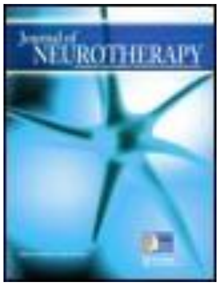

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Bispectral Analysis of the EEG: A Brief Technical Note

Jack Johnstone PhD [a b]

[a] Q-Metrx, Inc.

[b] Aspect Medical Systems, Inc.

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Bispectral Analysis of the EEG: A Brief Technical Note

Jack Johnstone, PhD

Electroencephalography (EEG) has traditionally been used in clinical neurology to evaluate epilepsies and encephalopathies. Recording and quantitative analysis of EEG is used increasingly to evaluate a broader range of neurobehavioral disorders. Important new applications further extend the utility of processed EEG measures to monitoring the depth of anesthesia (Sigl & Chamoun, 1994) and predicting patient response to psychotropic medication (Leuchter, Cook, Witte, Morgan, & Abrams, 2002).

One of the most exciting technological developments over the past decade is the application of bispectral analysis to EEG signals. Bispectral analysis is a computationally intensive technique originally used in geophysical applications. It was first used to study EEG signals by Kleiner, Huber, and Dumermuth (1969), Barnett, Johnson, and Naitpoh (1971), and Dumermuth, Huber, Kleiner, and Gasser (1971), and was studied with regard to characterizing nonlinear components of the EEG by Saltzberg, Burton, Burch, Fletcher, and Michaels (1986). However, the technology was not available for routine clinical use until work by scientists at Aspect Medical Systems, Inc. (Newton, MA) demonstrated the clinically efficacy of a derived index utilizing bispectral analysis for monitoring depth of anesthesia (Greenwald, Smith, Sigl, Cai, & Devlin, 2000; Rosow & Manberg, 1998).

Almost all biological systems exhibit nonlinear behavior. Bispectral analysis is a signal processing technique that characterizes signals aris-

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Jack Johnstone is President and CEO of Q-Metrx, Inc., and a consultant to Aspect Medical Systems, Inc.

Address correspondence to: Jack Johnstone, Q-Metrx, Inc., Suite 304, 2701 West Alameda Avenue, Burbank, CA 91505.

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ing from both nonlinear and linear generating processes. Importantly, this technique quantifies the degree of phase coupling, or instantaneous coherence, of the EEG signal. Most applications for coherence analysis involve spatial coherence, that is, the similarity of the signal recorded from two different electrodes on the scalp. For example, it is common to see estimates of the similarity of alpha activity recorded from the left occipital region compared to right.

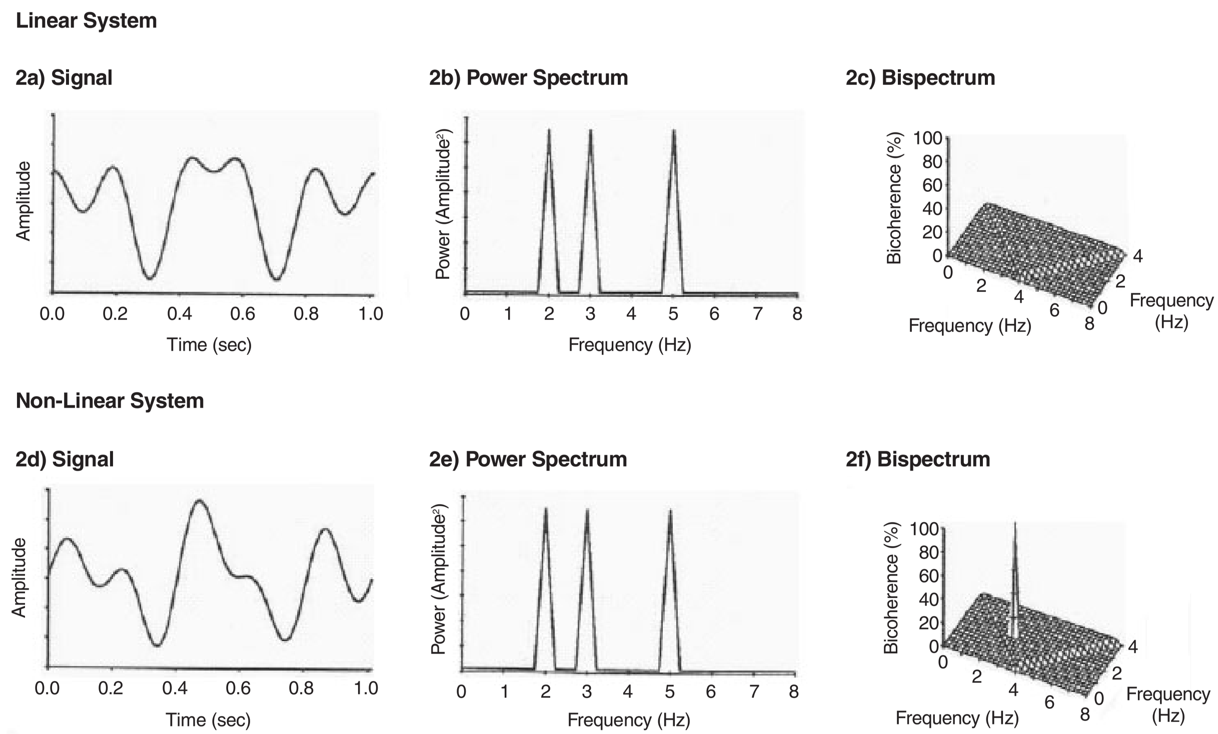
With bispectral analysis we evaluate the coherence or coupling among frequencies recorded from a single region. Since the method compares all frequencies with all others, it provides a more comprehensive evaluation on the signal. Harmonic relationships among frequencies are well characterized using the bispectrum. Certain EEG features have a significant bispectrum with respect to harmonic relationships. For example, the mu rhythm demonstrates significant correlations among 5, 10, 20, and 30 Hz activities (Dumermuth, Gasser, & Lange, 1975).

Figure 1 shows the power spectrum and bispectrum for two test signals. The first signal was generated from a linear system with no coherence among frequencies. The power spectrum and bispectrum are shown. The second signal was generated from a nonlinear system with clear coupling between 2 and 3 Hz seen with the bispectrum. Power spectral analysis is insensitive to the addition of the nonlinear component.

Until recently there has been no effective method for measuring the depth of anesthesia and associated loss of awareness. The Bispectral Index (BIS) developed by Aspect Medical Systems uses a composite of three qEEG measures. The display of the monitoring system provides a number from 1 to 100 indicating the depth of anesthesia. A measure of relative beta activity (the log of 30 to 47 Hz divided by 11 to 20 Hz) is used when the EEG has characteristics of light sedation. The bispectral measure "SynchFastSlow" (the log of the sum of the bispectral peaks over the range .5 to 47 Hz divided by the sum of bispectral peaks over the range 40 to 47 Hz) predominates during surgical levels of hypnosis. Measures of the amount of time where the EEG is suppressed ("burst suppression") predominates during deep anesthesia. BIS appears to be most sensitive to the hypnotic effects of anesthesia as opposed to analgesic effects (for review see Rampil, 1998).

The automated monitoring system developed by Aspect Medical Systems uses a single combined recording electrode placed on the forehead. This electrode contains an active, reference, and ground sensor and an additional sensor used specifically to monitor surface EMG. On-line techniques are used to detect and suppress artifacts commonly

FIGURE 1. Power spectrum and bispectrum sensitivity to nonlinearity.



This example shows a signal generated from a linear system that has the same power spectrum as a different signal generated from a nonlinear system whereas the bispectrum distinguishes the signals as dissimilar (with permission of Aspect Medical Systems, Inc.)

seen in the operating room environment such as eye blinks, 60 Hz interference, and electrocautery noise.

The Bispectral Index technique has been extensively validated with a variety of anesthetic agents over a large population of patients. It appears to be a robust measure of the hypnotic influence of anesthesia. Due to the ease of use of this method it is a candidate for use in related situations, such as measuring depth of sleep.The BIS does appear to reflect the stages of sleep in man (Takahashi, Sakai, & Matsuki, 1999). The means BIS values for the awake state and the classical stages of sleep are as follows:

Awake	93.9
Stage I	88.3
Stage II	80.6
Stage III	55.0
Stage IV	41.0
REM	88.8

The EEG during REM is desynchronized and appears similar to that seen during Stage I sleep.

An objective monitor of patient drowsiness has potential utility in routine EEG recording. There are patient populations that show patterns suggesting under-arousal and are similar to normal drowsy patterns. Many patients diagnosed as having attentional problems (ADD/ADHD) show elevated anterior theta frequency activity, a pattern similar to that seen commonly with normal drowsiness. A method to separate pathology from normal drowsy patterns could be very helpful in evaluation of individual patients. Similarly, many patients with head injury demonstrate hypersomnolence which might be differentiable from normal drowsiness utilizing technology such as bispectral analysis.

The BIS also reflects loss of awareness during induction of anesthesia. Lawful relationships have been documented between BIS values and the ability to respond to command as well as between BIS and measures of recall. As BIS values drop, the ability to respond and remember is impaired, notably at different rates. The use of BIS or a similarly derived measure might be used as an index of decline in disorders of awareness such as dementia and delirium. Preliminary work suggests decreased waking BIS values in patients with Alzheimer's disease.

The BIS and bispectral analysis of the EEG generally have the advantage of providing clinically important information while retaining a significant ease of use factor. The BIS can be used with minimal training by non-specialized personnel, and testing can be completed in less time than the routine EEG recording. Studies extending the use of BIS to other clinical populations and situations are currently under way. New technical advantages also may eventually allow for training voluntary modulation of these and related measures.

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