Brain Wave Signal (EEG) of NeuroSky, Inc.

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NeuroSky®
Brain-Computer Interface Technologies

The NeuroSky product families consist of hardware and software components for simple integration of this biosensor technology into consumer and industrial end-applications. All products are designed and manufactured to meet exacting consumer specifications for quality, pricing, and feature sets. NeuroSky sets itself apart by providing building-block component solutions that offer friendly synergies with related and complementary technological solutions.

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What is a Biosignal?

The term 'biosignal' is defined as any signal measured and monitored from a biological being, although it is commonly used to refer to an electrical biosignal. Electrical biosignals (bio-electrical signals) are the electrical currents generated by electrical potential differences across a tissue, organ or cell system like the nervous system.

Typical bio-electrical signals are ECG (Electrocardiogram), EMG (Electromyogram), EEG (Electroencephalogram) and EOG (Electrooculogram). GSR (Galvanic skin response) and HRV (Heart rate variability) are also thought of as bio-electrical signals, although they are not measured directly from electrical potential differences.

What is a Neuro-Signal?

Neuro means brain; therefore, 'neuro-signal' refers to a signal related to the brain. A common approach to obtaining neuro-signal information is an Electroencephalograph (EEG), which is a method of measuring and recording neuro-signals using electrodes placed on the scalp.

What is EEG?

An electroencephalograph (EEG) is the recorded electrical activity generated by the brain. In general, EEG is obtained using electrodes placed on the scalp with a conductive gel. In the brain, there are millions of neurons, each of which generates small electric voltage fields. The aggregate of these electric voltage fields create an electrical reading which electrodes on the scalp are able detect and record. Therefore, EEG is the superposition of many simpler signals. The amplitude of an EEG signal typically ranges from about 1 uV to 100 uV in a normal adult, and it is approximately 10 to 20 mV when measured with subdural electrodes such as needle electrodes.

The FFT (Fast Fourier Transform) is a mathematical process which is used in EEG analysis to investigate the composition of an EEG signal. Since the FFT transforms a signal from the time domain into the frequency domain, frequency distributions of the EEG can be observed. EEG frequency distribution is very sensitive to mental and emotional states as well as to the location of the electrode(s). Two types of EEG montages are used: monopolar and bipolar. The monopolar montage collects signals at the active site and compares them with a common reference electrode. The common electrode should be in a location so that it would not be affected by cerebral activity. The main advantage of the monopolar montage is that the common reference allows valid comparisons of the signals in many different electrode pairings. Disadvantages of the monopolar montage include that there is no ideal reference site, although the earlobes are commonly used. In addition, EMG and ECG artifacts may occur in the monopolar montage. Bipolar montage compares signals between two active scalp sites. Any activity in common with these sites is subtracted so that only difference in activity is recorded. Therefore some information is lost with this montage.

The 10-20 international system is used as the standard naming and positioning scheme for EEG measurements. The original 10-20 system included only 19 electrodes. Later on, extensions were made so that 70 electrodes could be placed in standard positions. Generally one of the electrodes is used as the reference position, often at the earlobe or mastoid location.

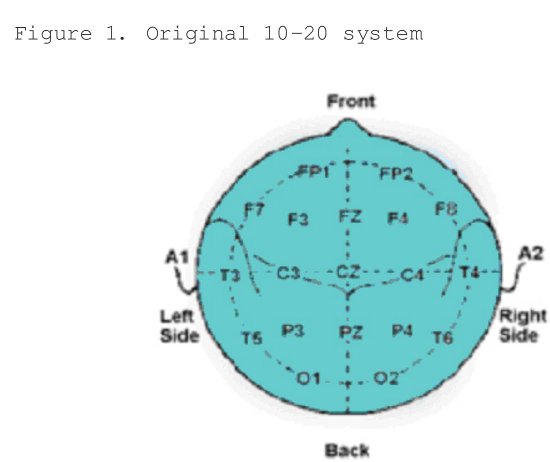

Figure 3.1: Figure 1

Normal EEG

EEG is generally described in terms of its frequency band. The amplitude of the EEG shows a great deal of variability depending on external stimulation as well as internal mental states. Delta, theta, alpha, beta and gamma are the names of the different EEG frequency bands which relate to various brain states, as described in the following pages.

Figure 2. EEG signal patterns

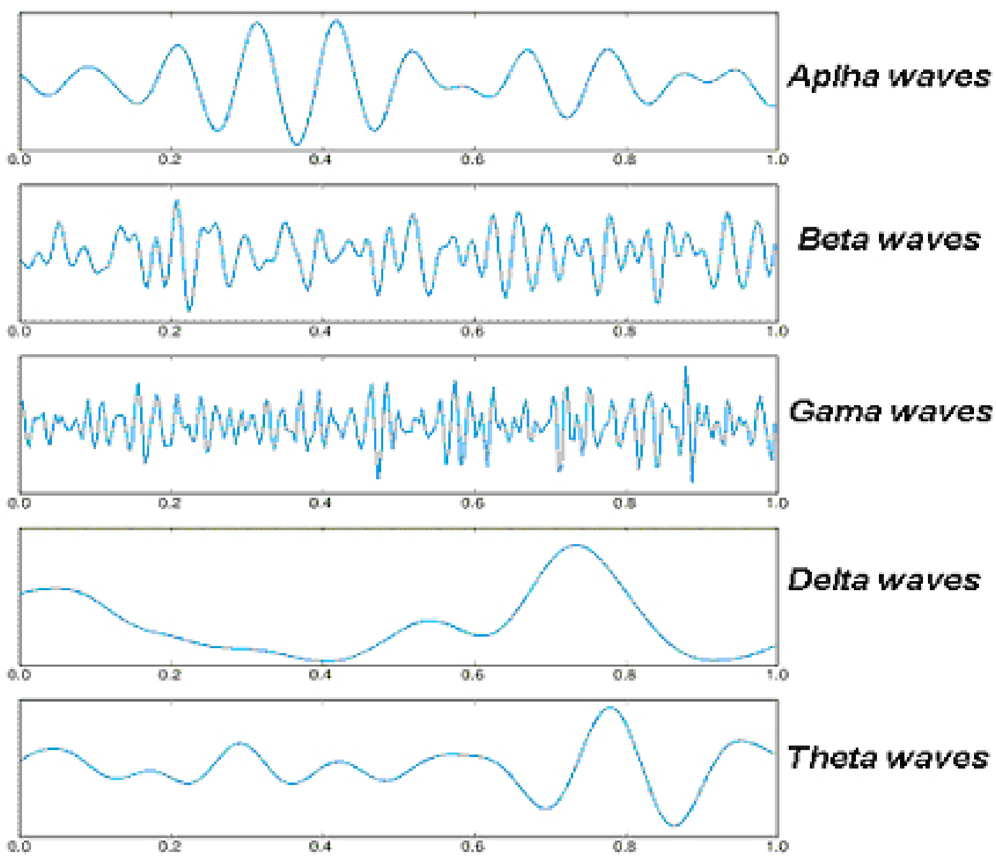

Figure 4.1: Figure 2

Table 1. EEG frequency bands and related brain states

Brainwave Type	Frequency range	Mental states and conditions
Delta	0.1Hz to 3Hz	Deep, dreamless sleep, non-REM sleep, unconscious
Theta	4Hz to 7Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8Hz to 12Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	12Hz to 15Hz	Formerly SMR, relaxed yet focused, integrated
Midrange Beta	16Hz to 20Hz	Thinking, aware of self & surroundings
High Beta	21Hz to 30Hz	Alertness, agitation
Gamma	30Hz to 100Hz	Motor Functions, higher mental activity

EEG Artifacts

Since EEG signals are very weak (ranging from 1 to 100 μV), they can easily be contaminated by other sources. An EEG signal that does not originate from the brain is called an artifact. Artifacts can be divided into two categories: physiologic and non-physiologic. Any source in the body which has an electrical dipole or generates an electrical field is capable of producing physiologic artifacts. These include the heart, eyes, muscle, and tongue. Sweating can also alter the impedance at the electrode-scalp interface and produce an artifact.

Non-physiologic artifacts include 60 Hz interference from electric equipment, kinesiologic artifacts caused by body or electrode movements, and mechanical artifacts caused by body movement.

EEG Signal of NeuroSky System

NeuroSky has developed a dry sensor system for consumer applications of EEG technology. The NeuroSky system consists of dry electrodes and a specially designed electronic circuit for the dry electrodes.

NeuroSky has been conducting benchmark tests of the dry EEG by comparing EEG signals measured by the dry sensor system with signals from the Biopac system, a well known wet electrode EEG system widely used in medical and research applications. EEG was simultaneously recorded by the NeuroSky system and the Biopac system. Electrodes for the two systems were placed at the same location, as close together as possible without interfering with one another. Gold-plated dry electrodes were used for NeuroSky system, while silver-silver-chloride disposable electrodes with gel were used for Biopac system. EEG was recorded for various conditions such as with the subject relaxing and in a meditative state, alert and in an attentive state, and during eye blink artifacts.

Following is a comparison of the raw EEG signals of NeuroSky and Biopac systems with the subject in a relaxed state.

Figure 3. Raw EEG signals of NeuroSky and Biopac systems
(Red line is Biopac, blue line is NeuroSky)

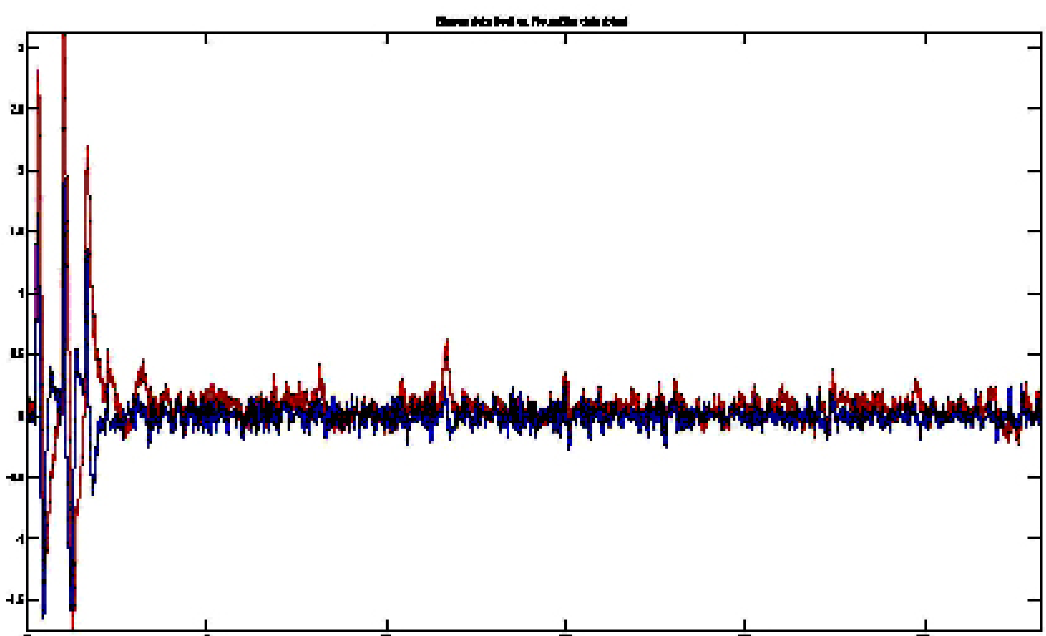

Figure 6.1: Figure 3

The red line represents the raw EEG signal of the Biopac system, while the blue line represents the raw EEG signal of the NeuroSky system. Both systems show a similar wave pattern during the resting state, as well as sensitivity to eye blinks.

The raw EEGs of the two systems were then compared more precisely over an interval of 10 seconds. The data analysis interval was arbitrarily chosen from 15 to 25 second in 30-second test data.

Figure 4. Raw EEG signals during the resting state

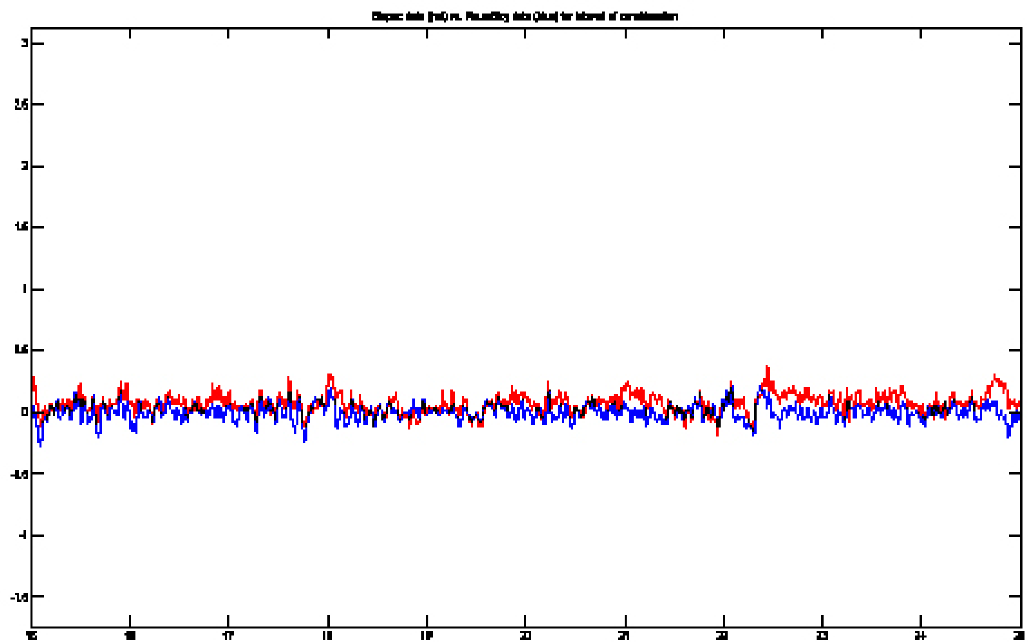

Figure 6.2: Figure 4

To compare the EEG signal characteristics of the two systems, the FFTs of the raw EEG were taken over one second for each system. Then, correlation coefficients for the resulting power density values were computed for frequency bands of one to 30 Hz.

Table 2. Correlation coefficient values of FFT results

Time (seconds)	Correlation Coefficient	Meditation Rating	Attention Rating
15 – 16	0.771	73	61
16 – 17	0.712	78	56
17 – 18	0.858	80	45
18 – 19	0.567	88	41
19 – 20	0.564	93	43
20 – 21	0.581	86	38
21 – 22	0.321	95	41
22 – 23	0.685	88	43
23 – 24	0.751	85	45
24 – 25	0.842	76	56
Average power spectrum	0.715		

As shown in table, the correlation coefficients of power spectrum between the two EEG signals were high enough. It means that frequency distributions of the two EEG signals are very similar.

In the following figures, examples of the raw EEG signal and its FFT for the NeuroSky system and the Biopac system are graphically presented. In the raw EEG graphics, there is a gap of 3 data points per second due to different sampling rate of the two systems (sampling rate of NeuroSky system is 128 Hz and that of Biopac system is 125 Hz.).

Figure 5. Raw EEGs and Power density values (15~16 second)

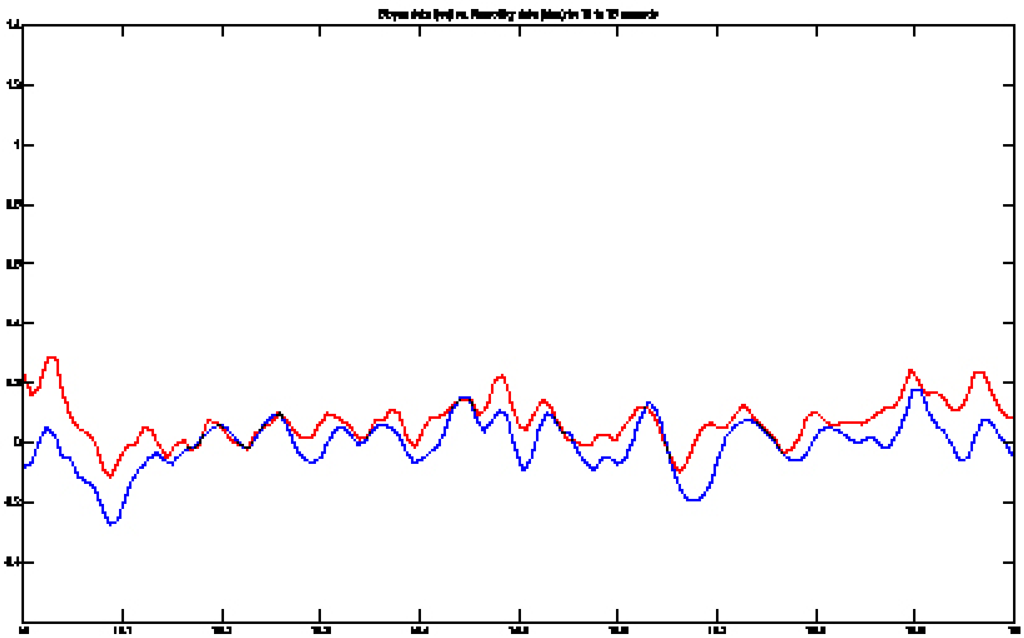

Figure 6.3: Figure 5.1

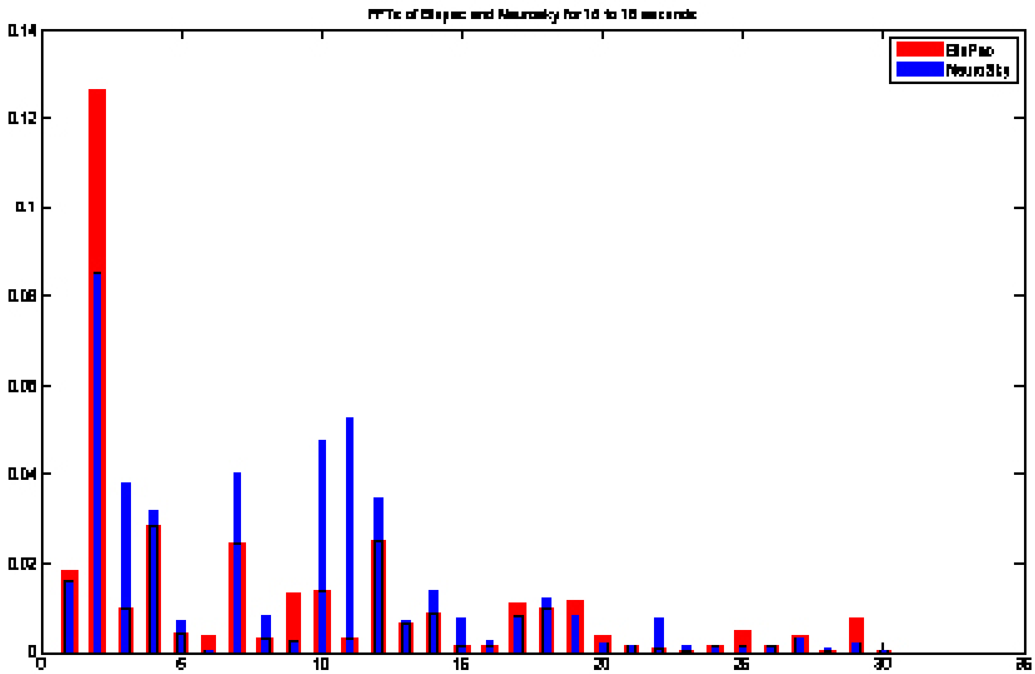

Figure 6.4: Figure 5.2

Figure 6. Raw EEGs and power density values (17~18 second)

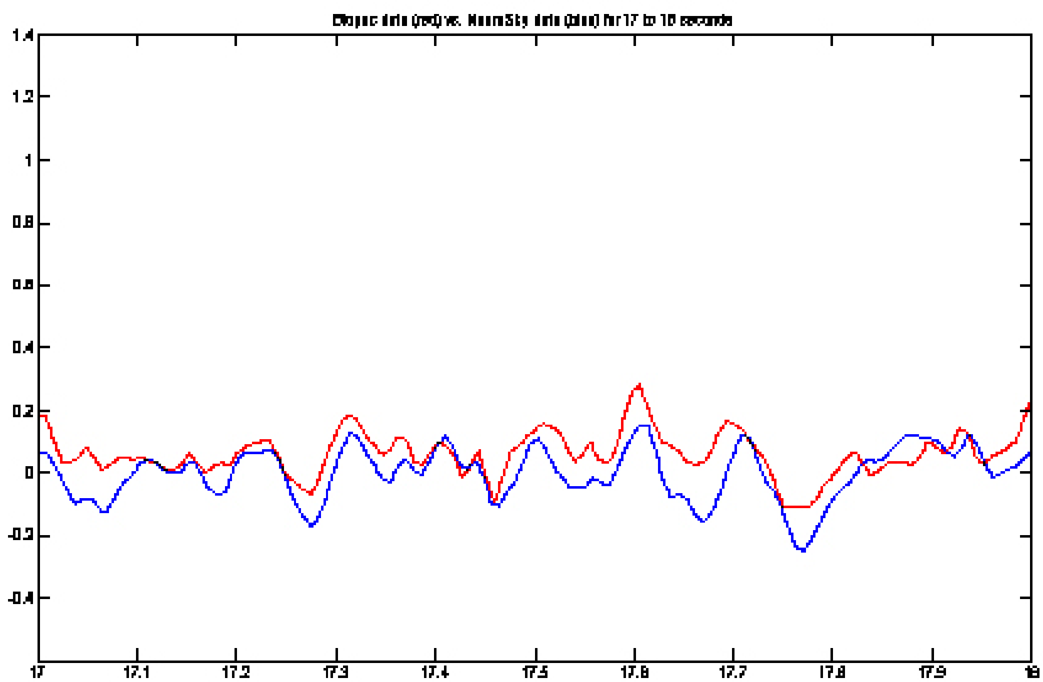

Figure 6.5: Figure 6.1

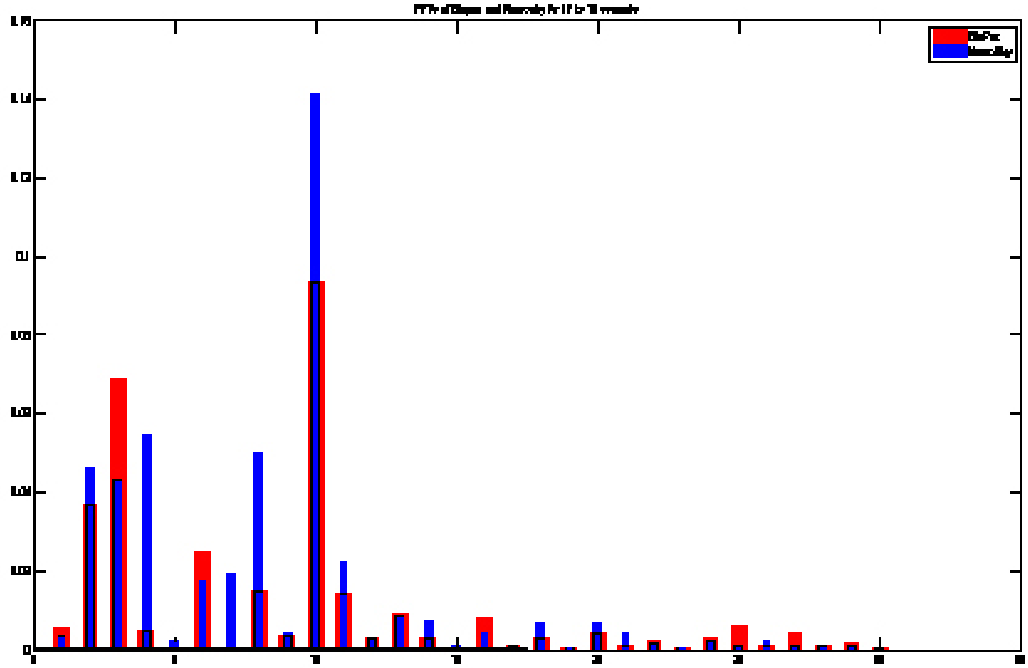

Figure 6.6: Figure 6.2

Figure 7. Raw EEGs and power density values (19~20 second)

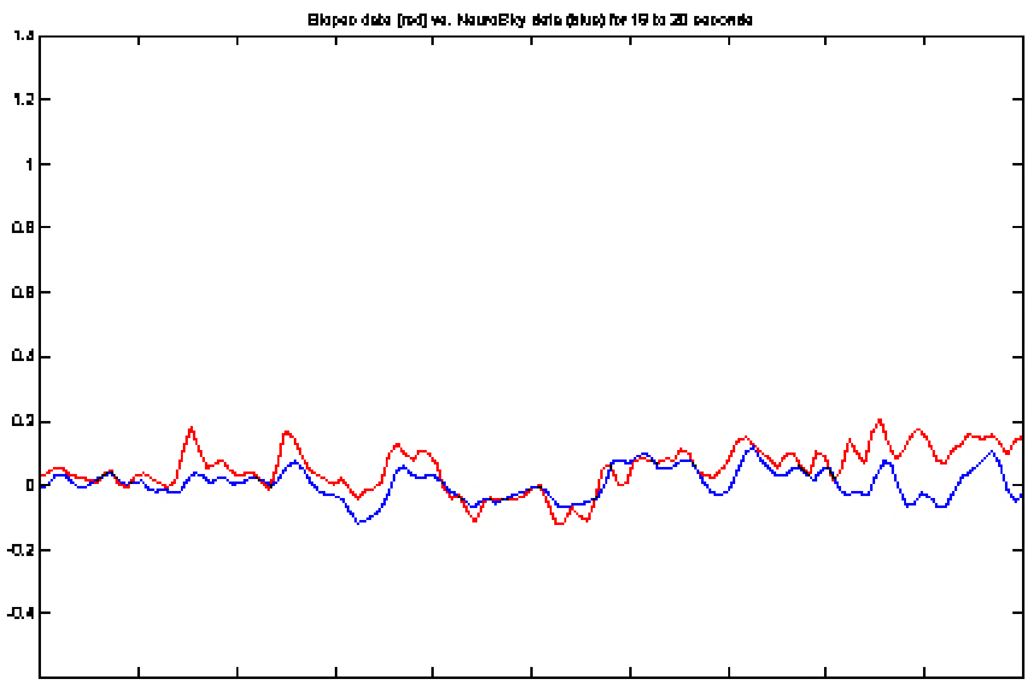

Figure 6.7: Figure 7.1

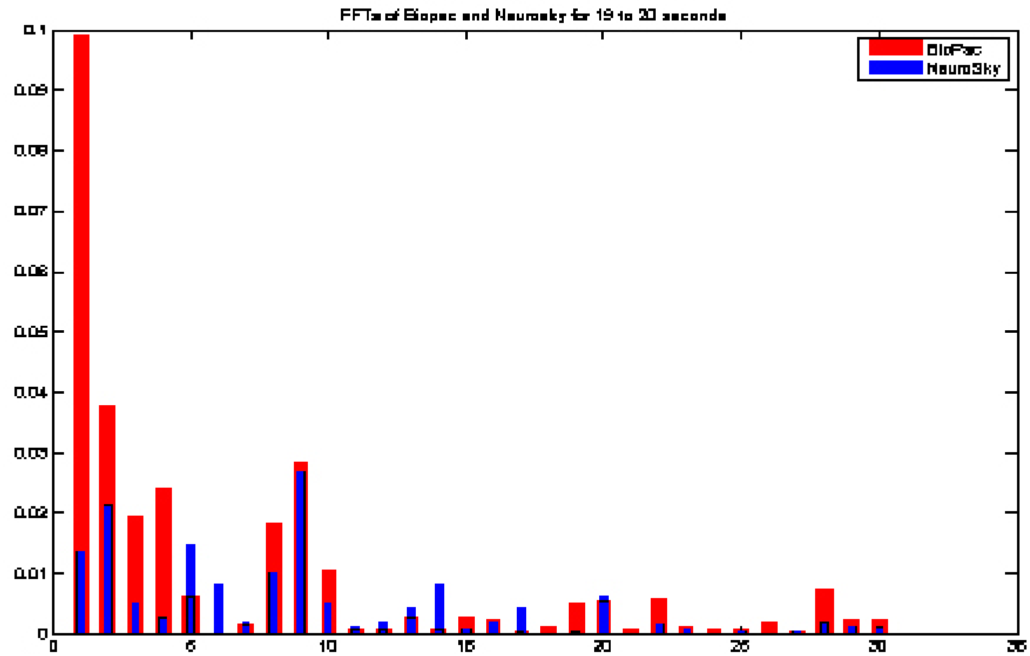

Figure 6.8: Figure 7.2

Figure 8. Raw EEGs and power density values (21 ~ 22 second)

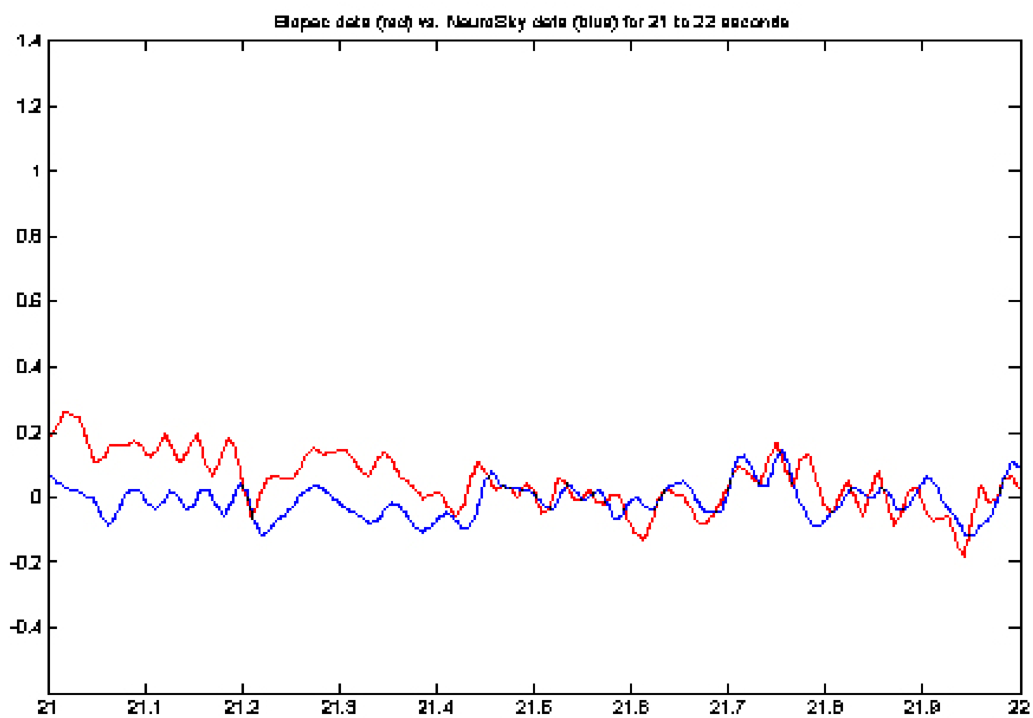

Figure 6.9: Figure 8.1

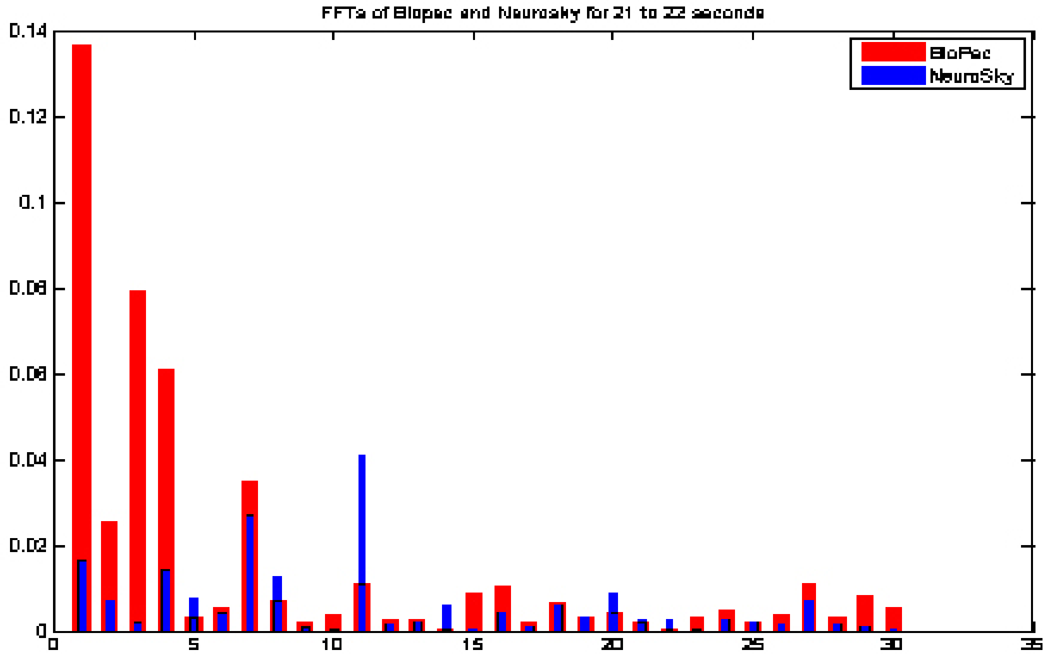

Figure 6.10: Figure 8.2

Next, the two systems were compared for a subject in an alert 'attention' state. Signals were arbitrarily sampled from 15 to 19 second in 30 second test data. As before, the FFT was performed for each second of data and the correlation coefficients were computed. The following results show that two EEG signals of NeuroSky system and Biopac system are very similar.

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Figure 9. Raw EEGs during 'attention' state
{{:figure9.jpg?400| Figure 9}}
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Table 3. Correlation coefficients of FFT results

Time(s)	Correlation Coefficient	Attention Level
15-16	0.916	76
16-17	0.858	83
17-18	0.648	91
18-19	0.601	91
Average Power Spectrum	0.936	

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Figure 10. Raw EEGs and power density values (16 ~ 17 second)
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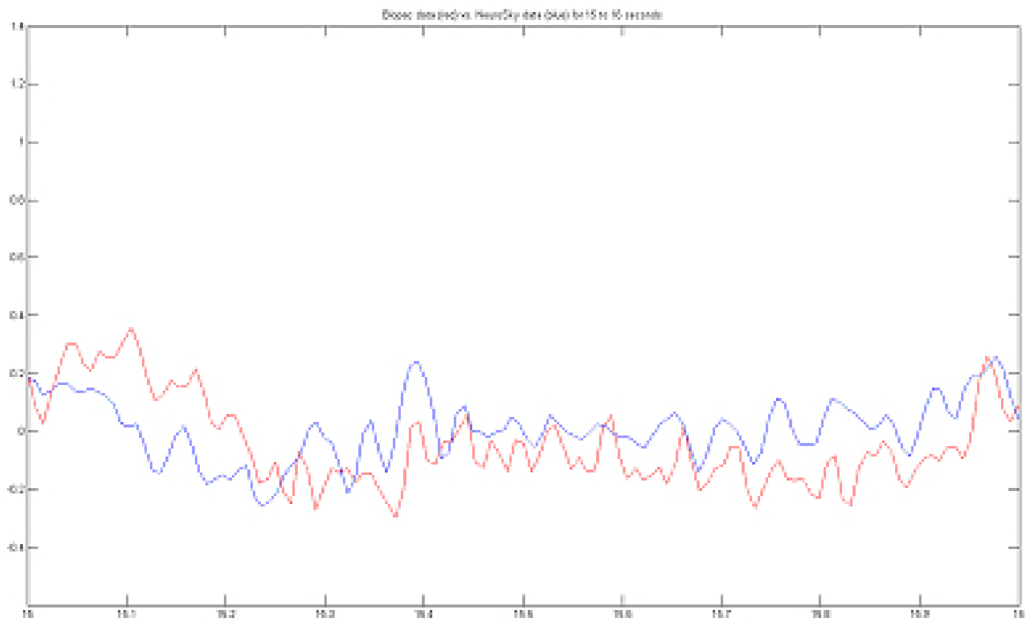

Figure 6.11: Figure 10.1

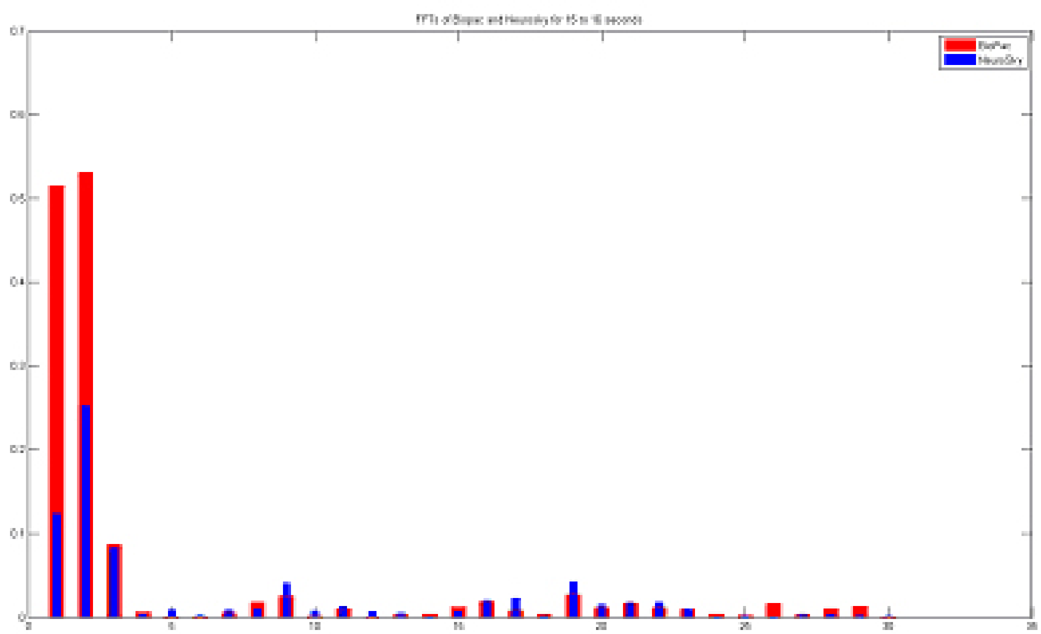

Figure 6.12: Figure 10.2

Figure 11. Raw EEGs and power density values (17 ~ 18 second)

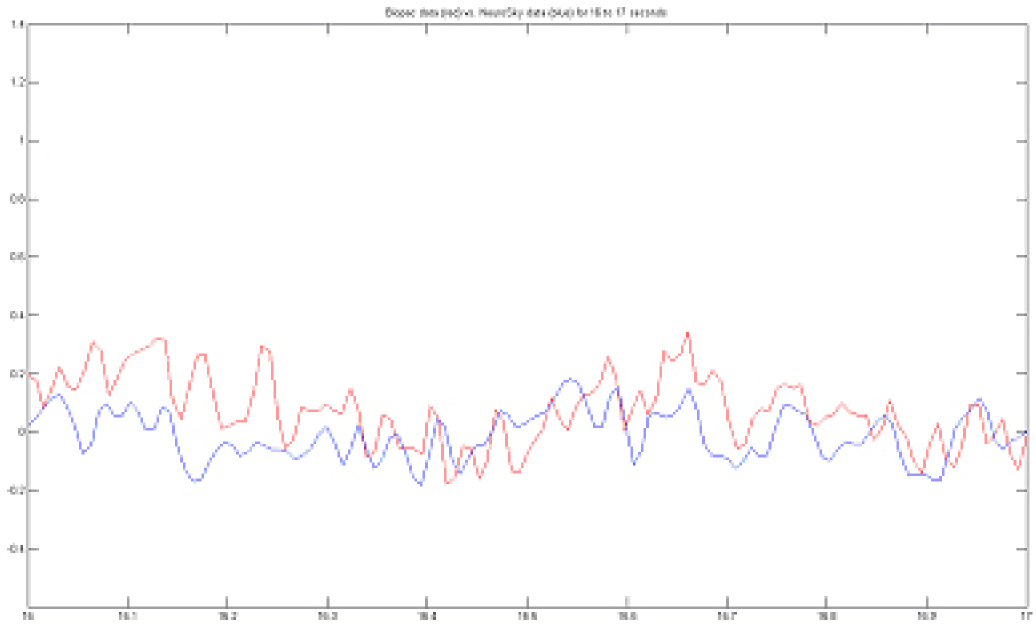

Figure 6.13: Figure 11.1

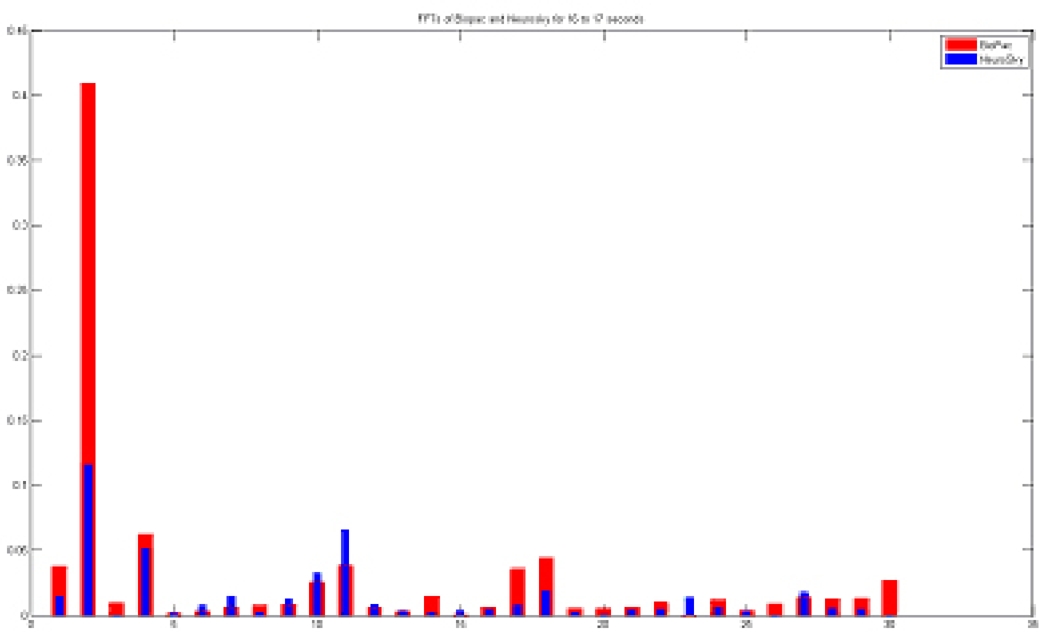

Figure 6.14: Figure 11.2

Figure 12. Raw EEGs and power density values (18 ~ 19 second)

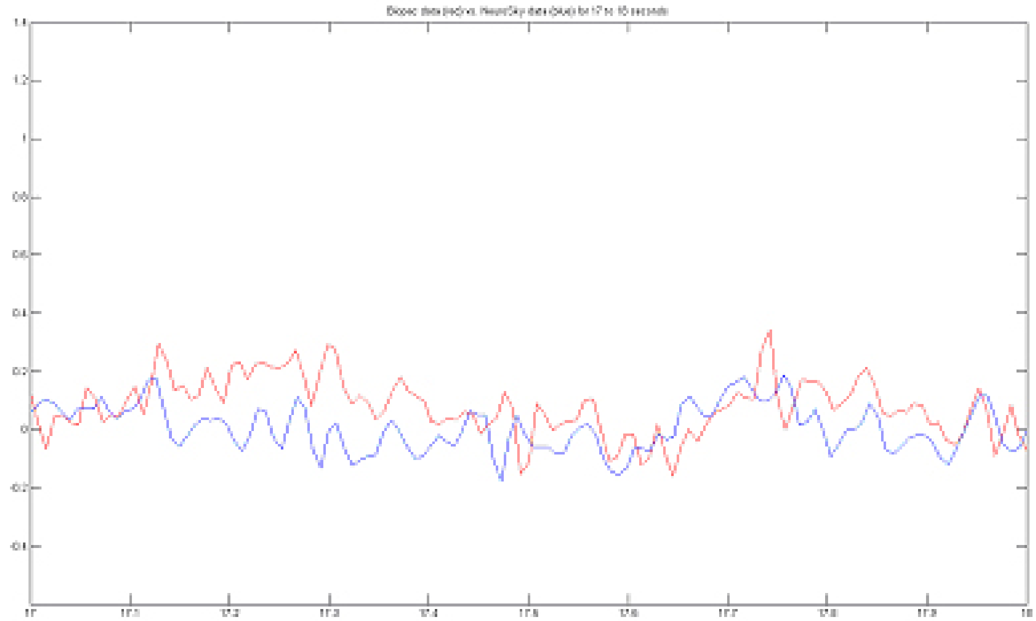

Figure 6.15: Figure 12.1

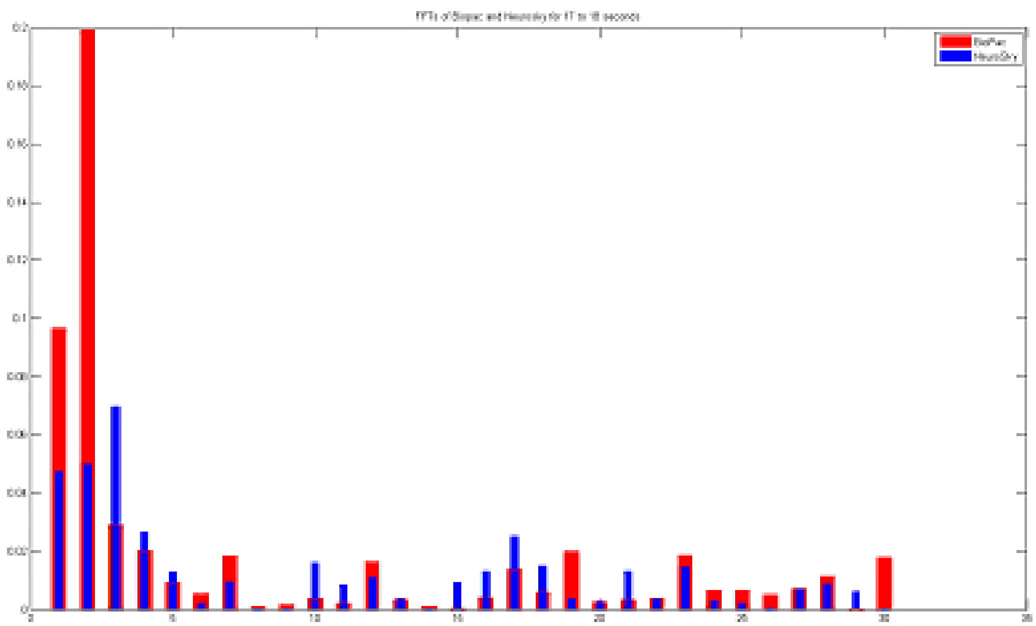

Figure 6.16: Figure 12.2

The following figure graphically compares the average power spectrums of the two signals. The power density distribution shows the same pattern except low frequency bands where power density of Biopac shows higher than that of NeuroSky system. This may be caused by low frequency fluctuation noise in Biopac data which uses wire of 3 feet long between the pre-amplifier and electrodes; the NeuroSky system (headset) uses a few inches of wire between the electrode and pre-amplifier.

Figure 13. Averaged power density values

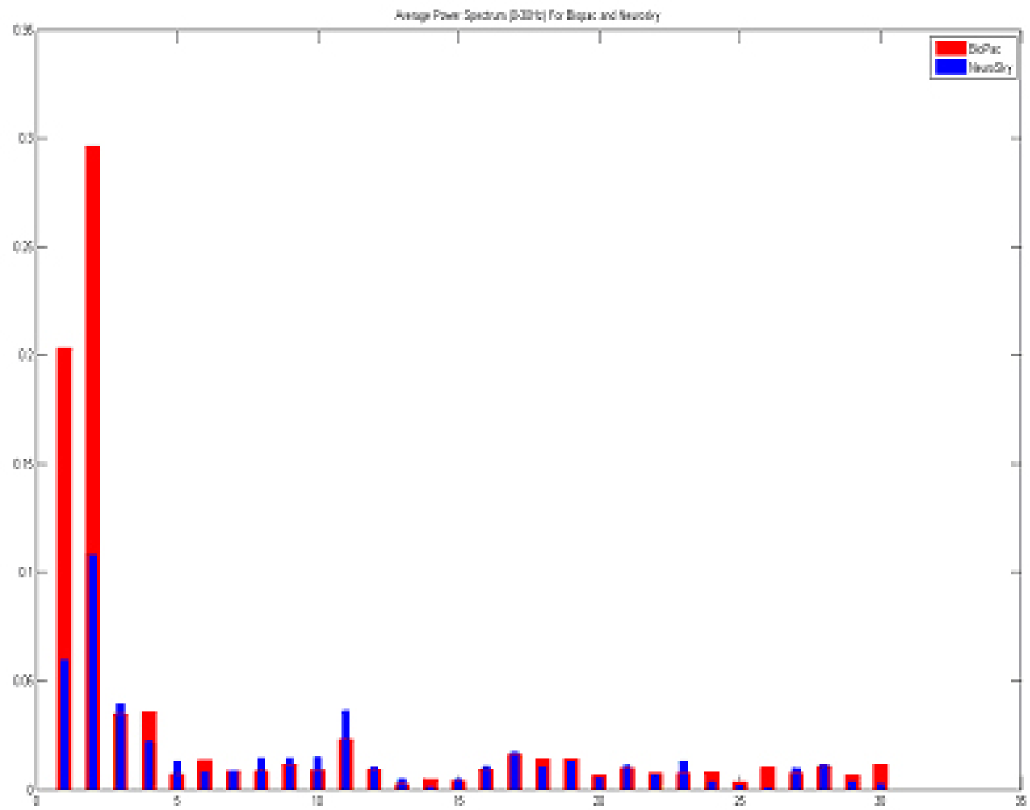

Figure 6.17: Figure 13

The response of the two systems to eye blinks artifacts in the EEG signal was also compared. The following shows the raw EEG signals of NeuroSky system and Bipac system, and both are sensitive enough to detect eye blink signals.

Figure 14. Raw EEGs with eye blink artifacts

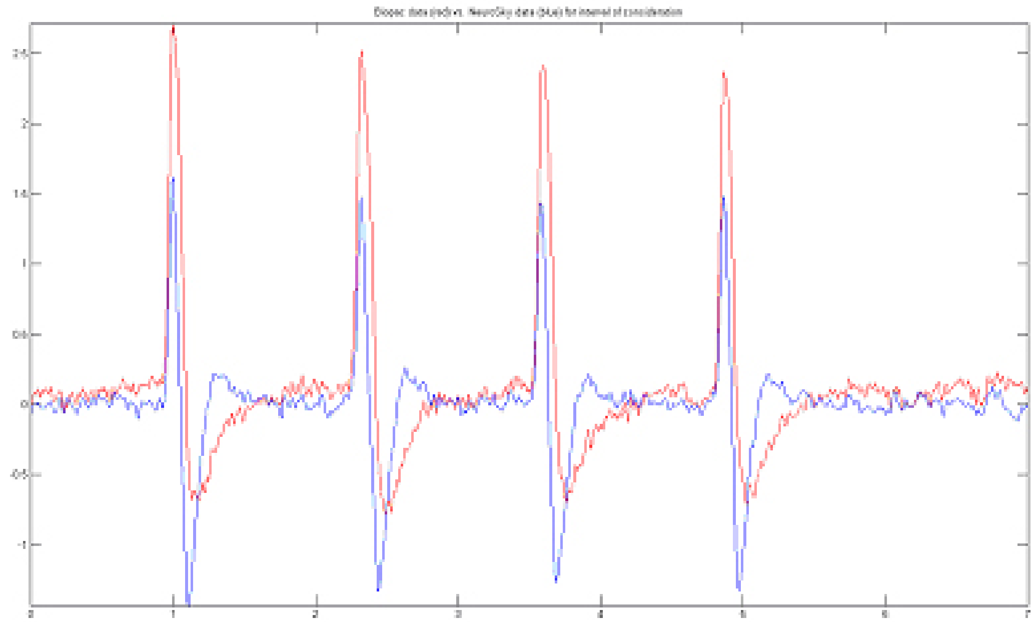

Figure 6.18: Figure 14.1

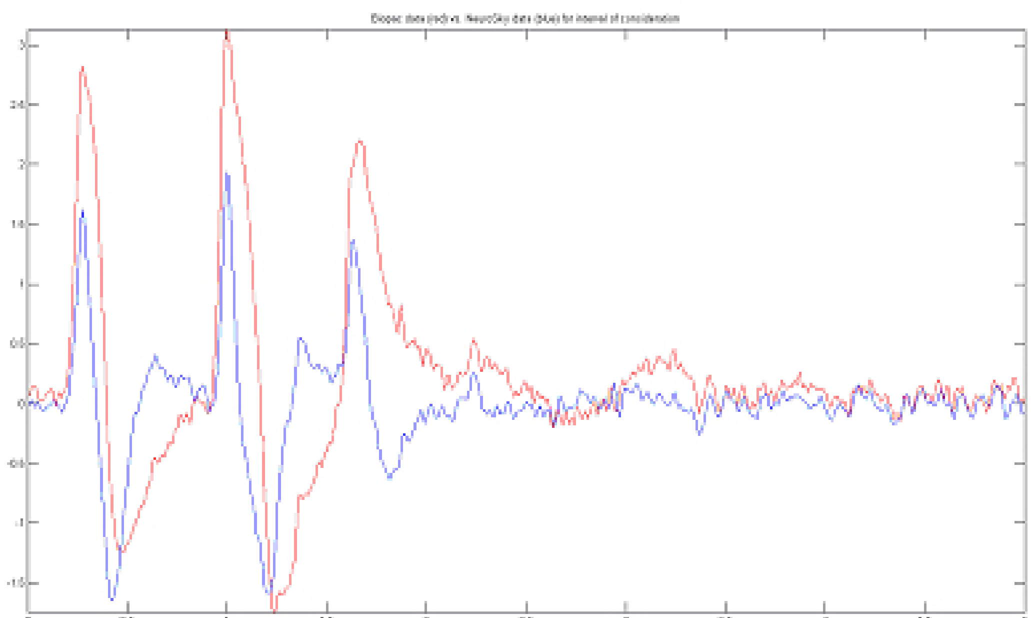

Figure 6.19: Figure 14.2

Summary

Raw EEG signals with dry electrodes of NeuroSky system were compared to those with wet electrodes with Biopac system. FFTs were performed to compare signal characteristics of the EEGs, especially power spectrums. Results show that EEG signals of NeuroSky system are compatible to those of Biopac system.

EEGs of Biopac system show a little bit more noise in low frequency bands. It may be caused by longer wires between electrodes and pre-amplifiers. The length of wires were 3 feet in Biopac system, while shorter than 10 inches in NeuroSky system. NeuroSky system also fixes the wires so that they cannot move during EEG measurement. As a result, NeuroSky system is more noise-resistant. NeuroSky system may have an advantage when it is used in real living environment and consumer product applications.