

Low-Cost Electroencephalography Device for Use in Biophysics Teaching

● IVANA ŠKRAŇKOVÁ
AND JAN ŠLÉGR

ABSTRACT

This paper describes the possibilities of supporting the teaching of neural tissue biology and biophysics through experiments with a simple, commonly available electroencephalography headset. Data are transmitted over a Bluetooth virtual serial port and can be analyzed in several ways by students or used solely as a potential motivational factor for teaching otherwise challenging and abstract curriculum about the human brain.

Key Words: *biophysics; electrocardiography; lecture demonstration.*

○ Introduction

Biophysics is an integral part of biology, even though it is not a standard part of the K–12 curriculum. That is why the Biophysical Society provides additional information and lesson plans (Biophysical Society, 2020). Teaching biophysics allows for a large number of demonstration experiments and laboratory work for students to complete in lessons.

Biophysical measurements include, for example, electrocardiography (ECG) measurements. Myers and Burgess (2003) showed how heart rate depends on body load and the independence of RR interval duration (interval between two maximas in ECG curve, which can be used to calculate heart rate). As an example, the principles of electromyography can be demonstrated and the correlation between the measured voltage on the muscle surface and grip force can be determined with the same ECG device (Corotto, 2017). Additionally, the lung capacity can be determined (Llewellyn, 1971) or experiments with a thermal imager can be done (Haglund et al., 2016).

Here, we present a simple approach to support teaching of challenging curriculum dealing with neural tissue in hands-on experiments. Unlike electrocardiography (ECG) and electromyography (EMG) measurements, where voltages measured on the human body are in the order of millivolts, electroencephalography (EEG) is measured on the head and voltages are in the order of

microvolts. This makes ECG and EMG measurements a much bigger challenge. Although not impossible, construction of an EEG amplifier in a typical school environment is challenging. Therefore, experiments with a commercially available, but relatively cheap, EEG headset are described below.

○ Biophysical Background

Neural tissue is responsible for the organization and coordination of most bodily functions. It consists of the central nervous system and the peripheral nervous system. The highly sophisticated composition of nerve tissue ensures the reception, management, transmission, and processing of information from the external and internal environment of the organism. Nervous tissue is formed from neurons and glial cells. Neurons are the basic unit of nervous tissue, which are able to send messages, in the form of nerve impulses (electrical signals), around the body through the spinal cord. Glial cells have a supportive function, provide the nerve cell with nutrition, and produce myelin and phagocytose defective neurons (Kahle & Frotscher, 2003).

Neurons can generate and spread electrical impulses through their highly specialized construction. They consist of a cell body containing a large spherical nucleus that is surrounded by the cytoplasm, as well as receptors and ion channels, which are responsible for the generation and spread of electrical impulses (an action potential). From the cell body, two types of long processes expand – dendrites and axons.

There is only one axon per cell body, but the number of dendrites varies (Brodal, 2003).

○ EEG Principle

Brain activity, which is a reflection of interneuron synapses, has been studied by the electroencephalography medical method (Bear et al., 2016). EEG is a noninvasive conventional electrophysiological



Figure 1. (Left) NeuroSky MindWave headset. (Right) NeuroSky demonstration software.

method that provides a record of the electrical activity in the central nervous system via electrodes, which are placed on the head. An electroencephalogram is a graphical record of EEG curves that registers differences in the changing electric field of the brain between two electrodes.

These electrodes are placed according to the prescribed International Electrode Placement System, or simply the “10-20” system (Klem et al., 1999). Each electrode is marked with a letter and a number. The letter characterizes an area of the brain over which the electrode is located and the number indicates the location of the electrode within the frontal, central, parietal, or temporal areas. Each electrode is 10% or 20% distant from the others. Bipolar electrode connections can be used to compare potential between two electrodes and allow precise localization of a bearing. A unipolar electrode engagement measures the potential between an active point of the brain tissue (the exploratory electrode) and a zero-potential point (e.g., an auricle). Several basic types of electrical activity are distinguished on the EEG record: alpha, beta, theta, and delta activity. These activities appear on the record in the form of waves that differ in the following graphoelements: shape, frequency, and amplitude (Misulis, 2013).

Alpha activity occurs when the eyes are closed. The occurrence of alpha activity is typical for physical and mental relaxation, rest, and calm, where regeneration processes are taking place. It is characterized by an amplitude of 20 μV and a frequency of 8–12 Hz. Beta activity manifests itself in a vigilant state of mental and physical activity, with open eyes. It has an amplitude of 5–20 μV and a frequency of 12–30 Hz. Theta activity occurs when the body and mind are in deep attenuation and are not responding to any sensory stimuli. It is characterized by drowsiness or deep relaxation. Long-term memory improves in this band. Theta’s rhythm ranges from 4 to 8 Hz, with an amplitude of $\sim 30 \mu\text{V}$. Delta activity is characterized by very slow waves with frequency <4 Hz and amplitude of $\leq 200 \mu\text{V}$ and occurs during deep sleep or unconsciousness. During delta activity, the organism is deeply regenerated (Majumdar, 2013; Rhoades & Bell, 2013).

Activation methods are used to enhance brain activity, causing the activation of pathological manifestations, and thus better definition of all graphoelements and diagnoses. Activities such as opening the eyes, hyperventilating through the nose and mouth,

photostimulation by a stroboscope, and sleep deprivation are used.

The primary use of EEG is in medical diagnoses, namely in the diagnosis of epilepsy. Epilepsy is characterized by epileptic seizures that result from abnormal brain activity. It is one of the most common neurological diseases (Misulis, 2013). An EEG is further used to investigate sleep disorders and is also used in psychiatric institutions.

○ Measurement Method for Classrooms

The NeuroSky MindWave Mobile headset was chosen because of the low price and Bluetooth capability (see NeuroSky, 2020a). At the time of this writing, the device is available from a number of dealers at a cost of \$90. There are many instructions available for interfacing with the headset (see, e.g., NeuroSky, 2020b; Pantech Solutions, 2020). For our purposes, we used a personal computer. The headset can be paired with a computer over Bluetooth, and a program called ThinkGear Connector (NeuroSky, 2015) allows other software to receive data from the headset. Of course, the measured data are not comparable to data from commercial medical EEG devices because only one differential electrode is used, instead of the many used in medical devices. However, even this one measured curve is sufficient for demonstration in the classroom and for simple tasks that students can perform by themselves.

For lecture demonstrations and motivational purposes, the software provided by the manufacturer (MindWave Mobile 2 can be used, which displays raw data as well as a visual representation of alpha, beta, gamma, and theta rhythms and calculated values of attention and meditation (Figure 1). Students can see how their brain activity affects the displayed values of attention and the shape of the measured EEG curve (e.g., while they try to solve a mathematical problem). The program window can be presented to the classroom via a data projector, and EEG curve changes representing changes in voltage, measured on the volunteer’s head, can easily be seen.

For advanced courses or integrated science learning, it may be interesting for students to write and use their own software for

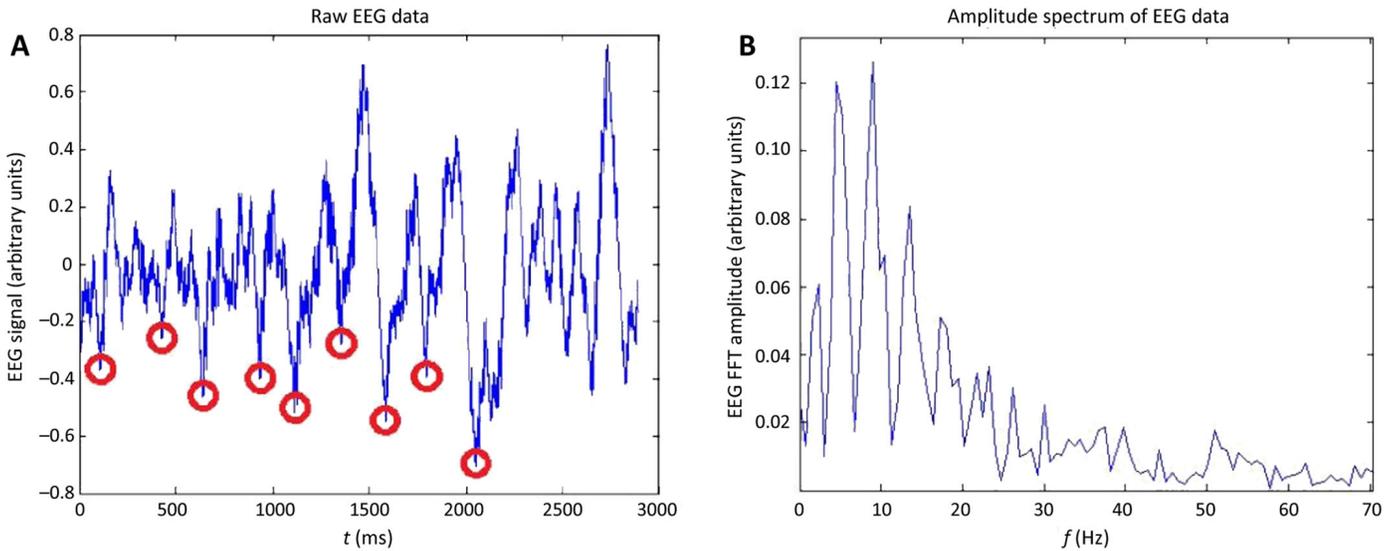


Figure 2. (A) Raw electroencephalography data obtained with the headset, with circled minima to estimate prevalent frequencies. (B) The spectrum of the data obtained by fast Fourier transformation.

E
E
G

Date: _____ Name: _____

LAB HANDOUT

Electroencephalography

> Fill gaps in the text and describe the picture

The basic functional and histological unit of nerve tissue is, which consists of the following parts:

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____

Transmission of nerve impulses is carried out by means of the so-called This connection consists of part (terminal axon of the neuron containing vesicles with), crevice and postsynaptic part (..... of the second neuron). Between the surface and the inside of the neuron, there is (under rest conditions) potential (-70 mV), which changes by depolarization of the membrane into potential (+40 mV), spreading further by the neuron. After the excitement, the charge distribution is restored to an initial value of -70 mV by the

> Arrange the following events to complement the above text correctly.

H Neurotransmitters flowing into the synaptic cleft

Ca²⁺ channels open R

M Binding of the neurotransmitter to the second neuron membrane receptors

I Spread of AP in the second neuron

A Ca²⁺ ions flowing into cell

B AP spread to the terminal axon region

Result → _____

Notes: _____

1

> Electroencephalography: fill the following text.

It is a non-invasive examination that provides a record of the electrical activity of the nervous system. This graphical record is called, and it uses placed on the surface of the head. The instrument that measures EEG is called and it includes an amplifier and a processor in addition to the electrodes. It is possible to use electrode connection or connection. Before the examination is applied to the scalp, which serves as a conductive environment. During measurement, for better recording, the following methods are used:

+

Why is EEG a non-invasive method?

Do you know any invasive medical examination? What causes its invasiveness?

How does EEG work?

> Fill in the following table with the characteristics of each type of EEG wave.

	EEG wave	Frequency (Hz)	Amplitude (μ V)	Manifestations
<p>----- jedna minuta -----</p>	Beta			
	Alpha			
	Theta			
	Delta			

> Positioning of electrodes on the head surface: fill in the names of the individual brain lobes.

F → lobe

C → lobe

T → lobe

P → lobe

O → lobe

The 10-20 system

Notes: _____

2

Figure 3. Lab handouts for the students (see text).

recording and processing data. We have modified the software sketch by Yang (2012), available for the Processing programming language, for our purposes. The Processing language is a counterpart of the Arduino programming language, and it dramatically simplifies and streamlines manipulation with the virtual serial interface, through which the headset communicates with the computer.

Raw data are stored in *.CSV (comma-separated values) data files and can be analyzed by the students. These data correspond to the measured electrical voltage on the head of the pupil (i.e., they are a record of the electrical activity of the brain).

Even if the fast Fourier transformation is not known to students, straightforward estimation of prevalent EEG rhythms can be made. The most significant minima (circled in Figure 2A) are approximately 100–200 milliseconds apart, which means that the most significant frequencies will be somewhere in about the 5–10 Hz range. This simple exercise can be done with a ruler and printed sheet of data and verified by computer calculations made by the teacher (Figure 2B).

Figure 3 shows lab handouts for students that can be used in the lesson. In the left panel, there is information about nerve tissue that students can fill out during a lecture. In the right panel, there is information about EEGs and several EEG curves that students can analyze independently (normal EEG, deep sleep, and EEG during an epileptic seizure). These materials can be downloaded from the authors' website (Šlégr, 2020), along with the software used.

○ Conclusion

We believe that laboratory exercises like this are beneficial not only for future medical doctors, but for all biology students. Biophysical measurements – laboratory exercises involving firsthand experience with medical devices – are especially popular because the students can be direct participants. If these laboratory exercises strengthen students' operational data-processing skills, they are doubly useful.

Although it may seem that these exercises are usable only at the college level, they can act as substantial motivational factors at the secondary school level. The cost of the EEG headset is within the means of most public schools.

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IVANA ŠKRANKOVÁ is a graduate student and JAN ŠLÉGR (jan.slegr@uhk.cz) is an Assistant Professor at the University of Hradec Králové, Hradec Králové, Czech Republic.