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Abstract

New innovative, affordable teaching tools are required to train a new generation of researchers for high-tech 21st Century jobs creating new drugs and technologies to cope with an aging population and understand neurological diseases and processes. An innovative Neuroscience laboratory course with 31 individual labs was developed to integrate wireless electrophysiology systems with a hands-on learning approach where the students can evaluate their own neurological signals. It allows Neuroscience programs to rapidly expand laboratories to accommodate larger incoming class sizes, with minimal staff training and without new facilities. A personal computer and the lab course kit are the only needed equipment, minimizing the requirements on the department. The compact, wireless system can turn any setting into a laboratory.

Introduction

A subset of these labs allows the teaching of the peripheral nervous system during ten 3-hr. labs. These include: Biopotential Basics, Electromyography I, Accelerometry, Electro-oculography, Electromyography II, Biomechanics, Environmental Controls, Gait Pattern Recognition, Motor Control, and a capstone Student Designed Lab.

The National Science Foundation reported that engineering education should include "integrative laboratory experiences that promote inquiry, relevance, and hands-on experience" (Ref. 1). With bioinstrumentation hardware and transducers, students are educated on instrumentation, neuro-electrophysiology and clinical applications. Labs are designed for both **undergraduate** and **graduate** students and are available in both **English** and **Spanish**. Students perform each lab using the wireless 12-channel data acquisition monitor, sensors and transducers, and included software. The monitor self-programs appropriate gains, resolutions, and sampling rates for each lab to simplify student setup. Real-time or saved data can be output to MATLAB®, LabVIEW®, ASCII, Excel, or other third party applications for custom analysis.

CleveLabs is a third generation teaching tool, taking the experiments off the lab bench and putting them into real life. The monitoring device is small, wearable, battery powered, and wireless, making the student untethered, replacing the artificial scenario of monitoring a person sitting at a desk with real-world monitoring, and allowing students to monitor themselves while participating in physical activity. Clinical labs provide hands-on experience that will help them become researchers and medical facility technical leads.

Methods

Ten peripheral nervous system labs are available for teaching a three-hour laboratory course for one or two credits. For this course we assume the student has already been exposed to basic electrophysiology labs such as: Data Acquisition Basics, Digital Signal Processing, Statistical Analysis, and a Post-Processing Toolbox that the students use to process saved data. Labs in Biopotential Basics, Electroencephalography I, and Electrocardiography I and II provide the student a background in electrophysiology testing. These preliminary labs are available in the CleveLabs Course as shown in Reference 2.

For this peripheral nervous system course, **Data Basics** are covered in a single Accelerometry lab. **Basic Physiology** is taught in three labs: Biopotential Basics, Electromyography I, and Electro-oculography. **Advanced Physiology** has two labs: Electromyography II (EMG versus force), and Biomechanics. Finally, four **Clinical Applications** labs include: Environmental Controls, Gait Pattern Recognition, Motor Control, and a Student Design Capstone Lab. Twenty-one other labs (for a total of 31) are also included in the lab course, and these can be mixed and matched with the 10 suggested labs, or taught in a different semester.

Advanced device design

Home testing, wireless devices, personalized medicine, and lower costs are four megatrends that are changing the face of medicine. Many universities still use older rack mounted analog equipment to teach electrophysiology. These large analog older machines are not compatible with any of these megatrends as they cannot be conveniently taken into the home, do not instantly provide wireless connectivity, and are too expensive to be provided to the patient or student to provide continuous monitoring at low cost.

The CleveLabs physiological laboratory course utilizes the BioRadio® 150, a lightweight, wireless physiological monitor with **12 physiology channels (Figure 1)** 8 programmable channels for **EMG** and **EOG** can also monitor ECG, EEG, & respiratory effort due to the programmable input range, sampling rate, and resolution; and a choice of AC or DC coupling.

•Accelerometry (2-axis) shows movement of the limbs or body.

•3 other channels are also available for Pulse oximetry, Airflow, and a Slow DC input.

The BioRadio 150 subject worn unit amplifies, digitizes, and telemeters data to a computer unit located up to 100 feet from the subject. The computer unit receives the telemetered data, removes the encryption codes, and transmits the data to the student's computer via a USB port. This hardware platform exposes students to state-of-the-art technology vs. traditional rack/table mounted equipment (Figure 2).

The BioRadio's wireless design removes cumbersome tethered leads and increases the flexibility of potential locations and applications, such as home monitoring. Both 900 MHz and 2.4 GHz system are available, so the CleveLabs can be used around the world. Furthermore, the BioRadio 150 can use a SD removable memory card to allow days of data to be recorded and viewed at a later time.

Discussion

10 Labs have been developed to provide hands-on experiments for teaching the peripheral nervous system. They are:

- Biopotential Basics:** This laboratory provides an introduction to the origins, measurement, and applications of human biopotentials. The lab gives important background information on concepts used for the course, with topics such as ionic currents, the Hodgkin-Huxley model of the giant squid axon, resting and active ion channels, and Nernst's potential. In addition, students are given an overview of different types of electrodes used to measure biopotentials.
- Electromyography I:** The basis for a skeletal muscle contraction will be reviewed from the point of efferent neurotransmitter release until the insertion of the myosin head. Recruitment properties of the muscle including spatial and temporal summation will be reviewed along with how twitches sum to form tetanic contractions. These concepts will be incorporated into introducing the electromyogram (EMG). Students will record EMG signal in order to determine the relation to the output force of a muscle and how fatigue affects the spectral content of the EMG signal.
- Electro-oculography I:** This laboratory introduces the anatomy and function of the eye and the related biopotential, the electro-oculogram (EOG). This laboratory will review the dipole created by the cornea and the retina and the change in the electric field as a result of eye movements. Students will examine how the EOG can be used to detect eye blinks and eye movement, as well as using electrode placement to differentiate between up, down, left, and right movement. The lab will expose students to basic eye movements such as saccades, vergence, vestibulo-ocular, and smooth pursuit. Additionally, students will learn how the observation of abnormal eye movements can be used to detect neurological disorders. (See Figure 3)
- Electromyography II:** This laboratory session illustrates the relationship between force and EMG. Students record EMG from their finger flexor muscles as they squeeze a hand dynamometer. A quantitative relationship between force and EMG is developed. Finally, students explore how the EMG signal changes when fatigue begins to occur.
- Accelerometry:** This laboratory session demonstrates the basics of accelerometry. Construction and principle of operation are discussed and compared with other motion sensing systems. Students learn how to calibrate the output of an accelerometer in both static and dynamic conditions. Finally, algorithms are developed to extract positional information from accelerometer data.
- Biomechanics:** Students are introduced to the use of a force plate and explore the pattern of muscle activity that occurs in the legs when an individual jumps. Students correlate different phases of a jump to different phases of muscle activity in the leg. The force plate output will be input to the BioRadio and students will learn how to filter EMG signals to remove noise and motion artifact as a result of jumping. The mechanical properties of muscle that allow activities such as jumping to occur are also examined.
- Gait Analysis:** Students will learn about the basics of the gait cycle and record surface EMG from their leg muscles while walking. The collected EMG signals will be processed using a sliding window integral and threshold detection to calculate stride time from the raw data. They will then quantify several features of their stride time and compare those features with a database of stride times from abnormal gaits of Parkinson's, Amyotrophic Lateral Sclerosis, and Huntington's disease subjects. (See Figure 4)
- Motor Control:** In a rehabilitation engineering application, students will use the EMG from their biceps and wrist extensor muscles to control the elbow angle and grasp of a virtual robot arm on the screen. Students will examine how the processing of the EMG signal affects the control of the robot arm, including the effect of high and low pass filtering characteristics. This example is related to control algorithms used to restore amputations with myoelectric prosthetics.
- Environmental Controls:** Students will learn how there is approximately a linear relationship between the DC component of the EOG signal and the position of the eye. Students will calibrate the EOG signal and use the DC component to control the position of a dot on the screen and the AC component to toggle the color of the dot. This example will be related to the development of a computer cursor control system for an individual with a high level spinal cord injury. (See Figure 5)
- Student Designed Laboratory:** Students use the knowledge gained from other laboratories and apply it to a biomedical engineering problem of their own design. Students form a hypothesis, design their own application for the BioRadio, and prove or disprove the hypothesis using the tools they have developed throughout this course.

CleveLabs provides 31 laboratory sessions.

Schools may present or omit selected sessions to fit their curriculum.

Basic Data Principles	Advanced Physiology
Data Acquisition Basics	Blood Pressure
Digital Signal Processing	Electromyography II
Statistical Analysis	Electrocardiography II
Image Processing*	Electroencephalography II
Wireless Medical Telemetry	Polysomnography
Breadboard Circuit Design	Pressure Based Airflow
Accelerometry	Pulse Oximetry
Post-Processing Toolbox	Speech Recognition
	Spirometry
	Biomechanics

Basic Physiology	Clinical Applications
Biopotential Basics	Alertness Detection
Electrocardiography	Biofeedback
Electroencephalography	Environmental Controls
Electromyography	Gait Pattern Recognition
Electrooculography	Heart Rate Detection
Respiration	Motor Control
	Student Designed Lab

CleveLabs provides 10 peripheral nervous system laboratory sessions.

This list provides the recommended one semester Peripheral Nervous System Lab Curriculum (10 labs)

Basic Data Principles	Advanced Physiology
Accelerometry	Electromyography II
Covered in prior lab courses or available as requested	Biomechanics

Basic Physiology	Clinical Applications
Biopotential Basics	Environmental Controls
Electromyography	Gait Pattern Recognition
Electrooculography	Motor Control

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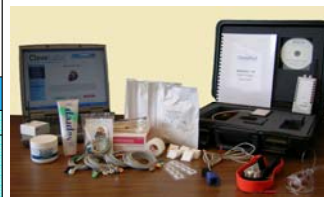


Figure 1 The CleveLabs kit provides all the hardware, software, and accessories needed for non-invasive human neurological tests (PC extra).



Figure 2 The BioRadio makes any room a lab and can be used outside for sports analysis or even to teach classes outdoors.

Figure 3 The EOG lab examines how the EOG can be used to detect eye blinks and eye movement. Students learn that the EOG biopotential provides information about the visual system and that an ophthalmologist can use the EOG to diagnose retinal disorders that can lead to blurred vision.

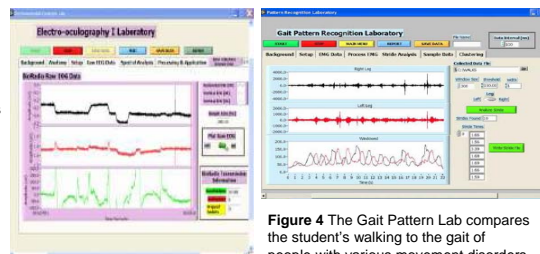
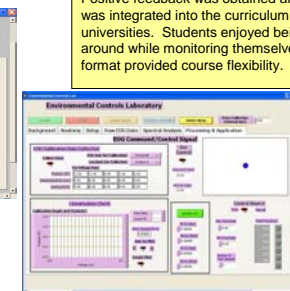


Figure 4 The Gait Pattern Lab compares the student's walking to the gait of people with various movement disorders.



Results

The CleveLabs system has been implemented at dozens of universities around the globe, from Malaysia to the UK. Many universities, including the **University of Southern California**, the **University of Toronto**, **Case Western Reserve University**, and **Lake Forest College** have used the labs to teach students from an introductory level to the 600 graduate level. A Spanish version is also available for Spanish-speaking countries.

Positive feedback was obtained after the course was integrated into the curriculum at various universities. Students enjoyed being able to move around while monitoring themselves. The modular format provided course flexibility.

Conclusion

The CleveLabs Peripheral Nervous System Laboratory Course allows universities to provide hands on lab instruction allowing the students to view their own neurological signals in real world situations. It does not require any special laboratory facilities. It is designed to provide everything the instructor needs, requiring no additional training. The manual has all the labs ready to go "straight out of the box."

Acknowledgements

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References

- [1] Meyers, C. and Ernst, E. "Restructuring engineering education: A focus on change", Division of Undergraduate Education Directorate for Education and Human Resources, National Science Foundation, Report on NSF Workshop on Engineering Education, 1995.
- [2] Schmidt, Robert N. A New Hands-on Laboratory Course for Teaching Neurosciences Using the Students Electrophysiology Signals, Poster 2007-T-100547-SIN, Society for Neurosciences, Nov. 2007, San Diego, CA.

Figure 5 The Environmental Controls labs show how EOG movements can be used to control other electronic systems.

