ELECTROPHYSIOLOGY FOR BIOENGINEERING

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The aim of this course is a theory and practical introduction of electrophysiology for engineers interested in biomedical measurement techniques. The main goals can be summarized as: (1) a key introductory knowledge, (2) good examples of biological mechanisms, (3) practical experimentation and, finally, (4) a state of the art of the medical industry based on electrophysiological principles.
In this paper we present the topics, organization and experiences related to these four goals we just presented.

1. Introduction

Electrophysiology is the study of the electrical properties of cells and tissues. Formation in this discipline means both the knowledge of the biological mechanism which produce the electrical changes as well as how to measure those changes of voltage or electrical current micro and macroscopically.

Along the last academic year 2008/2009, in the School of Engineers of San Sebastián (Tecnun), we committed ourselves on giving a course in electrophysiology particularized for 21 students of engineering. Taking as a starting point the knowledge that a regular student of engineering has, our challenge was how to face those themes about biology that a course in electrophysiology should have. Within this environment, students are familiarized with the hardware employed to measure electrical signals –like differential amplifiers or electronic circuits- and with concepts like electrical impedance, sample frequency or digital resolution. For our case, the challenge was to introduce new concepts like the action potential, the motor units or the sinus node of the heart.

There is an extensive scientific knowledge about electrophysiology both microscopically as macroscopically. Firstly, our goal was to find out the key knowledge to be taught during the introduction so that students can later on understand the electrophysiological meaning of the measurements they carry out in the laboratory and the working mode of the devices that will be introduced during the course.

Secondly, it is necessary to find out good examples of biological mechanisms where it is possible to explain and analyze the underling electrophysiological processes, like it is the case of the systole and diastole in the hearth.

Thirdly, we wanted the students to have a practical knowledge, so we particularized some experiments to learn how to measure and analyze electrophysiological processes, like making an electrocardiogram.

Finally, we talked about electrophysiological devices that can be found in the medical industry, like pacemakers and implantable cardioverter defibrillators.

In this paper we present the organization, topics and experiences related with these four steps parts. The second section of the paper introduces the topics of the course and the experiments, describing them chronologically. The third section presents those experiments carried out by the students using a computer as well as those experiments run in the laboratory. Finally, the fourth section includes the discussion and guidelines about the course as resulting conclusions from our experience by giving the course.

The total course consists of 4.5 ECTS credits. 3.5 credits are devoted to cover the theoretical part of this course and 1 credit for the experimental part.

2. Subjects of the course and theory

Figure 1 presents the subjects and timeline followed to teach the principles, applications and devices along the course. Complementary, table 1 shows the time management Next, the different parts are explained from the principles to the devices that the students have to deal with.

2.1. Biology

Eight hour classes are devoted to explain the necessary biology to understand the underlying processes. The topics about biology we chose are:

1) The action potential: where the internal process to activate and transmit the electrical signals within the cells is presented.

2) Chemical and electrical synapses: where the two types of conducting mechanisms for external signaling among cells are studied.

3) Anatomical and functional organization of the central and peripheral nervous system. The course has a general description about the nervous system. But at the same time, four parts are highlighted:

a) Motor cortex and basal ganglia and its relationship with Parkinson's disease so that later on it is possible to understand the deep brain stimulators devices.

b) Temporal lobe and its relationship with receptive language -which will come up later on as an example of brain mapping procedure.

c) Visual cortex -which will arise again when performing a laboratory experiment focused on registering visual action potentials.

Table 1. Time management for theory

Topic	Class hours	Personal working hours	
Biology	8	24	33%
Mathematics	4	12	17%
Electronics and physics	4	12	17%
ECG	1	3	4%
EEG	1	3	4%
MEG	2	6	8%
ICD/Pacemaker	2	6	8%
cochlear implants	1	3	4%
DBS	1	3	4%
Total	**24**	**72**	

d) Sympathetic and Parasympathetic nervous system -as it is important when carrying out the electrocardiogram as the volunteer is instructed to perform a Valsalva maneuver, affecting this way the rhythm of the hearth.

4) Anatomical and functional organization of the heart. We believe the heart is the best available example, as it is easy to explain and easy to understand by the students. The hearth will be an excellent example later on to come up with the experiments in the laboratory.

5) Anatomical and functional organization of the auditory system. This is another excellent example to engage students because of its beauty. Moreover, the explanation of the auditory system is necessary in order to realize later on the working mode of cochlear implants. It also happens to be an easy to understand physiological process as the students are familiarized with the Fourier transform.

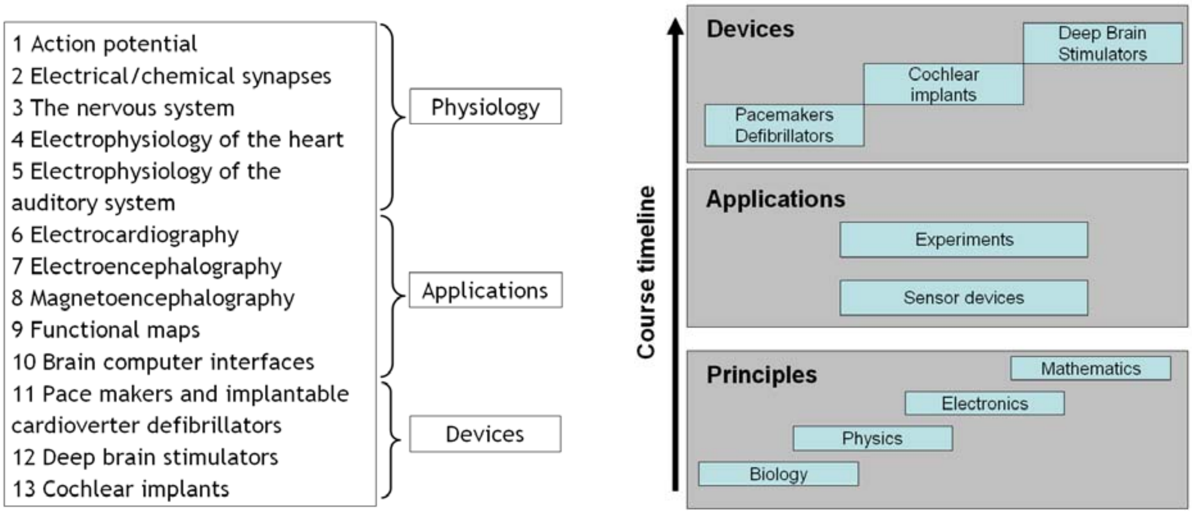

Figure 1 Subjects (left) and timeline (right) of the course

2.2. Mathematics

When teaching mathematics, students review concepts about digital signal processing -which previously have learnt by taking other courses- and how these concepts can be applied to electrophysiological signals. Different tools are reviewed like time-frequency transform. But other more specific mathematical tools are taught for the first time. These mathematical tools are not part of the students' background -as it is the case of principal and independent component analysis- and are very welcome for the analysis of electrophysiological signals.

During this part, the building of the forward model for localizing the electrical sources responsible of the measured signals is explained; as well as the different methods to obtain the inverse solution, like the single dipole model [1], minimum norm estimation [2], low resolution brain electromagnetic tomography [3] and Bayesian approaches [4].

2.3. Electronics and physics

In order to properly understand how to build up the forward model, the electromagnetic equations like the electrical conductivity or the propagation of magnetic waves are reviewed. For electronics, it is just necessary to review basic ideas about circuits in order to understand the Wilson Central Terminal for electrocardiography (see figure 2, right), how electrical sensors work and the differential amplifiers.

Finally –coming back to magnetism- the Josepshon effect and the superconducting quantum interference detector are explained. Those concepts happen to be new for most of the students and they are required to explain later on the magnetoencephalography.

2.4. Devices for measuring and stimulate based on physiology

Once the students have the previous knowledge, some important devices that can be found in the medical industry are explained as well as the companies that manufacture them.

Electrocardiography (ECG), electroencephalography (EEG) and magnetoencephalography (MEG) are introduced as devices for electrophysiological recording of the heart and the brain. Pacemakers and implantable cardioverter defibrillators, cochlear implants and deep brain stimulators are acutely explained as stimulating devices that can be found in many patients.

3. Practices during the course

The practices done during the course could be divided into two categories: practices using a computer and practices done in the laboratory. From our point of view, both types of practices were very interesting. However, the experiments done in the laboratory happened to be much more interesting from the students' point of view, in comparison with those exercises done by using a computer. Nevertheless, we do believe both types of exercises are very useful to really appreciate and understand what the course is about. Moreover, exercises using a computer allow the students to deal with signals that cannot be registered in the laboratory, as it is the case of MEG signals.

3.1. Practices using a computer

Practices using a computer consisted of processing EEG and MEG signals. Two programs and databases have been used. These two programs can be downloaded from the internet for free and run over MatLab. In addition, these databases have an easy to follow tutorial. Each student carried out the computer practice using a personal computer.

Firstly we used EEGLab [5, 6] as an introduction to processing EEG signals. This software allows carrying out basic preprocessing methods like filtering, frequency decomposition or removing artifacts and bad channels. Afterwards, students get to know how to achieve a topographical representation (Figure 2, left) and to make some observations related to the experiment that it's been analyzed.

Secondly, the software SPM [7, 8] was employed to analyze an experiment about face recognition. As in the previous software, SPM has also a tutorial and a data base, and –moreover- in this database there is a structural magnetic resonance image from the volunteer included. The motivation of using SPM is to show the students how to obtain electrical and magnetic sources based on the structural imaging and the recorded data (Figure 2, center). Particularly, the data base has EEG and MEG signals coming from the same experiment of face recognition which makes it possible to obtain the sources from both techniques (EEG and MEG) and to compare the results. Besides the SPM database, we also have another complete example to obtain the magnetic sources of an experiment about receptive language.

3.2. Experiments in laboratory

Volunteers were registered in the laboratory by the students. The 21 students were divided by groups of 3 people. For each recording, one member of the group freely volunteered as the subject for the study. Additionally, groups were allowed to bring a volunteer external to the course, but no one did it, as it just always happened to be a volunteer within the group.

Before carrying out the experiments, a specialist overlooked the recording system and provided us with some feedback about the way of dealing with the volunteers. The recording system we chose was a 32 EEG channels recording system from Brain Vision [12] with common reference. The system is built up by modules providing us with enough flexibility to be adapted both for EEG and ECG recording.

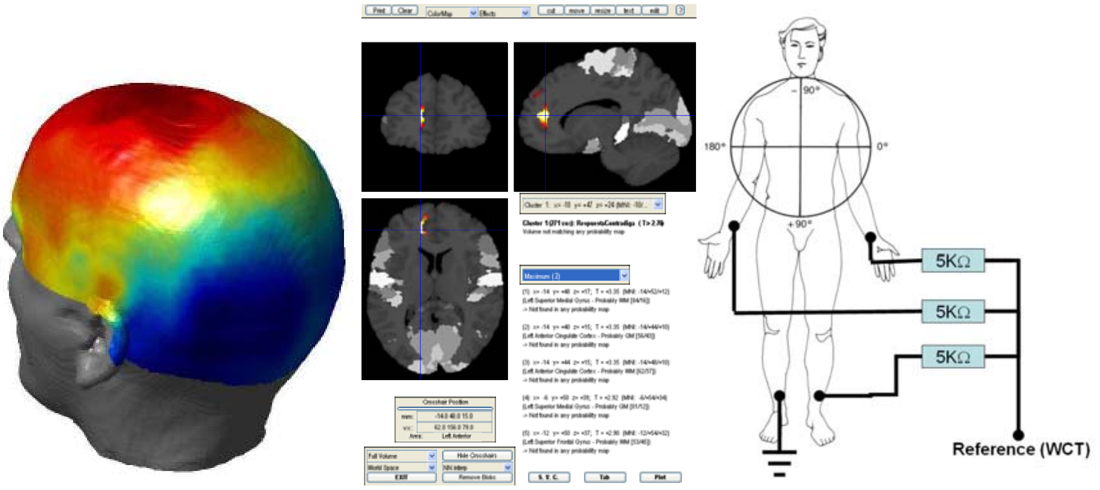

Figure 2 Left: Topographical representation of EEG data using EEGLab. Center: Source localization of EEG data using SPM overlapped over a structural MRI. Right: Layout of grounding and connection to the Wilson central terminal of the volunteer for electrocardiography.

A) <u>Electrocardiography</u>. In order to use the Brain Vision system for electrocardiography, a Wilson Central Terminal was built by shortcutting the right, left arm and leg through three 5KΩ impedances (see Figure 2 right). This allowed us to adapt the system, originally ready just for EEG recording, into a 12-lead ECG. Two tests were performed during the electrocardiogram. In the first test, the volunteer was asked to relax. On the second test, the subject had to perform the Valsalva maneuver for a second analysis. The students had to perform different analysis over the PRQS complex, like obtaining beats per minute and the angle of orientation of the heart.

B) <u>Visual evocked potentials</u>. Using a 32 channel cap [13] and activating the frontal channel (Fz) and the occipital channel (Oz), measurements were performed while the volunteer was visually stimulated by using a blinking chess box [14]. Phase locked responses with the stimulation were obtained as a differential measurement of the activated electrodes (Oz-Fz). The software to prepare the stimulation was Cogent, which is a freeware MatLab Toolbox for stimulus generation and presentation and runs under MatLab.

Table 2. Time management for practices

	Topic	Working hours
Using a computer	EEGLab	4
	SPM (EEG)	4
	SPM (MEG)	4
Registering in the lab	Electrocardiography	2
	Visual evocked potentials	2
	Brain Computer Interfaces	4
	Total	**20**

C) Brain Computer Interfaces. The platform BCI2000 [9-11] was used for this experiment in order to run the P300 speller module, which is an application that allows the students to write words by using the so called P300 response to unpredictable stimuli presented in an oddball paradigm [15]. By presenting a screen full of writable characters and by highlighting the different characters along time, a detectable positive response is obtained 300 ms after the desired character has been highlighted. For this experiment, the 32 EEG channels are activated and after a training period those that present the best response are selected.

4. Conclusions and final observations

Our experience over this course of Electrophysiology adapted to students of engineering has been positive. The students have learnt how to apply their knowledge to the biomedical field. The constructive feedback we were provided by the students has encouraged us to keep on giving the course.

Students were evaluated by a final exam (one half of the evaluation) and periodically by the laboratory practices (second half of the evaluation). The final exam can be downloaded at http://www.tecnun.es/asignaturas/electrofisiologia/. After grading them, we found out they had managed to understand quite well the most relevant things that were explained during the course. Not just the engineering aspects but also the medical side which was not expected to be familiar to them.

Next, some observations about the course are presented:

1. It is necessary to select carefully the topics and to synthesize properly the concepts related with biology. Too much information is out of the scope of the course as well as the area of expertise the students are heading to. We believe the basic concepts described along the paper are the kind of themes to deal with the students.

2. Understanding the electronics and the magnetism needed during the course is relatively easy for the students of engineering. However there is a need of investing time to properly explain those particular mathematical tools which are used during the analysis of electrophysiological signals, as some of these mathematical tools are unknown by the students.

3. Experiments based on databases and specific software running on computers are very useful to explain some of the ideas of the course. These experiments complete with those experiments that cannot be run in the laboratory, as it is the case of using MEG signals.

4. It is important taking care on those experiments to be run in the laboratory when using volunteers. We recommend performing passive and non invasive measurements and checking out the recording system with a specialist before using it.

5. Talking about medical devices and the industry is very useful for the students as it is a reference for them looking forward possible companies to join in the future as engineers.

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