Chapter 32

The Benefits of Combining Theoretical and Experimental Activities in Education in Biomedical Engineering

JAVIER RODRIGUEZ, JAVIER NAVALLAS and ARMANDO MALANDA

Public University of Navarra, Department of Electrical and Electronic Engineering, Campus de Arrosadía, 31006 Pamplona, SPAIN. E-mail: javier.rodriguez.falces@gmail.com

In biomedical engineering, informational lectures and computer simulations are valuable pedagogic tools; however, applied approaches to learning are known to enhance significantly these traditional theory-based approaches by providing students with access to experimental validation of the biological phenomena under study. As a result of collaboration between the Hospital of Navarra (Spain) and the Public University of Navarra, the master's degree in biomedical engineering (BME) at this university has promoted practical-oriented activities in both hospital and university laboratories. Such practical activities are especially useful for teaching and learning how biological systems function − in our case, the function of the motor unit (considered as the anatomical and functional unit responsible for the electrical activity related to the contraction of the skeletal muscle). In this paper, we report the experience of BME students with various teaching approaches, such as lectures, computer simulation and practical sessions at both university and hospital, that were used in order to learn about the electrical behaviour of the motor unit. The combination of traditional methods and practical-oriented activities has been a successful strategy for engendering interest in the field of biomedical engineering.

INTRODUCTION

Biomedical engineering (BME) has experienced steady growth over the last few decades. Following this trend, development of studies in the fields of biomedicine and biomedical engineering has been prompted by higher education in Spain. The relatively young Public

University of Navarra (established in 1987) has proved determined at incorporating changes and, in 2007, in order to adapt to the new environment of BME, established the Master's Program of Biomedical Engineering. This master's comprises most of the reference areas outlined for the BME curriculum by Bronzino [1].

One of the key aspects of our master's degree is collaboration between the Public University of Navarra and the Navarra health care system. Such collaboration has allowed students to carry out part of their training in the Hospital of Navarra. One of the main objectives of this cooperation is to establish a framework whereby students can validate the theoretical content of a subject (including the modelling and computer simulation of biological phenomena) with experimental sessions.

In accordance with the curriculum of our BME master's degree, there is a course entitled *Bioelectricity* that covers the main aspects of excitable cells, the generation of electrical potentials in the human body, and the measurement and visualisation of those potentials (electromyography, electrocardiography and electroencelography). Indeed, electricity is a cornerstone of BME studies as it is crucial for the comprehension of many biological phenomena [2]. In electromyography (EMG) studies, the motor unit represents the functional unit of a skeletal muscle that controls both its electrical activity and contraction mechanism [3, 4]. The *Bioelectricity* course aims to show students how the electrical behaviour of the motor unit can be: (1) explained theoretically, (2) predicted, (3) validated experimentally, and (4) tested experimentally. The current paper aims to discuss the pedagogical methods involved: (1) informational lectures for theory, (2) computer simulation for prediction, (3) the assistance of expert clinicians for experimental validation, and (4) the use of signal amplifiers for testing. We also report the experience of students when combining theoretical approaches and practical-oriented activities to gain insight into the functioning of the motor unit.

There is a widespread belief that students' understanding of a certain engineering topic is considerably improved if they are able to see the results of the experiments they run themselves [1, 5–8]. However, hands-on experience is not always possible when dealing with a biological system such as the motor unit, where study requires a specialist physician using a needle electrode that is inserted into the muscle [9]. Thanks to the collaboration between the Public University of Navarra and the Hospital of Navarra, students were able to attend certain sessions in the hospital's department of clinical neurophysiology, where they could check experimentally the electrical properties of the motor unit. Alternatively, the motor unit can also be studied non-invasively by using surface electrodes. Our laboratory in the university is equipped with several biomedical amplifiers, and so students can record the electrical signals resulting from muscle contraction using these types of electrodes. From direct observation of both intramuscular and surface signals, students can assess how accurately the electrical properties of the motor unit are described by mathematical models.

Traditional methods normally used to teach and study the electrical behaviour of the motor unit (mathematical models and computer-based modeling [10–14]) are valuable pedagogical tools for students pursuing graduate degrees. However, complex mathematical formulations and intricate algorithms are sometimes not intuitive and can be less suitable for teaching purposes. In the present work, we evaluate and discuss a teaching approach based on a combination of theoretical and experimental sessions whereby students benefit from direct contact with clinical practice and can evaluate the advantages and limitations of computer simulation in characterizing the properties of the electrical field generated by muscle contraction.

STUDENT BACKGROUND AND COURSE ENROLLMENT

The *Bioelectricity* course assumes students have certain background knowledge in mathematics, computer science and electronic circuits. Our students fell into three broad groups on the basis of their background profile. The first profile (comprising approximately half of the students attending the course) was characterized by a solid knowledge of signal analysis and signal processing. These students had also received some prior instruction in electromagnetism and in transmission systems. The second profile (comprising about one third of the students) was characterized by advanced knowledge on mechanics and industrial design. The third profile (comprising the rest of the students) had a good knowledge of computer architecture and networks. Table 1 shows for the three years the course has been running, the numbers of enrolled students according to their profiles.

Student Profile	*2007/2008*	*2008/2009*	*2009/2010*
Profile 1 (signal processing)	7	13	13
Profile 2 (mechanics)	4	7	7
Profile 3 (computer architecture)	2	4	3
Total	13	24	23

TABLE 1
STUDENTS AND PROFILES PER YEAR

Details of how each type of student reacted to the different learning approaches (theoretical, computer simulation and experimental) are provided in the discussion section.

LEARNING OBJECTIVES OF THE TOPIC

The goals set for the program were:

1. Theoretical Lectures:
    - Identify, formulate and solve problems and challenges in the field of muscle contraction.
    - Understand the functional and physiological behaviour of muscle.
    - Identify the different components and mechanisms involved in the excitation-contraction coupling of muscle.

2. Computer Simulation:
    - Predict the effects of changes in the physiological and anatomical features of the motor unit on the features of electrical potentials.
    - Write computer programs that incorporate the physiological and anatomical parameters of muscle.
    - Develop programming skills.

3. Practical Sessions in the Hospital:
    - Understand the professional and ethical responsibilities related to biomedical engineering practice.
    - Develop awareness of safety considerations.
    - Become familiar with experimental protocols and equipment.
    - Know the technical problems accompanying the recording of signals.
    - Validate the theoretical predictions of models.

4. Practical Sessions in the University Laboratory:
    - Develop practical skills and an intuitive grasp of applied sciences.
    - Develop awareness of the difficulties involved in recording experimental signals.
    - Resolve problems related to the recording of experimental signals.
    - Develop appreciation of the usefulness of computer simulation in predicting the behaviour of potentials.

LEARNING THE ELECTRICAL BEHAVIOUR OF MOTOR UNITS USING THEORETICAL APPROACHES

Structure and Functioning of the Motor Unit

The striated muscle is composed of a large number of parallel striated muscle cells or fibres, which spread out along the whole muscle. A muscle fibre contraction occurs when a muscle fibre shortens. Muscle contraction is created through the repeated activation of several groups of muscle fibres. Each group of muscle fibres is governed by a single motorneuron [3]. The terminal branches of the motorneuron are attached to the muscle fibres at the neuromuscular junctions (NJ) (Figure 1). The motor unit (MU) is the system formed by the motorneuron and all the muscle fibres that it innervates and represents the anatomical and functional unit of a skeletal muscle (Figure 1) [15]. The end-plate of a motor unit is the zone comprising all the neuromuscular junctions of its corresponding fibres [4].

For skeletal or voluntary muscles, contraction occurs as a result of conscious effort originated in the brain. The brain sends signals, in the form of action potentials, through the central nervous system to the motorneuron that innervates the muscle fibre. In response to this action potential, a muscle fibre is depolarized generating the intracellular action potential (IAP). As a result of the propagation of the IAP along the muscle fibre an electrical field is generated in the vicinity of the muscle fibres which can be detected by a skin surface electrode located near this field, or by a needle electrode inserted in the muscle. The resulting signal is called the muscle fibre action potential or single fibre action potential (SFAP). The motor unit action potential (MUAP) is the temporal summation of all the SFAPs from all the muscle fibres belonging to a certain motor unit.

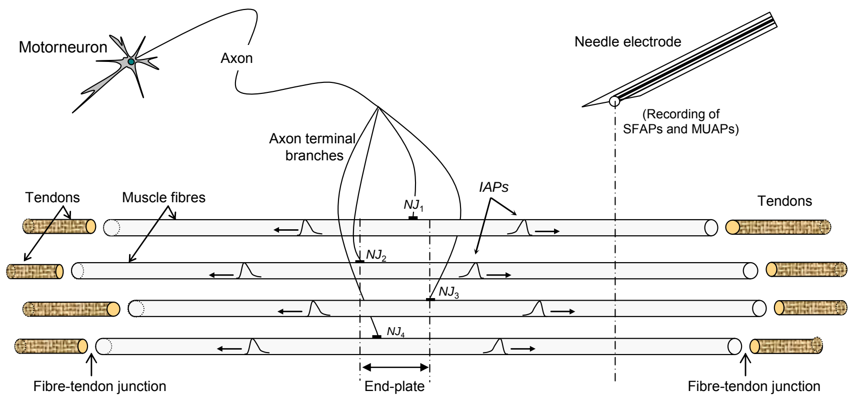

FIGURE 1
SCHEMATIC REPRESENTATION OF THE ELEMENTS OF A MOTOR UNIT

Analysis of Extracellular Potentials Using Computer Simulation

Mathematical descriptions of extracellular potentials (SFAPs and MUAPs) have been provided by a number of authors [16–18]. In most cases, a skeletal muscle fibre of finite length can be modelled as a time-shift invariant system, and therefore extracellular potentials can be described mathematically as a convolution of the excitation source (or input signal) and the transfer function (or impulse response) of the corresponding system. Based on such mathematical models, a set of simulation programs can be designed to allow students to develop a feel for the effect of changes in the motor unit parameters on the characteristics of the extracellular potentials such as the SFAPs or MUAPs. One of the main applications of the simulation programs is to illustrate how changes in electrode position affect the amplitude characteristics of extracellular potentials.

A total of four lectures (of approximately ninety minutes each) were devoted to teaching theoretical knowledge. These lectures covered physiology, mathematical modelling and implementation of simulation programs. Two additional sessions (of approximately ninety minutes each) were provided to allow students to get to know and manipulate the simulation programs and thus gain insight into the generation of electrical potentials produced by the motor unit.

LEARNING THE ELECTRICAL BEHAVIOUR OF MOTOR UNITS FROM EXPERIMENTAL SESSIONS

Recording Intramuscular Potentials with the Assistance of an Expert Clinician in the Hospital

To attend practical sessions in the hospital, master's degree students on the *Bioelectricity* course were divided into small groups (4-5 people per group). Two sessions (of approximately two hours each) were devoted to the analysis of potentials produced by muscle and recorded by intramuscular electrodes. In the first session, students were shown the equipment normally used by clinicians for their electrophysiological tests. This included the electromyograph, electrodes, and different types of needles (concentric, single-fibre, macro), stimulator devices and scanning devices. In the second session, students were shown how to perform needle insertions (this was done by expert clinicians) and how to search for adequate potentials from which to extract diagnostic information.

One major objective of these practical sessions is to make the student reflect on the problems accompanying real recordings. The first issue is to realize that extraction of signals require the cooperation of the patient, who is normally asked to make muscle contractions at a low intensity. Another issue is the difficulty in finding high quality potentials: several needle insertions are normally needed to detect appropriate signals. Other problems relate to "nonphysiological" factors (see Table 2). Other problems relate to physical, detection and anatomic factors (see Table 2). The impact of these factors on the signal has been assessed in some studies [19, 20]. Nevertheless, their influence is uncertain and depends on the experimental settings. Such factors are especially relevant to most of our master's degree students in view of their background profiles.

Important Aspects in Recording Extracellular Potentials	
Physical	Different kinds of noise Physical properties of tissue Electrode's physical comprehension on the muscle tissue Degree of crosstalk from adjacent muscles
Detection conditions	Electrode dimension and type Position of the recording electrode relative to tendon and end-plate Position of the recording electrode relative to the ground electrode Type of recording (monopolar, bipolar, belly-tendon, etc)
Anatomic	Geometry and dimension of fibres Geometry and dimension of motor unit territories Organization of fibres within the motor unit territory Distribution of the end-plate within the motor unit. Distribution of the tendon junctions within the motor unit.

TABLE 2
FACTORS THAT INFLUENCE EXTRACELLULAR POTENTIALS

Recording Surface Potentials in the University's Laboratories

Using a commercial biosignal amplifier (Biopac 2010) and bipolar electrodes, students recorded the surface activity of motor units. Students, in groups of two or three, had to set up the equipment and carry out experiments to visualize extracellular potentials recorded from the skin. Two sessions (of approximately two hours) were devoted to the analysis of surface recordings. There are three important aspects that make these experiments different from those performed in the hospital:

1) The role of the student in the experiment. For the intramuscular recordings performed in the hospital, the student had a passive role (the clinician did the insertions and showed students the functioning of the equipment). For the surface recordings performed at the university, the students carry out the tests themselves.

2) The person studied. In the hospital sessions, subjects were real patients (with specific muscle diseases). For experiments with surface detection, the subjects were the students themselves.
3) The ability to detect individual motor units. Whereas needle electrodes have an optimal selectivity to detect individual motor units, EMG signals registered with bipolar electrodes on the skin are the result of the spatial summation of various motor units.

Whilst the analysis of individual motor units with surface electrodes is difficult, students were able to benefit from their experience of recording with surface electrodes to study how different motor units are progressively recruited as the subject increases the level of muscle contraction. The protocol for this experiment is shown in Table 3.

1. Set up the equipment: • Connect the biosignal amplifier to the PC. • Connect the bipolar electrodes to the biosignal amplifier. 2. Place the electrodes over the subject's skin: • Select the muscle (normally the *biceps brachii*) • Roughen the skin to enhance signal detection. • Place the electrodes and fix them with tape. 3. Preparation of the subject: • The subject should be seated and relaxed. • Only the muscle under consideration (e.g. the *biceps brachii*) should be contracted to avoid excessive crosstalk. 4. Calibrate the biosignal amplifier (contract the muscle during 8 sec): 5. Design the task • The subject must contract the muscle and progressively increase the level of contraction up to his or her maximum level of voluntary contraction.

TABLE 3
PROTOCOL FOR THE SURFACE RECORDING OF AN INCREASING CONTRACTION OF A MUSCLE

Students should appreciate how the amplitude of the surface signal increases as the level of contraction increases. Students should be aware of the fact that the features of surface potentials also depend on the “nonphysiological” factors shown in Table 2.

EVALUATION METHODS

Various assessment methods were used to evaluate the level of attainment of learning objectives.

Theoretical knowledge from the information lectures was evaluated by a closed-book one-hour written exam consisting of four questions related to the functioning and structure of the motor unit. Two of these questions were purely theoretical, whilst the other two had a mathematical component.

During the two sessions devoted to computer simulation, each student was required to demonstrate successful completion and understanding of several tasks. One week before the session started, each student was given a sheet with the list of tasks to be accomplished. These tasks included reporting the results from the execution of certain computer programs, modifying the parameters of various algorithms and writing their own simulation programs. Students were required to hand in a report on the tasks at the end of each computer simulation session.

The evaluation method used for the two experimental sessions carried out in the university's laboratories was very similar to that described above for the computer simulation sessions. The only difference being that the tasks were entirely practical: the students were asked to perform several measurements of the electrical activity from the human body following the protocol outlined in Table 3. A report with the results and measurements of each task was handed in at the end of each session. A brief report of difficulties encountered during the sessions was also requested.

With regard to the hospital sessions, students were asked to provide a short report on the various aspects of the visit (technical problems accompanying the recording of signals; usefulness in validation of simulations; and whether the sessions were helpful in terms of gaining insight into the functioning of muscle).

To measure the degree of student satisfaction with the different programmed activities, in the last session of each activity, students were asked to fill in an evaluation form (Table 4) with the following points:

Evaluation Points	Grade from 1 to 10
• Concepts were clearly explained in the printed learning material provided. • The activity (theoretical, simulations or experimental) attracts my attention. • The learning materials were received in good time. • Academic counselors (teachers, physicians, etc) explained the concepts clearly. • The sessions (theoretical, simulations or experimental) were interactive. • Academic sessions (theoretical, simulations or experimental) were well organized. • Assessment criteria were clearly expressed. • Using the computer program (or performing the sessions) provides knowledge useful to the topic. • Overall, I am satisfied with the sessions (theoretical, simulations or experimental).	

TABLE 4
EVALUATION FORM FOR STUDENTS

RESULTS

Our evaluations of students for the four activities within the *Bioelectricity* course are summarized in Table 5.

As suggested by the data in Table 5, for each activity grades approximately fell into a normal distribution. The table reveals that students performed better in experimental activities than in theoretical ones. In fact, two students obtained less than 5.0 in the written theoretical exam, and four got less than 5.0 in the computer simulation tasks. Table 5 also shows that in the experimental sessions students responded more uniformly: grades have lower dispersion than those for theoretical sessions.

The results from the evaluation form filled in by students at the end of each activity are presented in Table 6.

Type of activity	Description of the activity	Grades (from 1 to 10) Mean ± Sd	Range	Nº of students graded
Theoretical	Lectures	7.1 ± 1.9	[4.7 – 9.2]	60
Theoretical	Computer simulation	6.3 ± 2.2	[3.5 – 8.7]	60
Experimental	Recording of intramuscular potentials	7.6 ± 1.5	[5.9 – 9.5]	60
Experimental	Recording of surface potentials	7.9 ± 1.3	[6.3 – 9.6]	60

TABLE 5
GRADES ACHIEVED BY STUDENTS IN THE FOUR COURSE ACTIVITIES

Type of activity	Description of the activity	Place	Nº of sessions	Degree of satisfaction (from 1 to 10) Mean ± sd	Nº of students that filled in the form
Theoretical	Lectures	University classrooms	4 (~ 90')	7.9 ± 2.3	56
Theoretical	Computer simulation	University laboratories	2 (~ 90')	6.5 ± 1.5	48
Experimental	Recording of intramuscular potentials	Hospital of Navarra (Neurophysiology Department)	2 (~ 120')	8.1 ± 1.2	47
Experimental	Recording of surface potentials	University laboratories	2 (~ 120')	8.3 ± 0.8	53

TABLE 6
STUDENTS' EVALUATIONS OF THEIR SATISFACTION IN THE FOUR COURSE ACTIVITIES

The degree of satisfaction was found to follow, approximately, a normal distribution in each activity. Table 6 shows that students' satisfaction was greater for experimental tasks than for theoretical ones. Again, students showed closer agreement when rating experimental tasks (dispersion in the grades of practical activities is less than that in the grades of theoretical activities).

DISCUSSION

Students of the *Bioelectricity* course in 2007, 2008, and 2009 responded positively to the ten classes (see Tables 5 and 6 for details) dedicated to the motor unit. They were satisfied with their educational experience combining lectures on theory with experimental laboratory sessions including computer simulation, direct observation of intramuscular recordings performed by expert clinicians, and experimentation with surface recordings carried out by themselves.

Fulfillment of the Learning Objectives

For most students, understanding how muscle works comes somewhat intuitively and this explains why lecturer explanations were followed well, irrespective of student background. Teachers were satisfied with the results of the written exam. More importantly, by the end of the topic students were able to identify the different components of the system and to describe the mechanism involved in the excitation-contraction coupling of the muscle. Thus, the goals of the theoretical part of the topic were met.

The educational background of students was important to performance in computer simulation activities. Those students with training in computer technology (profile 3, see Table 1) and some of the students with a background in signal processing (profile 1, see Table 1) were able to accomplish the assigned simulation tasks. The comments of these students were all positive, and students felt they had achieved the established learning objectives for these activities.

However, most students belonging to profile 2 (with a background in mechanics and industrial design) had little or no prior knowledge of the relevant computer programming and, as a result, performed poorly in programming tasks. Some of these students had difficulty achieving the minimum objectives outlined for the computer simulation activities. The poor performance of this group of students in this part of the curriculum led the course teachers to look for strategies to overcome the lack of programming skills and, consequently, students were provided with a set of more accessible simulation programs. Such programs provided a reference point from which students could optimize their functions. Another solution that we considered was to offer students a short course in the fundamentals of programming prior to the *Bioelectricity* course.

The good results of students in the experimental activities can be explained by the fact that most students had some previous hands-on training. Performance of students in these activities was not influenced significantly by their background. Following the teacher's pre-prepared instructions, students were able to set up the equipment necessary to carry out surface recordings in the university laboratory. Interestingly, students were self-sufficient on many experimental tasks and could sort out many problems related to the recording of experimental signals by themselves. All teachers involved were satisfied with the level of attainment of the objectives set for this part of the topic.

Regarding the visits to the hospital, the written reports of the students showed that they had understood the most important practical aspects of electromyography. They noticed the effects of changes in the position of the electrode on the properties of intramuscular potentials. They appreciated the difficulty in finding clean and acceptable potentials. Nearly all students reported on the ‘nonphysiological’ factors, especially physical noise and crosstalk from nearby muscles, that seriously compromises the quality of recordings. Finally, most students commented on the fact that, in order to perform needle insertions, special training was required, as a certain degree of pain is caused to the patient. In general, students met the objectives outlined for the visits to the hospital.

Students’ Comments on the Theoretical and Experimental Sessions

Analysis of figures in Table 6 indicates that most students were highly satisfied with the theoretical lectures. In our opinion, this finding, which was somewhat unexpected, was due to the fact that these lectures were students' first contact with a biological system and due to their feeling attracted by the topic. This was indicated in feedback and comments from students, for example, “I did not expect that skeletal muscles could work in such an intelligent way,” and, “Muscle contraction is fun, but the generation of potentials is more intriguing.”

Table 6 also shows that students gave computer simulation the lowest score (6.5) for satisfaction. This is not surprising given that the amount of programming experience of some of our master's students was low. Teachers of other courses within the master's degree also detected this deficiency. Students' comments included: “This is the first time I've seen programming code in Matlab and I feel rather lost,” and, “I get stuck in the programming part and cannot see the effects of the physiological parameters.”

After the two sessions with computer simulations students were appreciative of something more practical and experimental. Indeed, their comments on the experimental sessions carried out in the Hospital of Navarra were very positive, as evidenced in the high satisfaction score shown in Table 6. Comments made by students included: “It has helped me gain a more realistic view of the electrophysiology examination tests,” and, “I have realized how difficult it is to find high quality potentials.”

From the satisfaction forms, it was clear that most students were keen to do hands-on activities and agreed with this educational approach. Students were happy to undertake the surface recording experiments by themselves with minimal supervision. When setting up the equipment, they had to sort out a number of practical problems: (1) the connection between the devices, (2) the placement of the electrodes (reducing the noise level as much as possible), (3) the reduction of the baseline fluctuation due to interference from other devices, and (4) the minimization and accommodation of a number of artifacts (movement of the subject, bad connections, interferences, etc.) accompanying the recording of signals. These experiments allowed students to develop their practical skills, gaining a feel for the recording and interpretation of electrical potentials generated by muscle. These sessions were popular and, as one student said, “to record potentials from your own body is the most interesting part of the subject.”

CONCLUSIONS

We have described the experiences of biomedical engineering students in learning the electrical behaviour of the motor unit. For teaching we used a variety of approaches such as lectures, computer simulation and practical sessions at the university and the regional hospital. The combination of theory-laden lectures and practical-oriented activities was a successful strategy for engendering interest in the field of biomedical engineering. Specifically, the applied approaches to learning presented here have enhanced the traditional lectures in the following aspects:

- Practical sessions with computer simulation help students to anticipate the effects of changes in the parameters of the motor unit on the characteristics of electrical potentials.
- Experimentation with computer simulation is a good method to teach students how to include physiological and anatomical parameters into a computer program.
- Practice with computer simulation allows students to develop their programming skills.
- Practical sessions in the hospital offer students the possibility of: (1) interacting with clinicians, (2) getting familiarized with the experimental protocols and equipment used in the clinical setting, and (3) developing an interest in medical practice.
- Practical sessions in the hospital allow students to: (1) reflect on the technical problems and limitations inherent to the recording of signals, (2) validate

theoretical predictions of muscle models, and (3) appreciate the usefulness of computer simulation in predicting the behaviour of potentials.

- Experiments in the university laboratory require students to apply the knowledge of theoretical principles that they have acquired in lectures. Students receive the satisfaction of responding to the challenge of recording real signals.
- Experiments in the university laboratory require students to solve a number of problems associated with the recording of signals. The students benefit from these experiments, developing their practical skills and gaining intuition in applied sciences.

The positive response of students to hands-on activities has encouraged us to reflect on the balance between informational lectures and applied approaches. Additional practical activities, in which students can run experiments themselves, have been planned for future years.

ACKNOWLEDGEMENT

This work was supported by the Spanish Ministry of Education & Science under the project SAF2007-65383.

REFERENCES

1. J. Bronzino, "Biomedical Engineering: A Historical Perspective," in J. Enderle, S. Blanchard, and J. Bronzino (eds.), *Introduction to Biomedical Engineering,* 2nd ed., USA: Academic Press, San Diego, CA, 2005, pp. 1-29.
2. J. Malmivuo, and R. Plonsey, *Bioelectromagnetism: Principles and Applications of Bioelectric and Biomagnetic Fields,* Oxford, United Kingdom: Oxford University Press, 1995.
3. R. E. Burke, "Motor Units: Anatomy, Physiology and Functional Organization." In: *Handbook of Physiology. The Nervous System. Motor Control.* Bethesda, MD: American Physiological Society, 2, 1981, pp. 345–422.
4. F. Buchthal, F Erminio, P. Rosenfalck, "Motor Unit Territory in Different Human Muscles," *Acta Physiologica Scandinavica,* 45, 1959, pp. 72–87.
5. P. King, "Design and Biomedical Engineering," *International Journal of Engineering Education,* 15(4), 1999, pp. 282–287.
6. J. Viik and J. Malmivuo, "Biomedical Engineering as a Career Resource: Survey from Tampere University of Technology," *International Journal of Engineering Education,* 15(4), 1999, pp. 308–320.
7. D. S. Cordray, G. M. Pion, A. Harris, and P. Norris, "The Value of the VaNTH Engineering Research Center," *IEEE Engineering in Medicine and Biology Magazine,* 22(4), 2003, pp. 47–54.
8. Anonymous, "Criteria for Accrediting Engineering Programs − Effective for Evaluations during the 2008–2009 Accreditation Cycle," *Engineering Accreditation Commission,* ABET, Inc., Baltimore, MD, USA, pp. 19.

9. J. R. Daube, D. I. Rubin, "Needle Electromyography," *Muscle Nerve,* 39, 2009, pp. 244–270.

10. R. Lorente de Nó, "Analysis of the Distribution of Action Currents of Nerve in Volume Conductors," *Studies from the Rockefeller Institute for Medical Research,* 132, 1947, pp. 384–485.

11. R. Plonsey, "The Active Fiber in a Volume Conductor," *IEEE Transactions on Biomedical Engineering,* 21, 1974, pp. 371–381.

12. R. Plonsey, "Action Potential Sources and their Volume Conductor Fields," *Proceedings IEEE,* 65, 1977, pp. 601–611.

13. S. Andreassen, A. Rosenfalck, "Relationship of Intracellular and Extracellular Action Potentials of Skeletal Muscle Fibers," *CRC Critical Reviews in Bioengineering,* 7, 1981. pp. 267–306.

14. B. A. Albers, W. L. C. Rutten, W. Wallinga-de Jonge, and H. B. K. Boom, "Microscopic and Macroscopic Volume Conduction in Skeletal Muscle Tissue, Applied to Simulation of Single Fibre Action Potentials," *Medical and Biological Engineering and Computing,* 26, 1988, pp. 605–610.

15. F. Buchtal, "The Functional Organization of the Motor Unit: A Summary of Results," *American Journal of Physical Medicine,* 38, 1959, pp. 125–8.

16. G. V. Dimitrov, N. A. Dimitrova, "Precise and Fast Calculation of the Motor Unit Potentials Detected by a Point and Rectangular Plate Electrode," *Medical Engineering & Physics,* 20, 1998, pp. 374–381.

17. S. Nandedkar, E. Stålberg, "Simulation of Single Muscle Fibre Action Potentials," *Medical and Biological Engineering and Computing,* 21, 1983, pp. 158–165.

18. J. Rodríguez, A. Malanda, L. Gila, I. Rodríguez, J Navallas, "A Mathematical Analysis of SFAP Convolutional Models," *IEEE Transactions on Biomedical Engineering,* 52(5), 2005, pp. 769–783.

19. D. Farina, C Cescon, R. Merletti, "Influence of Anatomical, Physical and Detection-System Parameters on Surface EMG," *Biological Cybernetics,* 86, 2002, pp. 445-456.

20. C. Jensen, O. Vasseljen, R. H. Westgaard, "The Influence of Electrode Position on Bipolar Surface Electromyogram Recordings of the Upper Trapezius Muscle," *European Journal of Applied Physiology,* 67, 1993, 266-273.

Javier Rodríguez graduated from the Public University of Navarra, Spain in 2003. He obtained his PhD degree in 2007 from the Public University of Navarra. He worked as a consultant engineer (2004-2005) and as a systems engineer (2005-2006) in the private sector. He also worked for the Higher Scientific Investigation Council of Spain for a year (2006). In 2007 he became Assistant Professor in the Electrical and Electronics Engineering Department of the Public University of Navarra. Since then he has taught several subjects related to digital signal processing, image processing and biomedical engineering. His research focuses on signal processing applied to biomedical signals, modeling of biological systems, electromyography and sensory-motor interaction studies.

Armando Malanda graduated from the Madrid Polytechnic University, Spain in 1992. He obtained his PhD degree in 1999 from the Carlos III University, Madrid. In 1992 he joined the School of Telecommunication and Industrial Engineering of the Public University of Navarra. In 2003 he became Associate Professor in the Electrical and Electronics Engineering Department of this university. Since 1992, he has been teaching several subjects related to digital signal processing, image processing and biomedical engineering. His areas of interest comprise the analysis, modeling and simulation of bioelectrical signals, particularly EEG and EMG.

Javier Navallas graduated from the Public University of Navarra, Spain in 2002. He obtained his PhD degree in 2008 from the Public University of Navarra. He has also worked as a software engineer. He is presently Assistant Professor in the Electrical and Electronics Engineering Department of the university. His research interests are modeling of biological systems and neurosciences.