Instrumentation to Facilitate Learning in a First Bio-potentials Course

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Abstract

Engineering students in a new bioelectricity course, at both graduate and undergraduate levels, were provided the opportunity to measure bio-potential signals from their own person. Implementation of such an active approach was hypothesized to enhance the motivation to learn and to facilitate exploration of bio-potential signals from skin that were coming from deep within the body. Commercially available instrumentation facilitates these processes by providing a flexible interface to acquire, visualize, and analyze bio-signals. Anonymous assessment results of student attitudes and opinions regarding posed statements concerning bio-potential signals are presented. All students agreed that the laboratory experience provided insights into bioelectricity that they did not gather from text or lecture alone.

Introduction

Active learning is a well-studied approach to promote student understanding and problem solving. The laboratory component of a course on the engineering aspects of the operation of nerve and muscle extends this approach by employing an advanced computer assisted data acquisition system that facilitates the student's study of electrical signals generated within their own bodies. In this constructivist environment, interdisciplinary teams of biomedical and electrical engineering students were tasked to study and explore the dependencies of body surface electrical signals generated within the tissue in muscle bundles or in nerves. This took place following a baseline lecture series on the foundations of electrophysiology including Nernst-Planck theory, the role and control of protein gating to generate action potentials, Hodgkin and Huxley's fundamental papers, and models of potential measurement at a distance from volume current sources. These topics were supplemented by readings from the course text, Plonsey-Bioelectricity: A Quantitative Approach[1] and suggested reading from Keynes-Nerve and Muscle[2].

While under development, this interdisciplinary course presents a challenge to traditional engineering students as they are presented with theoretical and experimental concepts and then asked to assemble mechanistic models of system operation. The course title is Bioelectricity and it is offered as a multi-level elective to graduate biomedical engineering students and to both undergraduate and graduate electrical engineering students. The measureable engineering quantities resulting from bioelectric processes in the body are bio-potentials observed at the skin surface. Equipment enabling acquisition of such signals has been improving in capability and cost over the past few decades[3]. As institutions acquire and implement such systems, students may now acquire and analyze bio-potentials from their own bodies. The approach of this study was to explore the students understanding of the origin of bio-potentials that they had acquired. In addition, student response and attitudes relative to the augmentation of learning associated with the laboratory experience were obtained.

Methods

The hardware and software laboratory components used were obtained from ADI, ADInstruments, and consisted of PowerLab analog and differential voltage sensors with 24-bit resolution, an assortment of electrode pick-up types and sensors, and a web-hosted experiment management and operations software, LabTutor. Laboratory teams were assembled with usually three members in each team. A team ideally consisted of a graduate student from each of biomedical and electrical engineering, and an undergraduate EE student. Unmodified laboratory experiences were used as developed by the instrument vendor, ADI. Each lab session lasted 75 minutes. Relevant sensors or apparatus, a PowerLab instrument, and laptop computer were provided to each student team. Students performed the following laboratories during the course: Introduction to LabTutor, ECG and Heart Sounds, ECG and Peripheral Circulation, Electromyography (EMG), and Electroencephalography (EEG). Each of these experiences was stored on a server which was accessed by the student groups while in lab. Each student also had access to the pre-lab or background information, the data, and report interface provided by LabTutor-Online software. Student groups had adequate time to explore each exercise but frequently added to lab write-ups remotely. When satisfied, each group could “submit” the laboratory report and this was automatically emailed to the instructor from the server as a pdf attachment. The laboratories used in this work were as-provided by the instrument vendor and students were led by the script of the experience through each measurement, its setup, how data should appear, and through the inclusion of acquired data, its analysis, and then asked to discuss aspects of each experience. Changes to sampling rate, amplifier settings, or other parameters were not possible in this LabTutor mode of instruction. A LabAuthor software was also provided with the system and will be used by instructors to customize and augment laboratory experiences in the future. For the last week of scheduled labs the students were given access to the LabChart measurement software system and tasked to devise a hypothesis to test, or a method to acquire a bio-potential and to develop a control signal or system response to features of the signal. In this later case, student teams were able to adjust signal timing, adjust the input amplifier for proper utilization of the 24 bit A to D, perform arithmetic and other analyses on the signals, and generate data or response signals. Compared to the earlier labs using the LabTutor interface, the training wheels were completely off in the LabChart instrumentation case and the students very much enjoyed the challenge posed to develop their own content.

The following is an excerpt from the EMG laboratory[3]: Learning Objectives-By the end of today's laboratory you will be able to; 1) Record EMG during voluntary muscle contractions, and investigate how contractile force changes with increasing demand. 2) Examine the activity of antagonist muscles and the phenomenon of coactivation. 3) Record EMG responses evoked by stimulating the median nerve at the wrist. And 4) measure nerve conduction velocity from the difference in latencies between responses evoked by nerve stimulation at the wrist and the elbow. Also in the course of such laboratories, students explored the signal dependence of changing the distance between differential pick-up electrodes applied to their skin and switched the paired lead order to observe how it affected the signal. Figure 1 depicts the EMG electrode attachments to the upper arm and raw data, lower two traces. The upper two traces are the root mean square, RMS, data for quantification.

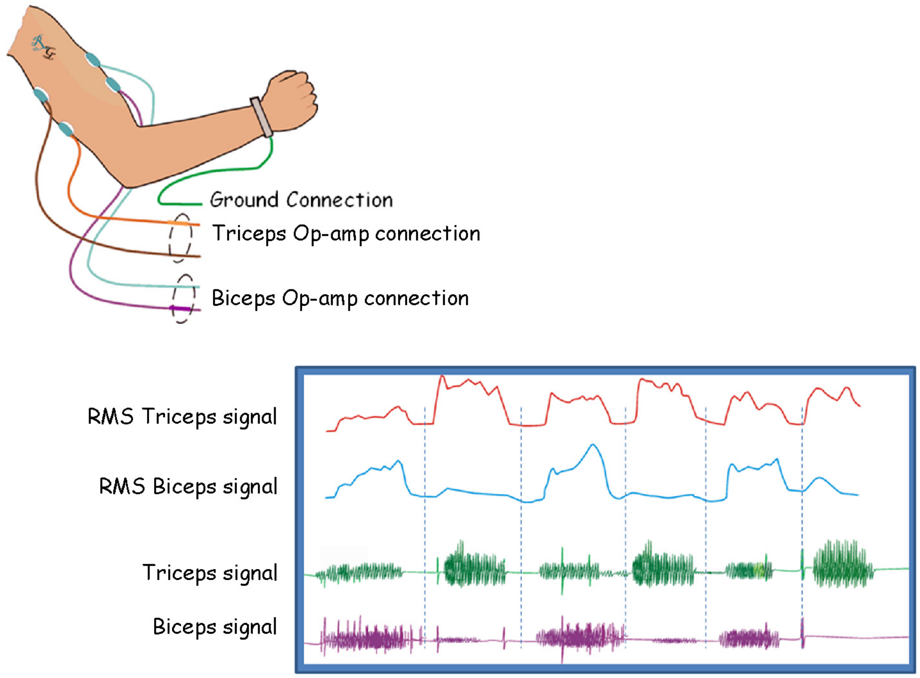

Figure 1. EMG connections to arm. Raw data, lower two traces, and RMS data for quantification, upper two traces. Modified from ADInstruments laboratory content with permission.

A variety of anonymous assessments were administered both prior to and following laboratory experiences. Students were also surveyed as to their attitudes and perceptions stemming from this active learning approach in comparison to the lecture based initial content in the course. Students were also assessed relative to their understanding of the origin of bio-potentials that they acquired.

Results and Discussion

To test understanding, students were asked to suggest the source or origin of the bio-potential signal acquired in three generic laboratory experiences; EMG, EEG, and ECG. For each set of these three labs, they were asked to provide their response to a statement regarding the bio-potential source in a five-element Likert response format[4] extending as five segments from strongly agree to strongly disagree. As the differences between the pairs of extremes, strongly agree/agree or the couple for disagree, are arbitrary, liberty was taken to compress these responses into three segments by adding the two *agree* components, the two *disagree* components, and presenting the neutral as stand-alone. Hence, a five element response was converted to a three element result in this work.

Figure 2 shows the response fractions to the statement: “The bio-potential source was nerve tissue,” for laboratory experiences associated with myograms (EMG), encephalograms (EEG), and cardiograms (ECG) respectively. For each sub-group (e.g., EMG), the left-hand bar represents the *disagree* response fraction, the center is the neutral case, and the right-hand bar is

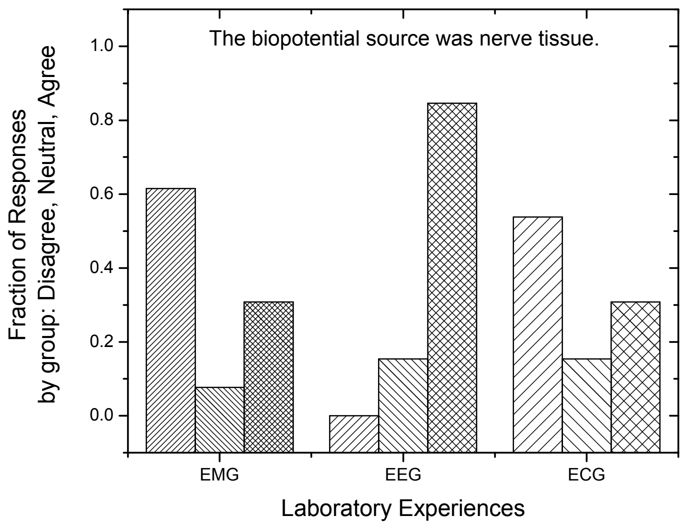

Figure 2. Fraction of responses, by laboratory grouping, to a statement regarding bio-potential signal source, shown at the top of the figure. For each group, left-hand bar is disagree, middle is neutral, and right-hand bar is the agree response.

the *agree* fraction. The best understanding is evident for the EEG case where one would expect that potentials would be only related to nerve activity and all responses were neutral or agree. However, the EMG and ECG responses demonstrate that a fraction amounting to 30% of students think that some of the potentials measured are associated with nerves. Perhaps, this response is due to an understanding that nerves innervate muscle fibers and cause them to fire, and hence they responded accordingly. However, the bio-potential sampling rate is much too slow to discriminate between action potentials and muscle bundle generated potentials, not to mention the differential signal power between a single nerve potential and that derived from a muscle bundle. It must be further noted that students did not adjust or set acquisition timing in these experiments so perhaps they did not appreciate or notice that EEG signals were acquired much faster than the EMG or ECG signals.

The next suggestion made was that the bio-potential originated in muscle tissue. Again, as seen in Figure 3, the best result was obtained from EEG. Yet there persists uncertainty among the students as to the origin of the signal especially in the case of ECG where 60% disagreed. Finally, students were asked to respond to the statement that the bio-potential measured in the laboratory originated from a combination of nerve and muscle tissue. Responses to the last statement are summarized in Figure 4. As in the first two statements, the best response was obtained for the EEG case. The students are clearly confused by this statement as seen in the EMG and ECG cases, where the “disagree,” “neutral,” and “agree” bars are nearly equal.

Since the bio-potential is coming from a distant muscle head removed by some distance from the sensing elements, the distance between the applied measurement electrodes had an effect on the observed signal value. Students had worked with spacing on the EMG labs so it was not surprising that all but 8% of responses agreed or were neutral regarding this issue. However, a total of 50%, combined, agreed or neutral responses were obtained from students relative to ECG and EEG signals with some responses being *not applicable*.

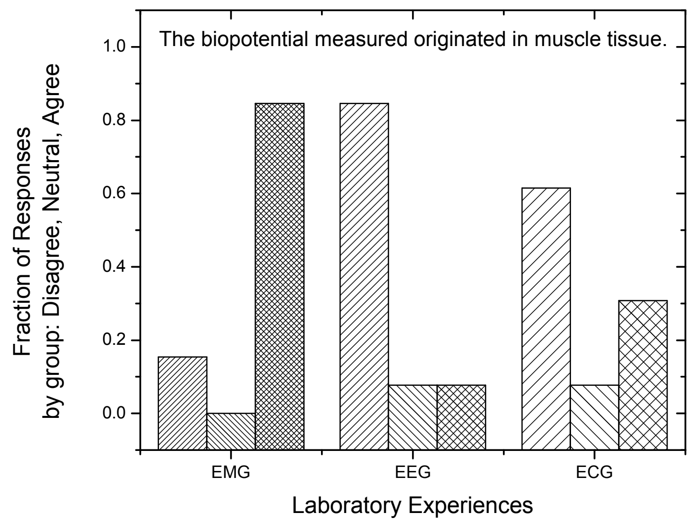

Figure 3. Fraction of responses by laboratory grouping to statement regarding bio-potential signal source, top of figure. For each group, left-hand bar is disagree, middle is neutral, and right-hand bar is agree response.

One hundred percent of students agreed that the laboratory background information established a connection for them between potentials measured and bioelectric theory. Further, although there was a large variation in experience of incoming students, 93% agreed that adequate biological background had been provided to complement the electrical topics of the course. All students also agreed that the text was useful and complemented the lecture and 93% agreed or were

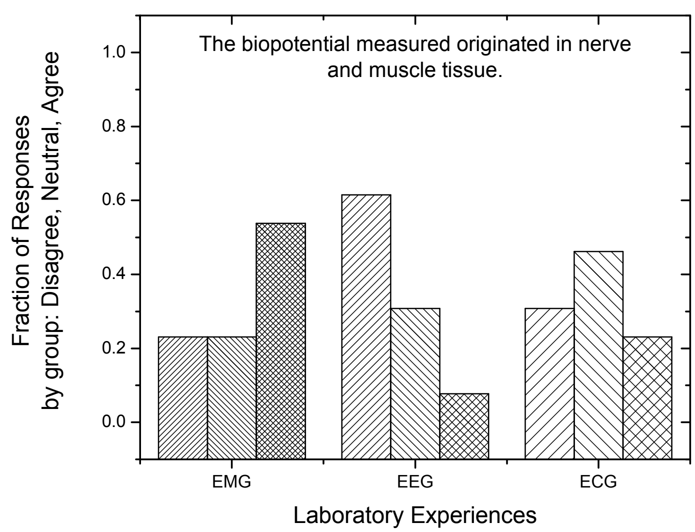

Figure 4. Fraction of responses by laboratory grouping to statement regarding bio-potential signal source shown above response bars in the figure. For each group, left-hand bar is disagree, middle is neutral, and right-hand bar is agree response.

neutral regarding the supplemental readings. In general students found no issues with the flexibility of the laboratory interface and felt confident that they were able to achieve their laboratory objectives.

Roughly 54% agreed that they knew very little about bioelectricity before taking the course, with 38% suggesting that they had some previous exposure to the topic. One hundred percent agreed that the laboratory measurements provided insights into bioelectricity that they did not gather from text or lecture. Yet 62% and 54% disagreed that the lab should be a standalone course or that they would learn more from a problem-based laboratory-only course structure respectively.

All of the respondents understood that the range of cell potential values is controlled by the Nernst potentials of the constituent ions. This parallel conduction model for nerve and muscle signal generation is basic to bioelectricity and although difficult to develop, months later, all students retained their understanding of this concept. Also, all now appreciate the contribution of Hodgkin and Huxley to engineering science and to society in general. Students provided many examples of the societal impact of Hodgkin and Huxley's contributions from present day literature.

A few of the titles of projects developed by student laboratory groups were; "The Effect of Heart Rate on Response Time Using LabChart," "Eye Tracker Lab Project," "Turning on and Dimming a Light Bulb with Arm and Finger Motion," and "Heart Rate Variability." Such titles demonstrate the diversity of investigations made accessible by this new instrumentation laboratory facility.

Conclusions

A new laboratory capability has been established that provides a large variation in available learning structures to engineering students, not just limited to bio-potentials. Students, probably for the first time, were able to acquire signals from their own bodies and derive significance from the interpretation of such signals. The results of this study demonstrate that more work is needed to improve the student's perceptions regarding the origins of the signals that they are acquiring. For example, an experience demonstrating timing issues may be appropriate.

Results also indicate that this should remain a lecture-lab format course. Considering the opportunities for active learning, the laboratory should be expanded. The only way to do this and maintain a significant lecture component is to increase the credits earned in this offering from 3 to 4. In addition, even though there is a fairly sharp learning curve, the LabAuthor capability provides easy modification and launching of laboratory experiences and will be utilized in further investigations of improving this course. Ninety-four percent of students who took this course will recommend it to their peers.

Bibliography

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4] J. Carifio and R. J. Perla, "Ten Common Misunderstandings, Misconceptions, Persistent Myths and Urban Legends about Likert Scales and Likert Response Formats and their Antidotes," *J. Soc. Sciences*, **3** (3), 106-116, (2007).