2006-1627: TEACHING PHYSIOLOGY OF EXERCISE TO BIOENGINEERING STUDENTS

Arthur Johnson, University of Maryland-College Park

Arthur T. Johnson is Professor in the Fischell Department of Bioengineering at the University of Maryland. His teaching and research interests are in exercise physiology and respiratory monitoring.

Karen Coyne, U.S. Army ECBC

Karen M. Coyne received her PhD from the University of Maryland and is now a part-time instructor in the Biological Resources Engineering Department.

Teaching Physiology of Exercise to Bioengineering Students

Abstract

Physiology taught to bioengineers can be done differently from physiology taught to others. Bioengineers use mathematical models in their work for other topics, so teaching bioengineers about physiology using mathematical models as an instrument of instruction can be effective. The physiology taught in this course revolves around exercise responses, but not aspects of disease. From a human health maintenance perspective, physiological responses to natural stresses can be very interesting and instructive.

Introduction

There are numerous reasons for a bioengineer to study exercise physiology. Many products and processes must be designed for people to use during their normal daily activities. These include clothing and footwear, exercise equipment, life support systems, ventilation equipment, protective equipment, vehicles, and assistive devices. The bioengineer should be aware of physiological adjustments that can be expected, such as changes in respiration or heart rate, and how those adjustments relate to the intended design.

Advances in medicine have progressed to the point where the sick, injured, or disabled now expect to be able to carryout activities as closely as possible to those they would perform were they not impaired. Equipment and devices must therefore be able to adjust to the rigors of exercise and not just be appropriate for the bedridden. Expected exercise adjustments must be known.

There is also the fascination of learning how the body reacts to natural stresses of exertion: what energy sources are used; how cardiovascular, respiratory, and thermoregulatory systems adjust; and what mechanical stabilities and instabilities are necessary?

Learning exercise physiology from an engineering perspective is different from learning the same subject from physiologists. The emphasis in engineering instruction is on quantitative analysis and prediction: being able to calculate expected responses before they occur. Also, engineers are taught to conceptualize process mechanics and control: to appreciate energy storage and dissipative components and to learn how they interact and change when controlled.

So, it was the intent of this course to introduce bioengineers to the concepts important to ergonomics, movement, and exertion conducted by the human body. The course is a requirement for students focusing on bioengineering within the Biological Resources Engineering Department, but is also offered as a technical elective to juniors and seniors majoring in other engineering, science, or math programs. The goal was not to include all physiological systems; therefore, there are no stomachs, livers, or kidneys covered in this course. Instead, the course focuses on the basics of quantitative analysis of energy mechanisms, biomechanics, and the mechanics and control of cardiovascular, respiratory, and thermoregulatory systems. The course is not intended to exhaustively cover physiology. Rather, sufficient physiology is included so that students can understand the models and equations used to illustrate these mechanisms and processes. Quantitative models are used as much as possible, but conceptual models are included where necessary.

Methods for Teaching the Class

Textbook

The book used for this course is “Biomechanics and Exercise Physiology,” by Arthur T. Johnson. The first edition is available on the world wide web at www.bre.umd.edu/johnson.htm. It is currently being rewritten for a second edition likely to be published later this year. It is the second edition that will be described.

The book has five chapters:

1. Exercise Limitations
2. Biomechanics of Movement
3. Cardiovascular Responses
4. Respiratory Responses
5. Thermoregulatory Responses

Each of these chapters includes qualitative descriptions of the physiology involved, prediction equations, and sections devoted to models that have appeared in the literature. The last three chapters have similar structures including sections on:

1. mechanics
2. control mechanisms
3. models

Worked examples appear throughout and draw from equations presented in the text along with extensive tables of numeric values of physiological variables. Examples range from simple readings from graphs and charts to curve fitting to model formulation to computer programming. The intention of these examples is to give the student an illustration of how a bioengineer would use published information about exercise physiology.

Many features enhance the textbook. Visual aids are supplied throughout the text and include ample graphs and tables as well as representative illustrations of many of the complex concepts. Left marginal notes allow identification of paragraph topics more easily than reading through the prose. Homework problems at the end of each chapter highlight key concepts covered in the text and assist the instructor in formulating assignments. A comprehensive bibliography at the end of each chapter can be used as the basis for a topical literature search. Finally, there is an extensive index that facilitates the location of items of interest.

Method of Instruction

The course is taught in two seventy-five minute sessions per week. The majority of the class meetings consist of a lecture format with example problems. Two labs and several problem sessions are conducted throughout the semester. One lab consists of a Matlab tutorial while the other demonstrates a test of maximal aerobic capacity. The Matlab tutorial was added in the current semester after students requested assistance on their 2005 end-of-semester course evaluations. Problem sessions are held at the end of the major sections to ensure that students understand the quantitative aspects of the course. Problems with which students struggled on homework assignments are reviewed also. Additional problems are included to highlight key concepts. While example problems have been covered in previous years, student comments on course evaluations prompted the addition this year of several full problem sessions throughout the semester.

Lectures

The course begins by taking students through a model development example to illustrate the different modeling steps (problem formulation, factor specification, data collection, assumption making, system characterization and mathematical description, model formulation, model calibration, and model validation) and show them how their decisions in the model development process affect the resulting model. Students are instructed to qualitatively and quantitatively evaluate models before using them. They are taught basic statistics for evaluating and comparing competing models and are told to consider the subjects used (young or old; healthy or ill), the methods used to collect the data, the conditions under which the data were collected (temperature, humidity), the range of data collected, and the techniques used to evaluate the model. Students are warned of the problems that can result when a model is applied beyond the scope for which it was developed. For instance, a model developed to predict oxygen consumption for low intensity exercise may not predict well for strenuous exercise.

Subsequent lecture material follows the flow of the textbook. For each of the major topic areas, general physiological descriptions are presented first, followed by illustrative models of various physiological aspects. The intention of the physiological description is the building of a foundation and framework for further quantitative consideration. Presentation of physiology is neither exhaustive nor cursory, but does tend to dwell on quantitative aspects as much as possible. Anatomical, histological, and morphological aspects may also be touched upon here.

As an example, respiration cannot be completely modeled without an appreciation for lung structure in relation to its function. Thus, a description of airway branching, beginning with the mouth and terminating with the alveoli, is given. The various respiratory muscles are also described. Quantitative aspects of this section deal with lung mechanical properties, convection and diffusion mass transport, and chemoreceptor outputs.

Each course unit ends with representative models from the literature. These models may not be the latest or most complex, but they are usually ones that particularly illustrate overall aspects of the physiological system. Models have been chosen to elucidate either mechanics or control. Mechanics models usually begin with an effort variable balance (pressure or concentration balance) or a flow-variable balance (air flow, blood flow, or heat balances) and bring in mathematical descriptions of mechanical elements. Control aspects are either ignored or highly simplified.

Control models usually begin with simple descriptions of their mechanical systems, with nonlinearities and complex mechanical arrangements usually ignored. Control aspects are handled in a more sophisticated manner, and incorporate various feedback, feedforward, or optimization techniques.

From these two types of models should come a quantitiative appreciation for the workings of physiological systems. Microcomputer versions of these models help to visualize results and demonstrate adjustments due to changes in parameter values.

In addition to the models in the textbook, the students are introduced to several new models or modifications to the old models that have appeared in the current literature. Also included are articles from journals showing new information about physiology, especially information that may contradict what we once thought. This is done to show students advancement in the field and that the field is always evolving. It also emphasizes that it is important to keep up with current literature and that students should question existing theories.

At the end of the semester, several comprehensive models are introduced. The challenge of developing these types of models, the limitations in applying them, and the reasons such models are needed are discussed. This year, the course will conclude with a discussion of the ethics of developing and using a model. Data integrity and responsible statistics will be emphasized.

<u>Homework</u>

Weekly homework problems are completed by groups of 3-4 students. It is anticipated that each student will spend approximately one to two hours working on the assignment, depending on the problems and the student's background. Problems are selected to emphasize important concepts covered in lecture and the textbook, exercise physiology terms (e.g., anaerobic threshold), an understanding of physiology, and model evaluation using statistics. Computational problems require students to select not only the appropriate equation, but to understand the physiology behind the equation as well. For example, to determine basal metabolic rate for someone with an artificial leg, the student must understand that the mass of the artificial leg should not be included in the calculation. Homework assignments also require students to review some of the models in the textbook. Students are asked to state model assumptions, to identify inputs and outputs, to identify variables, constants, and parameters, to state model limitations, and to classify the model as theoretical or empirical. Finally, problems are assigned that require students to develop simple models based on supplied data and to use those models to make predictions.

<u>Exams</u>

Mid-term exams focus on evaluating the student's understanding of exercise physiology terms, realistic values for physiological parameters (e.g., identifying resting heart rate) and knowing whether or not a calculated parameter is realistic (e.g., final heart rate for moderate activity for a young, healthy subject is 289 beats per minute: is this realistic?), the stages of the modeling process, how decisions in the modeling process affect the resulting model, and calculating parameters using appropriate equations (e.g., don't use an equation for young, healthy subjects to calculate a parameter for an elderly cardiac patient). The final exam provides the students with limited starting data (age, gender, activity) and requires the students to determine estimates for various parameters such as final heart rate, oxygen consumption, core body temperature and physiological work rate. Students must make assumptions in their calculations and must determine the appropriate order in which to make the calculations. Students are provided with a list of common equations prior to the exam. Students are allowed to bring additional notes and equations if they choose. The ability of the students to apply the modeling steps and to evaluate and select models is also covered on the final exam.

Projects

In most years, one modeling project was assigned. Groups of 3-4 students were formed by the instructor or chosen by the students. Each group selected a model from the textbook or from current literature. The students then coded the model in a computer language of their choice. Students were expected to show the impact of assumptions and parameter values on the model output and to demonstrate that the model worked correctly. While some student groups did excellent work applying the concepts taught throughout the semester, others failed to consider the impact of assumptions and model limitations on the model output.

Realizing that some of the students would benefit from more practice, four models were assigned in 2005. Assignments were structured so that students focused more on model development and concepts rather than just coding the model correctly. Students could earn a 75% for coding the model and showing that it functioned properly. Additional points could be earned by adding additional components to the model (e.g., including permeability of clothing worn for a heat transfer model), performing additional analysis (e.g., how does model output change if input parameters vary by 25%), or modifying the model (e.g., adjusting a model that predicts performance time for dynamic work to include a person wearing a respirator). Students did a much better job of analyzing the model and recognizing the impact of the assumptions and limitations of the models. However, students spent more time on coding the model than was intended.

As most engineering students are no longer taught a programming language, the students struggled with developing appropriate algorithms. To overcome this problem, two changes were made for the current year. Students in all engineering disciplines learn Matlab in their differential equations courses and biological resources engineering students additionally learn Matlab in a required computer applications course. So, a Matlab tutorial will be conducted and will provide students with coded examples of: requesting data input from the user, graph production, reading and writing to a file, displaying output on the screen, defining variables, and performing calculations using loops and other basic structures. The second change for this year is that three modeling projects will be assigned. Each student is expected to put four to six hours into each project. For the first and second projects, the students will focus on applying models, selecting the model most appropriate for a given situation, and evaluating the impacts of changes in input parameters and constants on model performance. Students will be able to modify the modules from the Matlab tutorial to include them in their models. The final model will require students to select a model that has been published in the last five years. The students will be required to code the model as well as evaluate the model performance and discuss its limitations.

Summary

Students in this course are taught exercise physiology from an engineering perspective. They are taught enough physiology to understand and apply physiological models and equations. Students are instructed to consider the conditions under which the equations and models were developed and subsequently the conditions for which they may be used. The students take this quantitative analysis and use it to make predictions of human responses. This approach provides the students with sufficient background to design various products that people use in their daily activities.