BIOMECHANICS EXPERIMENTAL DESIGN LABORATORY FOR UNDERGRADUATES

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INTRODUCTION

Experimental design for engineers is typically taught in graduate programs, through individual mentoring by faculty advisors, or in framework of graduate laboratory courses. Biomedical engineering (BME) students, however, should be trained in experimental design at the undergraduate level, because the (young) industries in this field are much more involved in research with respect to traditional engineering disciplines. In the Department of Biomedical Engineering at Tel Aviv University, Israel, we developed a laboratory course to provide students with skills in testing scientific hypotheses in biomechanics. Specifically, emphasis is on experimental design in biomechanics, as well as on data analysis and on communicating the scientific data with peers.

COURSE OBJECTIVES AND STRUCTURE

The first two meetings of this course take the form of frontal teaching and are dedicated to experimental design and statistical data analysis. The following contents are covered: sources of error, common statistical measures, hypothesis testing and tests of significance, confidence limits, correlations, regressions, experimental design, critical approach to research, and research reports.

The fundamental approach in this course is that students are provided only with some brief background and the list of available equipment for conducting experiments to test a given biomechanical hypothesis. "Recipes" of how to run the experiment are never provided. Alternatively, each group of 3-4 students is expected to search the literature based on the brief background provided, and design the specifics of the methodology accordingly. The laboratory instructors only provide mentoring and some general guidelines on how to use the laboratory equipment.

For example, students are introduced to the hypothesis that angular velocity and angular acceleration of the hip joint in the sagittal plane during treadmill walking depend on gait velocity. It is posted that a treadmill, a goniometer with amplifier and sampling (A/D) board and Labview 7 software will be available in the laboratory. Based on the hypothesis, students are expected to submit a 1-page summary of the theoretical background before the laboratory session. Students should characterize the engineering quantitative measures in the field and be familiarized with the terminology and analytical methods. In closure of that report, students should state whether they think that the hypothesis will turn out to be true or false and support their forecast by the literature. For the example above, students are requested to define the angular velocity and angular acceleration measures of joint function, determine the range of motion of the hip joint in the sagittal plane during gait, and explain how to calculate the angular velocity and acceleration using the raw data readings from the goniometer [1].

A second document which should be submitted before the lab session is a 1-page protocol containing the details of the experiment. Regarding the above example, students need to define in that protocol "slow" and "fast" walking for feeding the information to the treadmill. They also need to consider the sampling rate for angle data, and means for verifying that the goniometer is located at the same anatomical location for each subject. The procedure for data analysis should further be outlined (e.g. how to present hip angular velocity versus gait velocity and hip angular acceleration versus gait velocity).

When students arrive at the lab, they discuss their protocol together with the mentor. Students are then expected to follow their protocol, or revise it before the experiment based on feedback from the instructor, if it appears that the protocol will fail to test the hypothesis. Finally, students are expected to submit, within a week from the experimental session, a 3-page final report containing the revised (final) experimental protocol, the results and the conclusions as related to the original hypothesis. This report should be structured in a scientific format, and include an abstract, as well as results discussion and conclusion sections. In the example above, students need to list hip angular velocity values and hip angular acceleration values measured for each subject in a table, and show the average hip angular velocity versus gait velocity and hip angular acceleration versus gait velocity plots. Students are instructed to close their report with a definite conclusion regarding the original hypothesis, based on their findings. Within a week from submission of the final report, students receive the instructor's evaluation in form of a "reviewer's report". This format of evaluation mimics a scientific peer review (as for a manuscript submitted to a journal) and includes general and specific comments regarding the quality of the lab report. Specifically, feedback is provided on the structure and contents of the abstract of the report, on presentation of the results, statistical analysis, graphics and tables, and the completeness and quality of discussion.

Templates of all reports submitted by the students ("background", "protocol", "final") are provided. A (current) total of 6 different hypotheses are introduced during the course, covering topics in tissue mechanics, posture and gait analysis, exercise biomechanics, biomaterial testing, and cardiovascular implant testing (Table 1). These topics, being fundamental in biomechanics, were selected to cover a wide-spectrum of current problems, without compromising on in-depth exploration of the problems (as accepted in traditional lab courses). In addition to gaining the knowledge in biomechanics, students are educated to self-learning, and to conducting systematic and methodological research.

The last meetings of the course are dedicated to develop skills of communicating scientific data. In these sessions, each student group presents (using PowerPoint slides) a specific, randomly selected experiment in a scientific format, including the hypothesis, methods, results, and implications. Presentations are limited to a maximum of 12 slides, and each group member is given 2-3 minutes to present a portion of the presentation. The presentation sessions are also aimed to serve as a platform for sharing and exchanging ideas between student groups as of what is the best approach to perform a given experiment.

To successfully complete the course requirements, students should attend the introductory lectures, take a midterm exam on experimental design and data analysis, submit all “background" and "protocol” reports, attend all laboratory sessions, submit all final reports, and present their findings in the presentation session.

Table 1. Hypotheses introduced to students

Lab #	*Topic*	*Hypothesis*
1	**Tissue Mechanics**	Mechanical properties of fresh chicken femora are different than those of dried femora.
2	**Biomaterial Testing**	(a) Mechanical properties of semicrystalline bioresorbable polymers are different from those of amorphous ones and are affected by degradation; (b) Drug/protein incorporation in polymer matrices affects their mechanical properties.
3	**Posture Analysis**	Contact pressures during sitting are maximal in vicinity of the bony prominences of the pelvis.
4	**Gait Analysis**	Angular acceleration of the hip joint in the sagittal plane during treadmill walking depends on gait velocity.
5	**Cardiovascular Implant Testing**	The efficiency of the St. Jude (bi-leaflet) prosthetic heart valve is better than the Beyork Sheley (mono-leaflet) and the Starr–Edwards ball (Caged Ball) valves.
6	**Exercise Biomechanics**	Cardiovascular performances significantly differ between exercise and rest conditions and vary between trained and untrained individuals.

CONCLUSIONS

The most important aspect of the laboratory course described herein is in-depth exposure of students to experimental design, to statistical data analysis and to communicating experimental scientific data. The author believes that this type of training is a must in the undergraduate level of BME programs, due to the intensive research activity in the BME industry.

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