BODYWORKS: INTERACTIVE INTERDISCIPLINARY ONLINE TEACHING TOOLS FOR BIOMECHANICS AND PHYSIOLOGY TEACHING

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Abstract

Remote teaching can be both challenging and motivating. Professors and lecturers have developed innovative strategies to improve students' education and engage students in synchronous and asynchronous classes. In this Illumination paper, we describe BodyWorks: online tools to support courses in physiology, motor control, and biomechanics. The tools are interactive and easy to use, require low computer and internet demands, and can be used in many conditions and topics of study. All resources are freely available online in three different languages. We hope our initiative can help professors and students worldwide promote more interactive and engaging motor control and related topics classes for both synchronous and asynchronous formats.

Keywords: online education, programming, muscle activation, movement analysis, simulation, biomechanics, BodyWorks.

Introduction

Traditionally, physiological concepts related to human movement are taught by bringing students into the laboratory, putting sensors onto participants, and recording and analyzing data from the sensors. This style of teaching was impossible in 2020-21 due to the coronavirus pandemic [1]. Instead, institutions implemented obligatory remote or hybrid teaching methods.

Specific strategies differed between institutions based on available technical and financial resources [2]. For example, technical resources could include stable/unstable and continuous/intermittent access to the internet [3], the context of working from home [4], and teaching methods employed by professors [5]. Simulations can be particularly beneficial for teaching concepts related to movement production and regulation [6, 7]. Financial resources could include funding to purchase commercial software or computers with enough computational resources to perform simulations. These differences were particularly marked in institutions in developed vs economically developing countries [8].

Some freely-available, downloadable resources already exist. For example, OpenSim (https://opensim.stanford.edu) allows users to calculate joint angles and muscles forces. OpenSim has a relatively steep learning curve; ideally students will have some programming knowledge. Students also need a computer with enough computational resources to download and run the software. The software is also only available in English, which may not be one of the students' languages.

Another option is for professors to create their own online resources. These resources take time to create, however. A relatively high level of programming knowledge is also required to develop and implement interactive online tools [8, 9].

At the end of the day, while tools and simulations can be beneficial, they are challenging to implement, especially for undergraduate teaching.

Our proposal

We describe BodyWorks: interactive, online tools that integrate biomechanics and physiology teaching for undergraduate students of varying programs and backgrounds in technical topics of human movement. BodyWorks currently consists of three tools, focusing on kinematics, neuromuscular activation of muscle contractions, and analysis of electromyography (EMG) data.

Our goal was to develop fully online tools which do not require any installations or downloads. The tools should allow students to interactively test concepts that they learn in class. The tools should also display outputs in real-time that can be visualized, studied, and compared to other references. This interactive approach should allow students to study data visualization in a context that stimulates curiosity and creativity, which are important elements for learning [10].

BodyWorks

Kinematics Tool

The Kinematics Tool (http://www.articlesbyaphysicist.com/body_angles.html) allows users to break a motion into its component stages and then calculate kinematics (joint angles) (Fig. 1). For example, the walking cycle is frequently broken into 8 stages [11]. Within the tool, users can adjust the lower limb positions to represent these 8 stages, and then cycle through the 8 stages to make the stick figure "walk" on the screen. Walking has been used as an example, but users can create any motion they wish.

In addition to visually animating motion, the first tool also calculates and displays kinematics. Once the 8 stages of motion are created, the relative positions of the segments (torso, femur, tibia, foot) in each stage are known. Trigonometry is used to calculate the joint angles at the hip, knee, and ankle. Each angle is plotted on a graph to the right, allowing angle traces to be inspected and compared.

Figure 1: Kinematics Tool: Illustration of lower limb stick figure walking, with kinematics graphs plotted to the right.

Neuromuscular Tool

The Neuromuscular Tool (http://articlesbyaphysicist.com/muscle_emg.html) focuses on understanding muscle contractions (Fig. 2). Muscle contractions are caused by electrical signals (action potentials) sent from the brain, down nerves, and to individual muscle fibres. These electrical signals cause voltages, which can be measured non-invasively using two electrodes and plotted in an EMG trace (shown at bottom of the tool).

The tool has both a simplified version (an action potential goes to all fibres simultaneously) and a realistic version (action potentials travel down individual fibres separately). In both versions, users can place two electrodes either a specified distance apart (10 mm or 20 mm [12]), or at a user-defined "independent" spacing. Users can also control muscle recruitment (action potentials affect 0%, 50%, or 100% of muscle fibres) and activation timing (action potentials arriving at slow, medium, or fast frequencies).

Figure 2: Neuromuscular Tool: Action potentials moving down a nerve and into muscle fibres to cause muscle contraction. The action potentials cause voltage changes, resulting in EMG traces (plotted below).

EMG Analysis Tool

The EMG Analysis Tool (http://articlesbyaphysicist.com/emg_waves.html) helps users understand how signal processing is used to analyze EMG traces (Fig. 3). Signal processing can involve rectifying (changing all negative values into either positive values or 0's), filtering (removing data either above a high pass filter threshold or below a low pass filter threshold), or enveloping (both rectifying and low pass filtering).

These analysis steps can often be confusing at first. This tool allows users to interactively see the effects of each individual analysis step on raw EMG data. This EMG data is taken from the biceps/triceps and hamstrings/quadriceps during 5 different tasks [13]. The raw data are shown first. The analysis step type, frequency, and order can be then specified. Up to 7 analysis steps can be performed. Intermediate graphs are created to show the effects of each step. The user can also specify whether to view data in the time or frequency/spectrum domains.

Figure 3: EMG Analysis Tool: Example of signal processing steps of EMG data. The raw EMG data can be rectified, filtered, and/or enveloped. Results of each intermediate analysis step are plotted.

Practical Applications of the Tools

BodyWorks runs online, and there is no need to install software or plugins (though the tools can be downloaded and used offline if desired). The online resources were created using standard HTML 5, including javascript for the internal logic. We chose this setup for a number of reasons. Firstly, virtually every student will be able to run the tools and interact with the resource, since it runs in any browser. Secondly, there are no security implications: students do not need to install any application to run the program. Thirdly, all the logic executes in the student's browser, so the server hosting the website does not need to have a complicated back end. Virtually any server that can host a website should be able to host this sort of webpage without modification.

Below we present a few suggestions of activities that may help professors introduce the tool as part of their classes (Table 1).

Table 1: Proposed activities which implement BodyWorks tools within human movement courses.

Pedagogical Challenges and Solutions

There are several challenges relating to this sort of educational simulation that must be carefully navigated. Most of these simulations have multiple interactions possible, and so conveying how to use the simulation in a way that students find understandable can be more difficult than for more traditional printed media. Coupled with this, the display may also not be intuitive, and so care is needed to make sure that the student's interpretation of the simulation is correct.

Another interesting challenge is that simulations are very precise compared to written or spoken explanation, and so it is more difficult to avoid incorrect behavior. For instance, you could easily imagine an explanation stating that impulses travel down the nerves and reach the muscle. However, in a simulation, there is likely to be far more detail than this – for instance showing a chosen number of nerves and showing the impulses in sync or out of sync. The point where the nerves meet the muscle is drawn on the screen, and so is precise, whether accurate or not. Essentially, where natural language can approximate or omit details, simulations like these cannot easily do that. This can be a problem because the details shown can easily be wrong for a number of reasons: perhaps the true behavior is not known, perhaps the true behavior is too complicated to want to show truthfully to unfamiliar students, or perhaps the true behavior is too complicated or computationally difficult to build into an HTML document. A way round this is to state the approximations clearly, and provide references for aspects of the simulation that are believed to be correct.

Discussions and Conclusions

We believe that BodyWorks can be helpful for students of different levels. Although some of the simulations require knowledge of more complex concepts, the tools can be used from the first to the last class of a human movement course in topics related to physiology and biomechanics.

We did not perform a formal investigation of the impact of using the tools for teaching. However, we developed a pilot study with 25 kinesiology students after attending 4 introductory lectures about kinematics and kinetics of human movement. First, students chose a video or set of pictures of a motion. Then, students re-created the chosen motion within the Kinematics Tool. Most (52%) students simulated walking, while the remaining simulated kicking (21%), squatting (8%), jumping (4%), and single-joint movements like knee flexion/extension (15%). Many (72%) students also consulted additional references while re-creating their chosen motion. This pilot study shows how students used the tool while learning about human movement. We are aware that an important next step could be a deeper study of the impact of using these tools in teaching. We have not yet conducted pilot studies involving the Neuromuscular Tool or EMG Analysis Tool.

We conclude that the tools are a plausible strategy to complement lectures related to physiological and mechanical elements of human movement. We plan to continue adding resources to BodyWorks in the future. For example, we plan to include other options for motion simulation, additional EMG data analysis, and simulations of other physiological mechanisms. We are also working on creating lab worksheets to run alongside each tool. We are also very interested in including additional languages so that more students can make full use of the simulation tools. Please get in touch if you are interested in collaborating!

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Figures' captions

Figure 1. Kinematics Tool: Illustration of lower limb stick figure walking, with kinematics graphs plotted to the right.

Figure 2. Neuromuscular Tool: Action potentials moving down a nerve and into muscle fibres to cause muscle contraction. The action potentials cause voltage changes, resulting in EMG traces (plotted below).

Figure 3. EMG Analysis Tool: Example of signal processing steps of EMG data. The raw EMG data can be rectified, filtered, and/or enveloped. Results of each intermediate analysis step are plotted.

Table caption

Table 1. Proposed activities which implement BodyWorks tools within human movement courses.

Figure 1

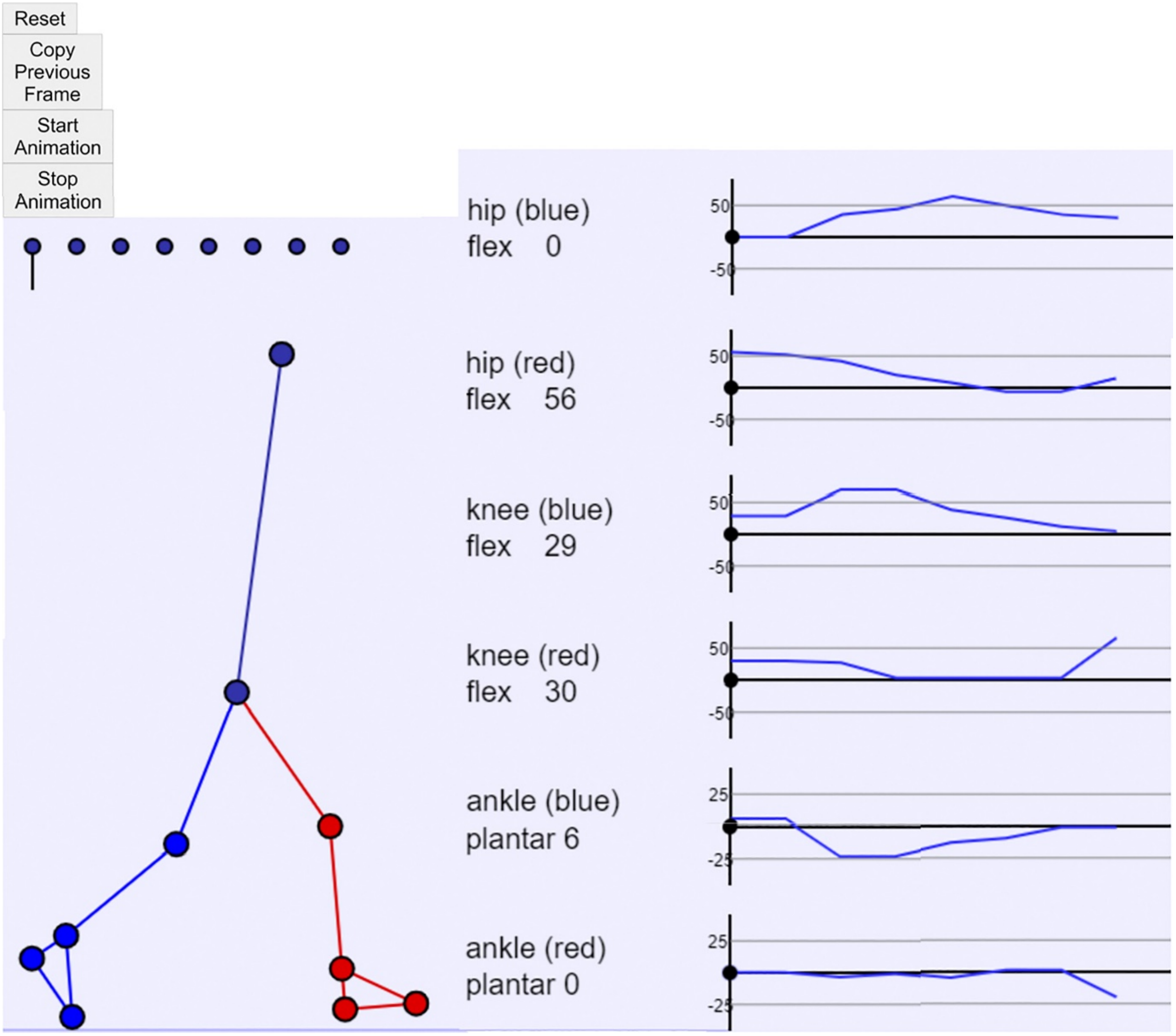
Reset
Copy Previous Frame
Start Animation
Stop Animation
hip (blue)
flex 0
hip (red)
flex 56
knee (blue)
flex 29
knee (red)
flex 30
ankle (blue)
plantar 6
ankle (red)
plantar 0
50
-50
25
-25

Figure 2

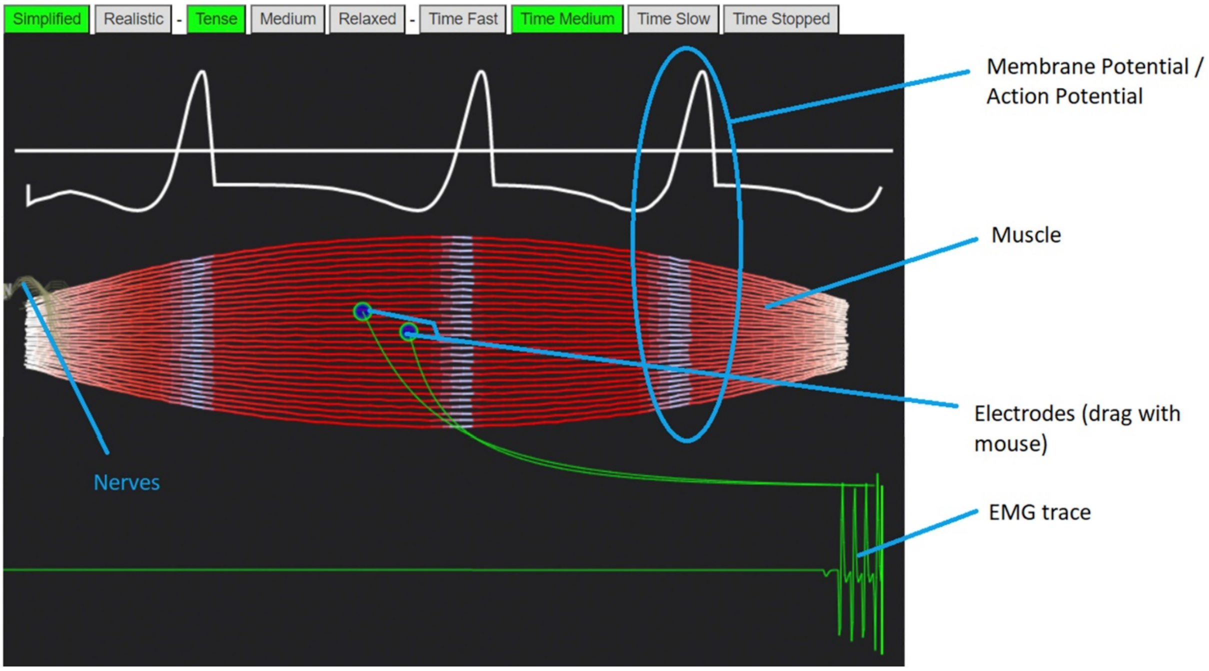

Figure 3

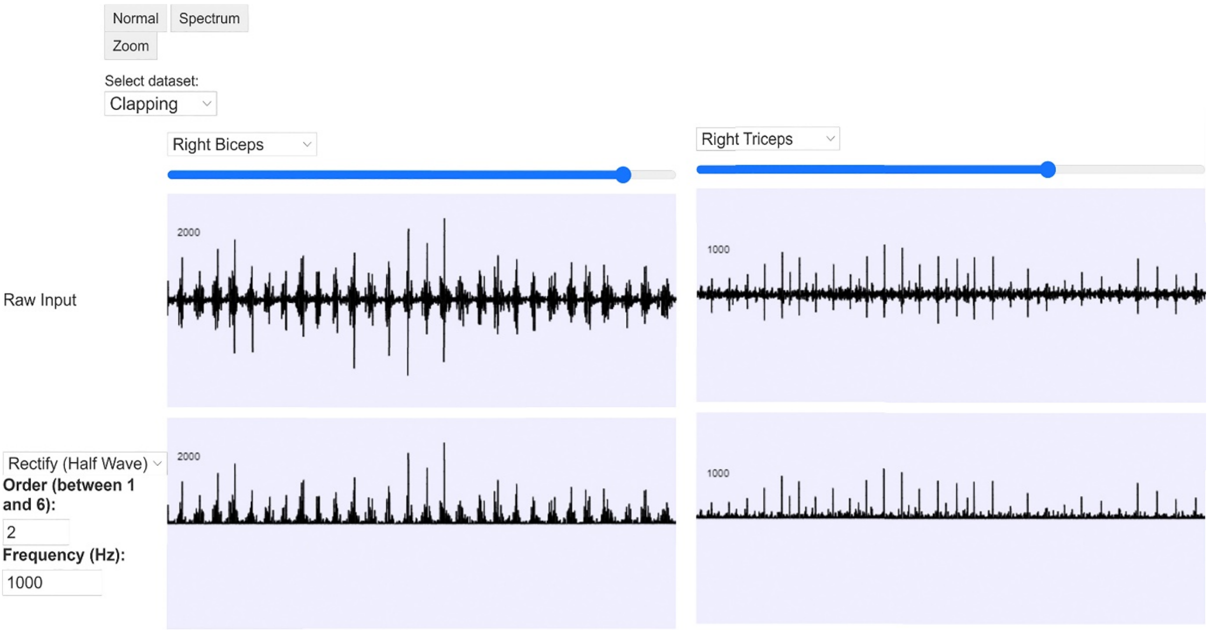

Table 1

BodyWorks Tools	Purposes	Potential Questions	Activities	Follow-Ups
Kinematics Tool (http://www.articlesbyaphysicist.com/body_angles.html)	To understand the kinematics characteristics of the lower extremity during locomotion	What are the sagittal plane kinematics characteristics of hip, knee, and ankle during walking?	This activity can be the follow-up of a lecture about the kinematics of human movement, or it can be part of a flipped classroom. For both cases, students can be requested to read references on the topic and use the tool to replicate the joint angles.	Compare walking and running kinematics, young and elderly gait, kinematics characteristics of other movements like sitting to standing, squatting, kicking, and jumping.
Neuromuscular Tool (http://www.articlesbyaphysicist.com/muscle_emg.html)	To visualize introductory concepts of neuromuscular electrical activation of muscle recruitment	What is the influence of action potential conduction velocity on muscle fiber activation?	This activity can be a follow-up for a muscle contraction lecture and a neurophysiology lecture addressing the physiology of motor units and muscle fiber recruitment. Students can change electrode placement, muscle recruitment, and activation timing to investigate the effects on the resulting EMG signals.	Discuss neuromuscular factors influencing force production, fatigue, muscle inhibition, and technical aspects of neuromuscular stimulation and acquisition of EMG signals.
EMG Analysis Tool (http://www.articlesbyaphysicist.com/emg_waves.html)	To visualize introductory concepts of signal processing	What is the influence of signal processing parameters on neuromuscular activation signals?	This activity can be combined with practical lessons about EMG recording during laboratory activities. Students can use the simulation tool to study the topics ahead of a laboratory lesson.	Study concepts related to signal processing, like applying filters to biological signals.

EMG, electromyography.