LESSON 1

Introduction

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Learning Objectives

After finishing this lesson, you should be able to:

- Defi e biomechanics, kinematics, kinetics, mechanics, mechanopathology, and pathomechanics.
- List the four parts that are used for a symbol in this text.
- Explain why you should study biomechanics.
- Explain how understanding biomechanics can improve performance and prevent injury.
- Describe the three sets of principles that are used in biomechanics.
- Explain the difference between kinematics and kinetics.
- Describe the rules for hierarchical modeling.

1.1 Biomechanics: Understanding the Rules Governing Movement

In the 1999 Warner Brothers movie *The Matrix*, Neo (played by Keanu Reeves) learns from Morpheus (played by Laurence Fishburne) that he has been living in a virtual reality of generated computer code (Figure 1.1). While in the Matrix, Morpheus is capable of doing incredible things, and he tells Neo that he can too as long as he understands the rules under which the Matrix operates:

Figure 1.1 Neo is capable of doing incredible things once he understands the rules of the Matrix.

What you must learn is that these rules are no different than the rules of a computer system. Some of them can be bent, others broken.

Although we do not live in a virtual reality programmed by machines (at least I do not think we do), we do live in a world that is governed by rules. And although we may not be able to bend or break these rules, we are capable of doing some pretty amazing things with our bodies if we understand them. **Biomechanics** is a branch of science that uncovers these rules by applying the methods of mechanics to the study of the structure and function of biological systems.[1]

With this impressive-sounding definition out of the way, two questions may immediately come to mind:

1. Why should I study these rules?
2. Who needs to know them?

The answer to the first question is to help people to move better. To be fair, many biomechanists study more than just people, and some do not necessarily study movement. However, that is the focus of this text. And by move better, I mean to improve performance or reduce the risk of injury, which may have more expansive meanings than what immediately comes to mind.

Important Point! We study biomechanics so we can help people improve their performance or reduce their risk of injury.

Performing better can have several connotations depending on the task. For example, you may wish to have someone jump higher or throw farther. These are obvious examples of a better performance. But you may also wish to decrease the amount of energy necessary to walk across a room or up a flight of stairs or simply be able to accomplish a task, such as buttoning a shirt or combing hair. Do not think that performance is limited to high-achieving athletic competitions. Performance occurs during any human activity, including those activities that are part of your everyday life.

Important Point! Performance occurs during any human activity, including those activities that are part of everyday life.

Many human activities are inherently risky, and you will never be able to eliminate all the injuries that can occur as a result of participating in those activities. Yet there are many ways that you can decrease the *potential* for injury. For example, certain ways of moving can place loads on the body that it was not designed to handle (called **mechanopathology**). Alternately, an injury or disease can change the way a person moves as she attempts to "work around" the condition (called **pathomechanics**), placing inappropriate loads on different structures (and/or degrading performance). In addition, environmental (e.g., a slippery floor) and other external factors (such as being hit by an opponent) can be potentially injurious. Understanding injury mechanics requires you to know something about the person, the environment and other people in that environment, and any equipment that is being used and the complex ways these factors interact.

In general, these two objectives (improving performance and decreasing injury risk) are achieved by modifying either a person's technique (the way the person moves) or the equipment that is used as part of the activity (Figure 1.2). It stands to reason that if the way a person moves limits performance or exposes that person to potentially injurious forces, then changing the way the person moves can improve performance or decrease risk of injury. Similarly, if there are environmental or external factors that are impeding performance or increasing the potential for injury, then equipment may help. As with performance, you should not use too narrow a definition for equipment. Biomechanists have certainly been involved in the modification of athletic equipment, such as helmets and ski poles, but they also study shoes and even the characteristics of floors or machines in industrial settings. So consider performance and equipment in the broadest sense of the terms.

Biomechanics The study of the structure and function of biological systems by means of the methods of mechanics

Mechanopathology The mechanics that result in an injury

Pathomechanics The mechanics that are a result of an injury

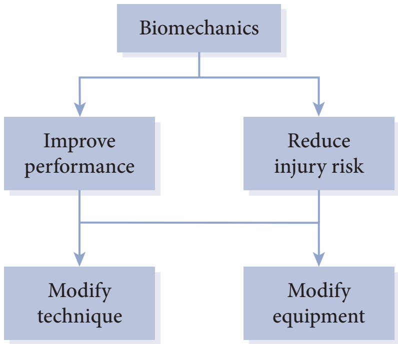

Figure 1.2 Biomechanics is used to improve performance or prevent injury by modifying either technique or equipment.

If the answer to the fi st question is that understanding biomechanics is important in helping people to move better, then the answer to the second question should be obvious: Anyone who is involved with the movement of people needs to understand the rules governing those movements. If you are (or are going to be) involved with teaching skills (e.g., a physical educator, personal trainer, dance instructor, or coach), preventing or rehabilitating from injury (e.g., an athletic trainer, a physical therapist, a chiropractor, or a physician), designing equipment to be used by people (e.g., an ergonomist or an engineer), or modifying the structure of the body (e.g., an orthopedic surgeon), you need to study biomechanics. Biomechanics is a rich fi ld with a broad number of applications. Th s text's focus is on understanding the core concepts—the rules governing human movement. You will learn more about the applications in discipline-specific texts.

1.1.1 Mechanical, Multisegmental, and Biological Principles

Now that you understand why you should know the rules of human movement, you can begin to study them. The rules can be roughly grouped into three sets of principles: mechanical, multisegmental, and biological (Figure 1.3).[2] Each of them will have a different focus in this text.

To understand the rules under which we move, you must fi st have an understanding of physics or, more specifi ally, classical mechanics. Classical **mechanics** is interested in the motion of bodies under the action of a system of forces. It basically deals with the motion on a physical (size and speed) scale of everyday things

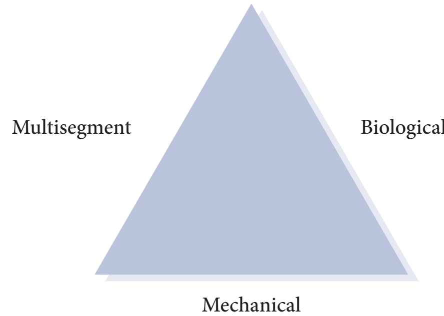

Figure 1.3 Principles of biomechanics.

that you can potentially see. It is called "classical" because it was developed based on the work of Sir Isaac Newton and those who followed him, but it excludes such "modern" topics as quantum mechanics (which deals with physics on an extremely small size scale) and the work of Einstein and relativity (which deals with physics on an extremely large speed scale).

Classical mechanics (Figure 1.4) is usually divided into two areas: things that are moving or things that are not. *Dynamics* deals with things that are moving and can further be broken down into kinematics and kinetics. **Kinematics** is the study of motion without consideration of the causes of that motion. **Kinetics** deals with the causes of that motion. *Statics* deals with loads on things that are not moving. An off hoot of

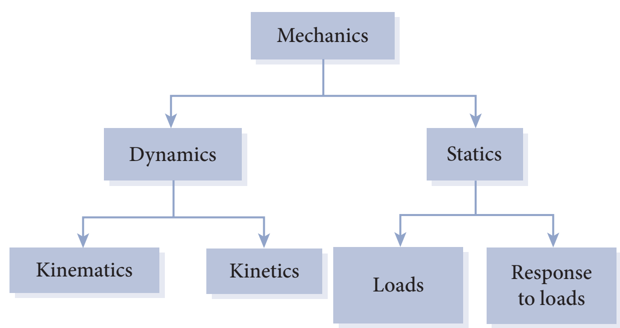

Figure 1.4 The areas of classical mechanics.

Mechanics The study of forces and their effects

Kinematics The study of motion without consideration for what is causing the motion

Kinetics The study of the forces that cause motion statics is materials science. Whereas statics deals with the loads applied to a body, materials science examines the material properties of that body and its response to a load. In biomechanics, this is often referred to as *tissue mechanics*.

If you have ever taken a high school physics class, you have learned some basic principles of classical mechanics (such as Newton's laws of motion), or what I just referred to as the fi st set of rules. The second set of rules is a bit more complicated, but they are an extension of the fi st. When you learned Newton's laws, you probably learned about them for a single body, such as a ball or pendulum. The human body is not a single element (although it can sometimes be modeled that way) but rather is made up of many connected segments. For example, the "simple" act of reaching for something requires movement of both the upper arm and forearm, and throwing requires the coordinated activity of the lower extremities, trunk, and upper extremities. Some unique properties emerge when the body is looked at as a system of interacting elements rather than a single body (or by looking at the parts in isolation). The second set of rules acknowledges the multisegmented nature of the human body.

The third set of rules is based on the fact that we are not inanimate objects or machines. As a biological being, you will not violate the laws of physics, but you do influence them in a particular way. Th s is where the "bio" portion of biomechanics comes in. For example, you may already know Newton's Second Law ($F = ma$). Do not worry too much about it if you do not; you will learn all about it in the lesson on linear kinetics. For now, suffic it to say that this law is one of the foundations of classical mechanics and you are as affected by it as any other object on Earth. However, in many instances, the source of the "F" in Newton's Second Law is your muscles.[3] Although the law will always hold up, a rather large number of factors based on the anatomy and physiology of your muscles influence the production of force.

1.1.2 Mathematics: The ode

The "code" of the Matrix was depicted in the film as "falling green digital rain," a combination of mirror images of half-width kana characters, Latin letters, and numbers (Figure 1.5). The program could be read because information was concisely represented by the code. By reading the code, people outside the Matrix could determine what was happening inside the program, but they had to understand the code.

Figure 1.5 The code of the Matrix.

Our world, too, is represented by a code, but it is not digital rain. Our code is written in the language of mathematics for many of the same reasons: It allows a relatively large amount of information to be concisely represented. All you have to do is know how to read the code.

Many people are scared of math, but it does not have to be *that* bad. Let us take a look at how it works. Consider the following equation:

$$c = a \times b^2 \tag{1.1}$$

Looking at the code, what does it tell you? Well, there are several useful pieces of information. First, some variable, c, is completely determined by two other variables, a and b. Second, increasing either a or b will increase c, so if you wanted to maximize c, you would want to increase a and b. Conversely, if you wanted to minimize c, you would have to decrease a and b. Thi d, the two variables are not "weighted" equally: b is squared. If you doubled a, then you would increase c by a factor of 2; however, you would increase c by a factor of 4 if you doubled b because it is squared.

Now, say that a was your variable of interest. You could rearrange Equation 1.1 as follows:

$$a = \frac{c}{b^2} \tag{1.2}$$

Now, a is determined by c and b. The variable c has the same effect on a as a had on c. Increasing one will increase the other by the same amount. Variable b is now the denominator. Th s means that if you increased b, you would decrease a. Doubling b would decrease a by one-quarter. In a similar way, you can rearrange the equation to solve for b and then make the appropriate analyses. It was a lot easier to learn this one line of code than memorizing various facts about the relations between a, b, and c. Was it not?

Th s text assumes that you have a rudimentary level of math skills, but there will be a number of refreshers, depicted as "Essential Math" boxes, throughout the lessons when I think they are needed. In fact, your fi st one is presented in Box 1.1. One thing that I think puts people off about math is that they spend so much time trying to get the "right number" that they lose sight of what goes into the equation or what the number actually means. In this text, you will focus on the equations and their interpretations. The numbers can come later.

A Note on Symbols

The language of math is a language of symbols. It is just more concise to abbreviate something such as force with an F or acceleration with an a. Unfortunately, although some symbols are universal, others are not. Physics, engineering, and biomechanics may all use different symbols for the same thing (physicists like to use p for momentum, whereas engineers like to use L). What is even worse is that sometimes the same symbol will have two different meanings in the same

Box 1.1
Essential Math: Algebra

When manipulating equations, the general rule is to perform the same operation on both sides of the equal sign to maintain the equality. Here are some examples to help you manipulate equations.

If two variables are added (or one subtracted from another) and you want to move a variable from one side of the equal sign to the other, then subtract it from both sides if it is positive and add it to both sides if it is negative, as in this example:

$$a = b + c$$
$$a - c = b + c - c$$
$$a - c = b$$

If two variables are multiplied (or one is divided by another) and you want to move a variable from one side of the equal sign to the other, then divide (if it is a multiplier) or multiply (if it is a divisor), as in this example:

$$a = \frac{b}{c}$$
$$a \times c = \frac{b}{c} \times c$$
$$a \times c = b$$

Sometimes you may have to perform successive operations to get to your variable of interest. Just pay close attention to the order in which you perform the operations. If a divisor is under only the variable, then you perform your addition and subtraction fi st, as in this example:

$$a = \frac{b}{d} + c$$
$$a - c = \frac{b}{d} + c - c$$
$$a - c = \frac{b}{d}$$
$$(a - c) \times d = \frac{b}{d} \times d$$
$$(a - c) \times d = b$$

If the divisor is under several variables, you must multiply fi st, as in this example:

$$a = \frac{b + c}{d}$$
$$ad = \left(\frac{b + c}{d}\right) d$$
$$ad = b + c$$
$$ad - c = b$$

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(continued)

And usually, by convention, you want to isolate your variable of interest on the left- and side of the equation. So the last equation is rewritten as follows:

$$b = ad - c$$

Notice that one equation had a multiplication sign and the other did not. If two variables are next to each other with no signs between them, then multiplication is assumed, as in this example:

$$ad = a \times d$$

book or fi ld (W is both weight and work; s is both seconds and speed). In addition, a capital letter may represent something different than a lowercase letter. So you must be careful when looking at different books and papers.

In this text, great care was taken to ensure that symbols have only one meaning, although a lowercase letter may have a different meaning than a capital letter. You will be introduced to them as they appear. For now, it is important to know about some of the conventions that are used. A symbol can have up to four parts (Figure 1.6). The main part of the symbol is the variable itself. The leading superscript indicates direction. It could be the direction in a particular frame of reference, such as x, y, or z (you will learn all about frames of reference in the next lesson), or a direction that is perpendicular ($\perp$) or parallel ($\|$) to a body of interest. The following subscript refers to the body, which is particularly important if you are keeping track of more than one. The following superscript indicates a change in time for the same variable. Time "zero," or the start, does not have a following superscript. Time point 1, which is some change from time zero, has a single prime ($'$). Time point 2, which is some change from time 1, will have a double prime ($''$), and so on. Rarely is there a need in this text for more than three primes.

Do not let all these symbols scare you off. You will gradually be introduced to them, and they make a lot of sense once you get the hang of them. In addition,

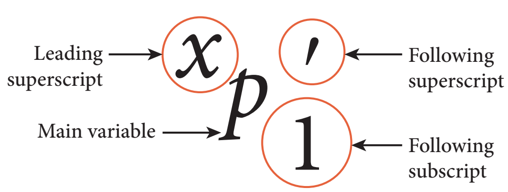

Figure 1.6 The four parts of a symbol.

super- and subscripts are used only when necessary for clarity. For example, if you are dealing with only one body, there will not be a need for a following subscript, and if the direction is obvious, there will not be a need for a leading superscript. In this way, things are kept as simple as possible.

1.1.3 Hierarchical Modeling: Keeping Track of the Variables

Equation 1.1 and its various manipulations are fairly easy to keep straight because you have to keep track of only three variables. What if you had access to even more lines of code? Consider the following equations:

$$a = d - e \tag{1.3}$$

$$e = \frac{g^2}{h+i} \tag{1.4}$$

Although c is still completely determined by a and b, each of those variables is determined by other variables, some of which are determined by still others. Thi gs can get a little messy, and it can be hard to keep track of all the variables. One aid to assist you with keeping track of things is called a deterministic model,[4] although the term *hierarchical model*[5] seems to be more appropriate and is used throughout this text.

The basic idea of a hierarchical model is presented in Figure 1.7. At the very top, you list your performance criterion, preferably in mechanical terms. In the level below, you include all the factors that determine that variable. It is that simple. The only real rules of hierarchical modeling are (1) the factors included in the model should be mechanical quantities, and (2) each of the factors included in the model should be completely determined by those factors that are linked to it from below.[4] Once you have identifi d all the factors, you can annotate those that you cannot control (usually by striking through the box). For example,

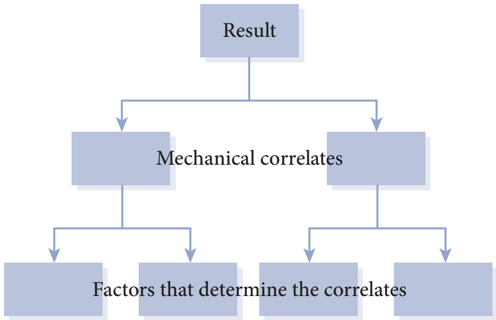

Figure 1.7 The hierarchical model.

you cannot control gravity. So although you want to include it in your model and keep track of its effects, you are not going to worry about trying to change it.

To give you an example, the hierarchical model for variable *c* using Equations 1.1 to 1.4 is presented in Figure 1.8. Your interpretation of the model is that *c* is determined by the following variables: *b*, *d*, *g*, *h*, and *i*. Notice that these boxes have nothing below them. Also, note that I did not include variables *a* and *e* in my interpretation because they were determined by other factors and it would be redundant to include them.

The equations were used to develop the model, and the model was used to help determine appropriate equations. They work together. You will see hierarchical models used throughout the text even when there are only a few variables. Th s was done to get you used to working with them. In addition, in many instances, the model will be added to in subsequent lessons as your understanding becomes more complex. Although there are some limitations to hierarchical models, they are a good way to keep track of variables and assist you in your thinking.

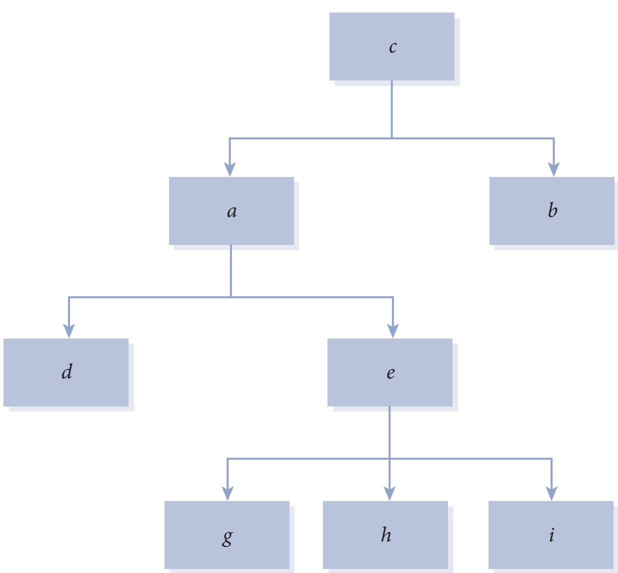

Figure 1.8 A hierarchical model of Equations 1.1 to 1.4.

1.1.4 Process Boxes

When looking at a mechanical system (or any system for that matter), we can think of it in terms of input(s), output(s), and a process that transforms input(s) to output(s). Examining the process is sometimes thought of as a "black box" if the process is hidden from view (or unknown). You do not know how the system does what it does. You can look at how the output changes only in response to changes in input. In contrast, a "white box" allows you to follow the internal process that connects the input to output. You know how the system works.

Examples of white boxes are represented in Figure 1.9. The top of the figu e shows a simple, one-step process. You can see how the input connects to the output. The bottom of the figu e shows a two-step process. Many mechanical quantities are described in this text, and we will be very interested in how these quantities change. Changing a quantity will be thought of as a process. I will use a white box (represented by dashed lines) to show the transformation between input and output. In doing so, I hope to provide a visual depiction of the underlying mechanics that will aid

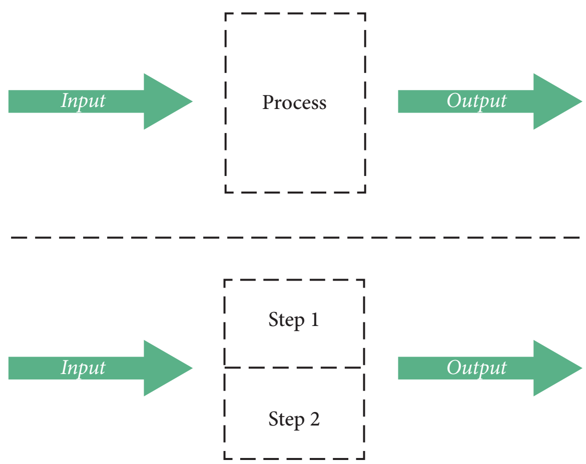

Figure 1.9 "White box" analyses of processes that transform an input into an output. Top: a simple, one-step process. Bottom: a two-step process.

in your understanding and serve as an intermediate step between concept formation and mathematical problem solving.

1.2 How to Use This Text

You may have been clued in by the last two sections of this lesson that this text makes extensive use of equations (but not necessarily numbers), hierarchical models, and process boxes to help you understand important concepts. Again, do not get scared by them. You will fi d that they are helpful aids in presenting information in a concise way and organizing your thinking. Look for the boxes on "Essential Math" to go over topics where you are rusty. If you have a strong math background, you can safely skip them.

In many ways, this text follows a "whole–part–whole" structure. The fi st part (Lessons 2–10) is organized around the principles of classical mechanics. In many ways, it is applied physics. And although the information is similar to what you would get in an introductory physics text, the examples used relate specifi ally to human movement. Because the connections to applied biomechanics may not always be evident, boxes on "Applied Research" will show you how these concepts are being used to solve everyday problems.

The second part of the text (Lessons 11–16) deals with the biological principles. You will begin by looking at the tissue level (muscle, tendon, bone, ligaments, cartilage) separately and then combine them into a single-joint system. You will then look at the specific joints in the lower extremities, trunk, and upper extremities. It is assumed that you have had at least some knowledge of anatomy, but the text looks at the topic in a slightly different way. For example, the quadriceps muscle group is not thought of as "knee extensors" but rather as producing a knee extensor torque. As you will see, the quadriceps group not only extends the knee, but just as important, it also controls knee flexi n in many cases.

Lesson 17 deals with the principles of a multisegmented body, which you may have heard referred to as a *kinematic* or *kinetic chain*. Lesson 18 attempts to tie the information from the previous 17 lessons together for a variety of activities of daily living and sport. It is hoped that, at the end of this text, you will be able to do the same thing for many activities not discussed in this text.

Case studies are used to help illustrate the concepts and show their utility in either improving performance or reducing injury. Smaller case studies are interspersed throughout each lesson, with more complete case studies presented at the end of most lessons. Rather than giving away the entire story at once, each case will gradually be revealed as you gain the requisite knowledge to make use of the newly discovered information. These cases will be summarized and completed in Lesson 18.

These case studies are fairy tales. There are clear story lines and (spoiler alert!) happy endings. They are designed to reinforce the lessons in this text, illustrate my thought process in problem solving, and demonstrate how biomechanics is used to improve people's lives. While fairly realistic, they are also "canned" scripts. Real life is not that tidy, but like most fi lds, you have to learn to solve easy problems before you can tackle the hard ones. These case studies are learning aids and should be treated as such.

Although some lessons and sections within lessons may be self-contained, a majority of the sections and lessons build on the previous ones. Rather than putting all the review questions at the end of each lesson, you will see "Competency Checks" at the end of each major section. Do not skip over them. The major sections are blocks of information, and it is important that you understand the block before moving on to the next one. If you cannot complete the Competency Check, you should review that block before moving to the next one. You will be glad you did.

Summary

In this lesson, you were introduced to the defin tion of biomechanics, the reasons for studying it, and the groups of principles that are derived from it. You were introduced to the importance of equations and hierarchical modeling and then to the topics in this text. Now, it is time to get started with your second lesson: linear kinematics in one dimension and one direction.

Review Questions

1. Define biomechanics, kinematics, kinetics, mechanics, mechanopathology, and pathomechanics.
2. List the four parts that are used for a symbol in this text. What does each part represent?
3. Why do you study biomechanics? How do you achieve these aims?
4. Describe the three sets of principles that are used in biomechanics.
5. Explain the difference between kinematics and kinetics.
6. Describe the rules for hierarchical modeling.

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