SECOND EDITION

Biomechanics

A CASE-BASED APPROACH

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In memory of Dr. Shane Frehlich and Dr. Jennifer Romack

Brief Contents

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Preface


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This text is designed to be a first course in human biomechanics. Although it was written with an undergraduate kinesiology student audience in mind, I believe it is equally well-suited for students in a graduate-level clinical curriculum, such as athletic training, physical therapy, and chiropractic medicine. This is more of an "ideas" book than a "methods" book, and it is written under the assumption that students have a rudimentary knowledge of anatomy and algebra. Trigonometry and geometry are used throughout the book, but "refreshers" appear at the appropriate places. I do not make use of calculus.

Personally, I think many students have a hard time with biomechanics because it is taught in an intimidating manner, with an emphasis on getting the "right numbers" without an understanding of what the numbers actually mean. I have chosen to take a different approach in this text. First, I have used a conversational writing style because I believe that information presented this way is easier to understand without sacrificing rigor. Second, I have tried to make the material less daunting and more meaningful by presenting a Section Question before each major section. Tying new concepts to everyday experience and highlighting research to show how information obtained in the lab can be applied in practice allows the student to better relate to the content. Third, I have placed an emphasis on concepts over computation and expressing these concepts physically, mathematically, and graphically. My hope is that students get an intuitive feel for which way the data should "go" before ever attempting to calculate a number. It might seem that my extensive use of equations contradicts this goal, but I wanted to introduce the symbolic logic behind the equations, and then draw a link between the concepts and the equations. Graph interpretation allows students to visualize this link. To further this goal, in this edition I have introduced "Process Boxes" to illustrate the link between inputs and outputs. I hope the process boxes serve as an additional way to express the link between the underlying concepts and the equations. Finally, nine case studies have been added to this edition. Each case study is gradually introduced after the requisite knowledge has been introduced. The case studies are then summarized and completed in the last chapter.

Each lesson opens with a set of Learning Objectives. Marginal Key Terms, Tables, Figures, Boxes, and Important Point boxed features are used throughout the text. Competency Checks are found after every major section and follow the first three areas of Bloom's taxonomy: remember, understand, and apply.

An alphabetized Glossary has been placed at the end of the book for optimum review and study. My goal in organizing the content in such a fashion is to lead students to better comprehension and optimal retention.

As for the material itself, I have organized the book into 18 lessons that cover the three levels of biomechanical analysis: whole body, joint, and tissue (bone, cartilage, ligament, tendon, and muscle). I chose not to move sequentially from one level to the next but to use a "whole-part-whole" organization. I begin with elucidating mechanical principles using the whole body level (point mass, center of mass, and rigid body models) and then discuss the basic material mechanics of biological tissues and unique properties of the muscle–tendon complex. Throughout my career, I have been influenced by a systems science perspective, which states that you cannot get a complete understanding of a system by examining the parts in isolation. For this reason, the muscle–tendon complex is then put into a joint system. After reviewing some mechanical properties of the individual joints of the musculoskeletal system, the mechanics of multijoint systems is then introduced. In Lesson 18, the three levels are integrated in the context of analyzing movement to improve performance and/or reduce the risk of injury.

I hope that this book provides you with an alternative perspective for teaching and learning the science of biomechanics. Comments and criticisms are welcomed and appreciated.

Sean P. Flanagan

New to the *Second Edition*

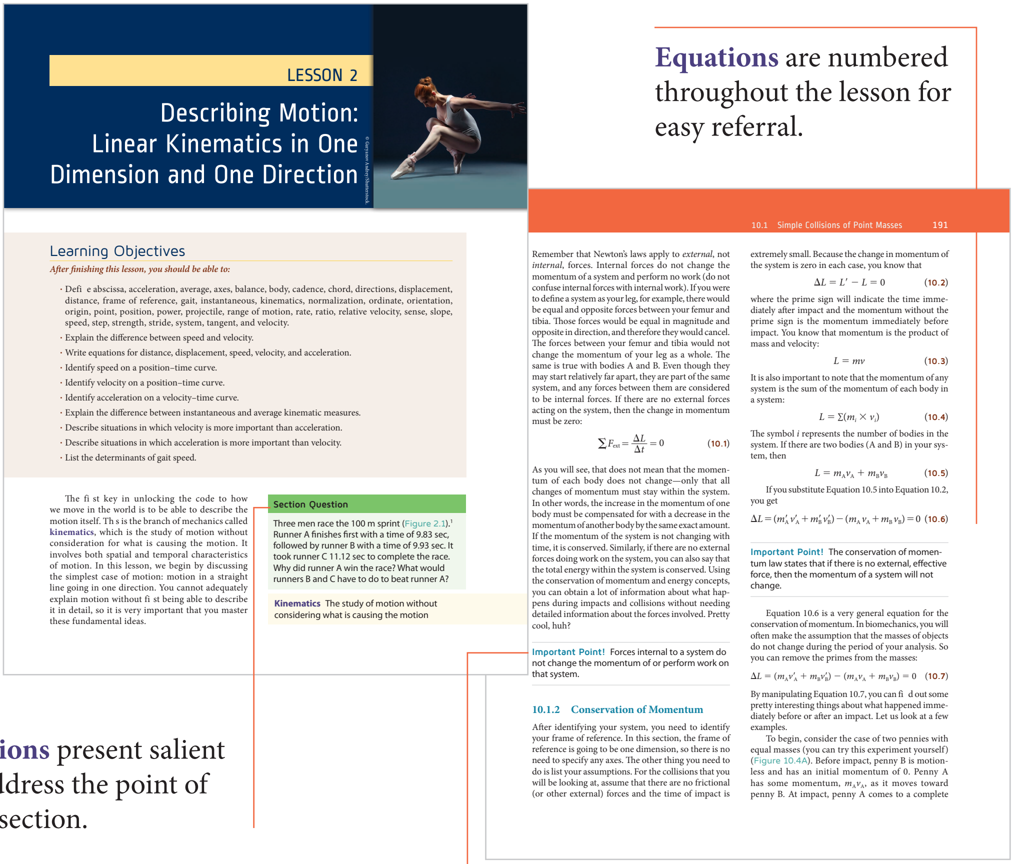
Some of the most significant updates to the *Second Edition* include the following:

- The use of vector diagrams has been greatly expanded throughout the text. These diagrams make it easier to visualize the material.
- "Process Boxes" are added throughout the text. Changing biomechanical quantities can be thought of as a process that transforms inputs into outputs. They provide a visual depiction of the underlying mechanics, which aid in their understanding and serve as an intermediate step between concept formation and mathematical problem-solving.
- Nine new, detailed case studies are added throughout the text. Rather than provide the case study all at once, each is gradually introduced after the requisite knowledge is presented in a lesson.
- Linear Kinematics in One Dimension is now presented in two lessons. Lesson 2 discusses Linear Kinematics in One Direction and Lesson 3 presents Linear Kinematics in Two Directions. Students first learn about position, displacement, velocity, and acceleration without having to concern themselves with changing directions. This should make the transition to changing directions easier.
- In Lesson 2, an "Essential Math" box is added concerning the conversion between frames of reference.
- A more complete treatment of vector addition is added to Chapter 4.
- Sections relating linear and angular position and linear and angular displacement are added to Lesson 5.
- An explanation of bicycle gears is presented in Lesson 5.

- A discussion of phase space is added to Lesson 6. Phase space is used rather than the time domain for some of the case studies.
- Quantifying bone mineral density is important in understanding the mechanics of bone. A box covering this material is included in Lesson 11.
- The discussion of chain configuration is expanded in Lesson 17 and the notion of configuration space is added to the discussion.
- The topic of compensatory motion is expanded in Lesson 17.
- Chain stiffness is added to Lesson 17.
- The inverted-U, along with a discussion of optimal versus maximal quantities of variables, is featured in Lesson 18.
- A summary of all nine case studies presented throughout the text is provided in Lesson 18. The conclusions of these cases are then discussed.

Pedagogical Features

Biomechanics: A Case-Based Approach, Second Edition incorporates a number of engaging pedagogical features to aid the student's understanding and retention of the material.



LESSON 2

Describing Motion:
Linear Kinematics in One
Dimension and One Direction

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Learning Objectives

After finishing this lesson, you should be able to:

- Define abscissa, acceleration, average, axes, balance, body, cadence, chord, directions, displacement, distance, frame of reference, gait, instantaneous, kinematics, normalization, ordinate, orientation, origin, point, position, power, projectile, range of motion, rate, ratio, relative velocity, sense, slope, speed, step, strength, stride, system, tangent, and velocity.
- Explain the difference between speed and velocity.
- Write equations for distance, displacement, speed, velocity, and acceleration.
- Identify speed on a position–time curve.
- Identify velocity on a position–time curve.
- Identify acceleration on a velocity–time curve.
- Explain the difference between instantaneous and average kinematic measures.
- Describe situations in which velocity is more important than acceleration.
- Describe situations in which acceleration is more important than velocity.
- List the determinants of gait speed.

The first key in unlocking the code to how we move in the world is to be able to describe the motion itself. This is the branch of mechanics called **kinematics**, which is the study of motion without consideration for what is causing the motion. It involves both spatial and temporal characteristics of motion. In this lesson, we begin by discussing the simplest case of motion: motion in a straight line going in one direction. You cannot adequately explain motion without first being able to describe it in detail, so it is very important that you master these fundamental ideas.

Section Question

Three men race the 100 m sprint (Figure 2.1).[1] Runner A finishes first with a time of 9.83 sec, followed by runner B with a time of 9.93 sec. It took runner C 11.12 sec to complete the race. Why did runner A win the race? What would runners B and C have to do to beat runner A?

Kinematics The study of motion without considering what is causing the motion

10.1 Simple Collisions of Point Masses 191

Remember that Newton's laws apply to *external*, not *internal*, forces. Internal forces do not change the momentum of a system and perform no work (do not confuse internal forces with internal work). If you were to define a system as your leg, for example, there would be equal and opposite forces between your femur and tibia. Those forces would be equal in magnitude and opposite in direction, and therefore they would cancel. The forces between your femur and tibia would not change the momentum of your leg as a whole. The same is true with bodies A and B. Even though they may start relatively far apart, they are part of the same system, and any forces between them are considered to be internal forces. If there are no external forces acting on the system, then the change in momentum must be zero:

$$\sum F_{\text{ext}} = \frac{\Delta L}{\Delta t} = 0 \qquad (10.1)$$

As you will see, that does not mean that the momentum of each body does not change—only that all changes of momentum must stay within the system. In other words, the increase in the momentum of one body must be compensated for with a decrease in the momentum of another body by the same exact amount. If the momentum of the system is not changing with time, it is conserved. Similarly, if there are no external forces doing work on the system, you can also say that the total energy within the system is conserved. Using the conservation of momentum and energy concepts, you can obtain a lot of information about what happens during impacts and collisions without needing detailed information about the forces involved. Pretty cool, huh?

Important Point! Forces internal to a system do not change the momentum of or perform work on that system.

10.1.2 Conservation of Momentum

After identifying your system, you need to identify your frame of reference. In this section, the frame of reference is going to be one dimension, so there is no need to specify any axes. The other thing you need to do is list your assumptions. For the collisions that you will be looking at, assume that there are no frictional (or other external) forces and the time of impact is extremely small. Because the change in momentum of the system is zero in each case, you know that

$$\Delta L = L' - L = 0 \qquad (10.2)$$

where the prime sign will indicate the time immediately after impact and the momentum without the prime sign is the momentum immediately before impact. You know that momentum is the product of mass and velocity:

$$L = mv \qquad (10.3)$$

It is also important to note that the momentum of any system is the sum of the momentum of each body in a system:

$$L = \Sigma(m_i \times v_i) \qquad (10.4)$$

The symbol i represents the number of bodies in the system. If there are two bodies (A and B) in your system, then

$$L = m_A v_A + m_B v_B \qquad (10.5)$$

If you substitute Equation 10.5 into Equation 10.2, you get

$$\Delta L = (m'_A v'_A + m'_B v'_B) - (m_A v_A + m_B v_B) = 0 \qquad (10.6)$$

Important Point! The conservation of momentum law states that if there is no external, effective force, then the momentum of a system will not change.

Equation 10.6 is a very general equation for the conservation of momentum. In biomechanics, you will often make the assumption that the masses of objects do not change during the period of your analysis. So you can remove the primes from the masses:

$$\Delta L = (m_A v'_A + m_B v'_B) - (m_A v_A + m_B v_B) = 0 \qquad (10.7)$$

By manipulating Equation 10.7, you can find out some pretty interesting things about what happened immediately before or after an impact. Let us look at a few examples.

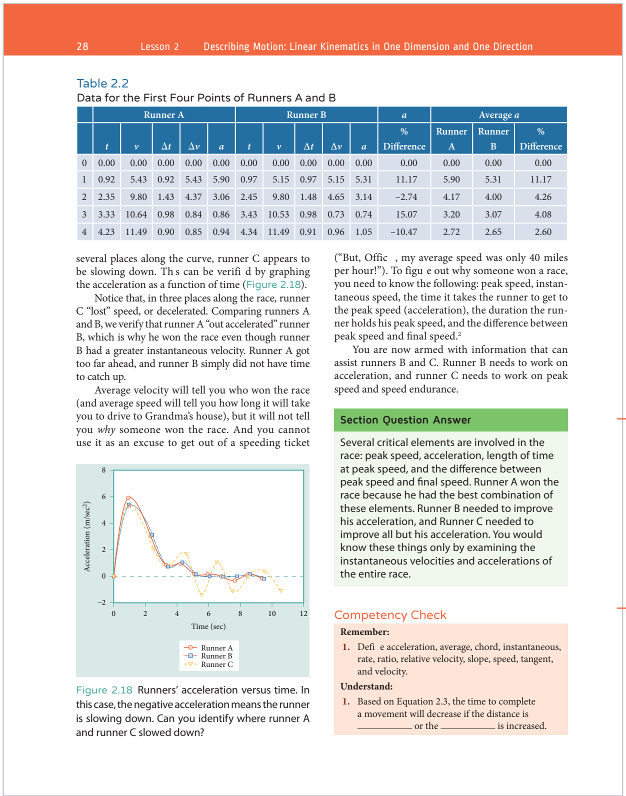
To begin, consider the case of two pennies with equal masses (you can try this experiment yourself) (Figure 10.4A). Before impact, penny B is motionless and has an initial momentum of 0. Penny A has some momentum, $m_A v_A$, as it moves toward penny B. At impact, penny A comes to a complete

Equations are numbered throughout the lesson for easy referral.

Each lesson starts with **Learning Objectives**, which highlight the critical points of each lesson.

Section Questions present salient questions to address the point of focus for each section.

Important Point! boxes clarify essential math concepts relevant to the content within the specific section.



28 Lesson 2 Describing Motion: Linear Kinematics in One Dimension and One Direction

Table 2.2

Data for the First Four Points of Runners A and B

	Runner A					Runner B					a	Average a		
	t	v	Δt	Δv	a	t	v	Δt	Δv	a	% Difference	Runner A	Runner B	% Difference
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.92	5.43	0.92	5.43	5.90	0.97	5.15	0.97	5.15	5.31	11.17	5.90	5.31	11.17
2	2.35	9.80	1.43	4.37	3.06	2.45	9.80	1.48	4.65	3.14	−2.74	4.17	4.00	4.26
3	3.33	10.64	0.98	0.84	0.86	3.43	10.53	0.98	0.73	0.74	15.07	3.20	3.07	4.08
4	4.23	11.49	0.90	0.85	0.94	4.34	11.49	0.91	0.96	1.05	−10.47	2.72	2.65	2.60

several places along the curve, runner C appears to be slowing down. This can be verified by graphing the acceleration as a function of time (Figure 2.18).

Notice that, in three places along the race, runner C "lost" speed, or decelerated. Comparing runners A and B, we verify that runner A "out accelerated" runner B, which is why he won the race even though runner B had a greater instantaneous velocity. Runner A got too far ahead, and runner B simply did not have time to catch up.

Average velocity will tell you who won the race (and average speed will tell you how long it will take you to drive to Grandma's house), but it will not tell you *why* someone won the race. And you cannot use it as an excuse to get out of a speeding ticket ("But, Officer, my average speed was only 40 miles per hour!"). To figure out why someone won a race, you need to know the following: peak speed, instantaneous speed, the time it takes the runner to get to the peak speed (acceleration), the duration the runner holds his peak speed, and the difference between peak speed and final speed.[2]

You are now armed with information that can assist runners B and C. Runner B needs to work on acceleration, and runner C needs to work on peak speed and speed endurance.

Figure 2.18 Runners' acceleration versus time. In this case, the negative acceleration means the runner is slowing down. Can you identify where runner A and runner C slowed down?

Section Question Answer

Several critical elements are involved in the race: peak speed, acceleration, length of time at peak speed, and the difference between peak speed and final speed. Runner A won the race because he had the best combination of these elements. Runner B needed to improve his acceleration, and Runner C needed to improve all but his acceleration. You would know these things only by examining the instantaneous velocities and accelerations of the entire race.

Competency Check

Remember:

1. Define acceleration, average, chord, instantaneous, rate, ratio, relative velocity, slope, speed, tangent, and velocity.

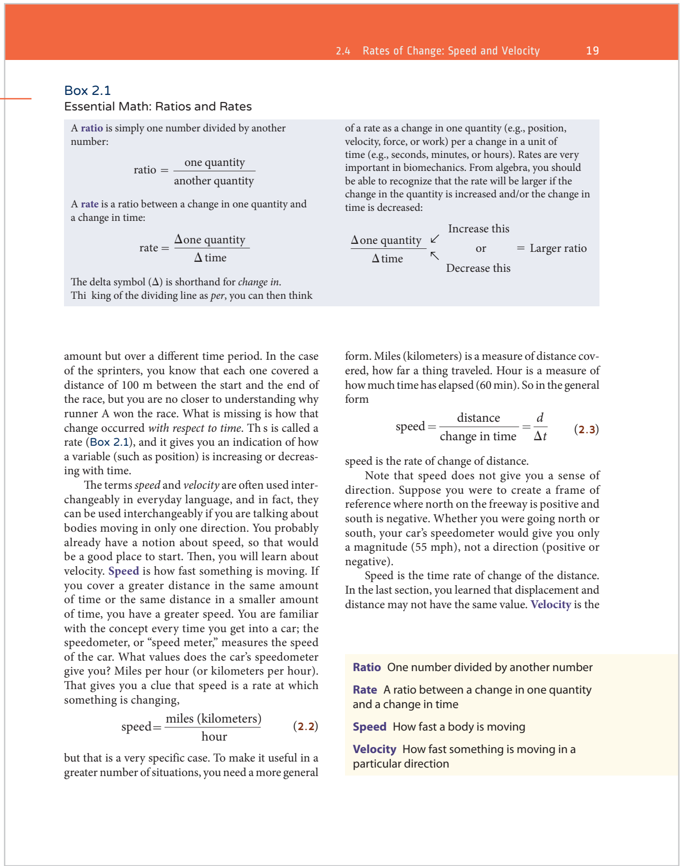
Understand:

1. Based on Equation 2.3, the time to complete a movement will decrease if the distance is ____________ or the ____________ is increased.

Section Question Answers provide contextual responses to each section question.

Using the first three levels of Bloom's taxonomy, **Competency Checks** ask students conceptual and quantitative questions to assist in gauging their understanding of the material.

Essential Math boxed features provide a review of mathematical material crucial to the understanding of biomechanics.



2.4 Rates of Change: Speed and Velocity 19

Box 2.1

Essential Math: Ratios and Rates

A **ratio** is simply one number divided by another number:

$$\text{ratio} = \frac{\text{one quantity}}{\text{another quantity}}$$

A **rate** is a ratio between a change in one quantity and a change in time:

$$\text{rate} = \frac{\Delta\text{one quantity}}{\Delta\text{ time}}$$

The delta symbol (Δ) is shorthand for *change in*. Think of the dividing line as *per*, you can then think of a rate as a change in one quantity (e.g., position, velocity, force, or work) per a change in a unit of time (e.g., seconds, minutes, or hours). Rates are very important in biomechanics. From algebra, you should be able to recognize that the rate will be larger if the change in the quantity is increased and/or the change in time is decreased:

$$\frac{\Delta\text{one quantity}\ \swarrow}{\Delta\text{ time}\ \nwarrow}\ \begin{matrix}\text{Increase this}\\ \text{or}\\ \text{Decrease this}\end{matrix}\ = \text{Larger ratio}$$

amount but over a different time period. In the case of the sprinters, you know that each one covered a distance of 100 m between the start and the end of the race, but you are no closer to understanding why runner A won the race. What is missing is how that change occurred *with respect to time*. This is called a rate (Box 2.1), and it gives you an indication of how a variable (such as position) is increasing or decreasing with time.

The terms *speed* and *velocity* are often used interchangeably in everyday language, and in fact, they can be used interchangeably if you are talking about bodies moving in only one direction. You probably already have a notion about speed, so that would be a good place to start. Then, you will learn about velocity. **Speed** is how fast something is moving. If you cover a greater distance in the same amount of time or the same distance in a smaller amount of time, you have a greater speed. You are familiar with the concept every time you get into a car; the speedometer, or "speed meter," measures the speed of the car. What values does the car's speedometer give you? Miles per hour (or kilometers per hour). That gives you a clue that speed is a rate at which something is changing,

$$\text{speed} = \frac{\text{miles (kilometers)}}{\text{hour}} \tag{2.2}$$

but that is a very specific case. To make it useful in a greater number of situations, you need a more general form. Miles (kilometers) is a measure of distance covered, how far a thing traveled. Hour is a measure of how much time has elapsed (60 min). So in the general form

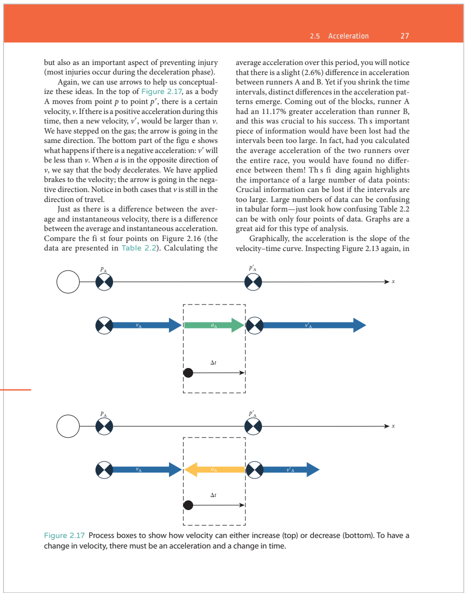
$$\text{speed} = \frac{\text{distance}}{\text{change in time}} = \frac{d}{\Delta t} \tag{2.3}$$

speed is the rate of change of distance.

Note that speed does not give you a sense of direction. Suppose you were to create a frame of reference where north on the freeway is positive and south is negative. Whether you were going north or south, your car's speedometer would give you only a magnitude (55 mph), not a direction (positive or negative).

Speed is the time rate of change of the distance. In the last section, you learned that displacement and distance may not have the same value. **Velocity** is the

Ratio	One number divided by another number
Rate	A ratio between a change in one quantity and a change in time
Speed	How fast a body is moving
Velocity	How fast something is moving in a particular direction



2.5 Acceleration 27

but also as an important aspect of preventing injury (most injuries occur during the deceleration phase).

Again, we can use arrows to help us conceptualize these ideas. In the top of Figure 2.17, as a body A moves from point p to point p', there is a certain velocity, v. If there is a positive acceleration during this time, then a new velocity, v', would be larger than v. We have stepped on the gas; the arrow is going in the same direction. The bottom part of the figure shows what happens if there is a negative acceleration: v' will be less than v. When a is in the opposite direction of v, we say that the body decelerates. We have applied brakes to the velocity; the arrow is going in the negative direction. Notice in both cases that v is still in the direction of travel.

Just as there is a difference between the average and instantaneous velocity, there is a difference between the average and instantaneous acceleration. Compare the first four points on Figure 2.16 (the data are presented in Table 2.2). Calculating the average acceleration over this period, you will notice that there is a slight (2.6%) difference in acceleration between runners A and B. Yet if you shrink the time intervals, distinct differences in the acceleration patterns emerge. Coming out of the blocks, runner A had an 11.17% greater acceleration than runner B, and this was crucial to his success. This important piece of information would have been lost had the intervals been too large. In fact, had you calculated the average acceleration of the two runners over the entire race, you would have found no difference between them! This finding again highlights the importance of a large number of data points: Crucial information can be lost if the intervals are too large. Large numbers of data can be confusing in tabular form—just look how confusing Table 2.2 can be with only four points of data. Graphs are a great aid for this type of analysis.

Graphically, the acceleration is the slope of the velocity–time curve. Inspecting Figure 2.13 again, in

Figure 2.17 Process boxes to show how velocity can either increase (top) or decrease (bottom). To have a change in velocity, there must be an acceleration and a change in time.

Process Boxes show transformations between inputs and outputs. Process Boxes provide a visual depiction of the underlying mechanics, which aid in their understanding and serve as an intermediate step between concept formation and mathematical problem-solving.

10.3 Effective Mass 201

where it is understood that m is the mass of the entire body and v is the velocity of the COM. When you are dealing with a multisegmented body and you want to know the momentum of the segment involved in a collision, then Equation 10.3 becomes

$$L = m_{\text{effective}} v_{\text{segment}} \quad (10.16)$$

Subsequent equations (Equations 10.4–10.14) should make similar distinctions when dealing with bodies that are anything other than point masses.

In many activities, you may be striking an object, such as in baseball, softball, tennis, golf, boxing, and martial arts. When striking an object, you actually want to create a large impact. Performance is generally improved if you transfer a large momentum to the object you are striking. So how would you transfer a larger momentum to the object? The beginning of the hierarchical model is presented in Figure 10.15. Momentum transfer depends on the effective mass and the velocity of the segment or implement that is actually striking the object. The velocity component needs no further elaboration. The effective mass can be increased in one of two ways.

First, the mass of the segment or implement can be increased. In some cases, this is not possible. A martial artist cannot appreciably increase the mass of his fist, although wearing a boxing glove could have this effect. In other cases, it comes with trade-off. Remember that momentum is the product of mass and velocity and the two affect each other. In general, as the mass of the object increases, it will be harder to increase its velocity. So these two competing factors must be balanced. The optimal mass/velocity combination will be different for every activity and every individual participating in that activity.

Second, the effective mass can be increased by linking the mass of the segment/implement to the masses of other segments in the body. This is done by a proper positioning of the segments and the appropriate muscle activation to stiffen the extremity. This is similar to stiffening the legs during a hard landing.

Figure 10.15 The beginning of a hierarchical model for a performance involving the impact of a multisegmented body.

Box 10.1
Applied Research: Effective Mass and Head Injuries in American Football

Head injuries in American football are a serious problem, particularly those resulting from helmet-to-helmet contact. In many cases, the injury to the offensive player receiving the impact is greater than the injury sustained by the striking defensive player. In this investigation, the researchers provide an explanation for why this is the case. Reconstructing actual, recorded game-time head injuries using instrumented dummies in the laboratory, they found that the striking player aligned his head, neck, and torso (called spearing), thus increasing his effective mass to 1.67 times that of the player being hit. In a follow-up investigation, they compared these impacts to punches to the head delivered by Olympic-caliber boxers. They found that these impacts did not transfer as much linear momentum as the football head strikes due to the lower effective mass of the fist.

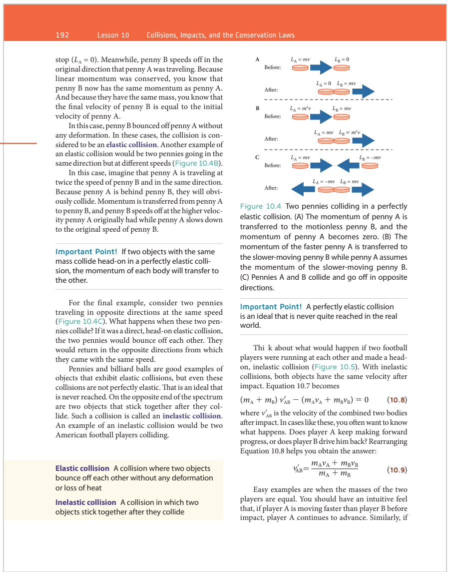
Data from Viano DC, Pellman EJ. Concussion in professional football: biomechanics of the striking player—Part 8. *Neurosurgery.* Feb 2005;56(2):266–278. Viano DC, Casson IR, Pellman EJ, Bir CA, Zhang LY, Boitano MA. Concussion in professional football: comparison with boxing head impacts—Part 10. *Neurosurgery.* Dec 2005;57(6):1154–1170.

Effective mass is an important concept in any physical activity that involves impacts either with a part of your body or with an implement. It can help explain why helmet-to-helmet contacts in football are so dangerous particularly to the defender (Box 10.1). It also explains the answer to the question at the beginning of this section: Why is it that one boxer can hit harder than another even if they both have the same mass and can deliver a punch with the same velocity?

Section Question Answer

Just because two boxers have the same mass and punch with the same velocity does not mean that they can deliver the same momentum to their intended target. Research[4,6] has shown that highly skilled fighters do indeed impart more momentum to the objects they are striking than lesser-skilled fighters with the same mass and punching velocity. The investigators determined that this must be due to the more highly skilled practitioners developing a greater effective mass by proper positioning of the arm and effectively stiffening the appropriate joints. Manny can hit harder than Floyd because he has a greater effective mass.

Applied Research boxed features provide examples that are helpful in illustrating biomechanical concepts and present evidence of the practical value of biomechanics.



192 Lesson 10 Collisions, Impacts, and the Conservation Laws

stop ($L_A = 0$). Meanwhile, penny B speeds off in the original direction that penny A was traveling. Because linear momentum was conserved, you know that penny B now has the same momentum as penny A. And because they have the same mass, you know that the final velocity of penny B is equal to the initial velocity of penny A.

In this case, penny B bounced off penny A without any deformation. In these cases, the collision is considered to be an **elastic collision**. Another example of an elastic collision would be two pennies going in the same direction but at different speeds (Figure 10.4B).

In this case, imagine that penny A is traveling at twice the speed of penny B and in the same direction. Because penny A is behind penny B, they will obviously collide. Momentum is transferred from penny A to penny B, and penny B speeds off at the higher velocity penny A originally had while penny A slows down to the original speed of penny B.

Important Point! If two objects with the same mass collide head-on in a perfectly elastic collision, the momentum of each body will transfer to the other.

For the final example, consider two pennies traveling in opposite directions at the same speed (Figure 10.4C). What happens when these two pennies collide? If it was a direct, head-on elastic collision, the two pennies would bounce off each other. They would return in the opposite directions from which they came with the same speed.

Pennies and billiard balls are good examples of objects that exhibit elastic collisions, but even these collisions are not perfectly elastic. That is an ideal that is never reached. On the opposite end of the spectrum are two objects that stick together after they collide. Such a collision is called an **inelastic collision**. An example of an inelastic collision would be two American football players colliding.

Elastic collision A collision where two objects bounce off each other without any deformation or loss of heat

Inelastic collision A collision in which two objects stick together after they collide

Figure 10.4 Two pennies colliding in a perfectly elastic collision. (A) The momentum of penny A is transferred to the motionless penny B, and the momentum of penny A becomes zero. (B) The momentum of the faster penny A is transferred to the slower-moving penny B while penny A assumes the momentum of the slower-moving penny B. (C) Pennies A and B collide and go off in opposite directions.

Important Point! A perfectly elastic collision is an ideal that is never quite reached in the real world.

Think about what would happen if two football players were running at each other and made a head-on, inelastic collision (Figure 10.5). With inelastic collisions, both objects have the same velocity after impact. Equation 10.7 becomes

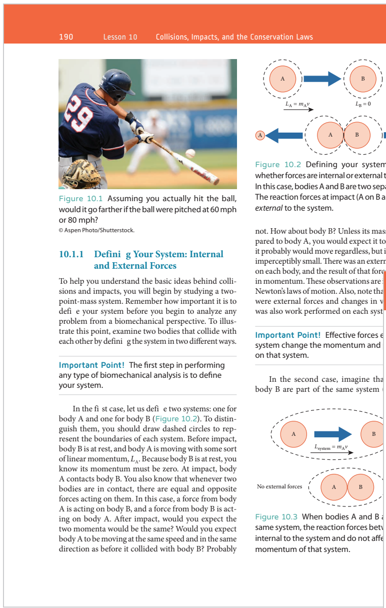
$$(m_A + m_B)\, v'_{AB} - (m_A v_A + m_B v_B) = 0 \quad (10.8)$$

where v'_{AB} is the velocity of the combined two bodies after impact. In cases like these, you often want to know what happens. Does player A keep making forward progress, or does player B drive him back? Rearranging Equation 10.8 helps you obtain the answer:

$$v'_{AB} = \frac{m_A v_A + m_B v_B}{m_A + m_B} \quad (10.9)$$

Easy examples are when the masses of the two players are equal. You should have an intuitive feel that, if player A is moving faster than player B before impact, player A continues to advance. Similarly, if

Key Terms are highlighted and defined in the margins throughout the lesson and compiled into a **Glossary** at the end of the book.



190 Lesson 10 Collisions, Impacts, and the Conservation Laws

Figure 10.1 Assuming you actually hit the ball, would it go farther if the ball were pitched at 60 mph or 80 mph?

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10.1.1 Defining Your System: Internal and External Forces

To help you understand the basic ideas behind collisions and impacts, you will begin by studying a two-point-mass system. Remember how important it is to define your system before you begin to analyze any problem from a biomechanical perspective. To illustrate this point, examine two bodies that collide with each other by defining the system in two different ways.

Important Point! The first step in performing any type of biomechanical analysis is to define your system.

In the first case, let us define two systems: one for body A and one for body B (Figure 10.2). To distinguish them, you should draw dashed circles to represent the boundaries of each system. Before impact, body B is at rest, and body A is moving with some sort of linear momentum, L_A. Because body B is at rest, you know its momentum must be zero. At impact, body A contacts body B. You also know that whenever two bodies are in contact, there are equal and opposite forces acting on them. In this case, a force from body A is acting on body B, and a force from body B is acting on body A. After impact, would you expect the two momenta would be the same? Would you expect body A to be moving at the same speed and in the same direction as before it collided with body B? Probably

Figure 10.2 Defining your system determines whether forces are internal or external to that system. In this case, bodies A and B are two separate systems. The reaction forces at impact (A on B and B on A) are *external* to the system.

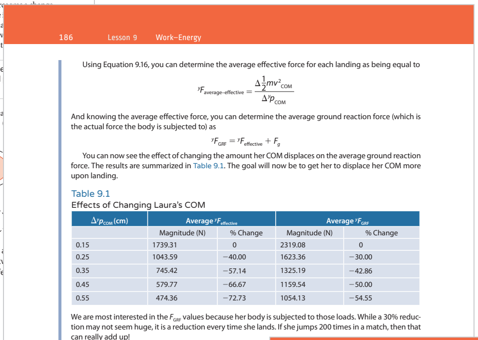
not. How about body B? Unless its mass is huge compared to body A, you would expect it to move. In fact, it probably would move regardless, but it just might be imperceptibly small. There was an external force acting on each body, and the result of that forc
in momentum. These observations are
Newton's laws of motion. Also, note tha
were external forces and changes in v
was also work performed on each syst

Important Point! Effective forces e
system change the momentum and
on that system.

In the second case, imagine tha
body B are part of the same system

Figure 10.3 When bodies A and B a
same system, the reaction forces betw
internal to the system and do not affe
momentum of that system.

A comprehensive and instructional **art package** includes photographs and illustrations throughout the book to encourage learning with a unique visual appeal.



186 Lesson 9 Work–Energy

Using Equation 9.16, you can determine the average effective force for each landing as being equal to

$${}^{y}F_{\text{average-effective}} = \frac{\Delta \frac{1}{2}mv^{2}{}_{\text{COM}}}{\Delta {}^{y}p_{\text{COM}}}$$

And knowing the average effective force, you can determine the average ground reaction force (which is the actual force the body is subjected to) as

$${}^{y}F_{\text{GRF}} = {}^{y}F_{\text{effective}} + F_g$$

You can now see the effect of changing the amount her COM displaces on the average ground reaction force. The results are summarized in Table 9.1. The goal will now be to get her to displace her COM more upon landing.

Table 9.1

Effects of Changing Laura's COM

$\Delta {}^{y}p_{\text{COM}}$ (cm)	Average ${}^{y}F_{\text{effective}}$		Average ${}^{y}F_{\text{GRF}}$	
	Magnitude (N)	% Change	Magnitude (N)	% Change
0.15	1739.31	0	2319.08	0
0.25	1043.59	−40.00	1623.36	−30.00
0.35	745.42	−57.14	1325.19	−42.86
0.45	579.77	−66.67	1159.54	−50.00
0.55	474.36	−72.73	1054.13	−54.55

We are most interested in the F_{GRF} values because her body is subjected to those loads. While a 30% reduction may not seem huge, it is a reduction every time she lands. If she jumps 200 times in a match, then that can really add up!

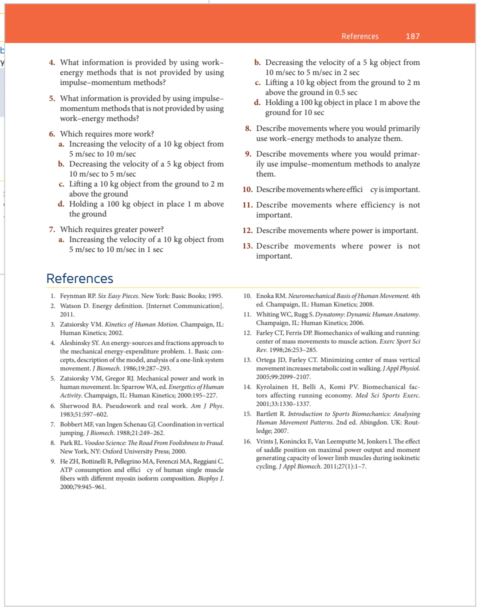
Summary

In this lesson, you learned about an alternative to Newton's laws for analyzing human movement. This method involved the concepts of work, energy, and power (Table 9.2). Because of some issues with using these concepts with biological systems, mechanical energy expenditure was introduced. The first law of thermodynamics was compared to the center of mass equation, and efficiency and economy were introduced. Impulse–momentum and work–energy methods provide complementary information and a more complete analysis of movement for several different tasks.

Tab
Key

Review Questions

1. Define efficiency, economy, energy, external (locomotor) work, gravitational potential energy, kinetic energy, mechanical energy expenditure, potential energy, power, strain potential energy, and work.
2.
3.



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4. What information is provided by using work–energy methods that is not provided by using impulse–momentum methods?
5. What information is provided by using impulse–momentum methods that is not provided by using work–energy methods?
6. Which requires more work?
    a. Increasing the velocity of a 10 kg object from 5 m/sec to 10 m/sec
    b. Decreasing the velocity of a 5 kg object from 10 m/sec to 5 m/sec
    c. Lifting a 10 kg object from the ground to 2 m above the ground
    d. Holding a 100 kg object in place 1 m above the ground
7. Which requires greater power?
    a. Increasing the velocity of a 10 kg object from 5 m/sec to 10 m/sec in 1 sec
    b. Decreasing the velocity of a 5 kg object from 10 m/sec to 5 m/sec in 2 sec
    c. Lifting a 10 kg object from the ground to 2 m above the ground in 0.5 sec
    d. Holding a 100 kg object in place 1 m above the ground for 10 sec
8. Describe movements where you would primarily use work–energy methods to analyze them.
9. Describe movements where you would primarily use impulse–momentum methods to analyze them.
10. Describe movements where efficiency is important.
11. Describe movements where efficiency is not important.
12. Describe movements where power is important.
13. Describe movements where power is not important.

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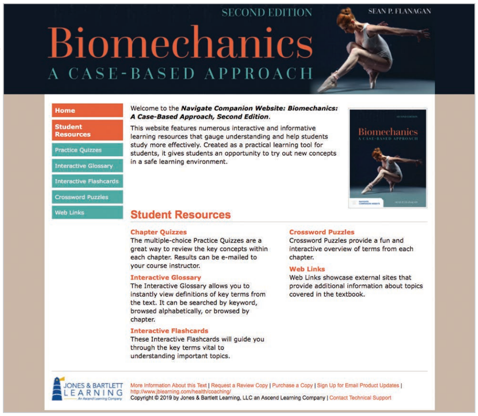

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