LORENA MARTIN, PH.D.

SPORTS PERFORMANCE MEASUREMENT and ANALYTICS

THE SCIENCE OF ASSESSING PERFORMANCE, PREDICTING FUTURE OUTCOMES, INTERPRETING STATISTICAL MODELS, AND EVALUATING THE MARKET VALUE OF ATHLETES

Sports Performance Measurement and Analytics

The Science of Assessing Performance,

Predicting Future Outcomes,

Interpreting Statistical Models,

and Evaluating the Market Value of Athletes

LORENA MARTIN

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Preface

"Impossible is just a big word thrown around by small men who find it easier to live in the world they've been given than to explore the power they have to change it. Impossible is not a fact. It's an opinion. Impossible is not a declaration. It's a dare. Impossible is potential. Impossible is temporary. Impossible is nothing."

—MUHAMMAD ALI

I have played sports my entire life. I began playing the sport of tennis at the age of thirteen, too late in the eyes of many tennis experts to become a top professional tennis player. I trained six hours a day from the first day that I won a match against a boy at a neighborhood tennis court. In an instant, I was addicted to the sport.

I dreamed of becoming a professional tennis player. I spent countless hours on the court, skipping hangouts, holidays, and dates just to hit tennis balls. I went on to play high school and college tennis. I dropped out of college to play professional tennis. I worked for an airline so I could travel inexpensively to compete in professional tennis tournaments around the world. Tournaments were (and still are) scattered across the globe, giving a person of lower socioeconomic status a very slim chance of making it. Through my tennis training and competition, I reached a Florida state ranking of number three and a top 200 women's professional ranking in the USA.

As an undergraduate, I majored in psychology. I wanted to learn about the psychological and behavioral profiles of successful professional athletes. I went on to get a master's degree in psychology.

After studying psychology, I wanted to obtain a deeper understanding of the importance of physiology and physical fitness variables in sports, such as muscular strength, power, endurance, anaerobic power, cardiorespiratory endurance, and flexibility. I felt it was essential to learn as much as possible about the processes going on inside an elite athlete's mind and body. I earned a doctorate in exercise physiology from the University of Miami and was recruited to conduct postdoctoral research in behavioral medicine at the University of California, San Diego.

I have always been driven to learn about statistics, about what is and is not being said by the numbers. I wanted to see which variables could be used to predict sport performance and to answer a simple question: "What are the qualities a person must have to become a world class athlete?" This question and many more may be answered through research, measurement, statistics, and analytics.

I went on to teach research methods and statistical design at Florida International University. Later I joined Northwestern University, where I currently teach introduction to statistical analysis as well as sports performance analytics.

As a teacher of sports performance analytics, I tried to find a book that encompassed sports-relevant anatomy and physiology and described athletic performance measures. I wanted a book that included statistical analyses and models used in various individual and team sports, along with statistics adopted by the sports industry. But I found no such book.

I chose to write this book to give athletes, coaches, and managers a better understanding of measurement and analytics as they relate to sport performance. To develop accurate measures, we need to know what we want to measure and why. This book provides new insights into constructs and variables that have often been neglected in sports to this day. It also reviews fundamentals of sports anatomy and physiology, sport measurement, and performance analytics.

This book serves many readers. People involved with sports, including players, coaches, and trainers, will gain an appreciation for performance measures and analytics. People involved with analytics will gain new insights into sports performance and see what it takes to become a competitive athlete. And students eager to learn about sports analytics will have a practical introduction to the field. Data sets and programs in the book are available from the book's website `http://www.ftpress.com/martin/`.

Many thanks to Thomas W. Miller, my consulting editor, for making this book happen, as it would not have been possible to complete without him. And special thanks go to my editor, Jeanne Glasser Levine, and publisher, Pearson/FT Press, for giving me the opportunity to publish my first book. Of course, any writing issues, errors, or items of unfinished business are my responsibility alone.

I want to give a special thank you to my brother and professional tennis player, Juan J. Martin Jr., who constantly provides me with insightful information based on his experience in professional sports and exercise physiology. I would also like to thank the Dallas Cowboys' Director of Football Research, Tom Robinson, for his instrumental remarks and comments. Thanks to Roy Sanford, a lead faculty member in Northwestern University's Master's Program in Predictive Analytics, who provided constructive critiques on statistical methods. I want to thank my mother, Estela Martin, for being there day and night and offering continued support. *Tambien, gracias a mi padre,* Juan J. Martin Sr., for providing me with a sports-like motivation, impelling me to complete this book. In addition, I would like to mention my dogs, which are always there for me and brought a smile to my face while working on this book.

Most of all, I want to thank God for making this possible.

Lorena Martin
San Diego, California
December 2015

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1 Anatomy and Physiology

"A muscle is like a car. If you want it to run well early in the morning, you have to warm it up."

—Florence Griffith Joyner

Understanding the basics of anatomy and physiology is fundamental to obtaining a more comprehensive knowledge of what it means to be an athlete. Let us start by answering the question, "What is an athlete?" We can think of an athlete as a person who is skilled at a sport, trains, and possesses physical attributes such as muscular strength, power, endurance, speed, and agility, to name a few.

The physical attributes and variables of an athlete will be detailed and explained in chapter 2. This chapter focuses on the fundamental anatomy and physiology of an athlete. The objective of this chapter is to help the sports data analyst, as well as athletes themselves, understand the human body and how its machinery functions during athletic events in order to comprehend how performance is affected by physiology. This chapter will open your eyes to new ways of thinking about number crunching and sports analytics. Knowledge of the main physiological mechanisms will make you a more competitive and insightful sports data scientist.

Table 1.1. *Types of Bones*

Type of Bone	Example of Bone
Long bones	Femur, Humerus, Tibia
Short bones	Tarsals of the foot, Carpals of the hand and wrist
Flat bones	Scapula, Sternum, Cranium
Irregular bones	Vertebrae, Sacrum, Mandible
Sesamoid bones	Knee Cap, there are four sesamoid bones in the hand, there are two sesamoid bones in the foot

Let us review the basic bone structure and anatomical information you should be aware of. The human body is made up of 206 bones and more than 430 skeletal muscles. The topic of anatomy alone could take several books to do it justice. We will cover the part of human anatomy and physiology most relevant to sports performance.

The study of bones is called osteology. Osteologists dedicate their lives to understanding how bones function. Bones are responsible for providing constant renewal of red and white blood cells, and are vital not only to our organs, but to gaining a competitive edge in sports performance. There are several types of bones: long bones, short bones, flat bones, irregular bones, and sesamoid bones. Long bones are associated with greater movement due to the lever length, compared to short bones which have limited mobility, but are known to be stronger. Please refer to table 1.1 for examples of each type of bone.

The musculoskeletal system is integral to human movement, as it is comprised of ligaments that connect bone to bone and tendons that connect muscles to bone. Consequently, when the muscle pulls on the bone, motion occurs. Depending on the method of classification or grouping, estimates of the number of muscles in the body range between 430 to over 900. In fact, each skeletal muscle is considered an organ that contains muscle tissue, connective tissue, nerves, and blood vessels. Much of the debate is a matter of definition in terms of how the muscles are quantified.

Like bones, muscles may be classified by type: smooth muscle is found in the blood vessels and organs, cardiac muscle is found in the heart, and skeletal muscle is abundant throughout the human body and is responsible for our daily movement.

Upper body muscles and muscle groups to become familiar with include the latissimus dorsi, trapezius, deltoids, rotator cuff, pectorals, biceps, triceps, and brachioradialis. Midsection muscles involved in sports performance include the rectus abdominus, external and internal obliques, and the transversus abdominis. Lower body muscles vital for many sports include the quadriceps, hamstrings, gluteus (maximus, minimus, medius), gastrocnemius, and the soleus. Please refer to table 1.2 for the locations of these muscles and their function in sports.

Many of you have heard of fast twitch and slow twitch muscle fibers. Most people are only aware of two fiber types, fast and slow, or white and red. However, it is much more accurate to say that there are hybrid fiber types that lie within the spectrum of Type I and Type II muscle fibers. More recently, the scientific field revealed three distinct categories of muscle fibers. These are Type I, Type IIa, and Type IIx muscle fibers. Type I fibers are commonly referred to as slow-twitch while both Type IIa and Type IIx are recognized as fast-twitch muscle fibers.

To facilitate understanding, we will focus on the differences between Type I and Type II because they are inherently different as they relate to the following characteristics: ability to utilize oxygen and glycogen as determined by aerobic enzyme content, myoglobin content, capillary density, and mitochondria size and density.

Typically, slow-twitch muscle fibers tend to be high in all the criteria mentioned above. In comparison, fast-twitch muscle fibers tend to be low in these characteristics, while having greater nerve conduction velocity, speed of muscle contractility, anaerobic enzyme content, and power output. Fast twitch fibers are known to have high glycolytic activity, meaning they utilize glycogen (the storage form of glucose, which many call sugar) at high levels, whereas slow-twitch muscle fibers rely on their oxidative capacity. Please refer to table 1.3 for additional muscle fiber type characteristics.

Table 1.2. *Muscles in Sport*

Name of Muscle	Location of Muscle	Function in Sport
Upper Body Muscles		
Latissimus dorsi	located in the posterior part of the body, largest muscle group in the upper body, also called the back	involved in extension and adduction of the shoulder as well as pulling motions; relevant for all sports
Rhomboids	located in the upper back underneath the trapezius and consists of two muscles; rhomboid major and minor	involved in retraction of shoulder blades relevant for all sports
Trapezius	located above and superficial to rhomboids extends from shoulders to neck muscles	involved in distributing loads away from the neck and keeping the shoulders stabilized
Deltoids	commonly referred to as the shoulders	involved in throwing motions used extensively in overhead athletes
Rotator Cuff	located in the shoulder area deep under the deltoids, muscles that hold the shoulder in place	involved in throwing motions; quarterbacks, pitchers, and tennis players when serving
Pectorals	commonly referred to as the chest includes pectoralis major and minor	involved in chest press strength, and abduction of the shoulder and pushing movements
Biceps	located in anterior part of the arm and called biceps because of the two heads of the muscle	involved in swinging motion; tennis players forehand and baseball swings; also involved in bending of the elbow and for picking up motions
Triceps	located in posterior part of the arm and called triceps because of the three heads of the muscle	extension of elbow; used to straighten the elbow; used in stiff-arm movement in football players
Brachioradialis and Pronator Teres	forearm muscles	utilized in sports using the wrist
Core and Midsection Muscles		
Rectus Abdominus	located in the anterior part of the body under the abdomen	utilized for flexion of the spine and core stabilization; relevant for all sports
External Obliques	located above and superficial to the internal obliques on each side of the trunk	utilized for sideways bending and rotation of the torso; integral for tennis strokes
Internal Obliques	located underneath the external abdominal oblique on each side of the trunk	utilized for flexion of the spine, sideways bending, trunk rotation and compression of the abdomen; relevant for all sports
Transversus Abdominis	located in the deepest layer of abdominal muscles that wraps around the torso	utilized for respiration and core stabilization; relevant for all sports
Lower Body Muscles		
Quadriceps	located in anterior part of thigh consisting of four muscles	responsible for extension of the knee; major source of strength for soccer players; relevant for all sports
Hamstrings	located in posterior part of thigh consisting of three muscles	responsible for flexion and bending of the knee; relevant for all sports
Gluteus Maximus, Gluteus Medius, and Gluteus Minimus	located in the area usually called the buttocks	utilized in explosive first step movements; integral for lower body strength and power
Gastrocnemius	located in the lower leg area and typically referred to as part of the calf muscle	utilized in jumping and tip-toe motions including being on the ball of your feet
Soleus	located in the lower leg area and typically referred to as part of the calf muscle	utilized in jumping and tip-toe motions including being on the ball of your feet

Table 1.3. *Characteristics of Fiber Types*

Characteristics	Type I	Type IIa	Type IIx
Motor neuron size	Small	Large	Large
Nerve conduction velocity	Slow	Fast	Fast
Contraction speed	Slow	Fast	Fast
Relaxation speed	Slow	Fast	Fast
Fatigue resistance	High	Intermediate/Low	Low
Force production	Low	Intermediate	High
Power output	Low	Intermediate/High	High
Endurance	High	Intermediate/Low	Low
Aerobic enzyme content	High	Intermediate/Low	Low
Anaerobic enzyme content	Low	High	High
Capillary density	High	Intermediate	Low
Myoglobin content	High	Low	Low
Mitochondria size/density	High	Intermediate	Low
Fiber diameter	Small	Intermediate	Large
Color	Red	White/Red	White

Adapted from Baechle and Earle (2008).

Table 1.4. Muscle Fiber Types and Sports

Sport	Type I Contribution	Type II Contribution
100 meter sprint	Low	High
800 meter sprint	High	High
Marathon	High	Low
Soccer	High	High
American Football Wide Receiver and Linemen	Low	High
Basketball	Low	High
Baseball Pitcher	Low	High
Tennis	High	High

Adapted from Baechle and Earle (2008).

It is evident that anatomy and physiology play a major role in sports performance. A sprinter may benefit from a greater number of fast twitch muscle fibers, whereas a long-distance runner will benefit much more from having a greater distribution of slow twitch muscle fibers. Refer to table 1.4 for Type I and Type II muscle fiber contribution in a variety of sports.

In addition to the controversy over the number of muscle fiber types, there also remains the question of whether one can train and modify one's own fiber type through conditioning. Several animal studies have shown that enzymes that would otherwise be dormant are activated through physical training, implying that there is a possibility of changing the fiber type to a certain degree.

Now that we have the basics of the skeletal and muscular system, let us consider the physiology of sports performance. First, we must realize that human metabolism includes both anabolic and catabolic processes that are ongoing in our bodies. Anabolic processes involve the synthesis of larger molecules from smaller molecules. Conversely, catabolic processes involve the breakdown of larger molecules into smaller ones, and are associated with the release of energy. Energy released in a biological reaction is quantified by the amount of heat that is generated. The amount of heat required to raise one kilogram of water one degree Celsius is called a kilocalorie. This corresponds to the energy found in food that is broken down within our bodies and stored in the form of adenosine triphosphate (ATP).

In the body, energy systems are responsible for providing the ATP (energy) that is utilized under varying intensities and durations of sport performance. There are three main energy systems at play during sports performance. They are the phosphagen (ATP-PCr) system, the glycolytic system, and the oxidative phosphorylation system. All three systems are constantly at work and interacting with each other, functioning on some level as they are not "all or nothing" systems. The predominance of one system is largely determined by the intensity and duration of the sporting activity, as well as the substrate (food source) that the athlete has consumed. Substrate utilization is a fancy term for the food that is being consumed by the athlete. Correspondingly, these three energy systems are also sometimes referred to as bioenergetics systems.

The athlete's ability to perform is based on his or her muscles' capacity to function and depends on the oxygen or glucose (substrate) availability. What does this mean? Well, if an athlete is sprinting, muscles within the body do not necessarily have the time required to be able to utilize oxygen, as a body at rest does. This causes the body to shift into an anaerobic state in which it can extract energy in the form of ATP, without the use of oxygen. However, when the human machine is running at a slower pace, the standard metabolic processes that utilize oxygen are allowed to occur in the mitochondria (the engine of the cell). Some might say that the human body is inherently intelligent and can be compared to a computer, in that after the program is built and algorithm established, it knows what to do on its own.

To simplify, the three energy systems will be referred to as the phosphagen, glycolytic, and oxidative systems. These systems produce ATP and replenish ATP stores within the human body. The body naturally stores ATP sufficient for basic cellular functions, not the amount necessary for sports. The phosphagen system utilizes an enzyme, creatine kinase, to maintain ATP levels during intense, explosive movements of short duration, allowing for the release of one mole of ATP or the equivalent of 0.6 kilocalories. The phosphagen system is heavily involved in sports that consist of high intensity, short-term explosive movements. This system is used in all sports at the point of initiation of activity—at the shift from sedentary to active.

Table 1.5. Rate/ Capacity of Adenosine Triphosphate (ATP)

Energy System	Rate of ATP production	Capacity of ATP production
Phosphagen	1	5
Fast Glycolysis	2	4
Slow Glycolysis	3	3
Oxidation of Carbohydrates	4	2
Oxidation of Fats and Proteins	5	1

Note: 1 = fastest/greatest; 5 = slowest/least

Adapted from Baechle and Earle (2008).

The glycolytic system is responsible for controlling glycolysis (breakdown of glycogen) for energy production, as well as the onset of lactate formation. Glycolysis is the term for the processes that break down glycogen stored in the muscles to glucose, ultimately yielding ATP. Remarkably, intensity and duration of the sport also dictates the type of glycolysis that occurs. There are two possible pathways: The shorter path, termed anaerobic (fast) glycolysis, consists of fewer steps that lead to lactate; the other path, aerobic (slow) glycolysis, has a longer trajectory and yields two to three moles of ATP or the equivalent of 1.2 to 1.8 kilocalories. Aerobic glycolysis is a slower process. It requires sufficient quantities of oxygen to operate, compared to anaerobic glycolysis which can function with limited amounts of oxygen.

Finally, the oxidative system is responsible for breaking down glycogen, fat, and protein. It is also responsible for producing ATP when the body is at rest or during long lasting, low intensity sporting activities. It is a commonly held belief that when training at low intensity, the body utilizes more fat than other sources (carbohydrates or protein) of energy. This concept is the result of a simplified interpretation of this third system.

The oxidative system's primary source of fuel is fat, since it initiates the release of triglycerides from fat cells. This leads to the roaming of free fatty acids in the blood, which are transported to the muscle fibers for oxidation (burned for energy). The breakdown of fat to glucose is called lipolysis and yields between thirty-six to forty moles of ATP or the equivalent of 21.6 to 24 kilocalories.

Additionally, this system is able to oxidize protein, however, protein is not its favored source of fuel. The mechanism of breaking down protein into energy is less than efficient. Proteolysis requires several steps to break down protein into amino acids, and eventually converts the products to glucose through another process called gluconeogenesis. A greater span of time is needed to synthesize ATP. Therefore, fat and carbohydrate are the preferred fuels for sport, because they yield energy at a much faster rate over longer periods. Please refer to table 1.5 for the rate and capacity of ATP production for each energy system.

The athlete's predominant energy system differs not only by sport, but also by player position or style of play within a particular sport. For instance, when a tennis player sprints to hit a forehand, a basketball player jumps explosively to slam dunk, a baseball player sprints to get on base, a quarterback throws the football, or a striker shoots to score a goal, their bodies are using the phosphagen system as the primary energy mechanism. If, on the other hand, a wide receiver is sprinting down the field for more than six seconds, his body has shifted from using the phosphagen system to a hybrid state consisting of both the phosphagen and glycolytic (anaerobic glycolysis) systems.

A soccer midfielder running non-stop, back and forth at a fast pace for the duration of one to two minutes is in a true state of anaerobic glycolysis. If the soccer player were to continue running for a longer period of time, ranging from two to three minutes, they are likely to be in a hybrid state of fast glycolysis and oxidative phosphorylation. Finally, a long distance runner who runs for prolonged periods of time at a slower rate is using the oxidative system as the primary mechanism for producing ATP. Refer to table 1.6 for the ranges of intensity and duration typical of each energy system.

In summary, the phosphagen energy system primarily supplies ATP for high-intensity activities of short duration. The glycolytic system is associated with moderate- to high-intensity activities of short to medium duration. And the oxidative system is the primary system at work during low-intensity activities of long duration.

Table 1.6. *Primary Energy System Duration and Intensity*

Duration	Intensity	Primary Energy System
0-6 seconds	Extremely High	Phosphagen
6-30 seconds	Very High	Phosphagen and Fast Glycolysis
30 seconds to 2 minutes	High	Fast Glycolysis
2-3 minutes	Moderate	Fast Glycolysis and Oxidative System
>3 minutes	Low	Oxidative System

Adapted from Baechle and Earle (2008).

Table 1.7. *Limiting Factors for Energy Systems*

Degree of Exercise	ATP and Creatine Phosphate	Muscle Glycogen	Liver Glycogen	Fat Stores	Lower pH
Light (Marathon)	1	5	4-5	2-3	1
Moderate (1,500 m run)	1-2	3	2	1-2	2-3
Heavy (400 m run)	3	3	1	1	4-5
Very intense (discus)	2-3	1	1	1	1
Very intense and Repetitive Motions	4-5	4-5	1-2	1-2	4-5

Note: 1 = Least Probable Limiting Factor; 5= Most Probable Limiting Factor

Adapted from Baechle and Earle (2008).

Table 1.7 describes the limiting factors of the bioenergetics systems. It shows how athletes, depending on the sport they play, involuntarily utilize bioenergetics systems. If we take a look at the discus thrower, it is important for their performance to have enough ATP and creatine phosphate in order to throw the discus in a powerful manner. On the other hand, if we take a look at marathon runners, they are much more limited by the amounts of glycogen (large amounts of glucose grouped together) stored in the muscles and liver because of its role in glycolysis and oxidative phosphorylation. Thereby, if they are limited in muscle or liver glycogen their performance will be hindered greatly.

Table 1.8 describes the primary system that will be utilized by percent maximum power and duration of exercise (sport). With this information we can learn to train our bodies to utilize different systems. For example, if you are an athlete that wants to improve utilization of the phosphagen system, then you would train one time (sprint) at 90 percent intensity for five seconds in

Table 1.8. Athletic Training and Energy Systems

Percent Maximum Power	Primary System Utilized	Typical Exercise Time	Range of Work-to-rest Period Ratios
90-100	Phosphagen	5-10 seconds	1:12 to 1:20
75-90	Fast Glycolysis	15-30 seconds	1:3 to 1:5
30-75	Fast Glycolysis and Oxidative	1-3 minutes	1:3 to 1:4
20-30	Oxidative	> 3 minutes	1:1 to 1:3

Adapted from Baechle and Earle (2008).

duration at a work to rest ratio of one to twenty, meaning you would rest (5×20) 100 seconds, or a minute forty. If however, you would want to improve your cardiorespiratory endurance, you would train at 20–30 percent for longer duration at a work to rest ratio of one to three at most.

Table 1.9 details physiological markers of performance outcomes. It is well documented in the literature that testosterone, growth hormone, and IGF-1 are strongly related to muscle mass development and maintenance as well as bone density. Lactate levels are commonly used to assess whether the athlete is fatigued. Training that requires high level of technique or skill should not be performed since coordination is significantly decreased and risk of injury is increased when high amounts of lactate are present in the blood. Additionally, the hormone cortisol is known to be extremely elevated when an athlete is overtraining causing inflammation and stress in the body, which chronically, may lead to injury.

More recently there has been extensive research on delaying aging. Telomeres are located at the end of our chromosomes within our DNA. You may ask, “Why is this relevant to sport?” Professional athletes are interested in prolonging their athletic careers and since telomeres have been shown to be strongly related to physical aging, this is a relevant marker of having an extended athletic career. Many studies have already shown that longer telomeres are associated with healthier and longer lifespans in both animal and human models. A newer method of assessing aging is Methylome analysis. It has been shown to have an even stronger correlation to physical aging than telomere length. It is now recognized as a measure of biological age and can have major implications for injury prevention and the extension of athletic careers.

Table 1.9. Physiological Markers of Athletic Performance

Physiological Performance Outcomes	Markers
Muscle mass development and maintenance	Testosterone, growth hormone, IGF-1
Bone density	Testosterone, estrogen
Fatigue	Lactate levels
Overtraining	Cortisol
Cellular aging	Telomere length and Methylome assessment
Heart function	Heart rate, stroke volume, heart rate variability, cardiac output, and blood pressure
Aerobic threshold	Aerobic enzyme content, VO_2 max
Anaerobic threshold	Respiratory rate

Heart function is important to athletic performance. The ability of the heart to distribute blood and oxygen to the muscles is fundamental for optimal performance. Heart rate is commonly used to assess intensity. For instance, many strength and conditioning experts utilize heart rate zones as indicators of exercise intensity (training). It is important to assess heart functionality by not only measuring heart rate, but also stroke volume, heart rate variability, and cardiac output.

Anaerobic and aerobic thresholds are also important to assess. Based on the sport, it is recommended that respiratory rate and VO_2 max be examined. Respiratory rate assessment is especially relevant for sprinters, whereas VO_2 max would be most appropriate for marathoners.

In order to obtain an accurate predictive model of sport performance, it is important to include cardiovascular physiological measures, such as heart rate, resting heart rate, heart rate variability, stoke volume, cardiac output, and blood pressure. It is also important to include measures of lactate threshold, insulin and glucose levels, a vision assessment, and markers of cellular aging. Physiological variables reflect the internal state of the body and yield a picture of the body's engine and how and why it runs the way it does.

Now you can begin to see the whole picture and conduct more relevant exploratory analyses. Knowledge of anatomy and physiology will make you a more marketable and competitive sports data analyst against those who only see the numbers, whether those numbers come from a laboratory setting, training facility, or wearable technology in the field. Wearable technology provides measurements related to anatomy and physiology, as well as physical measures discussed in chapter 2.

This chapter drew on various sources in anatomy and physiology, including *Essentials of Strength Training and Conditioning* (Baechle and Earle 2008) and the *Laboratory Manual for Exercise Physiology* (Haff and Dumke 2012). Those who want to pursue these subjects further may want to consult Tanner, Gore, et al. (2013) and Sherwood (2015) as well.

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