



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,
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and Evaluating the Market Value of Athletes**

LORENA MARTIN

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Contents

Preface	v
Figures	ix
Tables	xi
Exhibits	xiii
1 Anatomy and Physiology	1
2 Assessing Physical Variables	15
3 Sport Psychological Measures	41
4 Selecting Statistical Models	53
5 Touchdown Analytics	69
6 Slam Dunk Analytics	95
7 Home Run Analytics	117
8 Golden Goal Analytics	137
9 Game, Set, Match Analytics	157

10 Performance and Market Value	173
Statistics Glossary	187
Football Glossary	193
Basketball Glossary	201
Baseball Glossary	209
Soccer Glossary	227
Tennis Glossary	241
Bibliography	247
Index	289

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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Figures

5.1	Three-Cone Agility Drill by Player Position (NFL)	79
5.2	20-Yard Shuttle by Player Position (NFL)	79
5.3	Vertical Jump by Player Position (NFL)	80
5.4	40-Yard Dash by Player Position (NFL)	80
5.5	Broad Jump by Player Position (NFL)	81
5.6	Bench Press by Player Position (NFL)	81
6.1	Lane Agility Drill by Player Position (NBA)	104
6.2	Bench Press by Player Position (NBA)	104
6.3	Max Vertical Leap by Player Position (NBA)	105
6.4	Standing Vertical Leap by Player Position (NBA)	105
6.5	Three Quarter Sprint by Player Position (NBA)	106
6.6	Shuttle Run by Player Position (NBA)	106
6.7	Steals by Player Position (NBA)	107
6.8	Defensive Rebounds by Player Position (NBA)	107
6.9	Offensive Rebounds by Player Position (NBA)	108
6.10	Assists by Player Position (NBA)	108
6.11	Shooting Percentage by Player Position (NBA)	109
6.12	Player Efficiency Rating by Player Position (NBA)	109
7.1	Hits by Player Position (MLB)	126
7.2	RBIs by Player Position (MLB)	126
7.3	Runs by Player Position (MLB)	127
7.4	Home Runs by Player Position (MLB)	127
8.1	Number of Assists by Player Position (UEFA)	149
8.2	Number of Goals Scored by Player Position (UEFA)	149
8.3	Number of Passes Attempted by Player Position (UEFA)	150
8.4	Number of Passes Completed by Player Position (UEFA)	150
9.1	Professional Tennis Player Earnings by Nationality (ATP, WTA)	167
9.2	Professional Tennis Player Earnings by Rank and Sex (ATP, WTA)	168

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Tables

1.1	Types of Bones	2
1.2	Muscles in Sport	4
1.3	Characteristics of Fiber Types	5
1.4	Muscle Fiber Types and Sports	6
1.5	Rate/Capacity of Adenosine Triphosphate (ATP)	8
1.6	Primary Energy System Duration and Intensity	10
1.7	Limiting Factors for Energy Systems	10
1.8	Athletic Training and Energy Systems	11
1.9	Physiological Markers of Athletic Performance	12
2.1	Physical Measures and Fitness Models	16
2.2	Body Fat Percentage Categories	17
2.3	Body Mass Index (BMI) Categories	18
2.4	Body Density Equations Used to Calculate Body Fat Percentage	19
2.5	Repetition Maximum Coefficients	21
2.6	Repetition Maximum Values	21
2.7	Body Muscle Group Testing for Athletes (Part 1)	24
2.8	Body Muscle Group Testing for Athletes (Part 2)	25
2.9	Range of Motion of Select Single-Joint Movements in Degrees	27
2.10	ESPN's List of Ranking Sports by Coordination	36
2.11	Sport-Specific Skills	38
3.1	Sport Psychological Measures and Factors	50
3.2	Desirable Attributes of Measurements	51
3.3	A Measurement Model for Sports Performance	52
4.1	Overview of Statistical Methods	56
4.2	Review of Statistical Tests and Models	68
5.1	Football Performance Measures	78
6.1	Basketball Performance Measures	103
7.1	Baseball Performance Measures	125

8.1	UEFA Champions League Tournament Phase Leading Scorers	146
8.2	UEFA Champions League Tournament Phase Leaders in Assists	147
8.3	Soccer Performance Measures	148
9.1	Tennis Performance Measures	164
9.2	Annual Cost for Playing Professional Tennis	165
9.3	Annual Expenses for the 100th-Ranked Tennis Player	165
9.4	U.S. Minority Group Income and Education	166
10.1	Salaries of Top MLB Players	179
10.2	Salaries of Top NBA Players	180
10.3	Salaries of Top NFL Players	181
10.4	Salaries of Top ATP Players	182
10.5	Salaries of Top WTA Players	183
10.6	Salaries of Top MLS Players	184
10.7	Salaries of Top FIFA Players	185

Exhibits

5.1	Analyzing NFL Combine Measures (R)	82
5.2	Analyzing NFL Game Time Performance Data (R)	92
6.1	Analyzing NBA Draft Data (R)	110
6.2	Analyzing NBA Game Time Performance Data (R)	114
7.1	Analyzing MLB Player Performance (R)	128
7.2	Analyzing MLB Game Time Batting Performance (R)	130
8.1	Analyzing UEFA Assists and Goals Scored (R)	151
8.2	Analyzing UEFA Passes Attempted and Completed (R)	154
9.1	Analyzing ATP and WTA Player Earnings by Country (R)	169
9.2	Analyzing ATP and WTA Player Earnings by Rank and Sex (R)	172

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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 VO₂ max be examined. Respiratory rate assessment is especially relevant for sprinters, whereas VO₂ 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, stroke volume, cardiac out-

put, 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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Index

A

accessibility, *see* measurement, accessibility
adenosine triphosphate, *see* anatomy/physiology, adenosine triphosphate (ATP)
Adidas miCoach, *see* wearable technology, Adidas miCoach
aerobic capacity, *see* physical measures, aerobic power (aerobic capacity)
aerobic power, *see* physical measures, aerobic power (aerobic capacity)
aggressive baseliner, *see* tennis, aggressive baseliner
aggressiveness, *see* psychology, aggressiveness
agility, *see* physical measures, agility
all-court player, *see* tennis, all-court player
anaerobic power, *see* physical measures, anaerobic power
analysis of covariance, *see* statistics, analysis of covariance (ANCOVA)
analysis of variance, *see* statistics, analysis of variance (ANOVA)
anatomy/physiology, 1–13
 adenosine triphosphate (ATP), 7–9
 bioelectrical impedance analysis machine, 19
 body composition, 17–19
 body density, 18
 body fat, 17–19
 body fat percentage, 17, 19
 body mass index (BMI), 16–18
 bone density, 19
 bone types, 2
 bones, 2
 fibers, 5, 6
 glycolysis, 8
 glycolytic system, 7, 9
 Methylome analysis, 11
 muscle types, 3, 6
 muscles, 2–4

osteology, 2
oxidative phosphorylation system, 7–9
phosphagen system (ATP-PCr), 7, 9
physiological markers, 11, 12
skinfold body fat testing, 19
underwater weighing (hydrodensitometry), 18

ANCOVA, *see* statistics, analysis of covariance (ANCOVA)

anger, *see* psychology, anger

Anger Rumination Scale, *see* psychology, Anger Rumination Scale (ARS)

ANOVA, *see* statistics, analysis of variance (ANOVA)

anxiety, *see* psychology, anxiety

APQ, *see* psychology, Autonomic Perception Questionnaire (APQ)

ARS, *see* psychology, Anger Rumination Scale (ARS)

Association of Tennis Professionals, *see* tennis, ATP

ATP, *see* anatomy/physiology, adenosine triphosphate (ATP), *see* tennis, ATP

ATP-PCr, *see* anatomy/physiology, phosphagen system (ATP-PCr)

Autonomic Perception Questionnaire, *see* psychology, Autonomic Perception Questionnaire (APQ)

B

Babolat Play, *see* wearable technology, Babolat Play

back, *see* football, back (running back)

back row, *see* physical measures, back row

back scratch test, *see* physical measures, back scratch test

BAI, *see* psychology, Beck Anxiety Inventory (BAI)

balance, *see* physical measures, balance

- Balance Error Scoring System, *see* physical measures, Balance Error Scoring System (BESS)
- baseball
 - “out”, 218
 - “play ball”, 220
 - “safe”, 222
 - All Star Game, 209
 - American League, 209
 - around the horn, 209
 - at bats (AB), 209
 - bailing out, 209
 - ball, 209
 - base, 209
 - base coach, 210
 - base hit, 210
 - base on balls (BB), 209
 - base runner, 210
 - baserunner, 210
 - baserunning error, 210
 - bases loaded, 210
 - batter, 210
 - batter in the hole, 210
 - batter on deck, 210
 - batter’s box, 210
 - battery, 210
 - batting average (BA, AVG), 210
 - batting stance, 210
 - batting team, 210
 - behind in the count, 210
 - bench, 211
 - big leagues, 211
 - bloop single, 211
 - bunt, 211
 - call, 211
 - called game, 211
 - catcher, 123, 211
 - caught looking, 211
 - caught off base, 211
 - caught stealing (CS), 211
 - center fielder, 211
 - Championship Series, 211
 - changeup, 211
 - check swing, 211
 - choking up, 212
 - chop single, 212
 - closed batting stance, 212
 - closer, 212
 - clutch hitter, 212
 - coach, 212
 - command, 212
 - control, 212
 - cover the bases, 212
 - crowd the plate, 212
 - curveball (curve), 212
 - cut fastball (cutter), 212
 - cut-off position, 212
 - defense, 213
 - defensive indifference, 213
 - designated hitter (DH), 213
 - diamond, 213
 - dig in, 213
 - Division Series, 213
 - double (2B), 213
 - double play, 213
 - double-header, 213
 - double-switch, 213
 - dugout, 213
 - earned run average (ERA), 213
 - expected runs, 213
 - extra-base hit, 213
 - fair ball, 214
 - fair territory, 214
 - fan, 214
 - fantasy baseball, 214
 - fastball, 214
 - fielder, 214
 - fielder’s choice, 214
 - fielding error, 214
 - first base, 214
 - first baseman, 214
 - five-tool player, 214
 - fly ball, 214
 - fly out, 214
 - force out, 214
 - forfeited game, 214
 - foul ball, 214
 - foul territory, 214
 - foul tip, 214
 - frame (a pitch), 215
 - free agent, 215
 - full count, 215
 - game (G), 215
 - grand slam, 215
 - ground ball, 215
 - ground out, 215
 - ground-rule double, 215
 - hit (H), 126, 215
 - hitter, 215
 - hitting for power, 215
 - hitting slump, 215
 - hitting streak, 215
 - holding runner on base, 215
 - home plate, 215
 - home run (HR), 127, 215
 - illegal pitch, 216
 - in the hole, 216
 - infielder, 216

- inning, 216
- intentional base on balls, 216
- interference, 216
- knuckleball, 216
- lead-off hitter, 216
- leave the yard (go yard), 216
- left fielder (LF), 216
- left on base (LOB), 216
- lefty, 216
- line drive, 216
- lineup, 216
- live ball, 216
- live ball era, 216
- making the turn, 217
- manager, 217
- manufactured run, 217
- men on base, 217
- middle infielder, 217
- middle reliever, 217
- MLB, 122, 217
- National League, 217
- neighborhood play, 217
- no hitter, 217
- no-no, 217
- obstruction, 217
- offense, 217
- official scorer, 217
- on the field (team), 217
- on-base percentage (OBP), 217
- open batting stance, 218
- out, 218
- outfielder, 123, 218
- overslide, 218
- pace of play, 218
- passed ball, 218
- PECOTA, 219
- perfect game, 219
- pick off assignment, 219
- pick off play, 219
- pinch hitter, 219
- pinch runner, 219
- pitch, 219
- pitch count, 219
- pitcher (P), 122, 123, 219
- pitcher's duel, 219
- pitcher's park, 219
- pitcher's plate, 219
- pitching depth, 220
- pitching from the stretch, 220
- pitching mound, 220
- pitching rotation, 220
- pivot foot, 220
- place hitter, 220
- plate, 220
- plate appearance, 220
- platooning, 220
- pop-up, 220
- position number, 220
- position player, 220
- power hitter, 220
- productive at bat, 220
- pull hitter, 221
- pull the string, 221
- quick pitch, 221
- reaching for the fences, 221
- regulation game, 221
- relief pitcher, 221
- replay review, 221
- retouch, 221
- reverse curve, 221
- right fielder (RF), 221
- rounding the bases, 221
- run, 127, 221
- run batted in (RBI), 126, 221
- run down, 221
- runner, 221
- Sabermetrics, 119, 175
- sacrifice bunt, 221
- sacrifice fly, 222
- scoring position, 222
- screwball, 222
- season, 222
- second base, 222
- second baseman, 222
- secondary lead, 222
- semi-intentional walk, 222
- shadow ball, 222
- shift, 222
- shine ball, 222
- shortstop, 123, 222
- shutout, 222
- side-arm delivery, 223
- single (1B), 223
- slider, 223
- slugging percentage (SLG), 223
- small ball, 223
- spin rate, 223
- spitball, 223
- squeeze play, 223
- starting pitcher, 223
- steal (stolen base, SB), 223
- stepping in the bucket, 223
- strike, 223
- strike zone, 224
- strikeout (K), 224
- suspended game, 224
- sweep, 224
- switch hitter, 224

- switch pitcher, 224
- tag out, 224
- tagging up, 224
- take a lead (off base), 224
- take a pitcher deep, 224
- Texas Leaguer, 224
- third base, 225
- third baseman, 225
- three-bagger, 225
- throw, 225
- throwing error, 225
- tie game, 225
- tip a pitch, 225
- total bases (TB), 225
- triple (3B), 225
- triple crown, 225
- triple-play, 225
- two-bagger, 225
- umpire, 225
- umpire-in-chief, 225
- up the middle, 225
- up to bat (team), 226
- VORP, 226
- walk, 226
- walk-off balk, 226
- walk-off hit, 226
- walk-off home run, 226
- WAR (WARP), 226
- WHIP, 226
- Wild Card Game, 226
- wild pitch, 226
- windup position, 226
- World Series, 226
- baseball analytics, 117–137
- baseliner, *see* tennis, baseliner
- basketball
 - center, 97, 100
 - FIBA, 95, 97
 - NBA, 96, 97
 - point guard, 97, 98, 100
 - power forward, 97, 99, 100
 - shooting guard, 97, 100
 - small forward, 97, 98, 100
 - tip-off, 97
- basketball analytics, 95–117
- basketball term
 - air ball, 201
 - alley-oop pass, 201
 - assist, 201
 - assist percentage, 201
 - backcourt, 201
 - backdoor play, 201
 - bank shot, 201
 - baseline (endline), 201
 - basket, 201
 - bench, 201
 - block, 202
 - block percentage, 202
 - bonus, 202
 - bounce pass, 202
 - box out, 202
 - brick, 202
 - charging, 202
 - coast-to-coast, 202
 - collective bargaining agreement, 202
 - cut, 202
 - dead-ball foul, 202
 - deny the ball, 202
 - double dribble, 202
 - double foul, 202
 - double-team, 202
 - downtown, 202
 - DPOY, 202
 - draft, 203
 - dribble, 203
 - dunk (slam dunk), 203
 - fast break, 203
 - field goal, 203
 - flagrant foul, 203
 - foul, 203
 - foul out, 203
 - foul trouble, 203
 - free agent, 203
 - free throw, 203
 - frontcourt, 203
 - give-and-go, 204
 - goaltending, 204
 - gunner, 204
 - hang time, 204
 - high post, 204
 - hook shot, 204
 - hoop, 204
 - jump ball, 204
 - jump hook, 204
 - jump shot, 204
 - lane, 204
 - loose-ball foul, 204
 - lottery, 204
 - low post, 204
 - man-to-man defense, 204
 - NBA, 204
 - NBPA, 204
 - net, 204
 - open shot, 205
 - outlet pass, 205
 - over the limit (penalty situation), 205
 - overtime, 205
 - pace factor (pace of play), 205

- pick (set a pick), 205
- pick-and-roll, 205
- pivot, 205
- player control foul, 205
- point guard, 205
- possessions, 205
- power forward, 205
- press, 205
- quadruple-double, 205
- quarter (period), 205
- rebound, 206
- rejection, 206
- sag, 206
- salary cap, 206
- screen, 206
- set-shot, 206
- shot clock, 206
- sixth man, 206
- sky-hook, 206
- skywalk, 206
- squaring up, 206
- SRS, 206
- steal percentage, 206
- strength of schedule, 206
- stutter, 206
- switch, 206
- team fouls, 207
- technical foul, 207
- three-point field goal percentage, 207
- three-point field goals, 207
- three-point shot, 207
- three-point shot attempts, 207
- three-second violation, 207
- three-sixty (360), 207
- tip-in, 207
- tip-off, 207
- trailer, 207
- transition, 207
- traveling, 207
- triple-double, 207
- turnover, 207
- two-point attempts, 207
- two-point field goal attempts, 207
- two-point field goal percentage, 207
- veteran free agent, 208
- weakside, 208
- wing, 208
- zone defense, 208
- BATAK light board reaction test, *see* physical measures, BATAK light board reaction test
- Bayesian statistics, *see* statistics, Bayesian statistics
- BDI, *see* psychology, Beck Depression Inventory (BDI)
- BEAST90 protocol, *see* soccer, BEAST90 protocol
- Beck Anxiety Inventory, *see* psychology, Beck Anxiety Inventory (BAI)
- Beck Depression Inventory, *see* psychology, Beck Depression Inventory (BDI)
- BESS, *see* physical measures, Balance Error Scoring System (BESS)
- biceps curl, *see* physical measures, biceps curl
- binary variable, *see* statistics, binary variable
- bioelectrical impedance analysis machine, *see* anatomy/physiology, bioelectrical impedance analysis machine
- BMI, *see* anatomy/physiology, body mass index (BMI)
- body composition, *see* anatomy/physiology, body composition, *see* physical measures, body composition
- body density, *see* anatomy/physiology, body density
- body fat, *see* anatomy/physiology, body fat
- body fat percentage, *see* anatomy/physiology, body fat percentage
- body mass index, *see* anatomy/physiology, body mass index (BMI)
- bone density, *see* anatomy/physiology, bone density
- bone types, *see* anatomy/physiology, bone types
- bones, *see* anatomy/physiology, bones
- Bonferroni correction, *see* statistics, Bonferroni correction
- bootstrap sampling, *see* statistics, bootstrap sampling
- Bosco sixty-second continuous jump test, *see* physical measures, Bosco sixty-second continuous jump test
- Bosu ball, *see* physical measures, Bosu ball
- broad jump, *see* physical measures, broad jump
- C**
- CAAS, *see* psychology, Competitive Aggressiveness and Anger Scale (CAAS)
- cardiorespiratory endurance, *see* physical measures, cardiorespiratory endurance
- cardiorespiratory fitness, *see* physical measures, cardiorespiratory fitness (CRF)
- cardiovascular endurance, *see* physical measures, cardiovascular endurance
- Catapult, *see* wearable technology, Catapult

catastrophe model, *see* psychology, catastrophe model
 catcher, *see* baseball, catcher
 categorical variable, *see* measurement, nominal scale (categorical variable)
 Cattell Sixteen Personality Factor Questionnaire, *see* psychology, Sixteen Personality Factor Questionnaire
 center, *see* basketball, center
 characteristics, *see* measurement, characteristics
 chest press, *see* physical measures, chest press
 chi-square distribution, *see* statistics, chi-square distribution
 chi-square test, *see* statistics, chi-square test
 classical statistics, *see* statistics, classical statistics
 cognitive ability, *see* psychology, cognitive ability
 Colley rating method, *see* market value, Colley rating method
 comma-delimited text, *see* statistics, comma-delimited text (csv)
 Competitive Aggressiveness and Anger Scale, *see* psychology, Competitive Aggressiveness and Anger Scale (CAAS)
 Competitive State Anxiety inventory, *see* psychology, Competitive State Anxiety inventory (CSAI-2R)
 comprehensibility, *see* measurement, comprehensibility
 compression attire, *see* wearable technology, compression attire
 confidence, *see* psychology, confidence
 confusion, *see* psychology, confusion
 constraint, *see* psychology, constraint
 continuous jump test, *see* physical measures, continuous jump test
 coordination, *see* physical measures, coordination
 correlation, *see* statistics, Pearson product-moment correlation
 countermovement jump test, *see* physical measures, countermovement jump test
 counterpuncher, *see* tennis, counterpuncher
 creativity, *see* psychology, flow
 CRF, *see* physical measures, cardiorespiratory fitness (CRF)
 cross-sectional data, *see* statistics, cross-sectional data
 cross-validation, *see* statistics, cross-validation
 CSAI-2R, *see* psychology, Competitive State Anxiety inventory (CSAI-2R)
 csv, *see* statistics, comma-delimited text (csv)

D

data visualization, *see* statistics, data visualization
 defensive tackle, *see* football, defensive tackle
 dependent variable, *see* statistics, dependent variable
 depression, *see* psychology, depression
 descriptive statistics, *see* statistics, descriptive statistics
 Dot-Probe Task, *see* psychology, Dot-Probe Task (DPT)
 DPT, *see* psychology, Dot-Probe Task (DPT)
 drive theory, *see* psychology, drive theory
 dynamic flexibility, *see* physical measures, dynamic flexibility
 dynamic strength, *see* physical measures, dynamic strength

E

EA Sports Player Performance Index, *see* market value, EA Sports Player Performance Index
 Elo Ratings, *see* market value, Elo Ratings
 ESE, *see* psychology, Exercise Self-Efficacy (ESE)
 Exercise Self-Efficacy, *see* psychology, Exercise Self-Efficacy (ESE)
 experimental research, *see* statistics, experimental research
 explanatory model, *see* statistics, explanatory model
 explanatory variable, *see* statistics, explanatory variable
 explosive strength, *see* physical measures, explosive strength
 extent flexibility, *see* physical measures, extent flexibility
 extraversion/intraversion, *see* psychology, extraversion/intraversion
 extrinsic motivation, *see* psychology, extrinsic motivation

F

F distribution, *see* statistics, F distribution
 F-test, *see* statistics, F-test
 Fédération Internationale de Football Association, *see* soccer, FIFA
 fatigue, *see* psychology, fatigue
 FIBA, *see* soccer, FIBA
 fibers, *see* anatomy/physiology, fibers
 flexibility, *see* physical measures, flexibility
 flow, *see* psychology, flow

- Flow Questionnaire, *see* psychology, Flow Questionnaire (FQ)
- Flow State Scale, *see* psychology, Flow State Scale (FSS)
- football
- AstroTurf, 193
 - audible, 193
 - back (running back), 193
 - backfield, 193
 - ball carrier, 193
 - beat, 193
 - blackout, 193
 - blitz, 193
 - blocking, 193
 - call a play, 193
 - clipping, 193
 - complete pass, 193
 - conference, 193
 - controlling the game clock, 193
 - coverage, 194
 - cut back, 194
 - defense (defensive team), 194
 - defensive players, 75, 194
 - defensive tackle, 75
 - division, 194
 - double coverage, 194
 - down, 73, 194
 - down the field, 194
 - draft choice, 194
 - drive, 194
 - drop back, 194
 - drop kick, 194
 - eligible receiver, 194
 - encroachment, 194
 - end line, 194
 - end zone, 194
 - extra point, 195
 - fair catch, 195
 - fair catch free kick, 195
 - field, 195
 - field goal, 73, 195
 - field position, 195
 - first down, 195
 - forward pass, 195
 - forward progress, 195
 - foul, 195
 - franchise, 195
 - free agent, 195
 - free kick, 195
 - fumble, 74, 195
 - goal line, 195
 - goal post, 196
 - going for it, 196
 - hand-off, 196
 - hang time, 196
 - holding, 196
 - huddle, 196
 - in bounds, 196
 - incomplete pass, 196
 - intentional grounding, 196
 - interception, 74, 196
 - kickoff, 196
 - lateral, 196
 - line of scrimmage, 196
 - live ball, 196
 - loose ball, 196
 - loss of possession on downs, 197
 - midfield, 197
 - moving the ball, 197
 - necessary line, 197
 - neutral zone, 197
 - NFL (National Football League), 69, 70, 72, 197
 - NFL Championship, 197
 - NFL Combine, 77, 79–81, 101
 - offending team, 197
 - offense (offensive team), 197
 - offensive guard, 77
 - offensive players, 77, 197
 - offside, 197
 - open receiver, 197
 - out of bounds, 197
 - pass, 197
 - pass defender, 198
 - pass protection, 198
 - pass route, 198
 - pass rush, 198
 - personal foul, 198
 - picked off, 198
 - pitch-out, 198
 - place kick, 198
 - play, 198
 - play clock, 198
 - play-action pass, 198
 - players, 198
 - playoffs, 198
 - pocket, 198
 - point-after-touchdown (PAT), 73, 198
 - possession, 198
 - previous spot, 198
 - punt, 73, 198
 - quarterback, 73–75, 198
 - reading the defense, 198
 - receiver, 199
 - recovery, 199
 - red zone, 199
 - return, 199
 - roll out, 199

rookie, 199
 run, 199
 rush, 199
 sacks, 199
 safety, 199
 scoring, 199
 scrambling, 199
 series, 199
 sideline, 199
 single-elimination, 199
 snap, 199
 special teams, 199
 spike, 199
 spiral, 199
 spot, 200
 stiff arm (straight arm), 200
 Super Bowl, 200
 tackle, 200
 tackling, 200
 territory, 200
 third-and-long, 200
 tied game, 200
 touchback, 200
 touchdown (TD), 73, 200
 turnover, 200
 two-point conversion, 200
 Wild Card, 200
 winning percentage, 200
 football analytics, 69–94
 FQ, *see* psychology, Flow Questionnaire (FQ)
 FSS, *see* psychology, Flow State Scale (FSS)
 functional reach test, *see* physical measures,
 functional reach test

G

Games-Howell test, *see* statistics, Games-
 Howell test
 gender equality, *see* market value, gender
 equality
 generalized linear model, *see* statistics, gener-
 alized linear model
 glycolysis, *see* anatomy/physiology, glycolysis
 glycolytic system, *see* anatomy/physiology,
 glycolytic system
 goalie, *see* soccer, goalie
 Golden Slam, *see* tennis, Golden Slam
 goniometer, *see* physical measures, goniome-
 ter
 GPQ, *see* psychology, Group Environment
 Questionnaire (GPQ)
 Grand Slam, *see* tennis, Grand Slam
 gross body coordination, *see* physical mea-
 sures, gross body coordination

Group Environment Questionnaire, *see* psy-
 chology, Group Environment Question-
 naire (GPQ)

H

Hochbaum rating method, *see* market value,
 Hochbaum rating method
 home run, *see* baseball, home run
 homogeneity of slopes, *see* statistics, homo-
 geneity of slopes
 homogeneity of variance, *see* statistics, homo-
 geneity of variance
 homogeneity of variances, *see* statistics, homo-
 geneity of variances
 homoscedasticity, *see* statistics, homoscedas-
 ticity
 hydrodensitometry, *see* anatomy/physiology,
 underwater weighing (hydrodensitome-
 try)

I

IAT, *see* psychology, Implicit Association Test
 (IAT)
 Iceberg Profile, *see* psychology, Iceberg Profile
 Implicit Association Test, *see* psychology, Im-
 plicit Association Test (IAT)
 income disparity, *see* market value, income
 disparity
 independent observations, *see* statistics, inde-
 pendent observations
 independent variable, *see* statistics, indepen-
 dent variable
 individual zones of optimal functioning, *see*
 psychology, individual zones of optimal
 functioning (IZOF)
 inferential statistics, *see* statistics, inferential
 statistics
 infielder, *see* baseball, infielder
 injury, *see* physical measures, injury
 instrumental aggression, *see* psychology, in-
 strumental aggression
 intelligence, *see* psychology, intelligence
 International Tennis Federation, *see* tennis, ITF
 interval scale, *see* measurement, interval scale
 intrinsic motivation, *see* psychology, intrinsic
 motivation
 inverted-U hypothesis, *see* psychology, inverted-
 U hypothesis
 ITF, *see* tennis, ITF
 IZOF, *see* psychology, individual zones of opti-
 mal functioning (IZOF)

K

- Keener rating method, *see* market value, Keener rating method
- Kendall's tau, *see* statistics, Kendall's tau
- Kolmogorov-Smirnov test, *see* statistics, Kolmogorov-Smirnov test
- Kruskal-Wallis test, *see* statistics, Kruskal-Wallis test

L

- lane agility drill, *see* physical measures, lane agility drill
- lat pull-down, *see* physical measures, lat pull-down
- leg curl, *see* physical measures, leg curl
- leg extension, *see* physical measures, leg extension
- leg press, *see* physical measures, leg press
- level of measurement, *see* measurement, scale (level of measurement)
- levels of measurement, *see* statistics, levels of measurement
- Levene test, *see* statistics, Levene test
- Levene's test, *see* statistics, Levene's test
- light board reaction timer, *see* physical measures, light board reaction timer
- linear mixed effects model, *see* statistics, linear mixed effects model
- linear regression, *see* statistics, linear regression
- logistic regression, *see* statistics, logistic regression
- longitudinal data, *see* statistics, longitudinal data

M

- machine learning, *see* statistics, machine learning
- Major League Baseball, *see* baseball, MLB
- MANCOVA, *see* statistics, multivariate analysis of covariance (MANCOVA)
- MANOVA, *see* statistics, multivariate analysis of variance (MANOVA)
- market value, 173–186
 - Colley rating method, 175
 - EA Sports Player Performance Index, 175
 - Elo Ratings, 176
 - gender equality, 178
 - Hochbaum rating method, 176
 - income disparity, 177, 178
 - Keener rating method, 177
 - Markov model, 176
 - Massey rating method, 175

- Park-Newman rating method, 176
- performance ranking, 173–175
- performance rating, 173–175
- socioeconomic status, 163, 165, 166
- tennis player earnings, 167, 168
- Markov model, *see* market value, Markov model, *see* statistics, Markov model
- Massey rating method, *see* market value, Massey rating method
- maximal oxygen consumption, *see* physical measures, maximal oxygen consumption (VO2 max)
- maximal vertical reach, *see* physical measures, maximal vertical reach
- maximum vertical leap, *see* physical measures, maximum vertical leap
- measurement, 49–52
 - accessibility, 51
 - comprehensibility, 51
 - interval scale, 54
 - nominal scale (categorical variable), 54, 55
 - ordinal scale, 54, 55
 - ratio scale, 54, 55
 - reliability, 51
 - scale (level of measurement), 54
 - standardization, 51
 - tractability, 51
 - transparency, 51
 - validity, 51
- measurement theory, *see* psychology, measurement theory
- Methylome analysis, *see* anatomy / physiology, Methylome analysis
- midfielder, *see* soccer, midfielder
- Minnesota Multiphasic Personality Inventory, *see* psychology, Minnesota Multiphasic Personality Inventory (MMPI)
- MLB, *see* baseball, MLB
- MMPI, *see* psychology, Minnesota Multiphasic Personality Inventory (MMPI)
- model, *see* statistics, model
- Monte Carlo simulation, *see* statistics, Monte Carlo simulation
- motivation, *see* psychology, motivation
- Motus Sleeve, *see* wearable technology, Motus Sleeve
- multi-level categorical variable, *see* statistics, multi-level categorical variable
- multicollinearity, *see* statistics, multicollinearity
- multidimensional anxiety theory, *see* psychology, multidimensional anxiety theory
- multiple imputation, *see* statistics, multiple imputation

multiple limb coordination, *see* physical measures, multiple limb coordination
 multivariate analysis of covariance, *see* statistics, multivariate analysis of covariance (MANCOVA)
 multivariate analysis of variance, *see* statistics, multivariate analysis of variance (MANOVA)
 muscle types, *see* anatomy/physiology, muscle types
 muscles, *see* anatomy/physiology, muscles
 muscular endurance, *see* physical measures, muscular endurance
 muscular power, *see* physical measures, muscular power
 muscular strength, *see* physical measures, muscular strength
 Myontec Mbody Pro, *see* wearable technology, Myontec Mbody Pro

N

narcissism, *see* psychology, narcissism
 Narcissistic Personality Inventory, *see* psychology, Narcissistic Personality Inventory (NPI)
 National Basketball Association, *see* basketball, NBA
 National Basketball Players Association, *see* basketball, NBPA
 National Football League, *see* football, NFL
 NBA, *see* basketball, NBA
 NBPA, *see* basketball, NBPA
 neuroticism, *see* psychology, neuroticism
 NFL, *see* football, NFL
 NFL Combine, *see* football, NFL Combine
 nominal scale, *see* measurement, nominal scale (categorical variable)
 nonlinear mixed model, *see* statistics, nonlinear mixed model
 nonparametric, *see* statistics, nonparametric
 normality, *see* statistics, normality
 normality of distribution, *see* statistics, normality of distribution
 NPI, *see* psychology, Narcissistic Personality Inventory (NPI)

O

observational research, *see* statistics, observational research
 offensive guard, *see* football, offensive guard
 on-base percentage plus slugging (OPS), 218
 OptimEye S5, *see* wearable technology, OptimEye S5

ordinal scale, *see* measurement, ordinal scale
 osteology, *see* anatomy/physiology, osteology
 outfielder, *see* baseball, outfielder
 outlier, *see* statistics, outlier
 oxidative phosphorylation system, *see* anatomy/physiology, oxidative phosphorylation system

P

parameter, *see* statistics, parameter
 parametric, *see* statistics, parametric
 Park-Newman rating method, *see* market value, Park-Newman rating method
 Pearson product-moment correlation, *see* statistics, Pearson product-moment correlation
 performance ranking, *see* market value, performance ranking
 performance rating, *see* market value, performance rating
 phosphagen system, *see* anatomy/physiology, phosphagen system (ATP-PCr)
 physical measures, 15–40
 aerobic power, 31
 aerobic power (aerobic capacity), 31, 32, 159, 161
 agility, 16, 34, 77, 79, 99, 104, 122, 162
 anaerobic power, 29–31, 34, 80, 81, 105, 106, 141, 142, 159
 back row, 24
 back scratch test, 23
 balance, 16, 26, 28, 29, 160
 Balance Error Scoring System (BESS), 28
 BATAK light board reaction test, 34
 biceps curl, 25
 body composition, 16
 Bosco sixty-second continuous jump test, 30
 Bosu ball, 33
 broad jump, 81
 cardiorespiratory endurance, 16, 141
 cardiorespiratory fitness (CRF), 31, 32
 cardiovascular endurance, 31, 32
 chest press, 24
 continuous jump test, 30
 coordination, 16, 35, 36, 160
 countermovement jump test, 30
 countermovement vertical jump test, 142
 dynamic flexibility, 16
 dynamic strength, 16
 explosive strength, 16
 extent flexibility, 16, 23, 26
 flexibility, 16, 23, 26
 functional reach test, 26
 goniometer, 26

- gross body coordination, 16
- injury, 26
- lane agility drill, 34
- lat pull-down, 25
- leg curl, 24
- leg extension, 24
- leg press, 24
- light board reaction timer, 33
- lower strength, 20
- maximal oxygen consumption (VO₂ max), 31, 32
- maximal vertical reach, 99
- maximum vertical leap, 34, 105, 161
- multiple limb coordination, 16
- muscular endurance, 16, 22, 81, 99, 104, 122, 123, 160
- muscular power, 22, 30, 99, 122, 123, 160
- muscular strength, 16, 20, 81, 99, 160
- power, 30
- Proprio reactive balance test, 26, 29
- reaction time, 33–35, 76
- reaction time ruler test, 33
- recovery from injury, 26
- repeated-sprint ability (RSA), 140
- running speed, 16
- SAFTE, 39
- shoulder press, 25
- shoulder flexibility, 23
- shuttle run, 34, 79
- single leg stand, 26, 28
- SPARQ rating system, 33
- speed, 35, 79, 80, 106, 122
- sport-specific skills, 35, 38
- sprints, 29, 79, 80, 106
- squats, 25
- standing vertical leap, 34, 105
- Star Excursion Balance Test (SEBT), 28
- static squat jump, 30, 141
- static strength, 16
- strength, 16, 20
- strength testing repetitions, 20, 21
- SVT reaction test, 34
- three-quarter-court sprint, 34
- triceps dips, 25
- upper body strength, 20, 77
- vertical jump test, 30, 80, 99, 105, 106
- Wingate anaerobic cycle test, 31
- physiological markers, *see* anatomy / physiology, physiological markers
- pitcher, *see* baseball, pitcher
- player expenses, *see* tennis, player expenses
- PlaySight, *see* wearable technology, PlaySight
- point guard, *see* basketball, point guard
- Poisson distribution, *see* statistics, Poisson distribution
- Poisson regression, *see* statistics, Poisson regression
- population, *see* statistics, population
- population distribution, *see* statistics, population distribution
- post hoc analyses, *see* statistics, post hoc analyses
- posterior distribution, *see* statistics, posterior distribution
- power, *see* physical measures, power
- power forward, *see* basketball, power forward
- predictive model, *see* statistics, predictive model
- prior distribution, *see* statistics, prior distribution
- probability, *see* statistics, probability
- proportion, *see* statistics, proportion
- Proprio reactive balance test, *see* physical measures, Proprio reactive balance test
- ProZone image recognition system, *see* soccer, ProZone image recognition system
- psychographics, *see* statistics, psychographics
- psychological toughness, *see* psychology, psychological toughness
- psychology, 41–52
 - aggressiveness, 47, 50
 - anger, 46, 50
 - Anger Rumination Scale (ARS), 47, 50
 - anxiety, 44, 45, 50, 99
 - Autonomic Perception Questionnaire (APQ), 50
 - Beck Anxiety Inventory (BAI), 45, 50
 - Beck Depression Inventory (BDI), 50, 98
 - catastrophe model, 45
 - Cattell's Sixteen Personality Factor Questionnaire, 75, 98, 99
 - cognitive ability, 50
 - Competitive Aggressiveness and Anger Scale (CAAS), 47, 50, 75, 76, 99, 162
 - Competitive State Anxiety inventory (CSAI-2R), 50, 75, 76, 98, 99, 123, 161, 162
 - confidence, 42, 50, 99
 - confusion, 46, 50
 - constraint, 50
 - depression, 46, 50, 141
 - Dot-Probe Task (DPT), 50
 - drive theory, 45
 - Exercise Self-Efficacy (ESE), 50
 - extraversion / introversion, 50
 - extrinsic motivation, 42
 - fatigue, 46, 50
 - flow, 46

Flow Questionnaire (FQ), 50
 Flow State Scale (FSS), 46, 50
 Group Environment Questionnaire (GPQ), 50, 98
 Iceberg Profile, 46, 50
 Implicit Association Task (IAT), 75, 76, 98, 123, 163
 Implicit Association Test (IAT), 49, 50
 individual zones of optimal functioning (IZOF), 45
 instrumental aggression, 47
 intelligence, 48, 50
 intrinsic motivation, 42
 inverted-U hypothesis, 45
 Minnesota Multiphasic Personality Inventory (MMPI), 43, 50
 motivation, 42, 50, 52
 multidimensional anxiety theory, 45
 narcissism, 43, 50
 Narcissistic Personality Inventory (NPI), 43, 50
 neuroticism, 50
 psychological toughness, 44
 psychoticism, 50
 reactive aggression, 47
 Rosenberg Self-Esteem Scale (RSES), 48, 50, 52
 self-efficacy, 42, 50
 self-esteem, 50, 52
 situation-specific motivation, 42, 50
 Situational Motivation Scale (SIMS), 42, 50
 Sixteen Personality Factor Questionnaire, 47, 50, 52
 Sport Competition Anxiety Test (SCAT), 45, 50, 99
 Sport Motivation Scale (SMS), 42, 50, 99
 Sport Orientation Questionnaire (SOQ), 43, 50, 98, 123, 161
 Sports Anxiety Scale (SAS), 50
 state confidence, 50
 State Sport Confidence Inventory (SSCI), 43, 50
 State Trait Anxiety Index (STAI), 44, 45, 50
 tension, 46, 50, 141
 Thematic Apperception Test (TAT), 43, 50, 99
 Trait Sport Confidence Inventory (TSCI), 43, 50
 vigor, 46, 50
 Wechsler Adult Intelligence Scale-III (WAIS-III), 50
 Wonderlic Cognitive Ability Test, 50, 74, 75, 163
 psychoticism, *see* psychology, psychoticism

Q

quarterback, *see* football, quarterback

R

R, *see* statistics, R
 ratio scale, *see* measurement, ratio scale
 reaction time, *see* physical measures, reaction time
 reaction time ruler test, *see* physical measures, reaction time ruler test
 reactive aggression, *see* psychology, reactive aggression
 Readiband, *see* wearable technology, Readiband
 receiver, *see* football, receiver
 recovery from injury, *see* physical measures, recovery from injury
 regression, *see* statistics, regression
 reliability, *see* measurement, reliability
 repeated-sprint ability, *see* physical measures, repeated-sprint ability (RSA)
 resampling, *see* statistics, resampling
 Rosenberg Self-Esteem Scale, *see* psychology, Rosenberg Self-Esteem Scale (RSES)
 RSA, *see* physical measures, repeated-sprint ability (RSA)
 RSES, *see* psychology, Rosenberg Self-Esteem Scale (RSES)
 running back, *see* football, back (running back)
 running speed, *see* physical measures, running speed

S

Sabermetrics, *see* baseball, Sabermetrics
 SAFTE, *see* physical measures, SAFTE
 sampling, *see* statistics, sampling
 sampling distribution, *see* statistics, sampling distribution
 SAS, *see* psychology, Sports Anxiety Scale (SAS)
 scale, *see* measurement, scale (level of measurement)
 SCAT, *see* psychology, Sport Competition Anxiety Test (SCAT)
 scatter plot, *see* statistics, scatter plot
 SEBT, *see* physical measures, Star Excursion Balance Test (SEBT)
 self-efficacy, *see* psychology, self-efficacy
 self-esteem, *see* psychology, self-esteem
 Self-Esteem Scale, *see* psychology, Rosenberg Self-Esteem Scale (RSES)
 serve and volleyer, *see* tennis, serve and volleyer

- Shapiro-Wilk test, *see* statistics, Shapiro-Wilk test
- shooting guard, *see* basketball, shooting guard
- ShotTracker, *see* wearable technology, ShotTracker
- shoulder press, *see* physical measures, shoulder press
- shoulder flexibility, *see* physical measures, shoulder flexibility
- shuttle run, *see* physical measures, shuttle run
- SIMS, *see* psychology, Situational Motivation Scale (SIMS)
- simulation, *see* statistics, simulation
- single leg stand, *see* physical measures, single leg stand
- situation-specific motivation, *see* psychology, situation-specific motivation
- Situational Motivation Scale, *see* psychology, Situational Motivation Scale (SIMS)
- Sixteen Personality Factor Questionnaire, *see* psychology, Sixteen Personality Factor Questionnaire
- skinfold body fat testing, *see* anatomy / physiology, skinfold body fat testing
- slam dunk, *see* basketball, slam dunk
- small forward, *see* basketball, small forward
- SMS, *see* psychology, Sport Motivation Scale (SMS)
- soccer
 - added time, 227
 - advantage rule, 227
 - against the run of play, 227
 - aggregate score, 227
 - anchorman, 227
 - angle of the pass, 227
 - angle of the run, 227
 - angling, 227
 - arc (penalty arch), 227
 - area chica, 227
 - assist, 149, 150, 228
 - assistant referee, 228
 - attacker, 228
 - attacking half, 228
 - attacking midfielder, 228
 - attacking team, 228
 - auto goal, 228
 - away, 228
 - away goal, 228
 - away goals rule, 228
 - AYSO, 228
 - B team, 228
 - back, 228
 - back and face, 228
 - back four, 228
 - back header, 228
 - back heel, 228
 - back pass (pass back), 228
 - back pass rule, 228
 - back tackle, 228
 - ball watching, 229
 - banana kick, 229
 - BEAST90 protocol, 140, 141
 - bench, 229
 - bend, 229
 - booking, 229
 - box, 229
 - box-to-box midfielder, 229
 - break, 229
 - breakaway, 229
 - burn, 229
 - captain, 229
 - cards, 229
 - center, 229
 - center back (central defender), 229
 - center circle, 229
 - center forward, 140, 229
 - center half (center back), 140, 229
 - center line, 229
 - center midfielder, 140, 229
 - challenge, 229
 - channels, 229
 - charge, 230
 - chest (chest trap), 230
 - chilena, 230
 - chip, 230
 - chip pass, 230
 - clear, 230
 - cleats, 230
 - closing down, 230
 - club, 230
 - combination play, 230
 - commit, 230
 - conditioned play, 230
 - Confederations Cup, 230
 - control, 230
 - control (the ball), 230
 - corner, 230
 - corner arc, 230
 - corner ball, 231
 - corner flag, 231
 - corner kick, 231
 - corridor of uncertainty, 231
 - counterattack, 231
 - cover, 230
 - cross, 230
 - crossbar, 231
 - cul-de-sac, 231
 - cup-tied, 231

- danger zone, 231
- decoy run, 231
- defend deep, 231
- defender (defenseman), 142, 231
- defensive half, 231
- defensive midfielder, 231
- deflection, 231
- diamond, 231
- direct free kick, 231
- disallow, 231
- dive, 232
- diving header, 232
- draw (D), 232
- dribble, 232
- dribbling, 232
- drop back, 232
- dummy, 232
- early ball, 232
- eighteen-yard line, 232
- El Clasico, 232
- end line, 232
- equalizer, 232
- European Champions League, 232
- expulsion, 232
- extra time, 232
- FA, 232
- fair charging, 232
- fair play, 233
- fake (feint), 233
- fakeover, 233
- FC, 233
- FIFA, 142, 233
- FIFA Ballon d'Or, 233
- FIFA World Cup, 233
- final whistle, 233
- first half, 233
- first team, 233
- first touch, 233
- fist (boxing), 233
- fixture, 233
- flat four, 233
- flick pass, 233
- footwork, 233
- formation, 233
- forward, 234
- forward line, 234
- foul, 234
- free agent, 234
- free kick, 234
- front block tackle, 234
- front header, 234
- front tackle, 234
- full back, 234
- full time, 234
- Futebol, 234
- Galácticos, 234
- give and go (one-two pass, wall pass), 234
- goal, 149, 234
- goal area (penalty box, 234
- goal average, 234
- goal kick, 234
- goal line, 234
- goal posts, 234
- goal side, 235
- goalaso, 235
- goalie (goalkeeper, keeper), 235
- golden goal, 235
- ground ball, 235
- hacking, 235
- half, 235
- half volley, 235
- half-time (interval, break), 235
- halfback, 235
- halfway line, 235
- hand ball, 235
- hat-trick, 235
- head, 235
- head coach, 235
- high press, 235
- hits the post, 235
- holding midfielder, 236
- holding the line, 235
- horseshoe formation, 236
- indirect kick, 236
- injury time, 236
- intercept, 236
- jockeying, 236
- kick-off, 236
- last defender, 236
- Laws of the Game, 236
- league, 236
- League Cup, 236
- left back, 236
- left winger, 236
- line of recovery, 236
- linesman, 236
- lineup, 236
- lofted pass, 236
- long ball, 237
- long shot, 237
- man short, 237
- man-on, 237
- manager, 237
- mark (marking), 237
- match, 237
- match officials, 237
- measured ball, 237
- metodo system, 237

- midfield, 237
- midfield anchor, 237
- midfielder, 142, 237
- mistimed tackle, 237
- multiball system, 237
- Mundial, 237
- narrowing the angle, 237
- netting, 237
- obstruction, 238
- off the ball, 238
- off-season, 238
- offensive player, 238
- official caution, 238
- offside, 238
- olympic goal, 238
- on offense, 238
- one-touch, 238
- one-touch pass, 238
- one-touch soccer, 238
- one-two, 238
- open space, 238
- out of bounds (out of play), 238
- overtime, 238
- pace, 238
- pass, 238
- pass and move, 238
- pass back (back pass), 239
- penalty area, 239
- penalty kick, 239
- penetration, 239
- peripheral vision, 239
- play maker, 239
- plyometrics, 239
- pressure training, 239
- ProZone image recognition system, 140
- receiving, 239
- running with the ball, 239
- save, 239
- shadow play, 239
- shielding, 239
- show, 239
- sliding tackle, 239
- soccer ball, 239
- support play, 239
- sweeper, 142, 239
- switching play, 239
- tackle, 239
- tackling, 239
- taking a player on, 240
- target man, 240
- through pass, 240
- throw-in, 240
- trials, 240
- turning an opponent, 240
- volley, 240
- world rankings, 175
- soccer analytics, 137–157
- socioeconomic status, *see* market value, socioeconomic status
- SOQ, *see* psychology, Sport Orientation Questionnaire (SOQ)
- SPARQ rating system, *see* physical measures, SPARQ rating system
- spatial data, *see* statistics, spatial data
- Spearman rank-order correlation, *see* statistics, Spearman rank-order correlation
- Spearman's rho, *see* statistics, Spearman's rho
- speed, *see* physical measures, speed
- Sport Competition Anxiety Test, *see* psychology, Sport Competition Anxiety Test (SCAT)
- Sport Motivation Scale, *see* psychology, Sport Motivation Scale (SMS)
- Sport Orientation Questionnaire, *see* psychology, Sport Orientation Questionnaire (SOQ)
- sport-specific skills, *see* physical measures, sport-specific skills
- Sports Anxiety Scale, *see* psychology, Sports Anxiety Scale (SAS)
- SportsVU, *see* wearable technology, SportsVU
- sprints, *see* physical measures, sprints
- squats, *see* physical measures, squats
- SSCI, *see* psychology, State Sport Confidence Inventory (SSCI)
- STAI, *see* psychology, State Trait Anxiety Index (STAI)
- standardization, *see* measurement, standardization
- standing vertical leap, *see* physical measures, standing vertical leap
- Star Excursion Balance Test, *see* physical measures, Star Excursion Balance Test (SEBT)
- state confidence, *see* psychology, state confidence
- State Sport Confidence Inventory, *see* psychology, State Sport Confidence Inventory (SSCI)
- State Trait Anxiety Index, *see* psychology, State Trait Anxiety Index (STAI)
- static squat jump, *see* physical measures, static squat jump
- static strength, *see* physical measures, static strength
- statistics, 53–67
 - analysis of covariance (ANCOVA), 187
 - analysis of variance (ANOVA), 60, 61, 64, 187

- Bayesian statistics, 67, 187
 - binary variable, 187
 - Bonferroni correction, 64
 - bootstrap sampling, 187
 - chi-square distribution, 187
 - chi-square test, 64, 187
 - classical statistics, 67, 187
 - comma-delimited text (csv), 187
 - cross-sectional data, 187
 - cross-validation, 188
 - data visualization, 188
 - dependent variable, 66
 - descriptive statistics, 188
 - experimental research, 188
 - explanatory model, 188
 - explanatory variable, 188
 - F distribution, 188
 - F-test, 188
 - Games-Howell test, 61
 - generalized linear model, 188
 - homogeneity of slopes, 188
 - homogeneity of variance, 57, 61
 - homogeneity of variances, 189
 - homoscedasticity, 65, 66
 - independent observations, 60, 65
 - independent variable, 66
 - inferential statistics, 189
 - Kendall's tau, 57, 58
 - Kolmogorov-Smirnov test, 59
 - Kruskal-Wallis test, 61
 - levels of measurement, 189
 - Levene's test, 59, 61, 189
 - linear mixed effects model, 67, 189
 - linear regression, 189
 - logistic regression, 66, 189
 - longitudinal data, 189
 - machine learning, 67
 - Markov model, 189
 - model, 189
 - Monte Carlo simulation, 189
 - multi-level categorical variable, 189
 - multicollinearity, 63, 66
 - multiple imputation, 189
 - multivariate analysis of covariance (MANCOVA), 190
 - multivariate analysis of variance (MANOVA), 64, 66, 190
 - nonlinear mixed model, 190
 - nonparametric, 61, 67
 - normality, 57, 61, 65
 - normality of distribution, 190
 - observational research, 190
 - outlier, 60, 66, 190
 - parameter, 190
 - parametric, 67
 - Pearson product-moment correlation, 55, 57, 190
 - Poisson distribution, 190
 - Poisson regression, 190
 - population, 190
 - population distribution, 190
 - posterior distribution, 190
 - predictive model, 191
 - prior distribution, 191
 - probability, 191
 - proportion, 191
 - psychographics, 191
 - R, 77, 82, 92, 101, 102, 110, 114, 124, 128, 130, 145, 151, 154, 166, 169, 172, 191
 - regression, 64–66, 191
 - resampling, 191
 - sampling, 191
 - sampling distribution, 191
 - scatter plot, 191
 - Shapiro-Wilk test, 59
 - simulation, 192
 - spatial data, 192
 - Spearman rank-order correlation, 192
 - Spearman's rho, 57, 58
 - t distribution, 192
 - t-test, 58–60, 192
 - time series, 192
 - traditional statistics, 192
 - Tukey test, 61
 - strength, *see* physical measures, strength
 - strength testing repetitions, *see* physical measures, strength testing repetitions
 - Super Bowl, *see* football, Super Bowl
 - Super Slam, *see* tennis, Super Slam
 - SVT reaction test, *see* physical measures, SVT reaction test
- ## T
- t distribution, *see* statistics, t distribution
 - t-test, *see* statistics, t-test
 - tackle, *see* football, tackle
 - TAT, *see* psychology, Thematic Apperception Test (TAT)
 - tennis
 - ace, 241
 - ad court, 241
 - advantage, 241
 - aggressive baseliner, 160, 162
 - all, 241
 - all-court player, 160, 162, 241
 - alley, 241
 - alternate, 241
 - angles, 241

- approach shot, 241
- ATP, 166–168, 241
- Australian Formation, 241
- backhand, 241, 242
- backswing, 241
- bagel, 242
- ball toss, 242
- ballperson, 242
- baseline, 242
- baseliner, 160, 162, 242
- break, 242
- breakpoint, 242
- bye, 242
- call, 242
- center line, 242
- challenge, 242
- Challenger Tour, 242
- change-over, 242
- chip and charge, 242
- clip the line, 242
- code violation, 242
- counterpuncher, 160–162, 242
- court, 242
- crosscourt, 243
- Davis Cup, 243
- deep, 243
- deuce, 243
- double bagel, 243
- double fault, 243
- doubles, 243
- down the line, 243
- drop shot, 243
- Entry System, 243
- fault, 243
- Fed Cup, 243
- flat, 243
- follow-through, 243
- foot fault, 243
- forced error, 243
- forehand, 243
- Futures, 243
- game, 243
- Golden Slam, 158, 244
- Grand Slam, 158, 244
- groundstroke, 244
- Hawk-Eye, 244
- hold, 244
- I-Formation, 244
- inside out, 244
- International Tennis Federation, 160
- ITF, 244
- let, 244
- linesmen (line judge), 244
- lob, 244
- love, 244
- Match Point, 244
- miss-hit, 244
- mixed doubles, 244
- natural gut, 244
- net, 245
- no man's land, 245
- NTRP Rating, 245
- out, 245
- overhead (smash), 245
- overrule, 245
- passing shot, 245
- player expenses, 163, 165
- racquet, 245
- racquet head, 245
- rally, 245
- receiver, 245
- referee, 245
- return, 245
- second serve, 245
- serve, 245
- serve and volleyer, 160, 161
- set, 245
- set point, 245
- singles, 245
- slice, 245
- spin, 246
- split step, 246
- stance, 246
- stroke, 246
- Super Slam, 158
- T, 246
- tennis ball, 246
- Tennis Hall of Fame, 246
- tiebreaker, 246
- topspin, 246
- umpire (official), 246
- underspin, 246
- unforced error, 246
- volley, 246
- Wildcard, 246
- winner, 246
- WTA, 166–168, 246
- tennis analytics, 157–173
- tennis player earnings, *see* market value, tennis player earnings
- tension, *see* psychology, tension
- Thematic Apperception Test, *see* psychology, Thematic Apperception Test (TAT)
- three-quarter-court sprint, *see* physical measures, three-quarter-court sprint
- time series, *see* statistics, time series
- touchdown, *see* football, touchdown
- tractability, *see* measurement, tractability

traditional statistics, *see* statistics, traditional statistics

Trait Sport Confidence Inventory, *see* psychology, Trait Sport Confidence Inventory (TSCI)

transparency, *see* measurement, transparency
triceps dips, *see* physical measures, triceps dips

TSCI, *see* psychology, Trait Sport Confidence Inventory (TSCI)

Tukey test, *see* statistics, Tukey test

U

U, *see* psychology, inverted-U hypothesis

underwater weighing, *see* anatomy/physiology, underwater weighing (hydrodensitometry)

upper body strength, *see* physical measures, upper body strength

V

validity, *see* measurement, validity

value, *see* market value

Vert, *see* wearable technology, Vert

vertical jump test, *see* physical measures, vertical jump test

vigor, *see* psychology, vigor

VO2 max, *see* anatomy/physiology, VO2 max, *see* physical measures, maximal oxygen consumption (VO2 max)

W

WAIS-III, *see* psychology, Wechsler Adult Intelligence Scale-III (WAIS-III)

wearable technology

Adidas miCoach, 37

Babolat Play, 37, 39

Catapult, 37

compression attire, 39

Motus Sleeve, 39

Myontec Mbody Pro, 39

OptimEye S5, 39

PlaySight, 37, 39

Readiband, 39

ShotTracker, 39

SportsVU, 37

Vert, 37

Zebra, 37

wearable technology (wearables), 37–40

Wechsler Adult Intelligence Scale-III, *see* psychology, Wechsler Adult Intelligence Scale-III (WAIS-III)

Wingate anaerobic cycle test, *see* physical measures, Wingate anaerobic cycle test

Women's Tennis Association, *see* tennis, WTA

Wonderlic Cognitive Ability Test, *see* psychology, Wonderlic Cognitive Ability Test

World Series, *see* baseball, World Series

WTA, *see* tennis, WTA

Z

Zebra, *see* wearable technology, Zebra