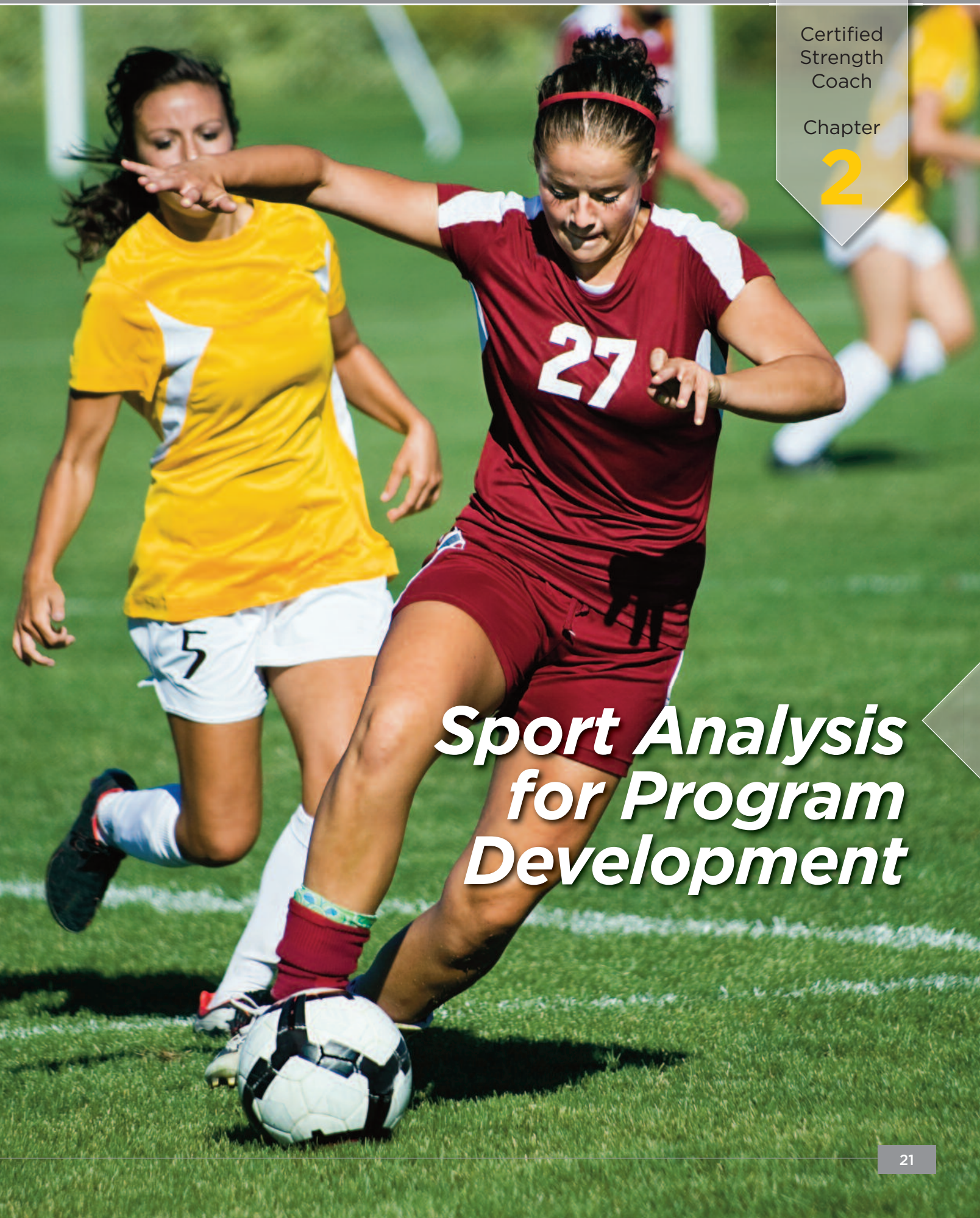


# Sport Analysis for Program Development

# Introduction



Development of an effective strength and conditioning program aimed at promoting specific adaptations is based on the defined need(s) of a particular sport. This is accomplished by analyzing the actions and supportive physio-metabolic factors that account for optimal performance, often labeled a **motion analysis**. The major goal in using motion analysis is to obtain an objective understanding of the crucial factors that contribute to success in a given sport. An athlete's performance can then be compared to elite levels within the sport to identify deficits as well as elements that contribute to success by position. Individual sports typically provide a straightforward analysis of fundamental variables that characterize the sport; team and ball sports on the other hand have a wider range of interrelated, critical variables that dictate success in competition. It is important to recognize what needs to be analyzed during the development of a training program, as well as the objective meaning of the data as it relates to performance. The total distance covered during a basketball game for instance is not very important, whereas the total distance covered at high (versus low) intensity is very relevant. Depending on the method of analysis (i.e., notation, video, and/or computerized), physical, technical, tactical, and behavioral aspects can be assessed to create the training foundations for player development.

**DEFINITIONS**

**Motion analysis –**

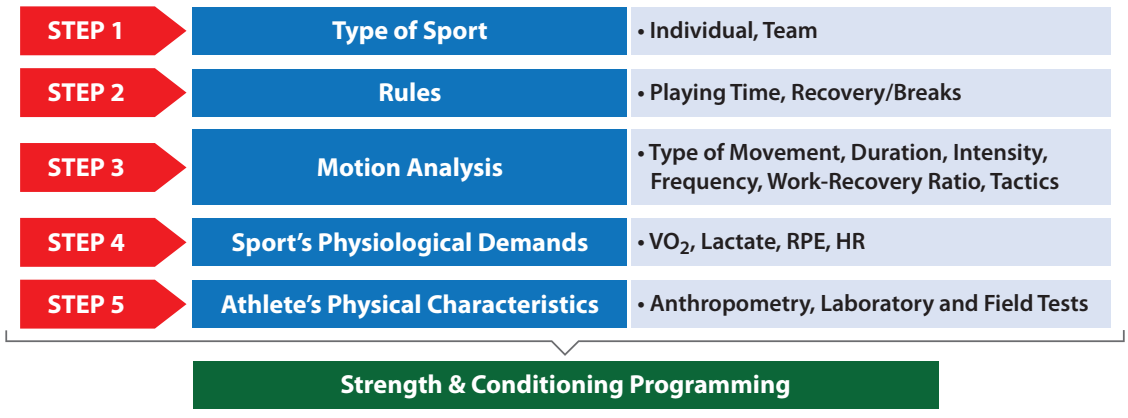
*An analysis of the crucial actions and supportive physiological factors that account for optimal performance and success during a given sport*

**Work-recovery ratio –**

*The relationship of work and rest intervals employed during a bout of training with specific intent toward desired adaptations*

Physical variables such as the type of movement, distance covered, intensity, frequency, changes in direction and **work-recovery ratio** all provide a reference of the athlete's overall physiological demands. Due to these variables and the nature of competitive events, a physical analysis is much more easily quantified for individual sports than team sports. When the average physiological values provide insufficient data to identify key differentiating elements within the sport, it is better to rely on the analysis of physiological and motion characteristics during high-intensity actions. There are two reasons to direct focus on the high intensity aspects of the game or sport: 1) the majority of game outcomes are dependent on actions that occur at the highest intensities or with the most effort; and 2) it is the high velocity/intensity actions that most commonly dictate the capacity to perform at an elite level. Therefore, analysis of the high intensity actions performed, and the means that drive success during those actions, are often the ones that provide the most useful information for programming decisions. Figure 2.1 shows a step-by-step sport analysis method to obtain the necessary information for a comprehensive strength and conditioning program.

**Figure 2.1 Step-by-Step Sport Analysis Method**



The collected information must be thoughtfully integrated in the training process to correct for deficiencies identified on the field, court, ice rink, etc. It should also be used as a feedback mechanism or analytical tool that properly evaluates the effectiveness of the training program as it relates to athletic development. The data will direct the training program to focus on specific outcomes (based on objective criteria) that serve a purpose in performance enhancement, whether it be neural, metabolic, or musculoskeletal. If the data does not provide information for the program constructs, the analysis is essentially a waste of time. The first step is to objectively analyze the performance and interpret the findings. Analytical metrics will allow for comparisons between levels and can provide relevant data to identify the major obstacles to success. For instance, if bat speed is a major difference between Division 1 and Division 3 athletes in baseball, it would make sense to not only work on swing mechanics but also on explosiveness in the weight room. Pertinent data can be used to plan and implement select training variables to improve the athlete or team to a reasonable degree. Premeditated training can only provide so much benefit in a quantified period of time, so the needs of the athlete or team must be prioritized and balanced in an ongoing program. We will discuss periodization in later chapters as it relates to this concept. Attempting to address everything at once is irrational; rather, focusing the training on key deficiencies in a coordinated manner will lead to a higher degree of success. Of additional relevance is the fact that human performance is the result of multiple factors acting together, which supports taking an integrated approach.

Varying coaching styles used by head sport coaches add a level of complication to the development of a **needs analysis**. Each coach will present a slightly (or significantly) different coaching style and acknowledge performance variables to a greater or lesser extent based on his/her preferences for success. Consider this concept with basketball: one coach may decide to emphasize the high-intensity components of cutting, driving, and rebounding to challenge a team at one-on-one interaction; whereas another may emphasize the team's ability to run the court at the highest controlled pace to challenge the opposition from a metabolic standpoint. Additionally, variables that may play a primary role in performance may exist, but objectively quantifying them is a challenge. These variables can include actions or skills such as the use of body movements to "juke" an opponent or to tight rope the out-of-bounds marker during a reception in football. These aspects can make the overall sport analysis more complicated. A football combine, for instance, does not identify an athlete's ability to be in the right position for a reception or to generate a head fake that can stop an opponent flat in their tracks. Although it is possible to quantify most of the typical movements and physical characteristics of a given sport, it is inappropriate to use obtained data to assume absolute prediction of performance. The attractiveness of sport is based on unpredictable or unquantifiable factors that do not always follow the same patterns. This may sometimes explain why an undersized athlete, a slower athlete, or even a seemingly "un-athletic" individual can succeed at specific tasks during competition with greater success than someone who "fits the mold" of the sport on paper. Recall that analysts suggested Doug Flutie would struggle in college and never succeed in the pros because he was too small; on the contrary, he led the Canadian league in passing before moving to the NFL. There is always someone too small, too slow, or too "something" that will complicate the evaluation process.

**DEFINITIONS**

**Needs analysis –**

*The identification, organization, and prioritization of physiological needs applicable to improving performance or health measures during sport participation or structured exercise*

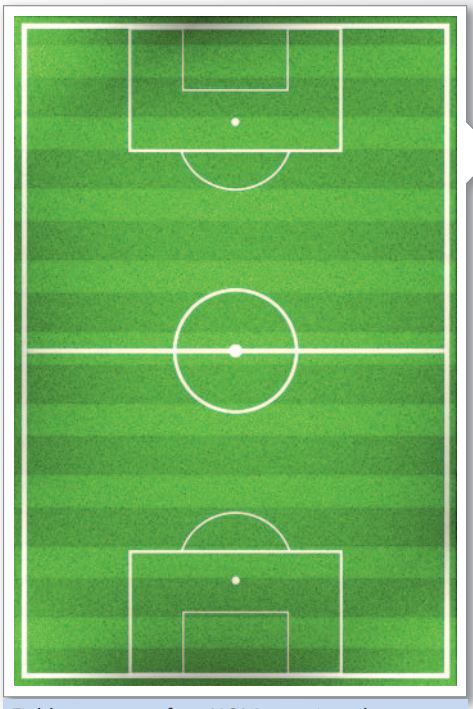




At the physical level, data collected from motion analysis provides a better understanding of a player's response to competition, training, and recovery.

## Soccer

Soccer is the most popular sport in the world, although its allure in the United States is significantly less than Europe and Central and South America. Historically, the knowledge of coaches and their perception of the game and players have been used as the main tool for training decisions. However, the use of more objective tools to analyze the game has become increasingly popular in the last decade, partly due to improved accessibility to new technologies such as global positioning system (GPS) devices that provide the data for a comprehensive breakdown of the game. At the physical level, data collected from motion analysis provides a better understanding of a player's response to competition, training, and recovery. The use of this data is even more important as a feedback and assessment tool because it can provide performance-based information related to specific training and can compare variables (distance covered and intensity at specific velocities) which highly correlate with laboratory (e.g., $VO_2$max tests) and field fitness tests (e.g., yo-yo beep test). By using the obtained data, it is possible to determine a player's strengths and weaknesses, which can then be factored into the training program for game preparation.



Field parameters for a NCAA sanctioned event must have a length of 100-110 m (110-120 yds.) and a width of 60-73 m (65-80yds.).

Understanding the basic rules of soccer is necessary when creating a framework for player development as it pertains to the specific physical demands of the game. A traditional soccer match consists of two equal periods of play lasting 45 minutes with a 15 minute half-time interval. The game is played by two teams, each consisting of no more than eleven players. Field parameters for a NCAA sanctioned event must have a length of 100-110 m (110-120 yds.) and a width of 60-73 m (65-80yds.). Unlike American football, which allows for constant player substitution, in soccer only three to seven players may be nominated to be substitutes, indicating some athletes must play the full 90 minutes of the game.

As with other intermittent sports, soccer conditioning is rooted in the specific intensities that make a difference in the outcome of the game. Quantifying the work rates by position makes it possible to obtain a physical profile of each player's performance during an event and allows

**The physical contribution of each player to the total team effort can be quantified by using the following indicators:**

- **The activity intensity**
  - Expressed as the overall distance covered at a specific speed of movement (also indicates the energy characteristics of the game)
- **The distance covered**
  - Global measure of work-rate; the action of each player can be classified by:
    - Type
    - Intesity (or quality)
    - Duration (or distance)
    - Frequency
    - Positional role
- **Exercise-to-rest ratios**
  - Represents the demands of the game reflecting the metabolic conditioning elements

for comparisons to desired values. This data can then be used as a feedback tool for goal setting in the training and conditioning program.

There are two methods used to quantify a player's movement profile during a soccer game: time spent performing the action (duration) or distance covered during the action. Each approach provides relevant data for the analysis which can be later utilized in programming. The physical profile of a player can be further validated by evaluating physiological variables such as heart rate (HR), lactate accumulation, **rate of perceived exertion** (RPE), oxygen consumption, and other blood markers during a competitive event.

The overall motion analysis of a soccer game indicates that players perform over 1,000 different movements while accelerating or decelerating. These movements include various types of game skills such as headers or tackles as well as specific, multidirectional actions that change based on varying game scenarios. Compared to linear movements, multidirectional movements are more likely to induce fatigue due to the amount of tissue employed to maintain stability during changes of direction. The dynamics of soccer require, on average, a change of activity every six (6) seconds. When using total distance covered to analyze the game, most field players cover around 9-14 km (an average of 11 km during a game), with the majority of the distance covered at a relatively low intensity. Due to the tactics used by each team, the total distance covered may vary, generally by about one kilometer between games. When total distance covered or time spent during the game is broken down categorically according to speed thresholds, it is easier to understand the true physical requirements of the game by volume, intensity, and work-recovery ratios [1]. Table 2.1 provides an example of a general category threshold used within several studies. The use of both distance covered (in meters) and time spent (in seconds) at each category provides an opportunity to estimate the work-recovery ratios crucial for programming metabolic-specific fitness. Figure 2.2 depicts analysis of the game using both methods for a better understanding of the overall physical requirements of a standard 90-minute game. As a general reference, of the average 10.6 km covered during a game, the percentage of distance covered averaged 0.2% standing, 35.1% walking, 39.5% jogging, 16.1% running, 6.6% high speed running, and 2.4% sprinting. The average percentage of time spent at each category reflects 5.7% standing, 58.8% walking, 26.3% jogging, 6.6% running, 2.1% high speed running, and 0.6% sprinting.

**DEFINITIONS**

**Rate of perceived exertion (RPE) –**

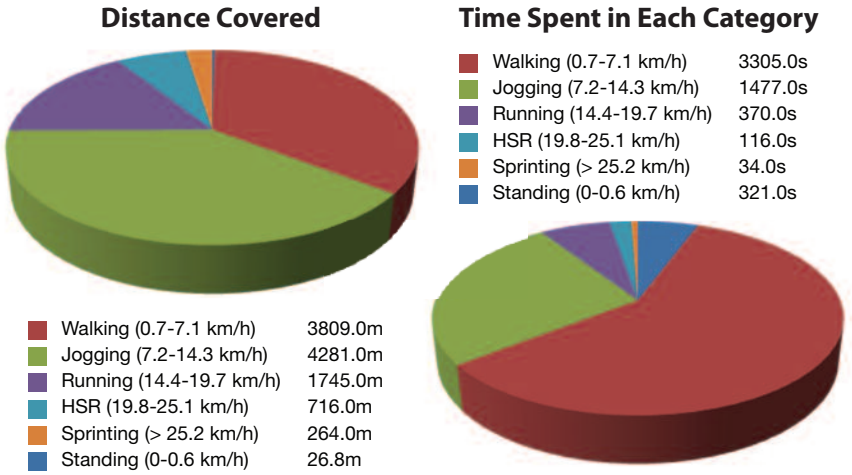
*Individual perception of exertion quantified by a scale numbered 6-20 used to monitor subjective effort during a bout of activity*

**Table 2.1 Movement speeds in soccer**

| Category | Speed threshold |
|---|---|
| Standing | 0-0.6 km/h |
| Walking | 0.7-7.1 km/h |
| Jogging | 7.2-14.3 km/h |
| Running | 14.4-19.7 km/h |
| High-speed Running | 19.8-25.1 km/h |
| Sprinting | > 25.2 km/h |

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sport Sciences, 21*(7), 519-528.

**Figure 2.2 Distance covered and time spent in each category during a soccer game**



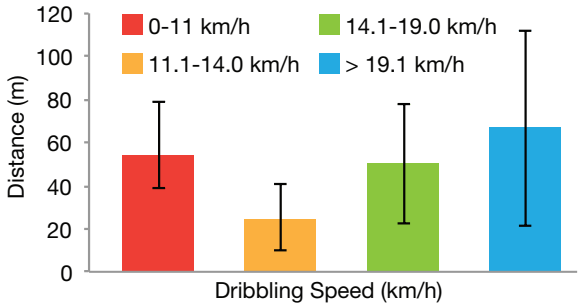

*Adapted from Bradley, 2009.*

The average recovery time between maximal sprints ranges from 65-75 seconds; players statistically perform a high speed run every 30 seconds. From the previous data it is possible to estimate a work-recovery ratio for high and low intensity activities. Based on distance covered, the ratio between low- to high-intensity activities is 2.2:1; however, when using the time spent during each activity, the ratio is about 7:1. Taken at face value, this ratio indicates that aerobic metabolism predominates during a game, but of greater relevance is the fact that game outcomes are actually based on anaerobic-driven actions [2]. Therefore, if the emphasis in training is based simply on breaking down percentages, the player would be inappropriately trained for success.

## Ball Possession

Despite the fact that the soccer ball is the most distinct element of the game, players run most of the time without possession of the ball. This not only stresses the main role of conditioning for performance (getting to the ball) but also indicates the limited possibilities of creating and executing plays during the game. The monitoring of 20 Spanish Premier League matches and 10 Champions League games showed that the total distance covered with the ball ranged between 119–286 m, which corresponded to 1.2–2.4% of the total distance covered [3]. The distance and velocity covered with the ball during French League play is illustrated in figure 2.3, showing mean and peak speed during runs of 12.9 ±1.0 km/h and 24.9 ±2.4 km/h, respectively. Overall, players had 46.7 ±9.1 individual possessions per match with about 53.4 ±8.1 seconds in possession of the ball with variations based on position. The mean distance covered, time, and touches per possession was 4.2 ±0.7 meters, 1.1 ±0.1 seconds and 2.0 ±0.2, respectively; with speed at ball reception at 10.3 ±0.9 km/h [4].

**Figure 2.3 Distance covered with ball possession at different speeds**




*Adapted from Carling et al., 2010.*

It should be clear that although the total distance covered during a soccer match is an acceptable general reference, the best indication as to the condition of the team is gained by observing the total distance covered at high intensities. This has direct implications in soccer performance as it has been shown that distances covered at high intensities is a distinguishing characteristic between players at different performance levels. Elite players execute on average, 28% more high-intensity running than their moderately-skilled counterparts [5]. As expected, the distance covered at a high-intensity pace is greater in the first half compared to the second half of the game. Furthermore, breaking down the game every 15 minutes indicates that during the final 15 minutes of the game, outfield players (all players but the goalie) perform less high-intensity running and sprinting compared to the rest of the game [5]. Interestingly, no difference has been observed between a player's conditioning level and the total distance covered with or without ball possession during high-intensity running; all players covered on average, 1,135 m with ball possession and 1,590 m without ball possession. In addition, when breaking down the game into five-minute increments, the peak distance covered at high-intensity running was approximately 241 ±78 m, while in the following five-minute period, the amount of high-intensity running dropped to 114 ±57 m, clarifying the metabolic impact [1].

## Positional Role

The positional role on the field dictates the physical requirements of each player during a soccer game. Player positions are commonly defined as goalkeeper (GK), central defender (CD), external defenders (ED), central midfielders (CM), external midfielders (EM) and forwards (F). Due to the difference in physical requirements on the field, goalkeepers are analyzed separately

from the rest of the team, all of whom are collectively referred to as outfield players.

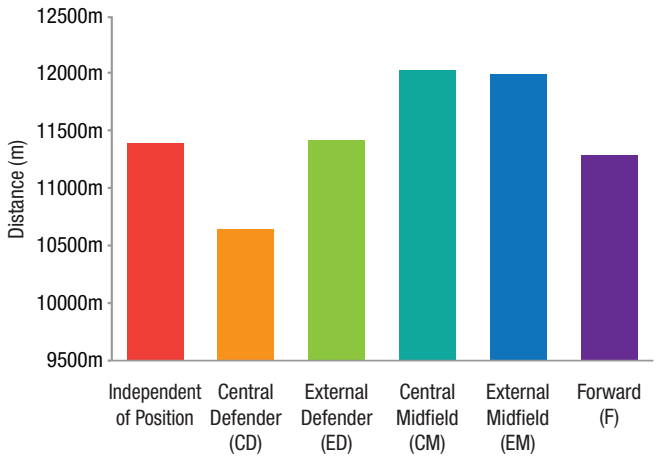
Although the average distance covered during the game is 11 km, differences exist by positional role in outfield players (Figure 2.4), indicating that:

- CM and EM players cover a greater distance than defenders (CD and ED) and forwards (F)
- CD covered shorter distances than that of any other group
- ED did not significantly differ from forwards

When the distance covered by position is analyzed by velocity of movement, the data indicates that [3]:

- At low intensity (0–11 km/h), there are no significant differences between players of any position.
- CD cover a shorter distance compared to all other playing positions at all work intensities greater than 11 km/h. At the highest intensity (>23 km/h) there are no differences with CM players.
- At 11.1–14 km/h, no differences are observed between ED and F. There is no significant difference between ED and F in all other intensities.
- CM players cover the greatest distance at intensities between 11.1-19 km/h, while EM cover the highest distance at intensities >19.1 km/h.
- At >23 km/h or sprinting, there are no differences between ED, EM and F, whereas CD and CM covered a shorter distance.

**Figure 2.4 Distance covered by playing position**




*Adapted from Di Salvo et al 2007.*

## *Physiological Characteristics of Soccer*

During the full duration of a game, elite soccer players perform a variety of movements at different intensities in an intermittent fashion. Players will perform several high-intensity activities interspersed with recovery periods of low-intensity movement (i.e., jogging, trotting, or walking). Due to the amount of recovery the average intensity values are skewed, making use of stress indicators such as HR fairly limited in predicting the true physiological intensity of the game. The average HR during the game indicates that players perform at intensities close to anaerobic threshold (i.e., 80-90% of HRmax) [7]. The average estimated oxygen consumption during the game is about 70% of $VO_2$max, although estimations are limited by the use of HR to predict oxygen consumption and the interplay between anaerobic and aerobic metabolism. The analysis of soccer activities also indicates that $VO_2$ ranges from 2.5-4.5 L, which corresponds to 70-95% of $VO_2$max (moderate- to high-intensity actions) [8,9,10]. The periods of high-intensity activity during the game promote greater lactate accumulation, with values ranging from 4-6 mmol/L. No substantial differences have been observed between elite and non-professional players in terms of relative intensity; however, absolute intensity remains highest amongst professional players [11]. This clearly demonstrates the need for high levels of conditioning for success in the sport. The sporadic nature of the game places the energy demands across all metabolic systems. The numerous, brief, high-intensity actions draw on immediate and intermediate sources for sufficient energy. This underscores the need for explosive and high-tension exercise for the promotion of sport-specific metabolic efficiency. A common error is not recognizing



Average measured HRs during competition indicate that players perform at intensities close to anaerobic threshold.

**Table 2.2 Physical characteristics of soccer players**

| Variable | Range |
|---|---|
| Age (yr) | 21.5 - 31.1 |
| Height (cm) | 175 - 187 |
| Body mass (kg) | 68 - 82.6 |
| Body fat (%) | 7.3 - 9.7 |
| BMI (kg/m$^2$) | 21.4 - 24.4 |
| $VO_2$max (ml/kg/min) | 56 - 65 |
| Aerobic threshold (% $VO_2$max) | 80 - 85 |
| CMJ height (cm) | 46.1 - 62.7 |
| 5-10-5 (Pro agility) (s) | 4.26 - 4.53 |
| 40-yd sprint (s) | 4.55 - 4.91 |
| Bench press 1RM (lbs) | 143 - 209 |
| Squat 1RM (lbs) | 288 - 372 |

**DEFINITIONS**

**Ballistics –**

*Velocity-based lifts that emphasize concentric acceleration with a goal being to notably surpass gravitational rate; examples include heavy throws, box jumps, and the Olympic lifts*



soccer as an explosive sport warranting training similar to other sprint-based activities. Glycogen represents the limiting energy substrate for soccer performance as post game storage is reduced by 40-70% of pregame values. The rate of muscle glycogen utilization and recovery dictates the appearance and delay of fatigue in soccer [12]. The physical characteristics of competitive soccer players are summarized in Table 2.2.

## Summary

Soccer can be categorized as an intermittent sport due to the high-intensity actions interspersed with the moderate-to-low intensity activities observed throughout the game. This places high demands on the phosphagen and glycolytic systems, making glycogen storage and recovery critical to performance. The game requires high intermittent endurance capacity to perform skilled actions at maximum intensity in a repeated manner over the full 90-minute event. This requires an emphasis on developing efficiency in anaerobic byproduct buffering and underscores a need for high oxygen consumption capacity, despite $VO_2$ not being expressed in a uniform fashion during the game. The ability to maintain sprint performance towards the end of the game is a distinct factor between teams of different competition levels, suggesting that soccer-specific speed training should be an integral part of the training program. Additionally, the hundreds of varied types of actions performed during the game indicate the importance of agility, quickness, and reaction time development in soccer-specific conditions. This supports the need for simulated game play such as three-on-three training in the conditioning program of athletes. Dynamic strength requirements place emphasis on Olympic and compound exercises as requisite exercise selections for soccer players. Likewise, power actions will promote full expression of a player's skills; making plyometrics, **ballistics**, and resisted sprint training integral training methods.

### *Goalkeepers (GK)*

**Key Actions:** Vertical jumps, sliding, lateral leaps and slides in all vectors, short sprints and tackles

**Goals:** GK cover the shortest total distance in a game; however, they are involved in key burst actions that heavily influence the game outcome. This suggests a need for anaerobic power training as a mainstay for position-specific athletic development. Dynamic strength training using Olympic and compound exercises are preferred and should be used in combination with ballistic GK drills for power improvements. Although it is generally believed that the functions of a GK place little demand on aerobic capacity, it is crucial for promoting rapid phosphagen system recovery. Multidirectional anaerobic drills should be used for conditioning to promote the necessary agility and dynamic reactions needed for this position; furthermore, position-specific drills with applicable work-recovery ratios are recommended to stimulate improved efficiency of the phosphagen system.

### *Central Defenders (CD)*

**Key Actions:** Short sprints, tackles, headers, sliding, and opponent contact to maintain position

**Goals:** Although CD cover less total distance at any intensity compared to any other field player, the intermittent demands of the game still require a high aerobic capacity, particularly to aid in recovery from the short-duration, specific actions performed during the soccer match (i.e., tackles and headers). Some of the distinctive anthropometric characteristics of CD are their height and

leanness in combination with elevated quantities of lean mass compared to other players. Dynamic strength exercises focusing on the lower extremities (including the hip adductor musculature) are important for injury prevention. Power training via plyometric and ballistic activities that develop jumping ability is critical to the position. CD require a powerful trunk-leg system for optimal performance when defending set pieces (i.e., corner kicks, free kicks) and crosses. Additionally, backwards movements are important in this field position for tactical and technical purposes.



## *External Defenders (ED)*

**Key Actions:** Short and long sprinting, tackles, sliding, quick change of direction

**Goals:** ED cover more total distance than CD as well as greater distances at high velocities. The position involves performing defensive plays as well as participation in attacking actions requiring short- and long-distance sprints. Their involvement in the game includes a high number of actions with possession of the ball. These demands make aerobic endurance, more specifically intermittent aerobic endurance, an elevated requirement for this positional role. Sprint performance is requisite to tactical responsibilities as well, so anaerobic efficiency is a key element in training. Dynamic strength work and power development using compound ballistic exercises, resisted sprint exercises, and plyometrics are relevant training modalities which should be integrated in the program.

## *Central Midfielders (CM)*

**Key Actions:** Distance covered, physical challenge, ball checking, and quick turns with the ball

**Goals:** CM require the highest relative aerobic power among players as they cover the largest distance during the game. Greater $VO_2$ values demonstrated during analysis correlate with the number of sprint efforts made per game. Clearly, the better the condition of a given CM, the more sprint attempts will be made; which can have a significant impact on a game's outcome, particularly in the second half. This cross in energy systems indicates an emphasis on intermittent endurance training using varied work-recovery ratios (from 1:1 to 1:10) for 5-60 second durations, interspersed with active recovery periods. Sprint training should cover distances from 5-20 m, with a special focus on 5 m speed and multidirectional changes, as this positional role requires the highest percentage of short (5 m) sprints compared to any other position. Furthermore, CM must have a strength level that allows them to challenge physical plays and offensive players. This requires strength training using a total-body emphasis and training of sport-specific functions. The demand to perform short explosive actions, coupled with the necessary ability to perform quick turns with the ball for short and long passes in a repeated fashion indicates the need for explosive, multidirectional training under soccer-specific environments.



## *External Midfielders (EM)*

**Key Actions:** High-intensity intermittent runs, acceleration, quick change of direction with the ball

**Goals:** The total distance covered by EM during the game, equaling approximately 12.0 km, indicates the high aerobic power demands of this position. Overall, EM cover a greater total distance than CD, ED and F. Additionally, this positional role requires the greatest distance covered while in possession of the ball. Due to the fact that EM are the critical link between defense and offense, the ability to repeatedly perform short bouts of intermittent activity near aerobic capacity

(with minimal recovery) is fundamental. Furthermore, EM must develop a high sprint capacity as they routinely perform explosive sprints covering anywhere from 5-20 m. This warrants power-based training. It cannot be emphasized enough that comprehensive (aerobic/anaerobic) conditioning is crucial for this position.

### *Forwards (F)*

**Key Actions:** Carry out attacking technical skills at a fast pace, sprinting, physical challenges, and vertical jump

**Goals:** Consistent with other field players, F require a high aerobic power level to support the demands placed on the phosphagen system during the performance of positional-specific sprint actions. Next to EM, forwards cover the greatest sprinting distance; they also engage in the greatest number of total sprints per game, including leading sprints. Soccer-specific sprinting drills are required for this position as F receive and control the ball while moving and sprinting at significant intervals during a game. The need to develop high anaerobic power output is evident, as F must perform various explosive movements as well as engage in aggressive jumping actions; on average, they perform one vertical jump every five to six minutes. Olympic weight lifting, ballistic vertical and horizontal work, and resisted sprint exercise used with complex or contrast sets (the combination of one high strength exercise followed by a high power exercise of similar biomechanical characteristics) are the preferred methods of training. These methods as well as many others will be addressed in a later chapter.

## Tennis



Tennis is generally composed of short-duration periods of work performed at near-maximal to maximal intensity, with relatively longer-duration recovery periods involving moderate- to low-intensity activity.

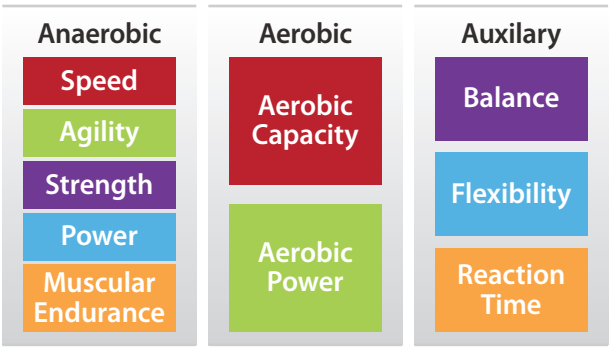
Analysis of the physical requirements suggests tennis is a sport characterized by the repeated performance of intermittent, multidirectional activities. Tennis is generally composed of short-duration periods of work performed at near-maximal to maximal intensity, with relatively longer-duration recovery periods involving moderate- to low-intensity activity. There is a wide range of near-maximal intensity activities performed during a tennis match, such as sprinting in different directions, acceleration and deceleration over short distances, jumping, and execution of powerful overhead movements. The multidirectional nature and stop-and-go actions require the recruitment of varying muscle groups; the serving stroke used and position/direction of acceleration indicate the specific demands that must be considered in a performance enhancement program. The physical requirements of tennis are also intimately related to the type of surface it is played on (soft clay or hard courts), which explains the variability in play duration and total work among matches. Additionally, the strategies and tactics used on the different court surfaces will affect the physical requirements during a given match; players normally have a surface preference that is based on their ability to express their potential. When playing on other surfaces, players change their strategy to adapt their playing style to the surface, which sometimes focuses on minimizing the player's weaknesses associated with the particular surface.

Other variables, such as the length of the match (i.e., three or five sets), the type of ball used, and the level of competition can also affect the player's physical requirements. For example, the qualifying games for a spot in the main bracket of a tournament can sometimes be more physically and mentally demanding than the first round of the tournament itself. As competition increases,

often so does the effort necessary to win. Due to the nature of one-on-one competition, match-ups and style can also add to intensity variations over tournament play.

The specific demands of the game are heavily rooted in the performance-related components of fitness. While tennis requires power, agility, reaction time, and speed, it is important to recognize that an ideal combination of these variables may not exist. Rather, there are general characteristics that exist among elite tennis players (Figure 2.5). On a side note, because tennis is unilaterally dominant, measures of fitness do not always identify inherent limitations associated with bilateral imbalances or common agitators such as **upper-cross syndrome**. While these issues play a role in all sports, the repetitiveness of specific actions in tennis makes movement restriction and imbalance significantly relevant. Evaluations should include acceleration/deceleration strength relationships and skeletal efficiency through postural and functional assessments.

**Figure 2.5 General characteristics of elite tennis players**




*Adapted from Kovac M, 2007.*

## *Match Activity*

The International Tennis Federation (ITF) rules provide for a five (5) minute warm-up period prior to each match. However, when the first service of the match is put in play, play should be continuous until the match finishes. Between points, a maximum 20-second break is allowed. When the players change sides at the end of a game, a maximum 90-second break is allowed. At the end of each set, there is a set break of a maximum 120 seconds [ITF Rules]. In general, the duration of a tennis match ranges anywhere from one to more than five hours; with playing time ranging by 20-30% on clay courts and 10-15% on the faster surfaces. The work-to-rest ratio during tennis play is about 1:1 to 1:4. These values are surmised from the average duration of work being 5-10 seconds and the average duration of breaks being 10-20 seconds. Although it is hard to quantify, there are typically 300-500 high-intensity efforts in a three-set tennis match (more in longer matches). This suggests each rally, in which players cover approximately 8-12 m, may last approximately 8-10 seconds. The breakdown of distance covered during each rally identifies that tennis players make four (4) directional changes while running an average of 3 m per shot; this includes the performance of 2.5-3 different strokes per rally [13,14]. Certainly generalizations can be made, but all of these reference values are subject to change depending on the surface, length of the match, gender, specific player characteristics, playing situation (serving vs. returning) and tactics (attacking vs. defending). For example, the longest rallies are seen on clay, (e.g., French Open), while more offensive attacks and consequently the shortest rallies are seen on grass (e.g., Wimbledon).

**DEFINITIONS**

**Upper-cross syndrome –**

*A condition in which the musculoskeletal system experiences a loss in function due to imbalances in the connective tissue that acts on the shoulder complex observed as an undesirable joint positional change*

**Table 2.3 Player movement patterns**

| % of distance covered per stroke | Distance (m) | Characteristic |
|---|---|---|
| 80% | 2.5 m | Within player-ready position |
| 10% | 2.5 - 4.5 m | Sliding actions |
| 10% | + 4.5 m | Cross-court sprints |

Ferrauti A, Weber K, Wright P R. Endurance: Basic, Semi Specific and Specific. In: Reid M, Quinn A, Crespo M, eds. Strength and Conditioning for Tennis. London: ITF Ltd, 2003. 93–111.

Even though the intensity of match play can be estimated using standard indicators such as maximal oxygen consumption, HR, lactate, and RPE; an analysis of the movement characteristics of the game provides a better understanding of true competitive intensity and physiological

demands. Average intensity values of about 60–70% of $VO_2$max , 60-80% of maximal heart rate, 2-4 mmol/L of lactate, and a RPE value of 4 on a 1-10 scale (or a 13-14 on a 6-20 scale) have been previously documented, but provide limited transference to strength and conditioning programs [13,15,16,17].

## *Physiological Characteristics of Tennis*

Similar to soccer, the intermittent aspects of tennis define the competitive outcome and provide knowledge of the sport's demands. As expected, it is the ability to engage in high-intensity actions during competition that predict success as well as provide the details for training to improve tennis performance. Recent demonstrations show that examining RPE values after selected games can be a useful technique to quantify on-court intensity. This is based on the fact that RPE and blood lactate concentration values have been shown to be significantly correlated with rally duration time and strokes per rally; with higher values present when the athlete is serving the ball (RPE=13.5/20 and 12.2/20; La=4.4 and 3.0 following serving and receiving games respectively) [13,18]. Another viable option to quantify the intensity and demands of the game is the use of performance measurement under work/recovery conditions similar to those seen during an actual tennis match. When replicating the work demands of a game using on-court tennis drills, researchers observed differences in physiological measurements/indicators both during and after the event. These values indicate the high-intensity demands of the game, with observed lactate and RPE values during (La=2.1-4.4 mmol/L; RPE=2.6-5.1/10) and after (La=4.4-10.6 mmol/L; RPE=4.3-7.6/10) performance, respectively [13,19]. Other variables, such as measured body mass deficit (weight loss during a game) following hard and clay court tournaments, indicate a greater body weight loss elicited during hard court play when compared to play on clay (1.05 ±0.49 vs. 0.32 ±0.56% respectively) [20].

**Table 2.4 Notational analyses of men's professional tennis matches played on hard and clay courts [20]**

| | Hard court | | Clay court | |
|---|---|---|---|---|
| **Physiological Variable** | **Mean (SD)** | **Min-max** | **Mean (SD)** | **Min-max** |
| Match duration (min) | 119 (36) | 84 - 171 | 79 (13) | 61 - 101 |
| Rally length (sec) | 6.7 (2.2) | 3.1 - 15.0 | 7.5 (3.0) | 2.8 - 17.9 |
| Shots per rally | 4.7 (1.4) | 2.4 - 8.4 | 4.5 (2.0) | 2.3 - 11.8 |
| Direction changes per rally | 2.5 (0.9) | 1.0 - 4.6 | 2.4 (1.3) | 1.2 - 8.4 |
| Time between games (sec) | 59.9 (18.1) | 23.9 - 108.6 | 50.0 (18.5) | 8.0 - 117.5 |
| Time between points (sec) | 25.1 (4.3)* | 16.7 - 34.4 | 17.2 (3.3) | 10.2 - 27.5 |
| Time between serves (sec) | 11.7 (3.2) | 5.2 - 22.1 | 10.6 (2.5) | 7.6 - 24.4 |

Values (n = 6) presented are mean (SD), minimum, and maximum
*Significant difference (p, 0.01) between the hard and clay court tournaments

# Summary

The intermittent nature of tennis, along with the variances in playing surface and competitive strategies indicate that conditioning programs for the sport must place attention on a wide array of performance-related components. Work-recovery ratios of 1:3-1:5 indicate that short, intermittent bouts of training, lasting up to 30 seconds, are appropriate for developing the aerobic requirements of the game (tennis players show $VO_2$max values over 50 ml/kg/min). Although

rallies last less than 10 seconds on average, games may last for more than five hours, which further supports the need for a specific, high-intensity endurance capacity. The ability to perform explosive strokes in combination with changes of direction place a central role on the development of explosive power and repeat, short-distance sprint capacity. Movement wise, tennis is a classic "chain sport," meaning it relies heavily on efficient force coupling between motion segments and provides repetitive demands of acceleration and deceleration. A chief goal of any performance enhancement program should be the development of maximal and repetitive force development while attempting to avoid gains in mass. This is relevant for multidirectional quickness as well as sparing energy. High-velocity, multidirectional movements place a heavy drain on energy stores compared to linear actions. Olympic weightlifting, multidirectional ballistic activities, and resisted sprint exercises can all serve as means by which to obtain positive adaptations. Likewise, the use of short, multidirectional agility and quickness drills are necessary to match the mobile demands of the game; here it is important to incorporate the technical components (e.g., approaching and recovering steps, different strokes, etc.) of the game to obtain specific and transferable adaptations. The development of appropriate strength levels with an emphasis on muscle balance is essential for both performance enhancement (i.e., ball velocity) and to reduce injuries (i.e., protection of joints, ligaments, tendons). Stresses placed on the rotator cuff musculature while performing explosive movements through extreme ranges of motion clearly indicate the importance of adequate strength and flexibility training to prevent injuries. Coaches should ensure high levels of functionality in the shoulder and scapula to reduce restrictions and avoid an impingement syndrome. The maintenance of a low percentage of body fat will also help tennis players reduce their total relative workload and therefore extend anaerobic endurance capacity; studies have shown values <12% for men and <23% for women are common of elite players [21,22].



The duration of each rally as well as playing times are shorter on hard surfaces.

## *Competition and Play on Hard Courts*

**Key Actions:** Short explosive movements and attacking actions

**Goals:** The use of intermittent training focusing on short work-recovery ratios (recall that rallies last up to 10 seconds) using varied action couples may be an effective methodology of training to obtain the required level of aerobic power for optimal performance on this type of surface. One of the goals should be to perform a relatively high volume of short, anaerobic-focused speed, strength, and power activities as the duration of each rally (as well as playing times) are shorter on hard surfaces. This is mostly due to the faster speed of the ball associated with reduced friction upon ground contact. Tactics selected on this surface traditionally place high demands on anaerobic systems as 58% of points won are at the net. Power training focusing on Olympic lifts, multidirectional ballistics, short-distance agility drills, and resisted sprint exercises are requisite training aspects. Additionally, function-based combinations of tennis-specific actions should be incorporated to harmonize force couples and ensure strength balance across the collective chains. To account for the physical drain of multidirectional velocity and change of direction, conditioning drills should include actions of varied length and height (e.g., center of mass changes) to replicate the demands of match play. Likewise, the shoe-surface interface should be considered for sticking versus sliding movements, a major contributing factor to injury on this type of competitive surface.

On clay courts, playing time is often 30% longer, based on the extended duration of each rally (~15 seconds).



## *Competition and Play on Clay Courts*

**Key Actions:** Sliding, playing time, and defensive actions

**Goals:** The development of high-intensity, intermittent endurance capacity is necessary to match

the requirements of the elevated playing time common to this type of surface. Playing time is often 30% longer, based on the extended duration of each rally (15 seconds). Therefore, work periods during training should be extended to 10-30 seconds using tennis-specific drills, with rest periods ranging from 30-60 seconds to emphasize intermittent endurance capacity. Although the distance covered per rally is directly related to the playing strategy (i.e., attacking or defending), most of the points (~64%) are still won when playing at the net regardless of serving or returning. This indicates that the development of power and speed are still crucial on these surfaces. Again, the preferred methods include explosive drills, Olympic lifts, and resisted movement exercises. Additionally, acceleration, deceleration and change of direction movements based on sliding mechanics must be addressed; particularly the **frontal plane** musculature associated with the hip and ankle. Furthermore, there is a higher muscular endurance requirement to match the repetitive strokes and actions of the match. Crosslink exercises using unilateral, asymmetrically-loaded movement patterns are relevant to aiding frequent directional changes. Improvements in localized stability, as well as dynamic constancy (center of mass control) are paramount, suggesting adjunct work on the vastus medialis, hip abductors and adductors, and obliques is necessary for improved dynamic stabilization.

**DEFINITIONS**

**Frontal plane –**

*A vertical plane which passes through the midaxillary line, dividing the body into ventral and dorsal sections*

## Basketball



To properly analyze the physiological demands of basketball, one must consider the unique nature of the game and the specific environmental conditions when compared with other team sports. Due to the fact that basketball is an indoor sport, analysis of a player's motions have been carried out using video analysis and accelerometer technology, with limited use of GPS technology due to the lack of satellite reception. While this limits the information available on total distance covered during a game, it is of little consequence for properly identifying relevant physiological demands. As with other team sports, the on-court physical demands depend on a player's position and size, but basketball is fairly unique in that it requires all players on the court to play a fairly constant and simultaneous role in both offense and defense.

Depending on the association that regulates the game of basketball, the rules will vary. Total playing time, duration of each quarter, time between quarters and halves, and the number and duration of time outs all differ significantly when comparing leagues, be it the NBA, WNBA, NCAA or FIBA (Table 2.5). These rule variations have implications not only at the tactical level, but also in the planning of conditioning programs.

Analysis of actual playing time indicates that around 46% of the total time is live play (approx 35 minutes ±1 minute), with a stoppage time close to 40 minutes. The motion analysis of basketball provides differing results depending on the categorical emphasis of the analysis. Therefore, the typical actions in basketball are grouped and evaluated using nine movement categories performed during competition. These categories include: standing still, walking, jogging, running, sprinting, jumping, and low-, moderate-, and high-intensity specific movements[23]. The average total number of movements performed by players during a game range from 950-1,100 [23], with a mean duration for all movements of less than three (3) seconds and a change of action every two (2) seconds. The on-

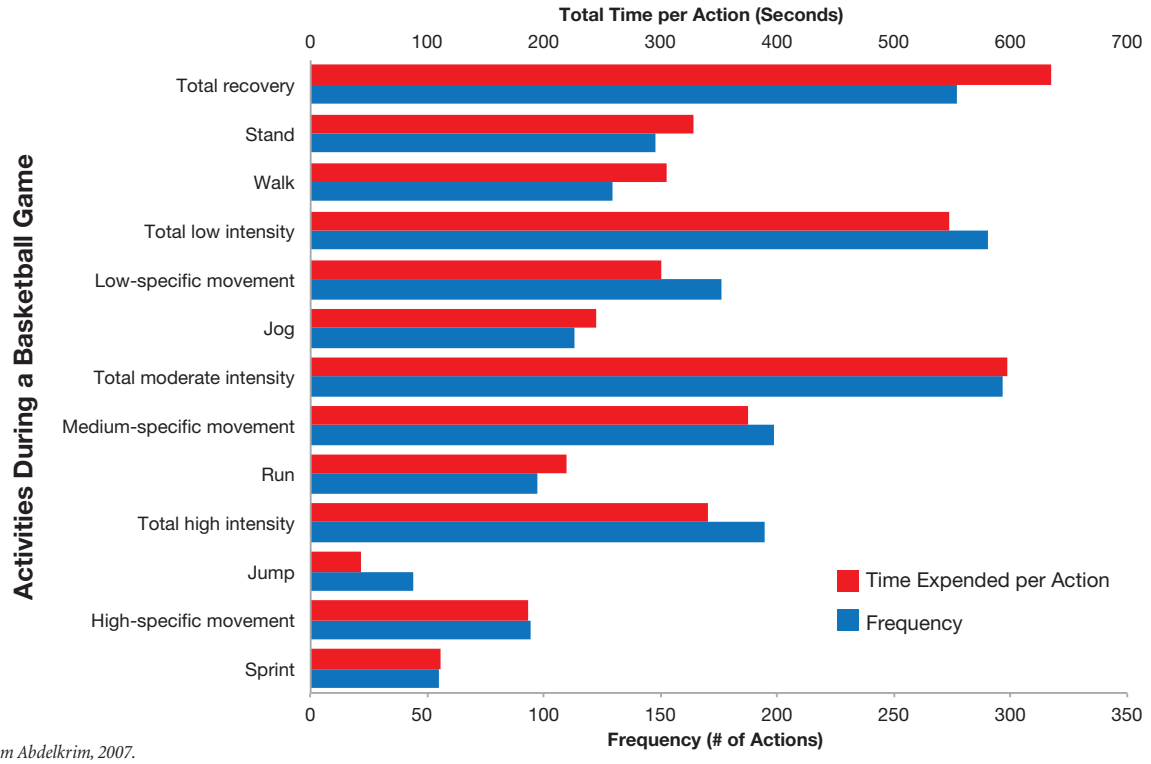
**Table 2.5 Basketball game regulations based on governing league**

| Rule | NBA | WNBA | FIBA | NCAA |
|---|---|---|---|---|
| **Playing Time** | 4 x 12 minute quarters; extra periods are 5 minutes | 2 x 20 minute halves; extra periods are 5 minutes | 4 x 10 minute quarters; extra periods are 5 minutes | 2 x 20 minute halves; extra periods are 5 minutes |
| **Time-Outs – Number And Duration** | • Six "full" time-outs per regulation time (with some restrictions; some mandatory time-outs for television are built into the 6); 3 time-outs per extra period<br>• Full time-outs are 60 seconds, except the first 2 time-outs in each period and the extra mandatory time-outs in 2nd and 4th periods, which are 100 seconds<br>• Full time-outs do not accumulate into over-time; one 20-second time-out per half, unused 20-second time-out in 2nd half may be carried into extra period | • One full time-out per half or extra period<br>• Four TV-type time-outs must occur each half (none in extra period)<br>• Full time-outs are 120 seconds in duration<br>• Full time-outs do not accumulate into extra period<br>• One 20-second time-out in 1st half, two 20-second time-outs in 2nd half, one additional 20-second time-out per extra period (one 20-second time-out can carry over from 2nd half, for a maximum of two in extra period) | • Two time-outs in first half, 3 in second half, 1 per extra period<br>• All time-outs are 60 seconds in duration<br>• Time-outs do not accumulate | • Four 30-second time-outs and one 60-second time-out per game<br>• Maximum of three 30-second time-outs and one 60-second time-out may be carried into 2nd half<br>• One additional 30-second time-out is added per extra period (any time-outs remaining from 2nd half may be carried into extra period)<br>• First 30-second time-out of 2nd half is extended to the length of a media time-out<br>• If coach requests 2 consecutive 30-second time-outs, players may sit, so long as the request is made when the first timeout is granted; normally, players must remain standing and on the floor during a 30-second time-out |
| **Field Goal in Last Minutes of Play (Stopping the Game Clock)** | Last minute of quarters 1, 2 and 3; last 2 minutes of 4th quarter and any extra period | Last minute of each period | Last 2 minutes of 4th period and any extra period | Last minute of 2nd half and any extra period |
| **Shot Clock – Time Allowed To Shoot** | 24 seconds | 30 seconds | 24 seconds | -30 seconds (Men)<br>-30 seconds (Women) |
| **Three-Point Line** | 7.24 m (23' 9") arc, which intersects with lines parallel to the sideline that are 6.7 m (22') from the basket at their closest point | 6.75 m (22' 1.75") arc | 6.75 m (22' 1.75") arc | 6.32 m (20' 9") arc |

*Adapted from Reimer, A. (2005). *Current regulations at time of publishing.*

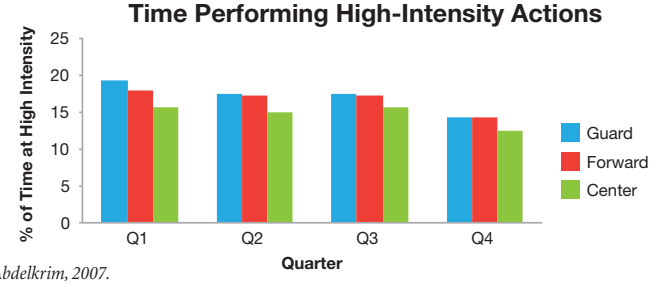
court position also affects the number of actions performed during the game, as seen by the 1,103 (±32), 1,022 (±45), and 1,026 (±27) activities performed by guards, forwards, and centers, respectively. Figure 2.6 shows the frequency of different activities performed during an average game [23], as well as the total live time expended during each action. When analyzing the physical demands of basketball by playing position, guards performed more total actions than forwards and centers. A closer analysis of these actions demonstrates that guards sprint and perform more high-intensity movements than other players. Figure 2.7 illustrates the breakdown of high-intensity actions by position and quarter. Interestingly, there is a considerable decrease in the time involved in intense activities in the last quarter, with centers showing an even more profound decrease than guards and forwards. This provides a reference for the total volume, intensity, and duration of basketball-specific actions. However, it is important to consider that the physiological stress necessary to improve and achieve maximal performance will not necessarily match the actual volume of actions performed during a game. The intensity provides a more direct reference for applications in the training program.

**Figure 2.6 Frequency and duration of activities during a basketball game**




*Adapted from Abdelkrim, 2007.*

**Figure 2.7 Breakdown of high-intensity actions by position and quarter**




*Adapted from Abdelkrim, 2007.*

## *Physiological Characteristics of Basketball*

The physiological demands of a game expressed in terms of oxygen utilization identify that during a practice game, players work at an intensity of ~65% of their $VO_2$max; 66.7% (±7.5) among men and 64.7% (±7.0) among women, respectively. A player's $VO_2$max value appears to correlate well with $VO_2$ during play (r=0.673) and the quantity of time expended engaging in running and jumping actions (r=0.935 and 0.962 for females and males, respectively) [24]. The mean HR for a given athlete during a basketball game can be as high as 91% of maximal HR, while the mean plasma lactate concentration during the game was found to be ~5.5 mmol/L; with even higher values seen during the first half of the game. Differences can also be observed according to position; guards present with higher mean HR and plasma lactate concentrations than centers. The performance environment (i.e., drills, scrimmage, or game) can clearly affect the physiological responses of the player; for example, while there are no significant differences in the HR and $VO_2$ requirements between offensive and defensive drills, the physical load of competitive games is far greater than that seen during scrimmage games [25]. This data provides a reference for the metabolic pathways utilized during a basketball game and suggests that the anaerobic pathways are more significant to energy production during a competitive event.

There are limited studies examining NBA athletes; European league studies are more common. Table 2.6 shows some of the characteristics of elite Serbian players. Guards tend to be older and more experienced than both forwards and centers, while centers have a higher percentage of body fat. Vertical jump height showed no significant differences between different positional roles, while the estimated percentage of fast-twitch muscle fibers was similar among all positions [26]. A negative correlation between weight and vertical jump and height and vertical jump does seem to exist.

**Table 2.6 Characteristics of elite Serbian basketball players [26]**

| Variable | Guard (*n*=20) | Forwards (*n*=20) | Centers (*n*=20) | Total (*n*=60) | Range |
|---|---|---|---|---|---|
| Age (y) | 25.6 ±3.2 ‡§ | 21.4 ± 2.8 | 23.2 ± 3.2 | 23.4 ± 3.5 | 16.8 - 32.4 |
| Professional experience (y) | 9.6 ± 3.2 ‡§ | 5.0 ± 2.7 | 7.1 ± 3.3 | 7.2 ± 3.6 | 2.1 - 13.8 |
| Height (cm) | 190.7 ±6.0 ‡§ | 200.0 ± 3.4 | 207.6 ± 2.9 | 199.5 ± 8.2 | 180.3 - 220.5 |
| Weight (kg) | 88.6 ± 8.1 ‡§ | 95.7 ± 7.1 | 105.1 ± 11.5 | 96.5 ± 11.2 | 75.6 - 121.2 |
| Body fat (%) | 9.9 ± 3.1 § | 10.1 ± 3.2 | 14.4 ± 5.6 | 11.5 ± 4.6 | 3.1 - 20.4 |
| Hemoglobin ($mmol \cdot L^{-1}$) | 131.7 ± 10.9 | 132.3 ± 10.4 | 132.1 ± 10.7 | 132.0 ± 10.7 | 119.2 - 145.7 |
| Hematocrit (%) | 0.41 ± 0.03 | 0.41 ± 0.04 | 0.41 ± 0.04 | 0.41 ± 0.04 | 0.39 - 0.44 |
| Forced vital capacity (L) | 6.5 ± 0.8 | 6.6 ± 1.0 | 6.6 ± 0.9 | 6.6 ± 0.9 | 5.5 - 7.6 |
| Forced expiratory volume in 1 s (L) | 5.4 ± 1.1 | 5.7 ± 0.9 | 5.8 ± 1.1 | 5.6 ± 1.0 | 4.9 - 6.8 |
| Estimated $VO_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$) | 52.5 ± 4.8 § | 50.7 ± 2.3 | 46.3 ± 4.9 | 49.8 ± 4.9 | 41.3 - 63.9 |
| HRmax ($b \cdot min^{-1}$) | 193 ± 2 ‡§ | 196 ± 5 | 195 ± 3 | 195 ± 3 | 186 - 208 |
| Vertical jump height (cm) | 59.7 ± 9.6 | 57.8 ± 6.5 | 54.6 ± 6.9 | 57.4 ± 7.7 | 31.1 - 89.6 |
| Vertical jump power (W) | 1,484.9 ± 200.0 § | 1,578.6 ± 137.5 | 1,683.0 ± 191.7 | 1,5821.1 ± 193.6 | 1,256.1 - 1,889.5 |
| Fast twitch† (%) | 65.1 ± 10.2 | 64.7 ± 8.9 | 62.4 ± 9.1 | 64.1 ± 9.4 | 45.2 - 79.5 |

* Values are expressed as mean ± *SD*; HRmax = maximal heart rate obtained in the last minute of shuttle run test; $VO_2$ = maximal oxygen uptake.
† Estimated percentage of muscle fiber types (fast twitch) of leg extensor muscles.
§ Statistically significant at $p < 0.01$ for guards vs. centers.
‡ Statistically significant at $p < 0.01$ for guards vs. forwards.
Statistically significant at $p < 0.01$ for forwards vs. centers.

A recent study compared NBA starters to nonstarters on their ability to maintain strength, power, and quickness during a competitive season. The starters played an average of 1813 ± 639 total minutes (27.8 ± 6.9 minutes per game) and nonstarters played an average of 543 ± 375 total minutes (11.3 ± 7.0 minutes per game) over the competitive season [27]. Also over a season, starters were able to maintain body mass (0.5 ± 1.2 kg), whereas nonstarters showed a significant loss in body mass (-0.9 ± 3.1 kg) [27]. Starters additionally showed a significant increase in vertical jump power (VJP) and measures of reaction time when compared to nonstarters [27]. All players were able to improve their squat power during the course of the basketball season [27].

**Table 2.7 Magnitude-based inferences on anthropometric and performance changes during a season of competition in NBA starters vs. nonstarters [27]**

| S vs. NS | Mean Increase (%) | Clinical inference | % Beneficial/ positive | % Negligible/ trivial | % Harmful/ negative |
|---|---|---|---|---|---|
| Body Mass | 1.3 | Possibly | 59.6 | 30.1 | 10.3 |
| Body Fat % | -9.6 | Possibly | 57.6 | 30 | 12.4 |
| VJP | 17.15 | Likely | 94.5 | 4.8 | 0.8 |
| Quickness | -0.29 | Unclear | 33.3 | 30.6 | 36.1 |
| Reaction Time | -5.66 | Possibly | 57.6 | 30 | 12.4 |
| SQT Power | -3.28 | Unclear | 34 | 27.6 | 38.4 |

*NBA = National Basketball Association; S = starters; NS = nonstarters; VJP = vertical jump power; SQT = squat

**Table 2.8 2012 NBA Draft Combine Results**

| | Guards | Forwards | Centers |
|---|---|---|---|
| Height | 5'11.75" - 6'7.5" | 6'5.25" - 6'10.75" | 6'11.5" - 7'1.25" |
| Weight (lbs) | 174.4 - 221 | 196.6 - 268.2 | 241.2 - 278.6 |
| Body Fat % | 3.6 - 12.5 | 3.2 - 11.3 | 5.2 - 11.4 |
| No-Step Vertical Jump (in) | 26 - 34.5 | 25.5 - 38 | 26.5 - 34 |
| Maximal Vertical Jump (in) | 29.5 - 41.5 | 30 - 40 | 29.5 - 40.5 |
| Bench Press (185lbs) | 0 - 17 | 0 - 20 | 7 - 19 |
| Lane Agility Test (s) | 12.03 - 10.57 | 12.77 - 10.48 | 12.35 - 10.14 |
| 3-Quarter Court Sprint (s) | 3.47 - 3.19 | 3.81 - 3.16 | 3.44 - 3.29 |

National Basketball Association (NBA). In 2012 NBA Combine: Athleticism Results. Retrieved July 10, 2013, from http://nbadraft.net/2012-nba-combine-athleticism-results.

National Basketball Association (NBA). In 2012 NBA Combine: Measurements. Retrieved July 10, 2013, from http://www.nbadraft.net/2012-nba-combine-measurements.



## Summary

Studies have shown different positional requirements in size, strength, speed, agility, and intermittent aerobic endurance in basketball [24]. This suggests strength and conditioning programs should be specifically suited to the position played. Key elements to all positions include muscular power, speed, agility, and aerobic power. Recent literature suggests basketball performance is more dependent on a player's anaerobic power and anaerobic endurance than on aerobic endurance when relative strength is consistent [23,24,25]. Short-term anaerobic per-

formance (particularly speed at distances ranging from 5-30 m) explosive strength, and agility should be the key elements in basketball conditioning programs as they have been found to be defining variables among elite players and predict playing time in Division I college players [23,24,25]. Additionally, the ability to sustain high-intensity efforts is demonstrative of elite players and is therefore another relevant variable to consider in athletic preparation [23,24,25,26,27]. To identify the specific relevance of each variable for performance enhancement, basketball positions are commonly separated into three groups (guards, forwards, and centers) but a possible argument can be made for separating positions into point guards, shooting guards and small forwards, and power forwards and centers due to the speed, size, and physical contact differences.

## *Point Guards*

**Key Actions:** Quick acceleration and deceleration with rapid turning, sliding, and change of direction



Guard play requires the highest $VO_2$max and fastest 5-10 m sprint speeds.

**Goals:** Point Guards set the pace of the game, requiring the highest $VO_2$max and fastest 5-10 m sprint speeds. Due to the need for speed and agility with limited body contact, mass is not a pertinent factor. In fact, slicing through potential contact with an opposing player is a key element related to the position. This requires greater ability to produce rapid bodily shifts during forward movements such as head fakes, rotational maneuvers, and "juking" actions. Training should emphasize anaerobic conditioning, improving hip power for speed, and dynamic stability with specific planning for agility and scenario-specific improvements in reaction time. Leg and hip strength is comparable to all other players relative to body mass, suggesting closed-chain, compound hip/ leg actions, such as heavy squats, are relevant in the program. Anaerobic capacity and explosive training are also important components; therefore, glycolytic-based ballistic activities can be effective. Due to the need for constant movement and change of direction to gain positional advantages, guards require excellent center of mass control; suggesting that an emphasis on dynamic equilibrium needs to be considered via incorporation of multidirectional agility exercises with a range of loading variations.

## *Shooting Guards and Small Forwards*

**Key Actions:** Long sprints, fast breaks, and transitional actions at high intensity

**Goals:** Shooting guards and small forwards demonstrate the fastest 30 m speed. Small forwards spend the most time running and are fastest at 30 m distances; followed closely by shooting guards, as much of the game is played in transition. Although repeat anaerobic bursts are highest among point guards, these positions should be appropriately conditioned over longer distances for higher levels of supportive aerobic endurance. Total body strength balance is relevant and should be developed via closed-chain, compound activities. Of note, a player's strength-to-weight ratio is a key predictor of top performers. The multidirectional aspect of "under the basket" play, along with the requirement to perform repeat, short-burst movements and sprints, underscores the need for explosive and ballistic training with various loaded conditions. Basketball training, particularly for guards, should encourage multiplanar conditions; a common error is overemphasizing **sagittal plane** activities.

**DEFINITIONS**

**Sagittal plane –**

*A vertical plane which passes through the midline of the body, dividing it into right and left halves*

## *Power Forwards and Centers*

**Key Actions:** Screening, boxing out, posting-up, and rebounding

**Goals:** Power forwards and centers spend the most time in direct physical contact with other



Centers perform the most physical contact with opposing players, even though they perform the least amount of total overall movements.

players. Centers perform the most physical contact with opposing players, even though they perform the least amount of total overall movements. Power forwards and centers are the strongest athletes on the team; thus justifying higher levels of compound hip work in a training program. They also demonstrate a need for greater mass for low-mid post positioning and attempts at ball possession. Upon comparison, these positions should have the greatest absolute power, but due to their size the players will likely have lower relative power (vertical and horizontal directions). Centers possess the greatest mass and the highest body fat among players, which may explain the slower speeds and lower relative power compared to power forwards as well as the greatest decline in intensity towards the end of the game. This suggests body composition may warrant consideration for an improved strength/power-to-weight ratio, even considering the fact that centers spend significantly less time in high-intensity movements and more time exerting isometric and dynamic strength. Although total-body strength and closed-chain stability (integrated strength) are relevant for all positions, centers and power forwards should maintain superior measures of strength and power. Sustainable strength from varied stance positions is important for post players, as is the integrity of hip/trunk endurance due to the constant pressure of lean-contact (isometric force) from other players. Improved force coupling within the hip and trunk, as well as ab/adductor stability, should be emphasized for these athletes. Slide disc work helps to serve these purposes. When considering basketball strength and power training, coaches must recognize challenges related to the physics of body proportions (i.e., long limbs). Traditional movements may need to be modified to accommodate observed difficulties among forwards or centers. For example, pulls from the floor should be performed from blocks, and squat depths should be specific to functional ranges among taller athletes. Furthermore, forward and lateral movements should account for limb length and knee position. Unilateral-based work from a split stance can aid in exercises where the physics of bilateral work becomes challenging. This is particularly applicable to very tall athletes who need to perform overhead work as significant mechanical stress will be placed upon central stabilizers due to the height of the center of mass relative to the base of support.

## Football



The United States does not allocate the same resources for clinical investigations of athletic performance when compared to other countries. Consequently, American football has not been thoroughly evaluated in controlled environments, with most of the existing data based on empirical observation. Only recently has the relationship between strength, speed, power, and optimal performance in the sport been scientifically confirmed [28]. Interestingly, the emphasis of strength and conditioning in most university settings is placed heavily on football. It could be argued that the existing foundations for the strength and conditioning profession, as well as programming methodology in the United States, is primarily based on America's most popular sport. Part of the reason for its popularity and need for specialized training lies in the fact that the sport is collision-based and played using repeated, maximally-intense bouts of activity. The sport is also fairly unique in that two competitions occur simultaneously. There is an offensive-defensive struggle at the line of scrimmage in concert with a downfield

competition between receivers and backs. Likewise, the game can switch from an aerial to ground attack at any time.

Compared to sports like soccer and tennis, which are played for longer durations, the entire game of American football is one hour in length; split into four 15-minute quarters with a 12-20 minute (NFL-NCAA) half time period. Although the total playing time is 60 minutes, no single player is ever on the field for this full duration; separate offensive and defensive players are used and, in many cases, certain positional players are substituted on both sides based on strategic adjustments made by the coaches. Additionally, a third aspect of the game occurs following a scoring event or exchange of a possession; the group responsible for play at these transitions are called special teams, and are comprised of an array of specialty players from both offensive and defensive positions. Due to the need for three operational units and back-up players for each positional role, American football teams are the largest of any sport and have the greatest number of specialty players serving select roles.

Early investigation related to injury risk assessment suggested the maximum time a player is exposed to play action in a complete football game is 13.5 minutes, with numerous players spending less than half this duration on the field during a game. Football is played using short action segments, or what is referred to as a series of plays. On average, football teams play around 14 offensive series in a game and between 4.6 (college) and 5.6 (NFL) plays per series; this equals an approximate total of 70 offensive plays per game [29]. Each play in a series may last only 5 seconds before stoppage. Video analysis suggests that each play lasts between 1.87-12.88 seconds, averaging 5.5 seconds for college and closer to 5.0 seconds in the NFL [30]. Once the referee has designated the ball's location following a play, the clock starts and the team (on offense) has 40 seconds to run the next play. It is estimated that collegiate athletes take on average 32.7 seconds between plays, whereas the NFL rest interval ranges between 26.9 to 36.4 seconds. It should be noted that during the final two minutes of the game the time interval between plays often decreases significantly as losing teams rush to score. When rest between series is considered, the average time between offensive possessions is 11.39 + 4.19 minutes [30].

## *Physiological Characteristics of Football*

American football is defined as a high-intensity, anaerobic sport characterized by intense bursts of work, followed by short rest intervals between plays [31]. The game is played at near-maximal to maximal effort; with each play requiring variations in movement and force output as determined by position or assignment. It is suggested that the physical demands on a player are based on several factors, including position, the style of offense employed by a team, and the defensive schematic presented by the opponent. For example, running plays require less time (4.86 ± 1.41 seconds) compared to passing plays (5.6 ± 1.71 seconds). Similarly, teams organize their offensive squad by using either a run- or pass-dominant strategy, placing different requirements on certain players. This certainly helps to explain why some players experience significant performance decline, measured as loss of peak force and power, from the first quarter to the halftime period. Players who are substituted throughout the game demonstrate a less significant decline in force output as recovery time aids intermittent performance requirements. This has become a common strategy used by coaches to manage positions such as the defensive linemen, who experience maximal-intensity demands during every play, as well as switching offensive receivers to fatigue



The physical demands of football are based on several factors, including the position played, the style of offense employed by a team, and the defensive schematic presented by the opponent.

defensive secondary players who do not substitute as frequently and must perform repeated sprints.

American football is clearly a phosphagen-driven sport. Reports suggest this immediate metabolic system fulfills 90% of energy requirements, with secondary support from the glycolytic pathway [30]. However, the published analysis suggesting the 9:1 ratio of phosphagen to glycolysis may be slightly exaggerated as players examined in a post-game period demonstrated 3- to 5-fold increases in serum lactate, suggesting a greater reliance on glycolytic pathways compared to what was initially believed. Recent findings suggest that glycolytic activity may be more dominant than originally proposed during all intense immediate work. The explosive nature of the sport-specific movements, and the high intensities employed in each play, should be replicated in training for both power and metabolic conditioning. Additionally, due to the continual need for high force output, football players must have sufficient aerobic support to quickly recover with short rest durations. $VO_2$max measurements of collegiate and professional football players have been found to be similar, with peak values of $VO_2$max recorded at 4.25 L/min (±0.27 L/min) [32]. This suggests that aerobic conditioning may be a factor in the performance decline commonly seen between subsequent quarters.

Although running distances as well as direction of movement varies by position, football is played using acyclical movements, which require a functional integration to perform a single action [33]. Players must be able to move efficiently in a direct course and control changes in body positions at high velocities. For instance, an offensive lineman drops back while exerting forward forces against a defensive tackle during a pass block; at the same time on the other side of the ball a defensive corner may need to backpedal, change direction, and then immediately dive laterally to block a pass thrown to the receiver in his zone. This integrated movement concept suggests that more emphasis should be placed on movement efficiency and athleticism than on individual muscle activity. It also speaks to the relevance of improving coordination between movement segments, the role of dynamic stability, and the need for flexibility to optimize performance. Unfortunately, these areas are often de-emphasized in traditional football programs in exchange for heavy loading dominated by sagittal plane actions.

When divisions of college football are compared, notable variations between metrics of size, strength, power, and speed can be observed [34]. Markers of strength, power, and speed have also been demonstrated as criteria that separate starting position players from those who serve back-up roles [35]. In the NFL, power, speed, and agility have been shown to be valid predictors of draft status, as well as the likelihood a college player makes a professional team [36]. Furthermore, when collegiate interdivision comparisons are made, measures of power are predictive of final NCAA team ranking, demonstrating the importance of ballistic and Olympic-based training for the sport [37].

Size and strength have historically been dominant variables related to player selection in both recruitment for college and the NFL draft. Interestingly though, among size variables, body composition plays a large role in successful performance [38]. In studies conducted on both university and professional football players, results demonstrated a relationship between body composition and strength, speed, and cardiovascular efficiency, suggesting players carrying excess fat experience some level of performance decline. A study comparing current body mass of NFL players showed that the most dramatic increases in body mass (compared to the 1970s) were observed among offensive and defensive linemen (Table 2.9). Height, on the other hand has essentially remained unchanged except for defensive backs [39].

It is believed that rule changes in drive-blocking style has changed dynamics of the game by reducing body mass needed for such "old school" blocking methods (now illegal) as scramble blocks, spearing, and posting with chop blocks [39]. Therefore, depending upon the offensive style, plays requiring pulling, cross-blocks, change-ups in pass blocking, and no huddle offenses may indirectly create differences in body mass among various NFL teams. Comparisons between data from the 1998 Atlanta Falcons and the 2005 Indianapolis Colts showed that the Colts' offensive and defensive lines had lower body fat percentages due to different styles of play and training factors [39]. It has been also theorized that defensive linemen could be lighter than offensive linemen due to the need for greater movement in coverage zones and for pass rushing [39].

**Table 2.9 Mean body size and body composition values by position (NFL)**

| Position | *n* | Height (cm) | Body mass (kg) | % Fat | BMI |
|---|---|---|---|---|---|
| RB | 4 | 180.0 ± 3.0 | 96.5 ± 8.1 | 7.3 ± 7.3 | 29.8 ± 2.7 |
| OL | 11 | 193.3 ± 3.8 | 140.0 ± 7.5 | 25.1 ± 2.5 | 37.1 ± 1.9 |
| QB | 2 | 192.0 ± 5.8 | 104.2 ± 2.6 | 14.6 ± 9.3 | 28.3 ± 2.4 |
| WR | 7 | 180.5 ± 3.9 | 85.6 ± 6.5 | 8.1 ± 2.8 | 26.3 ± 2.0 |
| TE | 4 | 194.4 ± 4.0 | 115.6 ± 7.2 | 15.1 ± 5.4 | 30.6 ± 0.9 |
| LB | 5 | 186.9 ± 2.6 | 107.8 ± 2.9 | 15.7 ± 2.8 | 30.9 ± 0.6 |
| DL | 7 | 191.6 ± 2.5 | 126.8 ± 2.4 | 18.5 ± 3.8 | 34.6 ± 1.4 |
| DB | 11 | 179.7 ± 4.5 | 87.1 ± 5.6 | 6.3 ± 2.8 | 26.9 ± 1.6 |
| K/P | 2 | 191.4 ± 5.9 | 95.3 ± 0.0 | 11.4 ± 8.3 | 26.0 ± 3.4 |

BMI = body mass index; RB = running back; OL = offensive line; QB = quarterback;WR = wide reciever; TE = tight end; LB = linebacker; DL = defensive line; DB = defensive back; K/P = kicker/punter

From: Kraemer, W. J., Torine, J. C., Silvestre, R., French, D. N., Ratamess, N. A., Spiering, B. A., . . . Volek, J. S. (2005). Body size and composition of national football league players. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 19*(3), 485.

Much of the associated research also points out that BMI is not a proper indicator of "health status" for football players; further analyses are needed to determine true health profiles for these athletes. This may be especially pertinent as players transition to more of a basic 'health and fitness lifestyle' after their careers have ended. Table 2.10 clearly demonstrates the fact that BMI is not a good indicator of health status for football players.

**Table 2.10 Health status by BMI and percentage fat criteria and correlations between body composition compartments and BMI**

| Position | BMI | Percentage fat | Body Compartment | BMI |
|---|---|---|---|---|
| RB | Obese | Healthy | Total mass | 0.957† |
| OL | Severly obese | Poor | Total lean mass | 0.870† |
| QB | Overweight | Healthy | Total fat mass | 0.907† |
| WR | Overweight | Healthy | Percentage fat | 0.856† |
| TE | Obese | Healthy | | |
| LB | Obese | Healthy | | |
| DL | Obese | Good | | |
| DB | Overweight | Healthy | | |
| K/P | Overweight | Healthy | | |

*BMI = body mass index; RB = running back; OL = offensive line; QB = quarterback; WR = wide reciever; TE = tight end; LB = linebacker; DL = defensive line; DB = defensive back; K/P = kicker/punter. † = p = .05

From: Kraemer, W. J., Torine, J. C., Silvestre, R., French, D. N., Ratamess, N. A., Spiering, B. A., . . . Volek, J. S. (2005). Body size and composition of national football league players. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 19*(3), 485.

These morphological changes in the average player by position have also occurred among Division I players. Total body mass, skin-fold thicknesses, and body fat were greater in Division I players during the early 2000s than the early 1980s and early 1990s [40]. Body fat varied according to playing position; with the defensive backs, offensive backs, and receivers being the leanest while the offensive linemen and tight ends had the greatest quantities of body fat [40]. As detailed in the previous examples, these values are likely due to newer training techniques and changes to the rules and strategies of the game.

Offensive and some defensive lineman, as well as some tight ends, have demonstrated an ability to play at the professional level with body fat values much higher than previously recommended. This may seem contradictory, as successful performance by linemen is associated with power production over repeated plays during a football game, and body fat is negatively correlated with this requirement. Additionally, when strength-to-weight values for linemen are compared to linebackers and running backs, linemen demonstrate lower values despite the higher strength demands of their positions. One consistency found in the literature is the negative impact excess body fat plays on performance measures, suggesting overall mass is not as relevant as composition relative to size. Furthermore, from a fitness perspective, the prevalence of metabolic syndrome associated with excess body fat was significantly higher among linemen compared to skill-position players (46% vs. 0%). Additionally, 20% of the players examined in research have demonstrated mildly abnormal ventricular wall thickness, despite no significant differences in vascular function between groups [41].

Another study evaluated the performance of 326 collegiate football players attending the 2000 National Football League combine and looked at whether draft status could be predicted from this event [42]. Height and weight were measured and the 225-lb bench press test, 10-yd dash, 20-yd dash, 40-yd dash, 5-10-5 (Pro agility), 60-yd shuttle, 3-cone drill, broad jump, and vertical jump assessments were used. Table 2.11 shows that the first and second round draft picks were (in general) taller , heavier, stronger, faster in all 3 linear running distances as well as in the 3 agility shuttles, and could jump both higher and farther when compared with the sixth and seventh round draft picks [42].

**Table 2.11 Characteristics of round 1 and 2 draft picks vs. round 6 and 7 draft picks [42]**

| | Rounds 1 and 2 | Rounds 6 and 7 |
|---|---|---|
| **Characteristics** | **Mean ± SD** | **Mean ± SD** |
| Height | 74.15 ± 2.57 | 73.8 ± 2.35 |
| Weight | 247.93 ± 49.86 | 245.56 ± 48.58 |
| Bench Press (225-lb) | 21.83 ± 6.75 | 20.59 ± 6.95 |
| 10-yd dash | 1.68 ± 0.11 | 1.71 ± 0.11 |
| 20-yd dash | 2.79 ± 0.18 | 2.85 ± 0.19 |
| 40-yd dash | 4.81 ± 0.31 | 4.93 ± 0.34 |
| Vertical jump | 33.31 ± 3.26 | 31.23 ± 4.15 |
| Broad jump | 113.39 ± 9.18 | 109.18 ± 9.84 |
| 5-10-5 (Pro agility) | 4.38 ± 0.29 | 4.45 ± 0.29 |
| 60-yd shuttle | 11.39 ± 0.26 | 11.53 ± 0.22 |
| 3-cone drill | 7.23 ± 0.41 | 7.46 ± 0.46 |

The data from this analysis is useful in multiple ways. First, the abilities of the sixth and seventh round draft picks demonstrates to coaches an idea of the minimal test requirements for playing in the NFL. Also, it can help coaches identify which tests are most important for athletic success. For example, it appears that the vertical jump was the most important test to determine draft success in the RB position, whereas the 225-lb bench press test had little to no effect on any position [42].

**Table 2.12 Top 15 combine results (by position) for the 2013 NFL draft**

| | 40-yd Dash (s) | Bench Press (225-lb) | Vertical Jump (in) | Broad Jump | 3-Cone Drill (s) | 5-10-5 (Pro agility) | 60-yd Shuttle (s) |
|---|---|---|---|---|---|---|---|
| QB | 5.11-4.59 | 15* | 34.0-26.5 | 8'4"-10'4" | 7.49-6.69 | 4.55-3.99 | NR** |
| RB | 4.60-4.34 | 20-36 | 33.5-43.0 | 9'11"-10'10" | 7.12-6.69 | 4.31-4.02 | 12.12-11.33 |
| WR | 4.50-4.27 | 13-26 | 34.5-39.5 | 10'1"-11'4" | 6.93-6.53 | 4.29-3.96 | 12.14-10.87 |
| TE | 4.99-4.5 | 16-31 | 30.5-37.5 | 9'2"-10'5" | 7.48-6.92 | 4.57-4.27 | 12.2-11.5 |
| S | 4.65-4.42 | 14-28 | 35.0-40.5 | 10'11"-11'2" | 7.07-6.64 | 4.34-4.00 | 11.62-11.53 |
| DL | 4.84-4.57 | 28-38 | 33.0-38.0 | 9'6"-10'8" | 7.20-6.84 | 4.51-4.26 | NR |
| LB | 4.75-4.47 | 21-36 | 32.0-41.5 | 9'9"-11'7" | 7.49-6.71 | 4.53-4.18 | 12.39-11.28 |
| CB | 4.48-4.36 | 14-22 | 35.5-40.5 | 10'5"-11'0" | 6.92-6.52 | 4.18-3.84 | 11.56-11.06 |
| OL | 5.11-4.71 | 28-36 | 28.5-34.5 | 8'11"-9'0" | 7.65-7.26 | 4.70-4.44 | NR |
| K/P | 5.05-4.74 | 11-24 | 29.0-33.5 | 8'10"-9'8" | NR | NR | NR |

*One QB reported **NR = No data reported.
NFL (February 26, 2013), 2013 COMBINE TRACKER. In NFL.COM Retrieved July 10, 2013, from http://www.nfl.com/combine/tracker

## Summary

Key performance areas in football include appropriate categorical measures of strength, speed, agility, endurance, and body composition. All football players have requisite strength by position, but sport success is more correlated with speed, agility, and power. This suggests, beyond injury prevention, resistance exercises should reflect strength training for speed and power. Anaerobic conditioning should work in a coordinated fashion with this effort to transfer weight room activities to on-the-field speed, agility, and endurance. Although positional requirements vary, football players should have a well-balanced musculoskeletal system with a powerful and functional trunk-hip relationship. Too often the programming emphasizes absolute strength over sport-specific strength – an error for athletic development. The use of heavy loading without the requisite skeletal foundations is another common error in programming for football. Excessive loading without first ensuring balanced musculature across joints, efficient trunk stability, and optimal flexibility leads to compensatory actions and faulty recruitment patterns. This is a real issue for many athletes, and coaches must therefore be cognizant of signs and symptoms of musculoskeletal dysfunction. A strong and efficient trunk combined with adequate flexibility is requisite to sprint speed and correct performance of compound and Olympic lifts. Individuals with deficiencies in these areas may require closed-chain, unilateral lifts during initial phases of periodization. Once baseline strength and segment connectivity is developed in a manner that allows for the effective transfer of force, training emphasis should shift to power and speed development. There are three primary categories related to position by which athletes can be grouped for comparison and training emphasis.



Linemen should be conditioned for quick-start power, while performing adjunct work to promote appropriate leanness and endurance for rapid recovery between plays.

### *Group #1: Offensive and Defensive Lineman*

**Key Actions:** Instantaneous starts to collision, blocking, charging and tackling

**Goals:** Offensive and defensive linemen should seek to increase closed-chain force production capabilities, increase the rate of force production (power), improve anaerobic/aerobic endurance, and optimize body composition. Size is relevant; however, increased mass should not be attained at the cost of speed or endurance. An optimal strength/power-to-weight ratio is imperative. Linemen must produce high levels of force in a very rapid manner; program activities should therefore employ a building-block approach to develop optimal strength which can then be applied to power movements, and subsequently produce enhanced speed on the field. Linemen should be conditioned for quick-start power, with adjunct conditioning for appropriate leanness and endurance to promote rapid recovery between plays. Sports nutrition-related education is also warranted for this population to avoid excess body fat relative to size. Conditioning metrics should be employed to prevent the notable decline in force output between the start of a game and the end of the first half. Programmatic emphasis should be based on the fact that the position is highly anaerobic with the understanding that inefficient re-phosphorylation is associated with suboptimal $VO_2$ levels. This may be most relevant for defensive ends that repeatedly rush the quarterback.

### *Group #2: Linebackers and Tight Ends*

**Key Actions:** Linebackers: Short distance; high speed collision, pursuit, tackling
Tight ends: Moderate distance; mod-high speed agility routes, blocking

**Goals:** Linebackers and tight ends are considered transitional players as the requirements of the positions warrant size, strength, and speed rankings that fall between linemen and offensive/defensive backs. Both positions require size and strength to manage routine impacts aimed at either taking down or breaking away from opponents. These athletes cover greater distances than required of linemen, and they exert higher levels of power during a run. A tight end may run, cut, and jump to receive a pass and then immediately drive through another player to break a tackle. This suggests dynamic stability should be added to enhance power generated while on the move, whether lateral, diagonal, backward, or forward. Backpedaling into a vertical jump to knock down a pass is one example of the many diverse movement combinations required of a linebacker. Linebackers see heavy contact and make many of the tackles, so they need size and strength to deal with the collisions. They also have to drop into coverage on certain defensive schematics, so they must also be fast and be able to change direction efficiently.


Quarterbacks can also be grouped according to type of play or skill set.

These positions may demand the most balanced performance measures related to strength, power, speed, agility, and endurance. Emphasis should be placed on a high strength-to-weight ratio as well as positional speed and power. Conditioning should stress agility, short distance speed, and repeat speed endurance. Tight ends statistically tend to present with greater body fat than linebackers; therefore, specific considerations for conditioning and nutrition should be individually applied. Their role in blocking supports a requisite size, so similar to linebackers there should be a hypertrophy component to the training. Unlike some other sports, American football requires mass and the ability to manage collisions as an element of success; therefore, endurance-hypertrophy and strength-hypertrophy phases are often necessary.

Quarterbacks may be grouped independently, or with tight ends and linebackers, due to anthropometric and strength similarities; however, the necessary actions associated with the position are notably different. Quarterbacks need to be quick and have the capacity to escape defenders moving at high speed, but they do not present with the fastest

absolute speeds over most distances, similar to tight ends. Quarterbacks at the collegiate level are often smaller and slower than those in the NFL, as the speed of the game is slower by comparison. At the professional level, quarterbacks may have 4.5-4.6 second 40-yard dash speed, or faster. Due to positional variations in speed, quarterbacks can also be grouped according to type of play or skill set. Quarterbacks like Michael Vick, for example, are smaller and much faster than the NFL average, making them more active in the backfield. They will commonly leave the pocket, presenting a significant ground threat to defenses but are also more susceptible to injury. Others, like Peyton Manning, are larger athletes who stand tall in the pocket and rarely run down field. The pocket passers must be stronger and larger as they are subject to more aggressive assaults by large outside linebackers, defensive ends, and tackles. Additionally, due to the high number of awkward hits quarterbacks endure, it is important to ensure attention is placed on flexibility and muscle balance specific to the position.

### *Group #3: Offensive and Defensive Backs and Wide Receivers*

**Key Actions:** Pursuit/breakaway speed and agility

Offensive and defensive backs are fairly similar in size; however, more notable dissimilarities exist at the elite level. Defensive backs are often leaner, whereas offensive backs are often stronger. Receivers are often taller than defensive backs, but their strength measures are consistent with offensive backs. Receivers and defensive backs are the fastest sprinters on the team and are often the most athletic.

**Goals:** The role of resistance training should focus on developing speed and power, with the use of compound strength exercises to support an Olympic-based program. An emphasis on flexibility and movement segment connectivity will support speed, multidirectional quickness, and agility. Offensive and defensive backs may require more lean mass as offensive backs must block and take repeated hits, whereas defensive backs must tackle, often struggling with larger receivers and tight ends. Size should not compromise speed, but smaller backs have been anecdotally criticized in their ability to stop large receivers and tight ends, making upper body strength more relevant by position.

**Important note:** It has been well documented that football players who have reduced their body fat to a more ideal playing percentage and/or improved their cardiovascular condition enhanced their performance over the previous year. These areas must be emphasized for optimal performance as significant negative correlations have been found between percent body fat and 40-yard sprint times; and the simple fact exists that excess fat results in wasted energy during any movement. An improvement in oxygen utilization from anaerobic sprint training was associated with improved energy substrate resynthesis and lactic acid buffering. Improved conditioning in turn is associated with more rapid recovery for intense, repeatable performances during a series. Of further relevance, improved conditioning is also associated with a reduced risk of injury associated with fatigue in the second half of play, when more injuries commonly occur. Optimizing body fat percentage by position carries one caveat: it is important the weight loss occur in the off season and progress slowly to maintain lean mass. Significant decline rates and becoming overly lean can often be more detrimental than beneficial.



## Baseball

Coined the national pastime, baseball has been criticized for its highly paid athletes who seemingly spend most of their time in a resting state. Baseball, much like football, is performed at maximal levels; however, the total work performed and the work-to-rest intervals represent a major difference between the two. A defensive player may go an entire inning without being required to perform game speed work if the ball is not hit to him and he does not get up to bat. For this reason, many games are viewed as a battle between pitchers and hitters more so than as a constant full-team competition. This places most of the stress and responsibility on the pitcher and catcher, as they are the only players required to perform an action every play. Even with the significant difference between the requirements of a starting pitcher and a back-up, the position clearly demands the greatest amount of work in a game.

### *Pitchers*

Although during baseball's early times, the pitcher was expected to throw complete games, in the 2014 Major League Baseball (MLB) season, only 2.4% of starters threw for a complete game according to the MLB. On average, a starting pitcher will now perform into the 6th inning before a relief pitcher is called in, and in many cases, he will be followed by a 9th inning closer. MLB starting pitchers throw about 95 pitches per game, or about 15 pitches per inning. As a team, the expected pitch count averages 146 pitches per game. The position demands both anaerobic power and endurance, as pitch speeds range from around 70 mph for a curve ball to more than 90 mph for a fastball. As we have seen in other sports, defining a set work requirement using general physical measures like $VO_2$ is complicated by the intermittent actions of the position. A clinical assessment of physical measures of six college pitchers (following a game scenario) demonstrated that the physiological stress of pitching corresponds with work intensity similar to continuous exercise at 45% of $VO_2$max for around 60 minutes. To the contrary, postgame enzyme response identifies the violent nature of the movements involved in pitching. Research has shown an increase in the muscle enzymes associated with significant muscle damage over the 24-hour period following competition [43]. This may explain the obvious need to rest starting pitchers appropriately between games.



When pitching, global accelerators and internal rotators far exceed the deceleration capabilities of the posterior musculature and external rotators. This promotes compensatory adjustments in scapular and capsule function, consequently increasing risk for injury.

**DEFINITIONS**

**Accelerators –**

*Global movers active during the concentric phase of movement*

**Decelerators –**

*Global movers active during the eccentric phase of movement*

Among pitchers, physical consistencies have been identified and analyzed over the maturation process from high school to college and from college to the professional level. Research suggests that pitching form also encompasses specific kinematic commonalities, as well as kinetic differences among quality pitchers in the different stages of development [44]. Of the 16 kinetic parameters measured, six appeared to notably differentiate performance capabilities among pitchers. Interestingly, five of these six key factors were velocity-specific, whereas only one was related to positional technique. This information demonstrates the relevance of proper throwing technique, but more importantly the role joint forces and torque play in pitching effectiveness. Measured differences suggest elite pitchers maintain longer arm length and greater relative strength [44]. These findings indicate that muscle, tendon, and ligament strength, as well as balance within force couples, are essential to performance. Additionally, the powerful forces generated from the positional shifts that occur while throwing should be developed appropriately with consideration for **accelerators** and **decelerators**. This will enhance velocity while minimizing the risk for injury. In many cases, the abilities of the global accelerators and internal rotators far

exceed the deceleration capabilities of the posterior musculature and external rotators. This promotes compensatory adjustments in scapular and capsule function, consequently increasing risk for injury.

**Table 2.13 Kinetic differences among pitchers throughout the maturation process**

| | High School | College | Professional |
|---|---|---|---|
| **Acceleration (Nm)** | | | |
| Elbow torque | 48 ±13 | 55 ±12 | 64 ±15 |
| **Deceleration (Nm)** | | | |
| Elbow proximal force | 630 ±140 | 770 ±120 | 910 ±140 |
| Shoulder proximal force | 750 ±170 | 910 ±130 | 1070 ±190 |
| Shoulder posterior force | 280 ±100 | 350 ±160 | 390 ±240 |

(Nm) = Newton-metre Adapted from Fleisig et al., 1999

## *Catchers*

Secondary to the pitcher, the catcher is the most active defensive player due to the position's involvement in each pitch and the assigned role of managing the defensive game from the field. Catchers experience significant stress on the low back, hips, and lower extremities due to routine variations in receiving and throwing stances as well as positional shifts from squatting to standing throughout the game. In most cases, a catcher will complete a full game without the relief of substitution. In addition to the 200 throws per game, catchers are expected to prevent and throw out stealing attempts by on-base runners. This requires an immediate high-speed throw (for a distance of 127 feet) to second base. To a lesser degree, the catcher must also perform the same task to first or third base as well as react to and pursue the occasional pop-fly. Catchers are normally heavier athletes relative to height as it is the only position on the field that must endure impact from runners during plays at home plate. Catchers can be expected to play between 8-10 minutes per inning, in addition to the warm-up periods between innings. This equates to more than an hour and a half of activity per game. As stated, the requirements for hip, knee, and back health are relevant; muscle balance and stabilization training must be emphasized for this position along with specific power enhancements.

## *Outfielders and Infielders*

Outfielders and infielders are required to engage in varying activities at near-maximal speed depending on the position and number of balls hit into their respective zone per inning. The distance traveled by infield players is often short and rapid as the ball comes off the bat very quickly, requiring immediate response time. Therefore, second and third basemen and shortstops must have excellent reaction time and be able to position themselves in front of the ball. The ball movement angles and velocity often require lateral reaches on the move, outstretched dives, and vertical jumps to catch balls hit above their position. They must also be adept at catching the ball on the move and in compromised positions. Once the ball is received, infielders must be able to complete throws from awkward positions and jumps, a feat requiring dynamic stability. This is often associated with base runners in their throwing lanes who



Infielders must have excellent reaction time and be able to position themselves in front of the ball.

attempt to impede them to prevent double plays. A first baseman has a less dependent role in fielding but must be able to respond effectively to varied throws and have excellent flexibility (particularly in the groin and adductors) to manage base contact on off-target throws. Infielders may also be required to perform high-speed, short distance sprints to field bunts as well as back up throw attempts to prevent erroneous throws from going out of play.

Outfielders are often characterized by superior visual acuity; the best are generally fast and have good reaction time and game sense associated with experience. That being said, a slower fielder may actually play over a better defensive player due to the need for offense in baseball. Baseball requires defenders to also play offense, which is often considered the more important skill. An excellent batter that performs as an average fielder will see more game time than another player demonstrating the reverse skill set. The number of play attempts in the outfield is usually between 0-4 per inning, and last less than three seconds. Therefore, field players must emphasize power for reaction, hitting, and multidirectional starts. Outfielders must cover more distance than infielders and should therefore work on 10-30 m acceleration. Additionally, while all baseball players throw the ball, outfielders must throw long distances and consequently should focus on strength and accelerator/decelerator muscle balance to prevent injury when throwing from the outfield to home plate or a specific base.

## *Physiological Characteristics of Baseball*

Since each player also plays offense, the ability to hit the ball is often the defining skill for elite players. This ability has more to do with visual characteristics, reaction time, and technique than any specific physical parameter. While height seems to be a preferred aspect for performance, the literature fails to identify a single requisite size that fits all positions when it comes to hitting proficiency. However, analysis of physical characteristics does suggest that certain profiles are consistent for defense [45]. Pitchers were found to be the tallest and generally maintain higher body fat than other players; whereas outfielders tend to be leaner and more muscular. First basemen were found to be the tallest of the infield players, and shortstops were consistently taller than second basemen who tend to be the smallest by measures of mass among infield groups. First basemen and catchers were found to be the heaviest of the infielders and are often key batters on the team. Cross-divisional comparisons suggest that lower divisions have the leanest players, possibly due to a younger age range, but demonstrate significantly less lean mass than AAA and MLB players. The MLB players were stronger, as determined by **hand grip dynamometry**, more powerful (vertical jump), and faster than all lower divisions; demonstrating a greater relevance of power over anthropometric comparisons between players [46].

**DEFINITIONS**

**Hand grip dynamometry –**

*The use of a specific instrument intended to predict total body muscular strength based on known correlations of grip strength*



The ability to hit a game-speed baseball is considered one of the most challenging skills in competitive sports. It is suggested that one must see and judge the ball in less than 0.25 seconds to hit it. Due to the fact that a major league pitcher can throw a baseball almost 100 miles per hour, a fast ball will reach the plate in about four-tenths of a second, traveling a distance of 60.5 feet from the pitcher's mound to home plate. The ability to hit the moving object is determined by the batter's timing. Consequently, a batter must identify the ball in less than 15 feet, judge its velocity and spin, and then start to swing in the next 20 feet of travel. A fastball will arrive at the plate about 0.25 seconds later, and the bat must already be there to make contact. This suggests the ability to hit a major league fast ball is close to the limits of human reaction time. A few thousandths of a second off in the timing and the ball is missed or hit foul. Similarly, hitting the ball only a few millimeters too high or too low results in a fly ball or a grounder. Many are surprised to hear that the visual aspect of the game explains why steroids are so relevant to disparities in baseball performance.

Certainly, greater strength, power, and size will move the bat faster and consequently increase the number of home runs a batter achieves, but the effects of steroids are most pronounced for sports specificity through improvements in visual acuity. It has been proposed that steroids/HGH increase cone function and therefore enable a batter to pick the ball up sooner; with the incorporation of faster bat speed, the significantly greater home run numbers of recent years maybe easier to understand.

The best hitters have three things in common: excellent vision, the ability to read the body language of pitchers to predict ball action, and the ability to produce high bat speed. Vision is so intimately tied to hitting that baseball legend Wade Boggs' batting average dropped when his vision declined to normal human levels, from 20:15 to 20:20. The location of human eyes suggests that we use tracking as part of our predatory instinct, therefore, those with better visionary capacity have an advantage. Getting a base hit 33% of the time is considered excellent, equaling that of a cheetah's success rate in predation. It is no surprise that both have very similar requisites for vision-directed neural signaling for success.

**Table 2.14 Anthropometric and performance comparisons among levels of play in professional baseball**

| Variable | Rookie (n=90) | A (n=84) | AA (n=50) | AAA (n=52) | MLB (n=62) |
|---|---|---|---|---|---|
| Age (yr) | 21.3 ± 2.5 † | 22.9 ± 2.1 † | 24.9 ± 2.2 † | 26.8 ± 2.7† | 28.7 ± 4.2† |
| Height (cm) | 185.2 ± 5.8 | 185.4 ± 6.1 | 185.5 ± 5.8 | 187.5 ± 6.9§†† | 186.7 ± 6.1 |
| Body mass (kg) | 92.0 ± 9.8 | 92.0 ± 9.6 | 96.0 ± 7.9§†† | 99.5 ± 12.0§†† | 101.2 ± 10.5§††¶ |
| Body fat (%) | 12.0 ± 3.5 | 12.4 ± 3.6 | 12.8 ± 2.9 | 13.7 ± 3.4§†† | 13.8 ± 3.0§†† |
| Lean body mass (kg) | 80.8 ± 7.0 | 80.8 ± 7.0 | 83.6 ± 5.8§†† | 85.7 ± 9.3§†† | 87.1 ± 7.9§††¶ |
| Vertical jump (cm) | 70.1 ± 7.6 | 70.1 ± 7.1 | 69.1 ± 7.1 | 71.1 ± 8.4 | 71.9 ± 8.2 |
| Vertical jump peak power (w) | 10,798 ± 791 | 10,823 ± 737 | 11,127 ± 622§†† | 11,435 ± 957§†† | 11,542 ± 539§††¶ |
| Vertical jump mean power (w) | 3835 ± 499 | 3850 ± 475 | 4052 ± 393§†† | 4235 ± 605§†† | 4298 ± 539§††¶ |
| Grip strength (kg) | 103.5 ± 12.5 | 105.2 ± 12.6 | 111.6 ± 12.7§†† | 115.6 ± 12.6§†† | 111.0 ± 16.0§†† |
| 10-yard sprint (s) | 1.57 ± 0.09 | 1.59 ± 0.07 | 1.58 ± 0.07 | 1.55 ± 0.09 | 1.52 ± 0.10§††¶ |
| 5-10-5 (Pro agility) (s) | 4.54 ± 0.19 | 4.48 0.54 | 4.42 ± .068 | 4.53 ± 0.20 | 4.42 ± 0.90 |

*§p ≤ 0.05 compared with rookie league. ††p ≤ 0.05 compared with A league; ¶p ≤ 0.05 compared with AA league.
†p ≤ 0.05 compared with all other groups.
Hoffman, J. R., Vazquez, J., Pichardo, N., & Tenenbaum, G. (2009). Anthropometric and performance comparisons in professional baseball players. *The Journal of Strength and Conditioning Research, 23*(8), 2173-2178

A batter's performance improves with experience and quantifiable increases in power output; repetitions in training are therefore relevant to optimize form and improve neuromuscular efficiency, both of which contribute to higher bat speed. This being said, batters of equal skill may have different techniques. When analyzed for kinematics, lead elbow speed and knee extension angle were defining differences between high-caliber and average hitters [47]. The same investigators suggest that faster hip speed likely accounts for more pronounced elbow velocity between hitters. The correlation of hip power to improved hitting capability has also been supported in other studies. In an evaluation of 343 professional baseball players, the largest determining factors between divisional levels of competition was power-based performance as predicted by agility, speed, and lower body power measures [46]. When examining anthropometric and performance comparisons among the different levels of play in professional baseball (Table 2.14), and how these measures correlate to home runs, total bases, slugging percentage and stolen bases (Table 2.15); it is clear that there are major differentiating characteristics among players which increase their chances of success and reaching an elite status [46].

**Table 2.15 Selected correlations (bivariate) between fitness components and baseball performance**

| | Home runs ($r, r^2$) | Total bases ($r, r^2$) | Slugging percentage ($r, r^2$) | Stolen bases ($r, r^2$) |
|---|---|---|---|---|
| Lean body mass | 0.478† | 0.292† | 0.474† | -0.188 |
| | 0.228 | 0.085 | 0.225 | 0.035 |
| Grip strength | 0.317† | 0.213† | 0.273† | 0.099 |
| | 0.100 | 0.045 | 0.074 | 0.01 |
| 10-yard sprint | -0.089 | -0.251† | -0.064 | -0.422† |
| | 0.008 | 0.063 | 0.004 | 0.178 |
| 5-10-5 (Pro agility) | 0.001 | -0.153 | 0.033 | -0.482† |
| | 0.000 | 0.023 | 0.001 | 0.232 |
| VJ PP | 0.481† | 0.281† | 0.471† | -0.216 |
| | 0.231 | 0.079 | 0.222 | 0.047 |
| VJ MP | 0.476† | 0.270† | 0.465† | -0.246† |
| | 0.227 | 0.073 | 0.216 | 0.061 |

*VJ PP = vertical jump peak power; VJ MP = vertical jump mean power. † p ≤ 0.05.
Hoffman, J. R., Vazquez, J., Pichardo, N., & Tenenbaum, G. (2009). Anthropometric and performance comparisons in professional baseball players. *The Journal of Strength and Conditioning Research, 23*(8), 2173-2178



Baseball is a power-based sport that primarily relies on hip acceleration with trunk cooperation. The upper body is secondary in force management.

## Summary

### *Batting*

The action of swinging a bat at the velocity necessary to hit a fastball requires a synchronized kinetic chain. This provides efficient transfer of energy across joint segments, particularly in the hips and trunk. Hitting is ballistic in nature; ground reaction force is accelerated from the combination of stable hip extension and fluid trunk rotation, which when combined with rotational inertia creates significant power. The energy must transfer across multiple segments to manifest in the hands; therefore, stable force couples and coordinated shoulder/limb action are paramount to hitting success. An emphasis should be placed on compound lifts (not machines) for pelvic/spine force coupling, strength training for pushing and pulling, and a key focus on leg/hip power and rotational speed. Baseball players should experience heavy loading in the hips and Olympic-based training. Hitters often place too much emphasis on upper body strength training and open-chain activities; but it must be understood that baseball is a power-based sport that primarily relies on hip acceleration with trunk cooperation. The upper body is secondary in force management. Likewise, musculoskeletal balance is relevant as the sport is asymmetrical and requires violent joint actions. This information lends itself to programming for contralateral balance and focusing on muscles that decelerate throws and swings. It is not uncommon for bilateral disparities to exist even among elite players. An emphasis on muscle balance should be employed to optimize skeletal movements to decrease the risk for injury. Major issues in baseball include joint capsule tightness and scapular dysfunction. Excessive pressing, particularly bench pressing, can actually decrease shoulder efficiency. More emphasis should be placed on closed-chain exercises like squats and kinetic chain interaction with rotation drills that incorporate the hips.

**Important note:** While criticisms can be made for an alarming level of antiquation in training programs for most sports, baseball may be the worst in this category. Many programs mirror bodybuilding-derived movements and are shrouded in superstition. Athletes are often told not to perform overhead actions, but commonly perform series of rotator cuff exercises and wrist curls. Certainly pitchers require a higher level of consideration, but overall baseball training should be more athletic, with less concern for upper body strength. A strength coach that is overly concerned with injury or overuse in the shoulder can rectify concerns by correcting movement restrictions, instructing proper technique in the lifts, and programming for muscle balance and movement synergy.

### *Sprinting*

As has been clearly illustrated, baseball is a game of extremely fast action followed by longer periods of intermittent rest. Sprinting speed makes a substantial difference during on-base efforts and the capacity for stealing bases. Outfielder speed can be the difference in a game where one run is frequently the deciding factor in a win or loss. Speed training should be emphasized in moderately-short distances as neural efficiency is more important than metabolic recovery between plays. Ballistic lifts and plyometric training should be emphasized to enhance stride frequency. Multidirectional starts should also be practiced, as much of the game stems from a fairly static position to an explosive initial movement.

### *Fielding*

Reaction time is extremely important for infielders and, to a slightly lesser extent, outfielder positions. Drills for lateral and forward explosiveness, as well as an improved vertical jump, should be utilized to improve reaction time and movement speed. Additional considerations for maximal overhand throwing should be included in the plan to expedite muscle balance and effective limb deceleration. Hand-eye reaction should also be practiced in conjunction with multidirectional movements as the ball may change trajectory upon a "hop" and require rapid adjustments to field.

### *Pitching*

Pitching requires a unique set of coordinated actions stemming from the ground, but manifesting in the throwing limb. Elbow torque and shoulder force are cited as relevant differences between good and great pitchers. Although endurance is often emphasized in pitchers, the real value lies in repeated power output. Pitchers should be trained to be explosive while paying attention to flexibility and muscle deceleration balance. It is also important to note that pitchers must develop high levels of dynamic balance as their actions are asymmetrical and stem from a small base of support. Activities emphasizing kinetic chain coordination and central stability are also relevant considerations. Specifically, a focus on hip and trunk training as well as foot-to-foot acceleration (asymmetrical/unilateral exercises) should be included in the training program. Pitchers should strengthen the hip from both bilateral and split stance positions to encourage sagittal and frontal plane hip stability, and perform primarily closed-chain trunk exercises. Conditioning focused on improved oxygen consumption should place greater emphasis on substrate rephosphorylation rather than **steady-state** aerobic activity common of the sport. A relevant concept for strength coaches working with pitchers is to understand that while strength correlates to anaerobic endurance, so does musculoskeletal efficiency: muscles fatigue slower when they function synergistically and under reduced musculoskeletal restriction.



Although endurance is often emphasized among pitchers, greater value lies in repeated power output.

**DEFINITIONS**

**Steady-state –**

*A period during which the body functions using aerobic metabolism where oxygen utilization matches demands; heart rate does not vary by more than 5 bpm*

## Sport-Specific Needs Analysis in Summary

The root of any strength and conditioning program lies in developing actions that win games and prevent injury. Observational data points to the fact that multidirectional movements at high speeds often dominate sports outcomes and varied directional movements are performed more often than linear actions. The physiological aspects of these movements inherently make them more difficult to perform, and changes in the center of mass make them much more fatiguing to manage compared to linear actions. Therefore, weight room activities and conditioning drills should reflect the athletic demands of the sport rather than fit into a traditional approach to strength training or bodybuilding. A needs analysis constructed from sport and player profiles will present the defining characteristics of the program, including relevant components of each training cycle. A periodized approach to foundational development of joint stability and connectivity (through a full range of motion) leading into strength and power based training will provide dramatic improvements to athletic performance. In most cases, siding with movement efficiency, quickness, and speed as well as other defining characteristics that make the elite athletes successful will most effectively serve the goals of athletic development.

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