SPORTS NUTRITION FOR AMERICAN FOOTBALL

An evidence-based guide for nutrition practice at Dallas Cowboys

The Gatorade Sports Science Institute

In partnership with

The Dallas Cowboys

2020

SPORTS NUTRITION FOR AMERICAN FOOTBALL

An evidence-based guide for nutrition practice at the Dallas Cowboys

“We must win.

We will win.

Win is the name of the game.”

Jerry Jones
February 25th, 1989

Sports Nutrition For American Football

How important a piece, to the overall puzzle of sporting success, is nutrition? Does it contribute 25%, 10%, 1%, less? Those are very difficult, if not impossible, questions to answer and I will not attempt to do so here. But what I will say is that for all athletes, including those within the Dallas Cowboys, the adoption of sensible sports nutrition strategies will help contribute to both short and long term success. A balanced diet spread across all the main food groups will provide the foundation for health and wellbeing, whilst focused sports nutrition approaches will allow a player to further maximize training adaptation, performance and recovery. Within these approaches, flexibility is crucial and periodization and personalization must be embraced to ensure these different goals can be met. For example, the nutrition choices to support training adaptation may be very different to those supporting performance and then recovery. Because of this, and because every player has different requirements based on genetics, physiology, metabolism, goals, likes, dislikes and tolerances, sports nutrition is not and cannot be simply 'black and white'. Rather, a broad continuum exists and each player can move up and down this continuum throughout their physical maturation and throughout their career. The Gatorade Sports Science Institute, in tandem with the Sports Fuel Brand Gatorade, has a strong partnership with the Dallas Cowboys. Like all good and successful relationships, trust and credibility have been built over time. This Sports Nutrition for American Football Guide is a collaborative document that contains the evidence base for the sports nutrition recommendations at the Cowboys. Importantly, this book should be considered as an evolving document….because sports nutrition continuously evolves.

Dr James Carter
Director of the Gatorade Sports Science Institute

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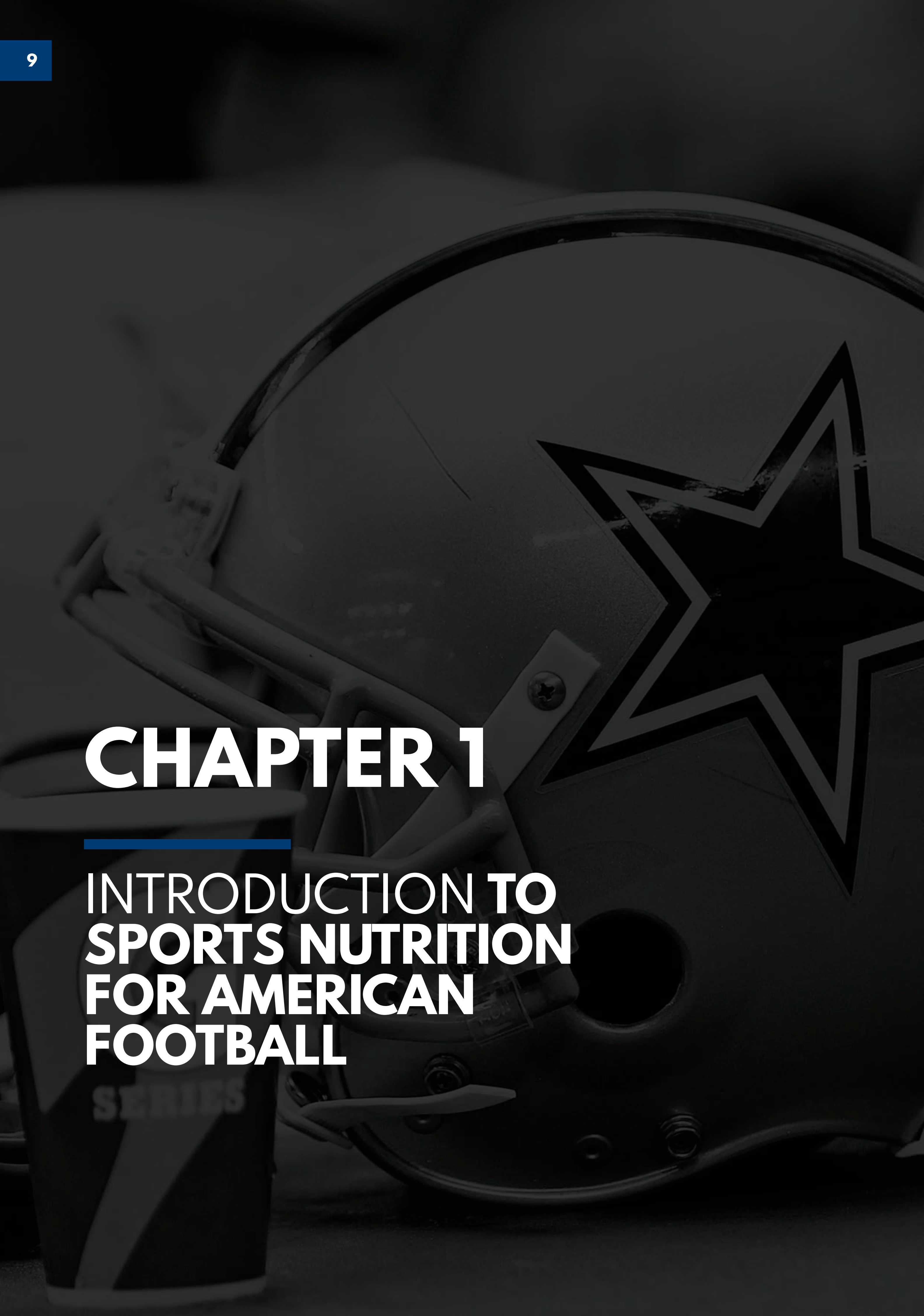

CHAPTER 1

INTRODUCTION **TO SPORTS NUTRITION FOR AMERICAN FOOTBALL**

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The Dallas Cowboys recognize that appropriate nutrition has a valuable role in optimizing the health and performance of their football players. The Gatorade Sports Science Institute (GSSI)'s mission is to help athletes improve their health and performance through innovation, research and education in hydration and nutrition science. Both the Dallas Cowboys and GSSI believe an evidence-based approach to nutrition is fundamentally important. Therefore, this book aims to compile the relevant scientific evidence to inform the delivery of sports nutrition in American football.

The Dallas Cowboys were established in 1960 and were the first modern-era expansion team of the National Football League (NFL). The NFL is composed of 32 teams broken into two conferences, the American Football Conference (AFC) and the National Football Conference (NFC). Both conferences have four divisions with four teams in each division. The Dallas Cowboys compete in the NFC East with the New York Giants, the Philadelphia Eagles, and the Washington Redskins. The Cowboys have a rich history, competing in eight Super Bowls, the second most in history, having won five and are one of two teams to win three Super Bowls in four years (1993, 1994, and 1996).

In today's game, players train and compete for the majority of the year. Prior to the regular season, pre-season training begins with Organized Team Activities (OTAs) in late May and early June while training camp officially begins in July. The Dallas Cowboys complete the first phase of their official training camp in Oxnard, California, and complete the final week of training camp at their home training facility in Frisco, Texas. Training camp includes four pre-season games. The NFL regular season is contested over 16 games beginning in September and concluding in December. The top 8 teams from each conference are selected to compete in the NFL playoffs which could increase the total game volume between three and four games, depending on seeding and success, culminating in the Super Bowl in late January or early February. Overall, the NFL schedule requires the players to compete between 16 to 20 games over a six month period. The games played over the season are done so at varying times and varying time zones, and across diverse environmental conditions. Environmental conditions can range from indoor, controlled environments (i.e. AT&T stadium where the Cowboys play their home games) to Miami, FL (~95 degrees F, ~60% humidity, and sea level altitude) to Denver, CO (~50 degrees F, ~40% humidity, and 5,280 feet above sea level) to Green Bay, Wisconsin (~10 degrees F, ~70% humidity).

The Dallas Cowboys practice facility was originally located in Valley Ranch, Irving, Texas. In 2016 they moved to "The Star" in Frisco, TX. The new facility, built in 2016, is a 91-acre campus housing the Dallas Cowboys World Headquarters and practice facility. Developed as a first-of-its-kind partnership between the City of Frisco and Frisco Independent School District, The Star is housed next to the Baylor Scott & White Sports Performance & Research facility, providing "state-of-the-art" resources for player development, monitoring and performance.

The GSSI's second US satellite research facility was opened in 2018, located within the Baylor Scott & White Sports Therapy & Research facility. The partnership between Dallas Cowboys and GSSI aims to advance our understanding on the demands of football and the nutrition requirements of football players. Over the years GSSI has partnered with the Dallas Cowboys using testing protocols to provide feedback and recommendations for player recovery and performance. For example, player recovery has

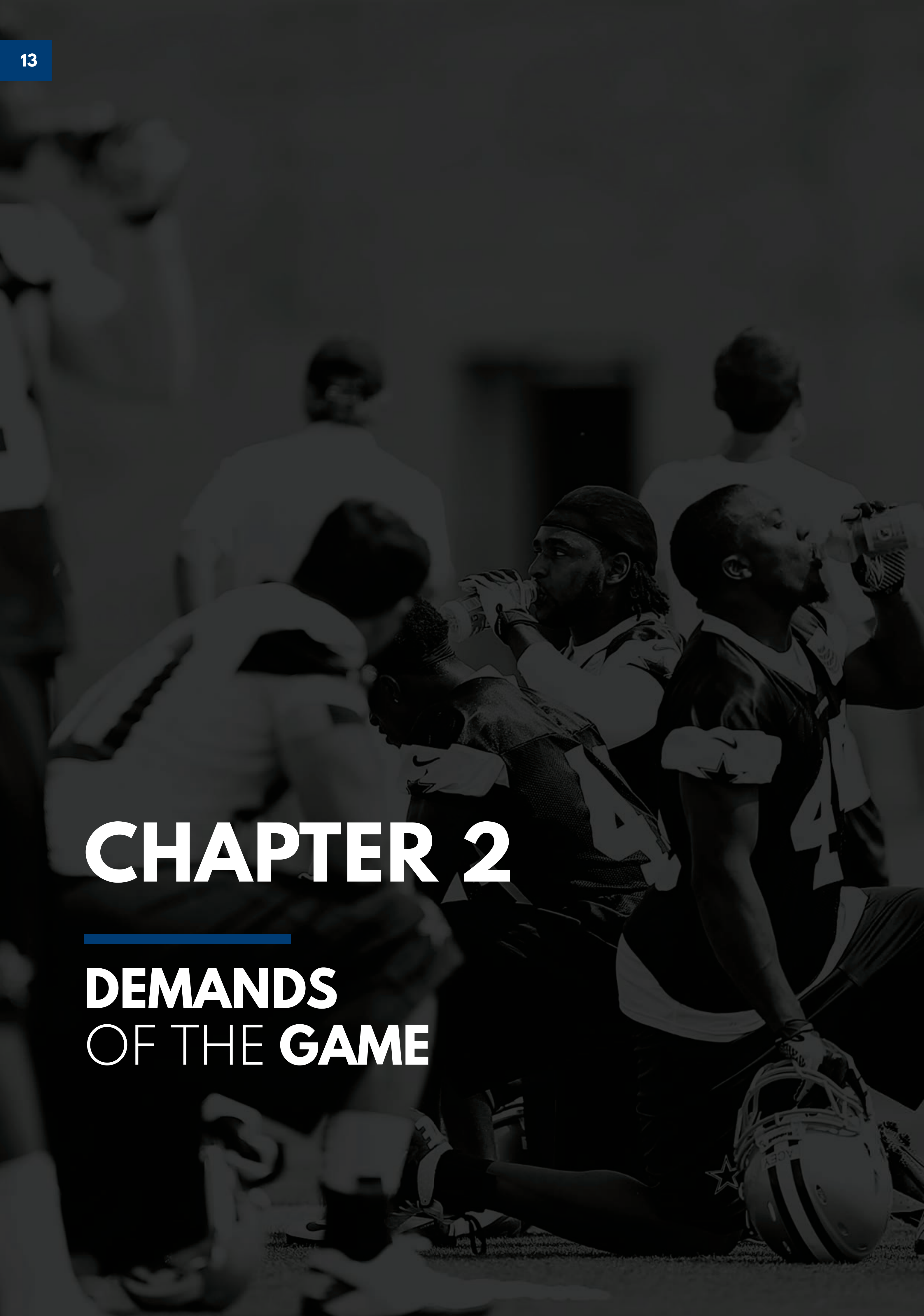
been monitored through neuromuscular function and biomarkers; in addition sweat testing has informed hydration and fuelling during practice. More recently, fuel utilization and resting metabolic rate laboratory tests have been used to better understand the overall energy needs of players.

Understanding the physical demands of football allows a scientific approach to the players practice and game nutrition requirements. Manipulating the quantity and timing of macronutrient ingestion aims to maximize the gains from practice as well as optimize performance and attenuate the recovery between games. However, to date, there has been a lack of materials which combine the football occasion (i.e. practice and games) with the appropriate nutrition recommendation.

To excel in football the players must complete the hours of practice required to achieve the physical and mental capabilities required to exhibit position specific skill proficiency, tactical awareness, as well as physical capabilities. To achieve this, players need to stay injury free and healthy. Sports nutrition plays an important role in preventing illness, reducing the risk of injury as well as optimizing recovery and adaptations from practice and competition. It is important to note that there is significant variation on the demands placed upon individual players. These physical demands are dependent on the players' specific position and role within the team. Thus, although key nutrition principles can be applied to the team, sports nutrition can also be personalized to the needs of the individual player.

The scientific evidence supporting sports nutrition practice continues to advance. A common challenge for practitioners embedded within a football team is to find time to collate the most recent body of research which underpins nutrition recommendations. Therefore, this current book summarizes the available scientific evidence in sports nutrition and applies this knowledge directly to football.

– Eric Freese, PhD and Ian Rollo, PhD



CHAPTER 2

DEMANDS OF THE GAME

DEMANDS OF THE **GAME**

Corey Ungaro & Steven Basham

Introduction

The purpose of this chapter is to understand the physical and technical demands of American football players by reviewing the energy systems and physical demands that support the dynamic and complex movements unique to each football position during competition. This information is vital for coaches, training staff and dietitians/ sports nutritionists to better understand the nutritional requirements necessary to support the energy demands of football. In this chapter, we first introduce the basic rules of the game and requirements to play football before discussing those studies which have investigated the physiological responses of the various playing positions.

Position	Responsibilities	Skillset & Physical Attributes
Offense		
Quarterback (QB)	Organize and manage offense, call plays, throw football, hand football off	Throwing arm strength, accuracy, and leadership
Running back (RB)	Run with the football, Catch football and block	Speed, strength, vision, agility
Fullback (FB)	Blocking, Run and catch the football	Strength, power
Wide receiver (WR)	Route running, catch the football, run with the football, run blocking	Height, hands, jumping ability, speed, route running
Tight End (TE)	Catch the football, Block	Size, hands, strength, route running
Offensive Linemen (OL)	Block, organize offense	Size, strength, power
Defense		
Defensive Tackle (DT)	Stop run, Rush the passer	Size, strength, power, agility
Defensive End (DE)	Rush the passer, Stop run	Size, strength, power, agility, speed
Weakside Linebacker (WB)	Stop run/pass coverage, Rush the passer	Speed, strength, cover ability
Middle Linebacker (MB)	Organize defense, Stop run/pass coverage, rush passer	Leadership, lateral speed, agility, tackling
Strongside Linebacker (SB)	Rush the passer, Stop run/pass coverage	Speed, agility, tackling
Cornerback (CB)	Pass coverage, Stop run	Speed, agility, cover ability
Free Safety (FS)	Organize defense, Pass coverage, Stop run	Speed, agility, cover ability
Strong Safety (SS)	Organize defense, Stop run, Pass coverage	Speed, size, tackling, cover ability
Special Teams		
Kicker (K)	Kick field goals, Kick-offs	Leg strength, kicking accuracy
Punter (P)	Punt ball	Leg strength, hangtime, accuracy
Long Snapper (LS)	Snap ball long distance, Block	Size, strength, power, long snap ability
Returner (KR/PR)	Catch Kicks, Run	Speed, vision, agility, hands

Rules of the Game

For those unfamiliar with the game, football revolves around the principal of two teams battling to score and defend their respective endzones. The offense aims to move the football down the field by either passing or running the ball, while the defense attempts to stop the offense from advancing down the field, ultimely negating the offense from scoring. Each team's offense is given four attempts (downs) to advance the football from the original line of scrimmage (LOS) past the first down marker, typically 10 yards from LOS. If the football successfully crosses the first down marker (i.e. offensive team still in possession of the ball) the offense will receive another set of four downs to advance the football until the ball crosses the goal-line for a touchdown or the offense converts a successful field goal kick. If the offense is unsuccessful at converting a first down or scoring points (or if the ball is intercepted by the defense), then the offense turns the ball over to the defense either by punting on fourth down or a change of possession from an unsuccessful attempt on fourth down. After scoring a touchdown, the team has two options: either kick a field goal (1 point) or attempt an offensive 2-point conversion play. The main players on the field at any given time are most likely on offense and defense. Outside of these units, special teams make up the rest of the team. A break down of positions and skills can be found in Table 1. For a more extensive explanation of the rules for football please see the National Football League (NFL) rule book here:

operations.nfl.com/media/3831/2019-playing-rules.pdf

Table 1

Football player positional overview and responsibilities

Game Duration and Characteristics

National Football League (NFL)and National Collegiate Athletic Association (NCAA) games consist of four 15-min quarters with a 12-min and 20-min break (halftime), respectively. An interval of at least two minutes is provided between the first and second and third and fourth quarters. The mean duration of a single play in football is approximately 5-6 s, with the mean rest duration between plays ranging between 34 to 36 s (Rhea et al., 2006; Iosia & Bishop 2008). In NCAA Division I football, players complete 14 ± 2 possessions of the football per game with 6 ± 3 plays per possession, with 1 ± 1 stoppages per possession, where a stoppage is defined as any penalties, injuries, time-outs, first down requirements, or end of quarter/halftime (Rhea et al., 2006). The mean duration between the transition of possession between teams (series) is 11 ± 4 minutes (Iosia & Bishop 2008). An NFL game will last approximately 3-h, during which players are engaged in football activity for ~11 min (Hoffman 2015). Thus, only 6% of game time is spent competing.

High school football is predominately structured as a 10-game regular season followed by 4-5 rounds of single-elimination playoff football games ending with the team that does not lose being declared the champion. In general, college football will have 10 to 13 regular-season games followed by a bowl game for those invited to play, with the top four teams playing a two-round playoff for the National

Championship with the team that does not lose acknowledged as the champion. In the NFL, the season is preceded with a 4-5 game pre-season followed by 16 regular-season games and a four-round single-elimination playoff format for the top 12 teams across the two conferences i.e. six from the American Football Conference and six from the National Football Conference, to determine the Super Bowl Champions.

Physical & Physiological Demands of American Football

The stature and body composition of the player are key attributes to football performance (Chapter 3). These characteristics may dictate which position the player will play, along with his performance and skill-based attributes. Further, the energy demands placed on each player vary, depending on the position they play and how many plays they are involved in throughout the game. Likewise, players must be able to manage the intense collisions during each play, consisting of approximately 5 seconds of high-intensity action. For example, a defensive back may be required to backpedal, cut, accelerate and tackle an opponent in one given play (Fullagar et al., 2017). To achieve this, players require physical attributes including strength, power and speed (Table 1).

Until recently studies have failed to accurately quantify certain variables associated with the energy and physical demands of football. One study examined the in-game positional movement profiles of thirty-three players from a NCAA Division I football team during a 12-game season using global positioning systems (GPS) technology. The data indicated that WR and DB had the highest average max speed with WR at 31.5 ± 2.2 km/h and DB at 31.1 ± 1.9 km/h. Both positions had the highest average sprinting distance per game with WR at 315.8 ± 163.2 m and DB at 247.0 ± 113.1 m during a regular season game (Figure 1). In comparison, RB had an average max speed of 28.8 ± 2.5 km/h and a sprinting distance of 101.2 ± 71.7 m and the LB position had an average max speed of 29.6 ± 1.2 km/h and a sprinting distance of 196.7 ± 104.7 m with OL and DL having the lowest average max speed and sprinting distance (Wellman et al., 2015). Moreover, studies have revealed no differences in total distance travelled between DLs and WRs during competitive in-season games. These data would suggest individual position demands may be indicative of the style of offense or defense played for each team, along with the style of play of their opponents. For instance, the total distance travelled for a WR may be reduced in a run-heavy offense compared to an up-tempo, spread offense, whereas, DLs total distance travelled along with maximum velocities may increase when facing up-tempo, spread offense with a dual-threat QB. In line with the above study, there have been reported differences among WRs and other non-linemen, where WRs covered fewer sprinting distances compared to both

TEs and RBs, while on the opposite side of the ball, LBs performed more sprinting distances than DBs (Ward et al., 2018).

Wellman et al. reported that the WR position covers the most total distance in a game with an average of 5530 ± 996 m throughout a 12-game season. Not surprisingly, the DB position followed with the next highest total distance covered with an average of 4696 ± 1115 m, followed by the LB position covering 4145 ± 980 m, the QB position covering 3752 ± 802 m and the OL position covering 3652 ± 603 m.

The WR and RB groups covered the most sprinting (≥23.0 km/h) distance 316 ± 163 and 101 ± 72 m per game, respectively for the offense. The WR position had the most maximum-intensity accelerations (>3.5 m/s) per game (22 ± 8). The DB and LB groups covered the most sprinting (≥23.0 km/h) distance 247 ± 113 and 197 ± 105 m per game, respectively for the defence. The DB position had the most maximum-intensity accelerations (>3.5 m/s) per game (21 ± 9) (Wellman et al., 2015).
Super Bowl Champions.

Impacts

In conjunction with the running metrics, Wellman et al., (2017) investigated accelerometer and GPS derived positional impacts (tackles/collisions), measured as G-forces (G), on Division I college football players throughout a season. Within the offensive group, WRs encountered light to moderate impact forces (5-6.5 G) compared to all other position groups, however RBs and QBs sustained more severe impacts (>10 G). On the defensive side of the ball DBs sustained more light impact forces (5-6 G), whereas DTs experienced heavier impact forces (7.1-10 G) (Wellman et al., 2017). (Figure 1)

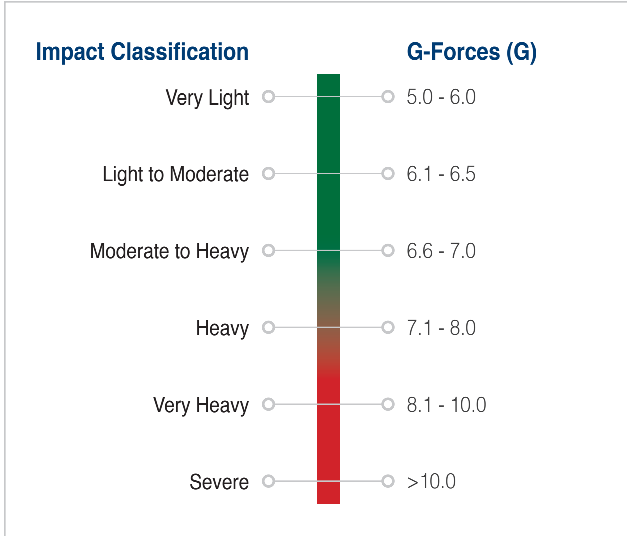


Figure 1
Impact Classifications (Wellman et al., 2017).

Offensive Positional Impacts Profiles	
Quarterback	2,476
Running Back	2,638
Wide Receiver	5,483
Tight End	3,706
Offensive Linemen	3,806
Defensive Positional Impacts Profiles	
Defensive Backs	3,657
Defensive Tackles	2,850
Defensive Ends	3,014
Linebackers	3,542

Table 2
Total of impacts experienced by position over a 12-game college season (Wellman et al., 2017).

Although non-linemen travel greater distances than lineman during a game, the responsibility of linemen create for a more static stance at the beginning of the play as a result from a shorter starting difference between defensive and offensive linemen resulting in greater and more frequent impact forces than non-linemen (Ward et al., 2018). These starting points allow for shorter running distances with greater acceleration and decelerations followed by quick change of directions (Wellman et al., 2017).

The quantity of impacts throughout a 12-game college football season has been captured per position (Table 3). Although there is no direct comparison for football on the physiological repercussions of collisions, similar team-sports involving impacts such as rugby, have been investigated. Data from these studies suggest total amount of impacts negatively modulates muscle damage and neuromuscular fatigue (Chapter 9). These findings suggest the amount of impacts experienced during a game may influence recovery from a football game. However, this is purely speculative as these correlations have not been completed in football.

Physiological demands

With respect to the physiological demands, football may be considered an anaerobic sport. The high intensity actions (e.g. blocking, pushing, tackling, jumping, etc) and running required for each play requires a combination of phosphocreatine (PCr) and anaerobic glycolytic energy systems (Pincivero & Bompa 1997). The different styles of offenses/ plays and injury-, tactical- and advertising-derived time-outs, result in variable recovery times between plays (46.9 ± 34 s) (Iosia & Bishop 2008). Consisting of adenosine triphosphate (ATP) and phosphocreatine (Pc), this energy system or ATP-Pc is the primary energy source for quick, explosive power and sprinting ability. The ATP-Pc system can supply energy for up to 10 s of work, before ATP-Pc levels are depleted or near depleted. The ATP-Pc system replenishes rapidly following depletion: after 20 s of rest, 50% of ATP-Pc energy stores are regained, and at 40 s of rest, 87% are recovered (Davis et al., 2016). The ability to resynthesize these energy stores is mostly reliant upon the oxidative capacity of a given muscle group since ATP-Pc restoration is predominantly reliant on aerobic metabolism (Bishop et al., 2004; Sanders et al., 2017). Researchers have also observed a rise in blood lactate concentrations three- to five-fold above baseline in players, which remained elevated despite frequent rest periods. This suggests that the anaerobic glycolytic pathway is also taxed during American football games (Hitchcock et al., 2007).

Although there is enough recovery time (> 10 min) between series, specific repeated plays with short periods of rest (i.e. 'up-tempo' football) may also place an additional demand on the aerobic system. This may be concerning given the cardiovascular endurance of football players is historically not well developed (Fullagar et al., 2017).

Maximal oxygen consumption (VO_2 max) is defined as the ability to transport and consume oxygen during exhaustive work and is related to cardiorespiratory fitness (Bisi et al., 2011). Minimal research has been conducted into the aerobic capacity of football players as the physical demands of the game do not rely heavily upon it. As a result, the cardiovascular developments of players are not emphasized during player training programs and practices. However, improvements in aerobic capacity have been reported in collegiate football players (via enhanced muscle oxygen uptake kinetics) over the duration of a season, suggesting an aerobic adaptation to the energy demands of football (Hoffman et al., 2005).

A small number of studies involving collegiate and professional football players examined the aerobic capacity of each position, and they discovered that the DB position tended to have one of the highest VO_2 max measurements (54.0 ± 5.5 ml/kg/min) with DL (46.3 ± 5.8 ml/kg/min) consistently having the lowest VO_2 max compared to all other positions

(Pincivero & Bompa 1997). In another study of 59 NCAA Division IAA football players, investigators demonstrated that the DB position again outperformed all other positions, aerobically, during a 1.5 mile run with a time to completion of 11.1 ± 0.9 min and the OL position performed the worst 13.4 ± 1.7 min (Barker et al., 1993).

Football Evolution

The game of football steadily has been evolving from decade to decade with innovative offensive and defensive schemes focused more on passing and rule changes that favour offensive scoring. As a consequence the players have evolved too. Secora et al. (2004) analyzed the physical and performance differences across Division I football players from 1987-2000. Overall, it was concluded that more modern football players weigh more, are stronger, jump higher, are faster, have more vertical jump power, and have more fat-free mass compared to their earlier counterparts.

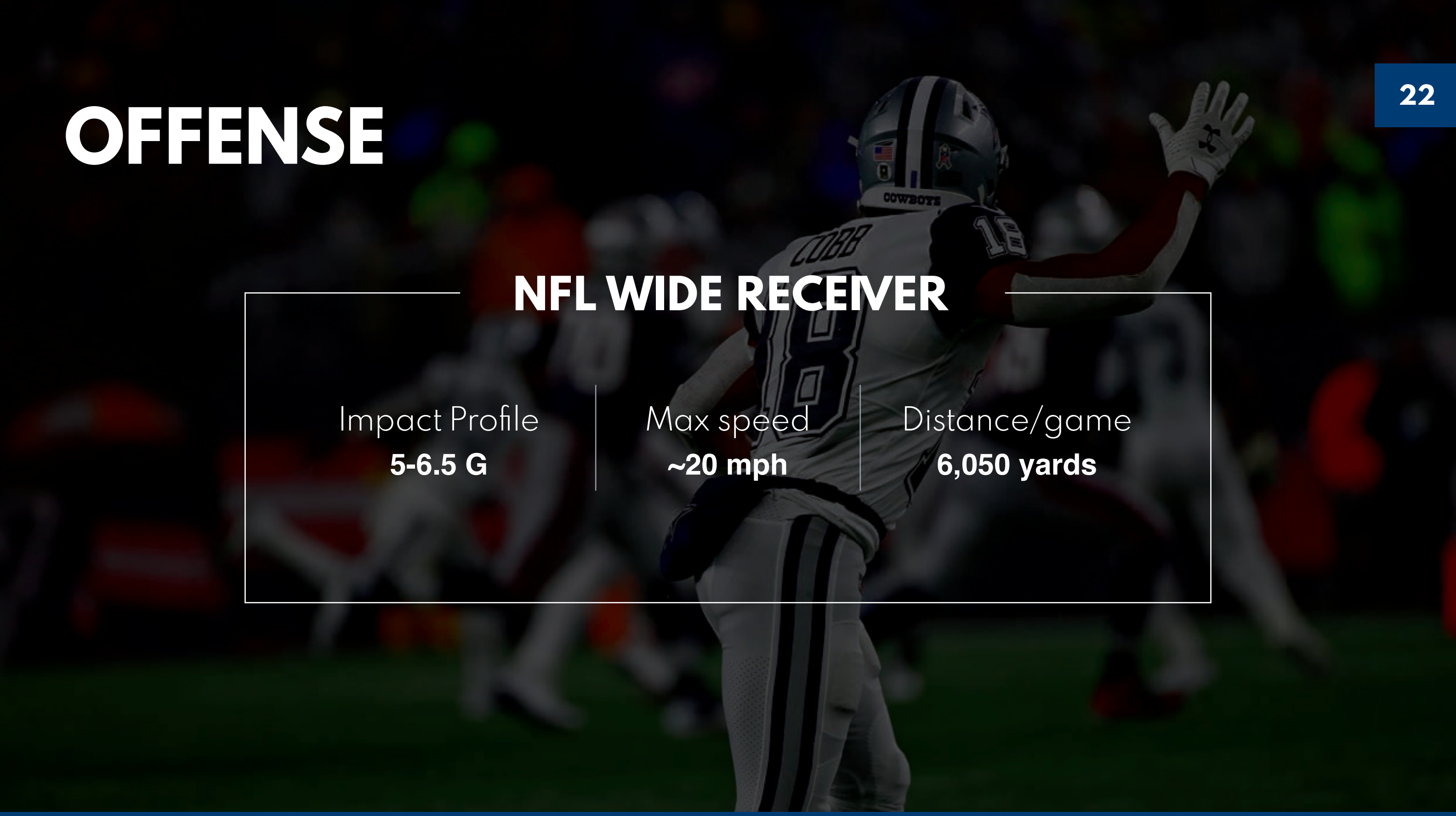
Specifically, quarterbacks in 2000, had significantly different body mass (94.6 from 89.2 kg), vertical jump (79.6 from 72.4 cm), bench press (155.9 from 126.1 kg), relative bench press (158.6 from 141.4%), power (186.3 from 167.5 kg-m/s) and fat-free mass (86.1 from 80.6 kg) than those in 1987. The strength scores represent the recorded 1 repetition maximum on the players. Running backs in 2000, had significantly different body mass (96.9 from 91.9 kg), vertical jump height (86.1 from 79.9 cm), bench press (169.5 from 152.1 kg), squat (226.5 from 214.1 kg), vertical power jump (198.1 from 181.1 kg-m/s), and fat-free mass (89.3 from 83.6 kg) than those in 1987, respectively. Tight Ends in 2000, had significantly greater body mass (114.2 from 106.2 kg), were stronger (bench press 167.7 versus 151.4 kg), more powerful (224.4 versus 202.9 kg-m/s), and had more fat-free mass (100.4 from 93.9 kg) than those players in 1987. Wide receivers in 2000, had significantly faster 40-yard times (4.49 from 4.57 s), were able to jump higher (vertical jump: 88.7 versus 78.7 cm), had a lower body fat percentage (6.5 from 8.1%), and were stronger (bench press: 146.6 versus 127.3 kg; squat: 194.5 from 177.1 kg), and more powerful (178.6 versus 167.7 kg-m/s) than those players assessed in 1987.

The reason for players evolution is multifactorial including improved coaching, strength and conditioning, and improved nutrition amongst others. Further research is required to determine how the game and physical requirements of the players have evolved from the year 2000 to 2020.

Summary

In summary, football involves intense collisions during bouts of high-intensity exercise (~5 s), which are repeatedly performed over a 60-min game (3-4 h in real time), with variable but prolonged recovery between efforts (~30 s). There are limited data outlining the physical and physiological demands of football overall and for each position. Additionally, little is known about how or if collisions experienced during football impact recovery and subsequent energy needs, both acutely and over a season(s). Thus, further research is required, in these areas to better understand the physiological demands of football.

Figure 2 ▸
Demand of games from Wellman et al. 2016



OFFENSE

NFL WIDE RECEIVER

Impact Profile	Max speed	Distance/game
5-6.5 G	**~20 mph**	**6,050 yards**

5-6 s / play

11 min

Q1	Q2	Q3	Q4

60 min

3-4h

DEFENSE

NFL DEFENSIVE TACKLE

Impact Profile	Max speed	Distance/game
7.1-10 G	**~16 mph**	**3,440 yards**

Chapter 2: Demands of the Game

SUMMARY

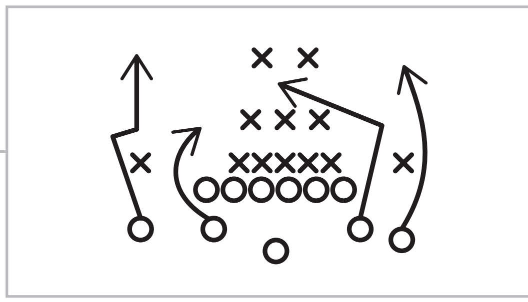
National Football League games consist of four 15-min quarters with a 12-min halftime. An interval of at least two minutes is provided between the first and second and third and fourth quarters.

15 min	15 min	12 min	15 min	15 min

~2 min

~5-6 sec

The mean duration of a single play in football



~34-36 sec

The mean rest duration between plays

Football may be considered an anaerobic sport involving high intensity actions (e.g. blocking, pushing, tackling, etc) **and running.**

The phosphocreatine (PCr) and anaerobic glycolytic energy systems are predominant energy systems to support football specific movements during plays.

The physical demands of experienced by the player are **specific to their playing position.**

In addition to running and skill requirements, players must endure **light to severe impacts** repeatedly over the season.

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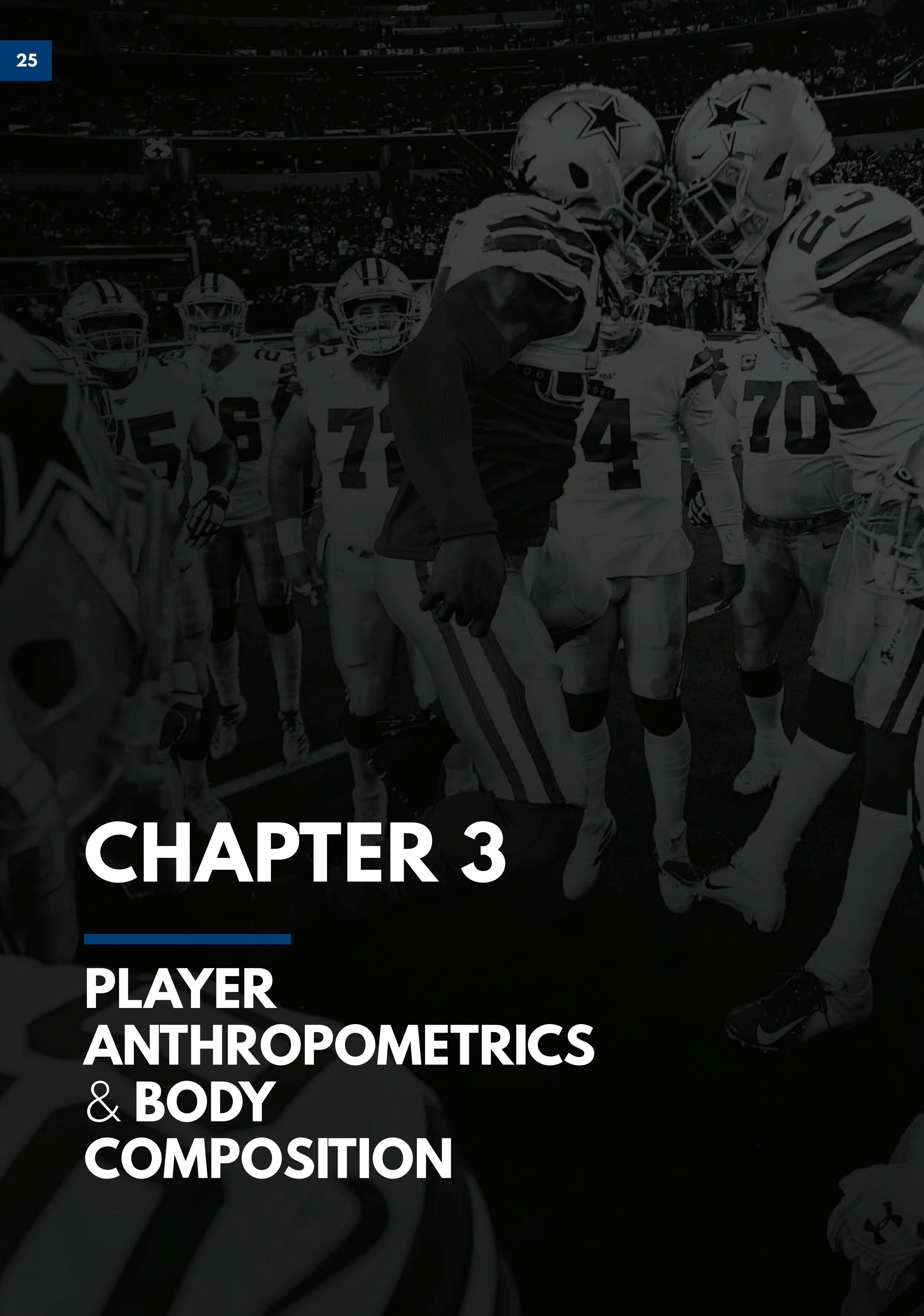


CHAPTER 3

PLAYER ANTHROPOMETRICS & BODY COMPOSITION

PLAYER ANTHROPOMETRICS & BODY COMPOSITION

Jon-Kyle Davis & Ian Rollo

Introduction

An objective for the football player is to maintain a body mass throughout the season that is required for their playing position (Chapter 2) but also appropriate from a health perspective. The energy intake and macronutrient content of the diet should be adjusted depending on the training or game day (Chapters 4 and 5) as well as the specific goals of the player. In football, "optimal" values of body fat and muscle tissue required for health and football specific performance are difficult to establish. This is because of the difficulty in measuring performance per se, which differs by playing position (Chapter 2). Therefore, there is no "one size" for all football players; rather the dietary requirements should be tailored to the individual player and modified depending on their role within a team (Impey et al., 2016).

The assessment and monitoring of both a player's fat and muscle are important considerations with regard to a football players performance. Consistent messaging throughout high school up to professional teams is an important education process on how to eat for health, performance and body composition management. Thus, the aim of this Chapter is to understand best practice with regards to body composition assessment and how the basic concepts of energy balance may be applied to body composition development and weight management in football.

Principles of Energy Balance

Energy balance in American football is a dynamic process (Galgani & Ravussin 2008). Energy is provided to the player via all foods and some beverages in their diet. This energy is used by the player in several fundamental processes including cellular maintenance, thermoregulation, growth, reproduction, immunity and locomotion (Loucks et al., 2011). When players train or compete in games, energy expenditure is increased significantly, which increases the need for additional energy to be ingested through the diet (Manore 2015). If the total energy expenditure of the player, including exercise-related expenditure and the energy required to support daily physiological function, exceeds that of energy intake, the player is said to be in negative energy balance. Alternatively, if energy intake exceeds total energy expenditure, the player will be in positive energy balance.

The maintenance of body mass over time is an indication that the player is in a state of energy balance where energy intake (total calories consumed) equals energy expenditure (total calories expended). To this end, daily or weekly monitoring of player body mass can provide a gross assessment of a player's energy balance over the season. To ensure meaningful differences in body mass can be assessed, the players' body mass should be recorded at the same time of day, with the same measurement device and when players are euhydrated and rested (Chapter 6).


DALLAS
COWBOYS
POWER LIFT
YORK

Importantly, the diet (energy intake) should be considered in concert with the training program (energy expenditure) to manage and modify body composition, achieve performance goals, optimize recovery and avoid ill health (Chapter 4). The main factors governing the energy expended during exercise are the intensity and duration of training and games. Therefore, the energy requirements will vary depending on the individual player and the phase of season / training / games/ recovery / rehabilitation they are involved. The estimated energy intake of different playing positions is displayed in Table 1.

All foods and several beverages in a players diet are characterized by their composition of macro and micro nutrients. Macronutrients are carbohydrate, proteins and fats, while micronutrients include vitamins and minerals. The energy content of carbohydrate and protein is approximately 4 kcal/g, whereas the energy value of fat is 9 kcal/g. The role and appropriate intake of protein and carbohydrate in the players to support training and game performance are discussed in Chapters 4 and 5. Fat is also an essential component of the players' diet, providing energy, facilitating the absorption of fat-soluble vitamins and also providing an essential structural component of cell membranes. The recommended daily intake of fat is 1.2 - 1.4 g/kg body mass (Institute of Medicine (IOM) Food and Nutrition Board 2005). Diets abundant in high fat foods are discouraged as they can replace those foods which contain the other macronutrients required for football performance, recovery and adaptation. Furthermore, because high fat foods are energy dense, they carry a risk of delivering excess calories and negatively impacting body composition goals.

Energy intake remains one of the most difficult measures to record accurately in sports nutrition. This is because the measures of energy intake are usually reliant on self-reporting or recall of those players completing them. This process frequently results in an under-reporting of dietary energy intake (Poslusna et al., 2009). Developing expertise in the assessment of energy intake requires an appreciation that there are different reasons for undertaking an assessment, different approaches to completing it and different tools that can be used (Burke 2015). The gold standard of energy intake assessment would require the players to weigh and record all the food and beverages in their diet. This information is then entered into dietary assessment computer programs for energy intake and breakdown of macro / micro nutrient content. Nevertheless, even accurate assessments only provide brief insights into the players' energy intake over the duration of the assessment.

Technological advances, through web based or mobile tablet applications, have provided novel ways to collect and process energy intake information. Many of these systems provide electronic versions of paper and pen questionnaires, such as 24 hour recall (Rangan et al., 2016). Key advantages of the technology are that applications can provide a huge data base of food pictures, be updated real time and provide rapid feedback. In the coming years we expect to see these new methods being used to gather information on food practices of athletic populations, including American football (Stumbo 2013; Burke 2015).

Position	RMR* (Kcal)	PA Factor	Thermic Effect of Food	Estimated daily energy intake (Kcal Range)
Defensive Lineman (DL)	2,781	2.0-2.1	1.1	6,100-6.400
Offensive Lineman (OL)	2,942	2.0-2.1	1.1	6,500-6,800
Running Back (RB)	2,367	2.1-2.2	1.1	5,500-5,700
Tight End (TE)	2,689	2.1-2.2	1.1	6,200-6,500
Linebacker (LB)	2,442	2.1-2.2	1.1	5,600-5,900
Defensive Backs (DB)	2,179	2.1-2.2	1.1	5,000-5,300
Quarterback (QB)	2,232	2.0-2.1	1.1	4,900-5,200
Wide Reciver (WR)	2,143	2.1-2.2	1.1	4,900-5,200

Body Composition Analysis in American Football

Football teams routinely monitor the body composition of their players for a variety of reasons, including: to assess a player's physical development over time, monitor energy availability status and also assess the impact of specific training or nutrition regimes. It is important to note that a player's physique is heavily determined by inherited characteristics, for example the height of a player will be determined through genetic predisposition (Davenport 1917). However, the players' body composition is determined through the influence of their training program and diet. Thus, importantly with regard to physical performance, changing body composition is one variable that a player can directly control.

◂ Table 1

Estimated range of daily energy intake (kilocalories) based on playing position (Cunningham 1980). RMR: resting metabolic rate, LBM: lean body mass.

METHODS TO ANALYZE PLAYER BODY COMPOSITION

An extensive range of methods to assess body composition currently exist. To our knowledge, the four main methods used to assess body composition in American football players are skin folds, ADP, BIA and DXA. For each method, a qualified and skilled practitioner is required to complete the measurements.

Skin Folds

A position statement on body composition was published in 2012 under the auspices of the International Olympic Committee's Medical Commission, providing a guide for practitioners working in sport (Ackland et al., 2012). In summary, the skinfold method was reported as a reliable 'in the field' measurement. Therefore, it is perhaps not surprising that the measurement of subcutaneous adipose tissue thickness is a common method used to assess body composition. This method is typically performed using callipers to measure skin folds at specific anatomical sites – described in full previously (Marfell-Jones et al., 2006). In brief, the skin folds site is approached by the finger and thumb at 90° to the surface of the skin. The skin fold is raised with parallel sides. The caliper is positioned 1

cm laterally from the peak of the fold and at the midpoint along the fingernail of the index finger. The caliper is released and a reading accurate to 0.1 mm is recorded after 2 s. This measure is completed at the eight sites defined by the protocol of the International Society for the Advancement of Kinanthrometry (ISAK): triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf (Marfell-Jones et al., 2006). Values are then expressed as a sum of the thickness of the anatomical sites assessed, together with circumference measurements (Ackland et al., 2012). Despite standardization, the skin folds method requires skilled personnel and can, therefore, lack the accuracy practitioners and athletes require (Ackland et al., 2012).

Athlete specific equations from skinfold, circumference measures, and age have been developed previously (Sinning et al., 1985). However, these equations may not be effective for all athlete subgroups such as basketball and American football players (Sinning et al., 1985). Oliver and colleagues (2012) recently developed multiple regression equations using 7 site-skinfold assessment and circumference measurements to estimate DXA-derived body fat percentage for the football player. However, Oliver's et al. (Oliver et al., 2012) equations were developed in the collegiate football player to provide a practical method for practitioners to incorporate in the field. Thus, futher work is required to validate these equations in high-school football and also professional players.

Bioelectrical Impedance Analysis

The BIA technique offers a method to non-invasively assess the fluid distribution and body composition of football players. The BIA works by passing an electrical current through the player's body. The resistance to that current, as a result of the specific resistivity and volume of fat free mass, which acts a conductor, is measured. Total body water is also calculated and the value can be used to estimate percentage body fatness (Kushner & Schoeller 1986; Davies et al., 1990; Beertema et al., 2000). The BIA machines vary in size and mobility. Advances in the technique have resulted in devices using both single and multiple frequencies of electrical current, with multiple frequencies reported to improve accuracy (Cornish et al., 1993; Shafer et al., 2009). Studies have reported BIA to have a strong absolute agreement with DXA for measurement of body fat percentage (ICC=0.87, 95% CI 0.46, 0.95) (Carter et al., 2013). Body mass scales with electrodes positioned on hand held paddles and on the foot plates are a typical method of applying the electrical current to the extremities of a player's body. The advantages of BIA are that the assessment can be "self-led" by the player, the duration of analysis is quick, 1-2 minutes, and the results are available instantly.

Air Displacement Plethysmography (ADP)

The ADP method is most commonly assessed by using a BOD POD™ (Gold Standard Model 2007A Life Measurement Instruments/COSMED). The ADP method is based on a two-compartment model of body composition (fat mass and fat-free mass), and uses the inverse relationship between pressure and volume (Boyle's law) to derive body volume (L). Once body volume is determined, the principles of densitometry are used to determine body composition from body density. Measurement devices are typically required to be calibrated at the start of each day using a known volume (50 L) and a second calibration is recommended prior to each player assessment. The weighing scales are also calibrated daily against a known weight (20 kg). To reduce the potential error as a consequence of isothermal air trapped in clothing and body hair, players are asked to wear minimal tight-fitting clothing and swim cap before being instructed to sit in a chamber, limit their movement and breathe normally. An equation is then used to predict thoracic gas volume and determine body fat from body volume (McCrory et al., 1998).

Standardization	Skin Folds	ADP	BIA	DXA
Completed by same qualified experienced professional	x	x		x
No activity or exercise before assessment	x	x	x	x
Players should be euhydrated			x	x
Players should complete the assessment fasted (>5h)		x	x	x
Standardized positioning	x	x	x	x
Use the same equipment/technology for each subsequent measure (for comparison purposes)	x	x	x	x

Table 2
Recommended standardization procedures for body composition assessment.

Dual-Energy X-Ray Absorptiometry

DXA is a clinical method with the primary purpose to assess bone mineral density (Ryan et al., 1993; Barry & Kohrt 2008). An additional function of a DXA machine is to assess body composition. This technology has become a commonly used method within football, providing a relatively precise estimate of fat mass, bone mineral content and lean mass.

Full details of DXA technology and standardization procedures have been reported previously (Clarys et al., 2010; Nana et al., 2016). In brief, players are positioned in a standardized position on the DXA bed. An X-ray beam passes in a posterior to anterior direction through the bone and soft tissue upward to a detector. Fat mass and fat free mass are differentiated by the ratio of X-ray beam attenuation at the lower energy relative to that at the higher energy. Consideration for using DXA in players should include the history of high levels of ionising radiation exposure (i.e. medical treatment following injury).

The popularity of DXA is most likely due to scans being relatively quick and easy to perform, while providing precise and attractive data to feedback to the players. It is important to note that DXA also has limitations and strict standardization procedures should be adhered to if meaningful changes are to be identified (Clarys et al., 2010; Nana et al., 2014). Recent reviews have concluded that when using DXA as the chosen method, details of the machine and software, subject positioning protocols, and analysis protocols should be reported and adhered to. This is because the error in DXA measurement of fat mass and muscle mass is approximately 1 kg. Although this may be better than most other techniques, small differences of interest to the practitioner and player during routine monitoring may still be difficult to detect (Clarys et al., 2010; Nana et al., 2014). Therefore, Table 2 summaries the recommended procedures for any small changes in body composition, regardless of technique used, to be confidently detected and correctly interpreted (Nana et al., 2015; Nana et al., 2016). Therefore, Table 2 summaries the recommended procedures for any small changes in body composition, regardless of technique used, to be confidently detected and correctly interpreted (Nana et al., 2015; Nana et al., 2016).

Figure 1

Steffes et al. 2013 used BIA for high-school body composition. DXA data for college (Bosch et al. 2019) and NFL players (Dengel et al. 2014)

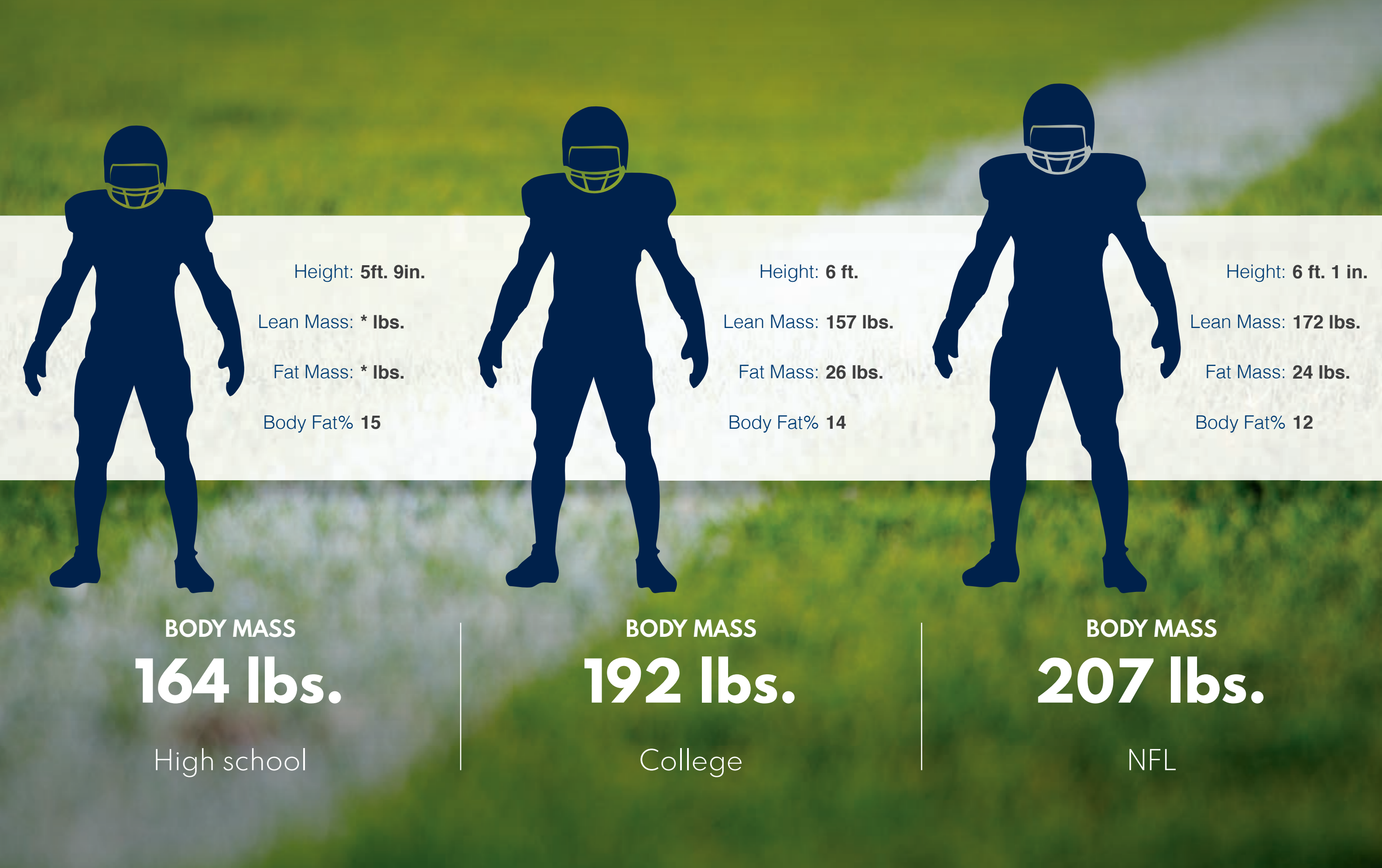
BODY COMPOSITION OF AMERICAN FOOTBALL PLAYERS

Professional Football

Body composition of football players have been researched over 70 years dating back to 1942 (Welham & Behnke 1942). This first study (Welham & Behnke 1942) examined physical characteristics of 25 professional football players for height, body mass, body composition, chest and waist circumference. Due to the nature of the game in 1942, positions were only divided into backs and linemen. In 1972 Wilmore et al. (Wilmore & Haskell 1972) further investigated body composition of 44 professional players through hydrostatic weighing. The professional players of 1972 were substantially taller and heavier compared to their 1942 counterparts. Most notably linemen were, on average, 6-7 cm taller and had an additional 18 kg of lean body mass (Wilmore & Haskell 1972). A number of studies have been conducted on professional football players' body composition since the 1970's (Kraemer et al., 2005; Dengel et al., 2014; Pryor et al., 2014). Body composition research methods have included skinfold assessment (Thompson 1959), ADP (Provencher et al., 2018), BIA (Oppliger et al., 1992), hydrostatic weighing (Wilmore & Haskell 1972), ultrasound (Melvin et al., 2014), and DXA (Dengel et al., 2014). The use of different methods and standardization protocols across the entity of literature makes comparisons between studies difficult.

The physical attributes required of American football players does appear to have evolved over time. In 2005 Kraemer and colleagues noted that players had an increased body mass compared to players in the 1970's.

Wide Receiver Comparisons from High-School to NFL Players



**Steffes et al. 2013 used BIA for high-school body composition. DXA data for college (Bosch et al. 2019) and NFL players (Dengel et al. 2014)*

However, this was only observed for offensive and defensive linemen. The stature and body fat composition between other playing positions had not changed significantly (Kraemer et al., 2005). Pryor et al. (2014) also observed the same results when comparing body composition of professional players from 2012 to previously published work from 1998 (Snow T 1998). The authors reported a trend toward lower body fat composition in linebackers, defensive linemen, offensive linemen, quarterbacks, and wide receivers suggesting a greater lean body mass in these positions compared to players 14 years earlier (Pryor et al., 2014).

One limitation to studies examining body composition across professional players is that assessments are reported from different periods of the season. Often a single team has been examined at a single time point during the year and these data have been used to make inferences across the league. Two exceptions have been the work of Dengel et al. (2014) and Provencher et al. (2018). In one of the largest studies that have examined body composition of football players Provencher and colleagues (2018) analyzed data from 1,958 players during the NFL Scouting Combine from 2010-2016. Using the same body composition assessment technique over the 6-year period (ADP) the authors noted a decrease in body fat percentage for all positions, except for defensive linemen, from 2010 to 2016. This was seen in relation to total body mass which remained relatively constant over the same time period (Provencher et al., 2018). Dengel and colleagues examined body composition of one professional football team from 2006 to 2011. The novel aspect of this study was that DXA was used to examine muscle imbalances (Dengel et al., 2014). This study also provides foundational reference size profiles and differences among various positions for college and NFL players (Table 3).

BODY COMPOSITION OF COLLEGE FOOTBALL PLAYERS

Significant changes have been noted for the evolution of the college football player at the Division I level for height and body mass (Olson JR 1985). Olson et al. (1985) observed that players from 1984 were taller, heavier, faster, and stronger compared to college football players at the Division I level from 1974. This same observation was also reported by Secora and colleagues (2004) who compared Division I football players from 1987 to 2000. Specifically, players had similar body fat percentage but a greater lean mass in 2000 compared to players in 1987 (Secora et al., 2004). It is important to note that the results from both studies were drawn from questionnaires sent to strength and conditioning coaches from various Division I Universities. Unfortunately, body composition methods across the Universities were not reported in these studies. Collectively, studies have showed similar trends in players having a greater body

OL = offensive linemen; **DL** = defensive linemen; **TE** = tight end; **LB** = linebacker; **RB** = running back; **DB** = defensive back; **WR** = wide receiver; **QB** = quarterback

	OL	DL	TE	LB	RB	DB	WR	QB
Height (cm)								
NFL	192.8 (4.1)	190 (2.9)	192.9 (2.1)	186.7 (3.9)	181.5 (4.1)	182.2 (3.1)	185.7 (3.9)	188.5 (3.6)
College	192.9 (4.9)	189.1 (3.7)	190.5 (5.5)	184.2 (3.1)	179.4 (3.9)	181.1 (4.1)	183.9 (6.5)	186.9 (4.9)
Body Mass (kg)								
NFL	140.9 (6.1)	132.9 (14.7)	113.9 (4.2)	109.9 (4.6)	105.4 (8.5)	90.8 (6.1)	94.0 (6.0)	103.6 (13.9)
College	135.5 (11.8)	120.4 (14.2)	107.4 (9.6)	102.0 (6.6)	95.1 (6.5)	87.8 (6.5)	87.2 (8.8)	93.9 (8.2)
% Body Fat								
NFL	28.8 (3.7)	25.2 (7.6)	16.8 (3.0)	17.0 (3.2)	16.0 (4.0)	12.1 (3.3)	12.5 (3.1)	19.6 (4.6)
College	30.8 (4.2)	23.5 (7.0)	19.8 (3.9)	18.8 (4.9)	15.3 (3.9)	13.3 (3.2)	14.1 (3.6)	17.2 (4.2)
Lean Mass (kg)								
NFL	96.5 (4.5)	95.2 (5.5)	90.7 (4.0)	87.3 (3.5)	84.5 (4.9)	76.1 (4.2)	78.3 (4.3)	78.9 (5.1)
College	89.5 (6.5)	87.6 (6.8)	82.2 (6.8)	79.5 (5.2)	77.3 (6.8)	72.4 (5.2)	71.6 (6.5)	74.4 (6.3)
Fat Mass (kg)								
NFL	39.3 (6.0)	33.3 (12.3)	18.4 (4.5)	17.9 (3.8)	16.3 (5.3)	10.6 (3.5)	11.3 (3.4)	19.5 (6.1)
College	40.1 (7.9)	27.8 (10.8)	20.5 (5.3)	18.5 (5.4)	14.1 (4.6)	11.2 (3.0)	11.9 (3.7)	15.5 (4.4)

Table 3

Positional body composition characteristics mean (+ SD). Data from Dengel et al. 2013 and Bosch et al. 2019 from DXA analysis.

mass, similar body fat percentage and a greater lean mass when comparing players from 1990-2000 (Oppliger et al., 1992; Barker M et al., 1993; Secora et al., 2004) to more recent publications (Melvin et al., 2014; Bosch et al., 2019). Nevertheless, not all studies have showed this same trend and instead suggest that the increase in body mass over the decades in college football players may be due to fat mass instead of increased lean mass (Noel et al., 2003). Specifically, modern Offensive linemen and Defensive Linemen players tend to have greater body mass and greater fat mass compared with players 50 years ago (1970-1980 (Wickkiser & Kelly 1975; Smith & Mansfield 1984)).

Most recently, body composition has been examined, via a DXA, on 467 college football players from four Division I universities (Bosch et al., 2019). This is the first study to the authors' knowledge that has examined body composition of college football players across multiple universities using a criterion method (DXA). Interestingly, this study showed body composition values comparable to professional football players (Table 3).

BODY COMPOSITION OF HIGH-SCHOOL FOOTBALL PLAYERS

Body composition of football players has been primarily examined at the college and professional level with few studies conducted with high-school players (Steffes et al., 2013). In the only study completed at the high-school level (to the authors knowledge), 123 football players from 7 different high schools were assessed using the BIA method (Steffes et al., 2013). This study found a lower body fat percentage and a greater body mass in college players compared to high-school football players (Steffes et al., 2013).

We would encourage future studies to capture and report body composition across multiple high-schools and geographic locations using the appropriate methods and standardization. This approach will allow for foundational reference values at the high-school level. In addition, this will also allow like-for-like comparisons to be made in the future and the physical evolution of the player to be tracked as they progress through into more senior codes of the game.

An example of body composition changes from high-school to the NFL is displayed in figure 1. The key findings for examining body composition for the college and professional football player are:

The position and on-field positional requirements of the player play an important role on body composition characteristics of the player.

Defensive linemen and offensive linemen have the highest reported body fat compared to other positions.

Positions that tend to mirror each other (i.e., offensive and defensive linemen, wide receivers and defensive backs) have similar physical characteristics and body composition.

Tight ends have similar upper body lean mass compared to offensive linemen but a fat mass that is more comparable to linebackers and running backs.

Running backs, wide receivers, and defensive backs to have the lowest percent body fat independent of testing method.

TRACKING & MANAGEMENT OF BODY COMPOSITION

Changes in body composition over a season for the football player were first described in 1959 (Thompson 1959). Using skinfold assessment, the authors examined the change in body composition for 34 college football players. Measurements were made prior to the start of the season and the last week of the season. Thirty-two out of thirty-four players showed a decrease in body fat throughout the season. On average players lost 2% body fat throughout the season with the majority of players (27 out of 34) losing weight ranging from 0.2-6.7 kg (Thompson 1959). Since 1959 several studies have been conducted tracking body composition over a season and throughout a player's college career (Stodden & Galitski 2010; Hoffman et al., 2011; Jacobson et al., 2013; Binkley et al., 2015; Trexler et al., 2017). Binkley and colleagues examined body composition of 53 Division I football players by a DXA pre and post season. Over the course of a season lean body mass decreased by 1.4 kg. Absolute fat mass showed no change, however percent body fat increased by 0.5% (Binkley et al., 2015). Body composition has also been analyzed during the off-season to track progression of the strength and conditioning program. On average players were reported to increase lean mass by 2.2 kg and decrease absolute fat mass by 1.4 kg (Binkley et al., 2015).

Body composition of Division I football players has also been assessed throughout a single year and longitudinally across 4 years. (Trexler et al.,

2017). Over a single year DXA assessments from 57 players showed, on average, that body fat percentage decreased by 1.3% and lean mass increased by 2.8 kg. Throughout a 4-year playing career a subset of players (13 out of 57) showed a significant increase in weight (6.6 + 4.1 kg) and favorable changes in lean body mass (4.3 + 3.0 kg). Other longitudinal studies have reported similar gains in lean body mass of 5-6 kg over 4 years (Stodden & Galitski 2010; Hoffman et al., 2011; Jacobson et al., 2013). Linemen were shown to significantly decrease body fat from year 1 to year 4 with minimal body composition changes recorded for wide receivers and defensive backs over the same time period (Jacobson et al., 2013). Speculatively, this could be due to receivers and defensive backs already reporting to college with a low body fat composition based on the physical demands of the position (Jacobson et al., 2013) (Chapter 2).

These results highlight the importance of monitoring body composition throughout the season.
Further, these studies show the need for nutrition education and incorporating appropriate intensities and volume in the weight room throughout the competitive season in order to maintain lean mass. This becomes an important component as studies have shown that strength can be maintained and even improved during the competitive season (Hoffman et al., 2011). Longitudinally the goal should be increases in lean mass compared to just

weight alone. Tracking the progression of a player periodically throughout the year and over the course of a career is important to understand the quality of mass and adaptations that have occurred.

Several studies have highlighted the importance of optimizing body composition changes for football players (Bosch et al., 2014; Binkley et al., 2015; Provencher et al., 2018). Miller et al. tracked performance data on 261 college football players from 1993-1998 at the same Division I university. The goal was to determine if body mass, body fat percentage, and player position was correlated with changes in physical performance (power clean, bench press, squat, vertical jump, 40-yd dash, and 20-yd shuttle) (Miller et al., 2002). The authors reported that the relative change (decrease) in body fat percentage was associated with improved verticle jump performance for all positions. Improvements were also noted for 40-yd dash and 20-yd shuttle runs for linemen and approached significance for all other positions with the 20-yd shuttle run. Increases in body weight were associated with improved performance for power cleans and bench press. Other studies have shown that drafted players from the NFL combine have been reported to have a significantly lower body fat percentage compared to undrafted players (Provencher et al., 2018). This has also been noted for college football players with starters having a lower body fat percentage that non-starters (Binkley et al., 2015) .

In general, many football players, independent of level or stage of their career, have two common objectives which are 1). gain lean muscle mass/ body mass; 2). lose body fat while gaining or maintaining muscle mass. Given the previously discussed principle of energy balance, there are several options available to achieve these goals. To gain body mass and lean muscle mass, the player should be in a positive energy balance. Particular attention should be placed on increasing or maintaining protein ingestion. In general, the

protein needs of players may be higher (1.6–2.2 g/protein/kg BM) than that recommended (0.8 g/protein/kg) for the general population (Phillips 2004). It is recommended that the appropriate quantity of protein is ingested at routine meals spaced throughout the day (Moore et al., 2009). As well as providing precursors for muscle growth and repair, diets rich in protein may also increase ratings of satiety and therefore can be effective in managing ad libitum energy intake (Weigle et al., 2005). Conversely, this may hinder those players attempting to gain lean body mass. In this circumstance similar quantities and timing of protein intake are advised while increasing energy intake to promote a positive energy balance.

Bosch et al. (2014) reported a threshold of 114 kg for football players in which lean mass starts to plateau and greater increases in fat mass occur. This would suggest that beyond 114 kg (250 lbs) achieving additional lean mass becomes more challenging while fat mass begins to increase at a faster rate. It is important to note that an increased fat mass tends to accumulate in the players abdominal region. This is especially prevalent when players have greater than 20% body fat when measured via DXA (Bosch et al., 2014). Thus, if a players goal is to increase body mass it is important to track the type of weight gained (i.e. lean mass or fat mass) and the lean mass threshold of 114 kg may be a useful benchmark.

If the aim of the player is to lose body fat the general recommendation is for weight loss not to exceed 1 kg per week (Burke & Deakin 2015). The main options are to reduce energy intake by up to 1000 kcal a day for a week, the other to increase energy expenditure by up to 1000 kcal/day per week (while keeping energy intake constant) or finally a combination of the two. For players already engaged in football training or in-season competition, a moderate approach to energy intake reduction i.e. 500–700 kcal/day is the recommended approach (Garthe et al., 2011). Although this method may take longer to achieve weight loss goals (Donnelly et al., 2009; Garthe et al., 2011), it may reduce the risk of the diet negatively impacting on daily performance and feelings of mood/motivation of the player (Achten et al., 2004). When energy intake is restricted, it is important to acknowledge the corresponding decrease in protein ingestion. Thus, players should be advised to adhere to the dietary guidelines provided in Chapters 4 and 5 acutely around training and games.

A summary of monitoring a players body composition is provided below:

> Over the course of the competitive season lean body mass has been shown to decrease. This highlights the need for nutrition education, strength training maintenance, and routine body composition assessment.

> Body composition assessment using criterion methods are recommended at the following times during the year: pre-season, start of the season, 1-2 times during the season (i.e., every 6-7 weeks, dependent upon length of season and respective level of play), the end of the season and periodically throughout the off-season training program.

> The goal should be to monitor changes in lean mass rather than just body mass/weight alone, and track these against performance indicators. Excess fat mass gains may have adverse effects on disease risk and be detrimental to performance for certain positions.

> Over the course of a player's college career significant changes are evident in lean body mass, with significant decreases in body fat most notably for linemen.

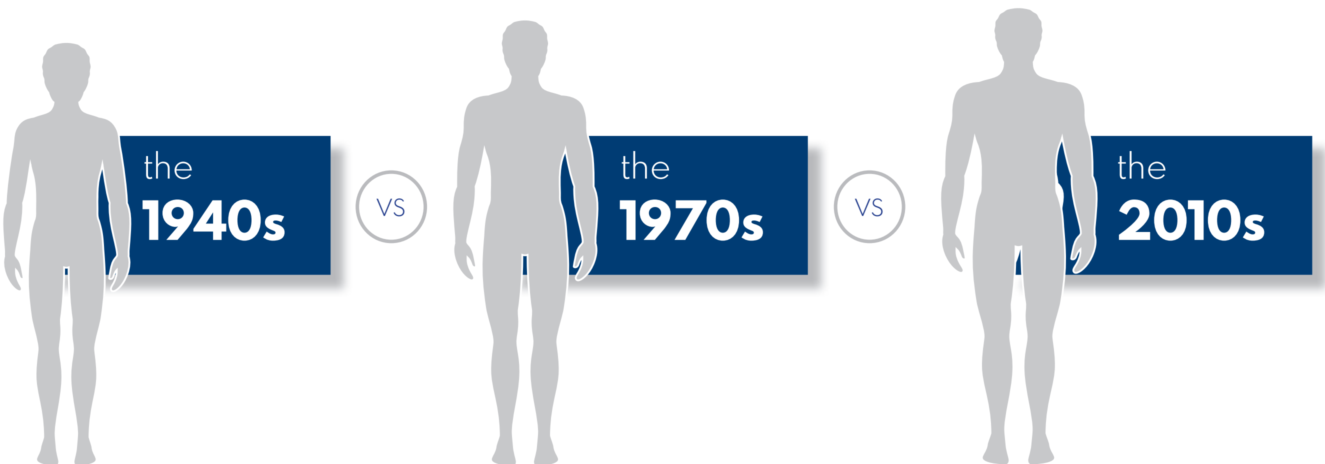
Summary

The physical attributes of football players have changed significantly. Modern players are substantially taller and heavier compared to those studied between the 1940s and 1970s. In general, the position of the player informs the body composition requirements: positions that mirror each other (i.e., offensive and defensive linemen, defensive backs and receivers) have similar physical characteristics and body compositions. Player body composition may be tracked over the season as well as throughout the off-season training program. There are various methods which can be used to assess body composition, however appropriate standardization is required. Appropriate sports nutrition education and implementation should complement the training programs used to optimize the players body composition throughout their career.

Chapter 3: Player Anthropometrics & Body Composition

SUMMARY

Modern players are substantially taller and heavier compared to those studied between:



The position of the player informs the body composition requirements: positions that mirror each other (i.e., offensive and defensive linemen, defensive backs and receivers) **have similar physical characteristics and body compositions.**

Player body composition may be tracked over the season as well as throughout the off-season training program.

There are various methods which can be used to assess body composition,

BOD POD BIA DXA Skinfolds

All require appropriate standardization. to assess body composition,

Appropriate sports nutrition education and implementation should complement the training programs used to optimize the players body composition throughout their career.

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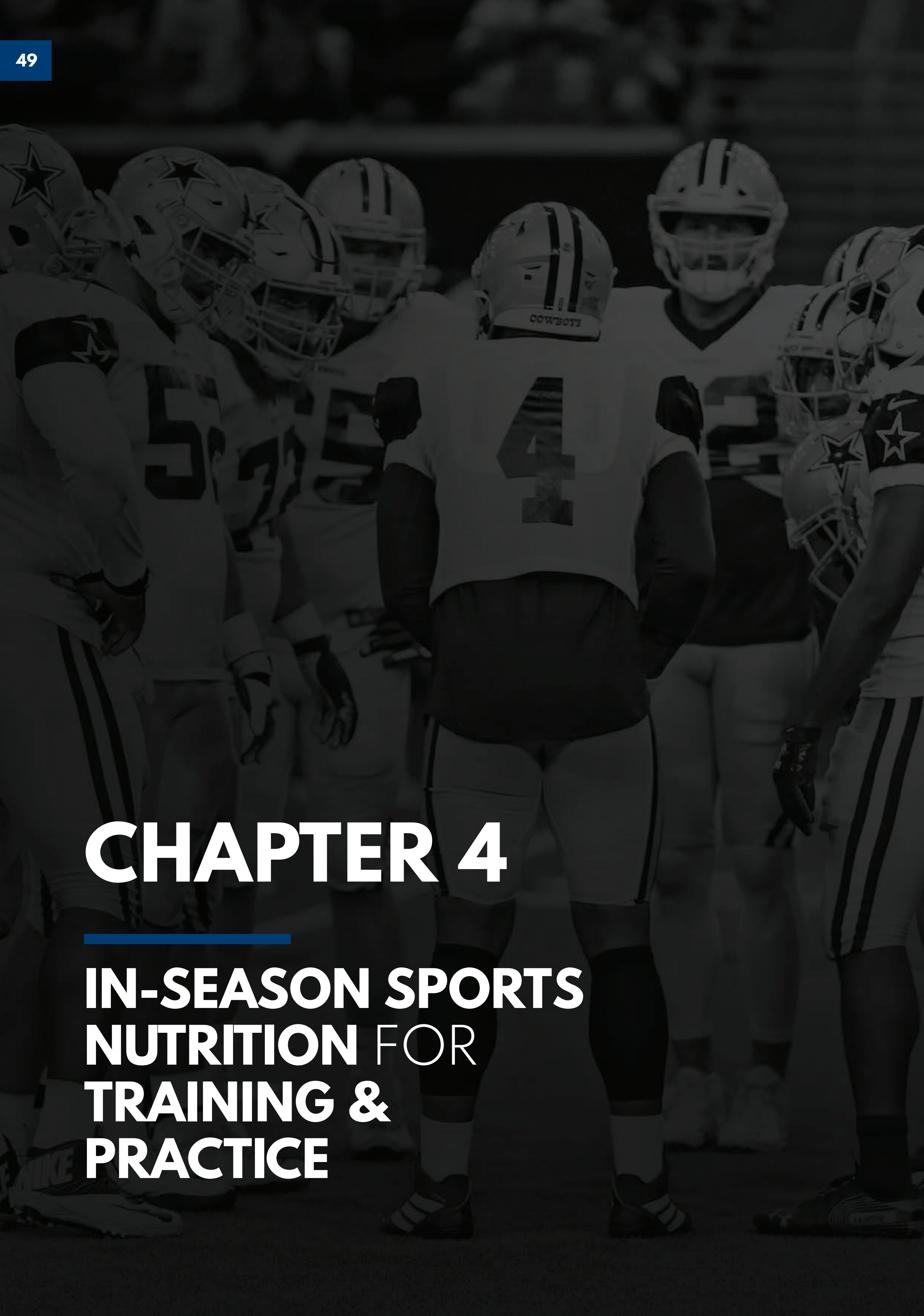
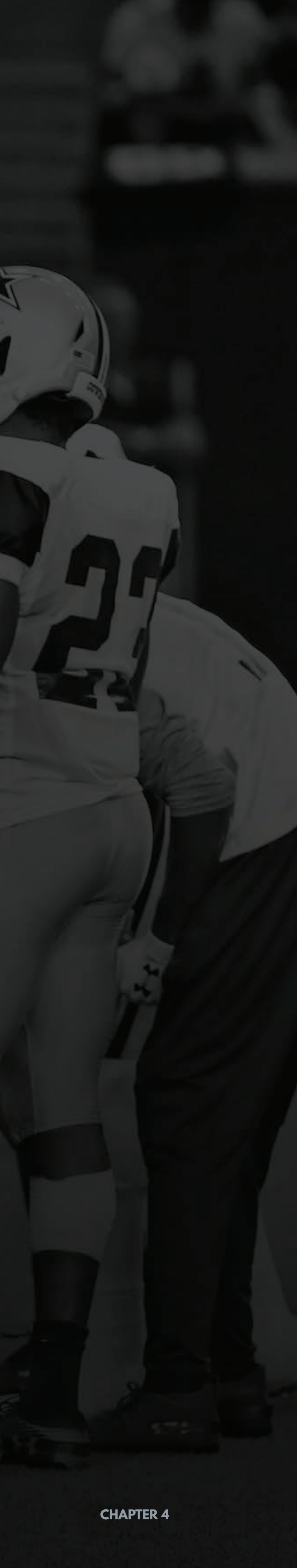


CHAPTER 4

IN-SEASON SPORTS NUTRITION FOR TRAINING & PRACTICE



IN-SEASON SPORTS NUTRITION FOR TRAINING & PRACTICE

Eric C. Freese & Scott Sehnert

Introduction

Sports nutrition plays a vital role in supporting the strength, speed, skills, and overall performance development of a player along with promoting recovery from the demands of football training and competition. Players train in multiple disciplines including Olympic lifting, speed training, conditioning, and individual skill development along with team-wide practices aimed at refining strategic approaches. Football is characterized by dynamic, multidimensional, and complex movements executed intermittently with brief periods of rest. More information on the physiological demands of football can be found in Chapter 2 along with the review by Fullagar et al., (2017).

Understanding the physical and physiological toll training, practice, and games has on the player is paramount to tailoring nutrition interventions at the individual level that can improve training adaptations (Hawley & Burke 1997; Philp et al., 2012); improve recovery from injuries and illnesses (Tipton 2010); improve performance (Hawley & Burke 1997; Williams & Rollo 2015; Jager et al., 2017); and aid in supporting long-term health (Tucker et al., 2009; Allen et al., 2010).

Additionally, nutritional needs of players vary according to position. The Cowboys roster is composed of players across a full spectrum of body sizes ranging from a 330 pound lineman to a 180 pound cornerback. The nutritional requirements of these two body types vary drastically without considering the difference in associated training demands between positions (Table 1).

Position	RMR* (Kcal)	PA Factor	Thermic Effect of Food	Estimated daily energy intake (Kcal Range)
Defensive Lineman (DL)	2,781	2.0-2.1	1.1	6,100-6.400
Offensive Lineman (OL)	2,942	2.0-2.1	1.1	6,500-6,800
Running Back (RB)	2,367	2.1-2.2	1.1	5,500-5,700
Tight End (TE)	2,689	2.1-2.2	1.1	6,200-6,500
Linebacker (LB)	2,442	2.1-2.2	1.1	5,600-5,900
Defensive Backs (DB)	2,179	2.1-2.2	1.1	5,000-5,300
Quarterback (QB)	2,232	2.0-2.1	1.1	4,900-5,200
Wide Reciver (WR)	2,143	2.1-2.2	1.1	4,900-5,200

Table 1

Estimated Range of Daily Kilocalorie (kcal) Intake Based on Player Position and Body Composition. *RMR was averaged across all Cowboys players at their respective positions based on data obtained from the BodPod. The number of tests on specific positions ranged from 22 (Quarterbacks) to 106 (Defensive Linemen). RMR, resting metabolic rate; PA, physical activity

Physical and mental readiness across the NFL season requires a systematic approach to ensure players recover and prepare adequately for the next game. The load imposed on a player during a game greatly impacts the nutritional, physiological, and psychological recovery necessary to return to a 'normal' state. Many factors, including but not limited to minutes played, snaps played, overtime, number of hits/contact, and distance covered (or any combination of) can play a role in manipulating the metabolic and musculoskeletal demand on the player and therefore the induced fatigue. This load experienced by a player is covered in more detail in Chapters 2 and 9.

Recovery from a football game can be influenced by many variables, including nutrition (Beelen et al., 2010; Burke & Mujika 2014; Beck et al., 2015), sleep (Halson 2014; Fullagar et al., 2015; Nedelec et al., 2015; Nedelec et al., 2015), and travel (Nedelec et al., 2015; Simmons et al., 2015). The recovery phase following competition allows a player to restore body fuels and repair damage to the musculoskeletal system. As such, nutritional strategies to promote recovery have primarily focused on carbohydrates and protein as well as fluid intake (Beelen et al., 2010; Burke & Mujika 2014; Beck et al., 2015; Heaton et al., 2017).

There are two distinct seasons across a year which require different sports nutrition guidelines to support the player training demands and goals. Off-season training is characterized by

adaptation, development, and preparation for the upcoming season while in-season training focuses on preparation, execution, and recovery from performance. Given the different training attributes and required nutritional strategies in these seasons, the focus of this chapter is to outline the role sports nutrition plays in supporting players throughout the NFL season by highlighting the nutrition needs to enhance recovery from the previous game and to adequately prepare for the next game and maximize performance. Altogether, personalized nutrition strategies to enhance the musculoskeletal and metabolic recovery processes along with supporting the nutritional requirements to maximize performance during training and competition can make large impacts on acute and long-term performance.

TRAINING PHASES DURING THE NFL SEASON

The 17-week season in the NFL includes 16 games and one bye week that occurs between weeks 4 and 12 for recovery purposes. Throughout the season, players experience weekly macro phases of "recovery" (the days following a game) and "preparation" (the days leading up to a game) cycles.

Within each phase, there are also micro phases of recovery and preparation. For example, recovery following practice and/or strength training is an important consideration to ensure players adequately replenish their muscle glycogen stores and repair damage to the musculoskeletal system to ensure practice preparation is not limited. Both phases have distinct nutrition necessities which will be discussed below, whilst nutrition on game day is discussed in Chapter 5. An example of the weekly cycle can be found in Table 2. To this end, this chapter will discuss the nutrition requirements for the phase of training "preparation" followed by nutrition for training "recovery".

Day	Event	Carbohydrate Intake g/kg/day	Protein intake g/kg/day	Phase
Sunday	Game Day	SEE CHAPTER 5		Competition
Monday	Light movement	4-5 g/kg/day	1.8 g/kg/day	Recovery
Tuesday	Off	4-5 g/kg/day	1.8 g/kg/day	
Wednesday	Full padded, high load, & intense practice	6-8 g/kg/day	1.8 g/kg/day	Preparation
Thursday	Shells, high load, & intense practice	6-8 g/kg/day	1.8 g/kg/day	
Friday	Lighter practice	5-7 g/kg/day	1.8 g/kg/day	
Saturday	Light walk-through	5-7 g/kg/day	1.8 g/kg/day	

Table 2

Typical weekly training schedule when games are played on Sunday. Monday night games push the schedule by one day. Additionally, every NFL team has one short week where they play on Thursday night following a Sunday game and which is managed differently team-to-team. The recommended range of carbohydrate ingestion mimics the likely variations in loads across the micro-cycle (e.g. "light" and "high" load days) as well as individual player training and body composition goals. For the purposes of this chapter, the 'Preparation' phase will be discussed first and 'Recovery' second.

NUTRITION TO PREPARE

During the NFL season, players are fluctuating between states of recovery and preparation with the ultimate goal of preparing their body to perform at the highest level every game across the 17-week season and playoffs. For example, a player may complete a strength session upon arriving to the training facility in the morning at 0600 before practice a couple hours later at 1100. This player has a brief window to implement a nutrition plan to effectively recover from his strength training session while also ensuring he is adequately prepared for practice. Depending on the duration, intensity, and volume of the strength training session, muscle glycogen levels could be depleted by up to ~40% (Koopman et al., 2006) highlighting the need for adequate carbohydrate feeding to ensure muscle glycogen replenishment.

Football, along with its training principles, is a high-intensity intermittent sport composed of short bursts of explosive movements (i.e. sprinting/blocking in football or strength training and sprinting for training). These short bursts of explosive movements require skeletal muscles to rapidly utilize and replenish adenosine triphosphate (ATP). Skeletal muscle ATP is generated through aerobic and anaerobic metabolic pathways. These two systems do not operate in isolation, rather they work synergistically such that ATP is produced utilizing anaerobic metabolism during high-intensity sprints while aerobic metabolism is utilized during the recovery period to resynthesize muscular ATP stores and ensure other physiological systems within the body are sufficiently fueled.

Anaerobic metabolism produces ATP at a much faster rate than aerobic metabolism; although aerobic metabolism can create up to 12 times the amount of ATP (even more ATP is produced by the oxidation of fatty acids). Given the speed at which ATP is created by these two pathways, aerobic metabolism is too slow to support the high rate of ATP necessary during high-intensity

movements utilized by football players. During a high-intensity sprint lasting 6 seconds (similar to the length of a football play (Iosia & Bishop 2008), the anaerobic production of ATP is fueled by glycogen degradation through glycogenolysis which contributes 50% of the ATP production, whereas phosphocreatine (PCr) contributes 48%, and the muscle's small store of ATP contributes the remaining 2% (Cheetham et al., 1986). The rapid generation of ATP utilizes muscle glycogen but is accompanied by the production of lactate and hydrogen ions which are associated with increased fatigue (Girard et al., 2011). However, during the recovery period between high-intensity bouts (or plays in football), aerobic metabolism is responsible for the re-synthesis of PCr as well as supplying the energy for the submaximal running between bouts. As the duration of training progresses and the total number of 'plays' increases, aerobic metabolism will increase energy contributions, especially during the lower intensity activities between sprints. (Balsom et al., 1999; Parolin et al., 1999). Given the need for rapid energy generation due to the high-intensity demands of football training, ensuring adequate glycogen availability before exercise is paramount to ensure players are adequately prepared for the stressors of the training.

Carbohydrates

Increasing the players muscle and liver glycogen stores is a priority when preparing Cowboys players for training. Research in repeated cycling sprints (Balsom et al., 1999) and soccer players (Balsom et al., 1999) has suggested muscle glycogen concentrations can be increased and performance improved with consuming a diet composed of 65% of carbohydrates, compared to 30%.

Players should aim to consume ~2.5 g/kg body mass of carbohydrates ~3 hours before training has been shown to increase muscle glycogen levels by 11-15% (Chryssanthopoulos, Williams et al. 2004, Wee, Williams et al. 2005). As practice and training approaches and the window to properly digest food consumed is shortened, players should aim to consume high-glycemic index carbohydrates over low-glycemic index carbohydrates due to their faster digestion and absorption kinetics. This results in more readily available glucose in the system circulation and/or for storage as muscle glycogen along with reducing the likelihood of gastric distress during practice and training. When sufficient carbohydrates are consumed to support the demands of training, the difference in glycemic index between carbohydrates is likely abolished. To date, no research has been completed comparing LGI and HGI pre-exercise carbohydrate meals on American football performance.

Fat and Protein

Fat and protein are important components of the player diet. Their role in recovery processes are discussed later in this chapter. Their consumption prior to training however may not confer additional benefits and may potentially impair performance. Protein and fat are satiating macronutrients due to the slow digestion and gastric emptying nature. This slowing in digestion and gastric emptying can increase the chance of GI distress, potentially leading to impaired performance in subsequent training or practice sessions and can reduce the ability for glucose from carbohydrates to be delivered to the systemic circulation and muscle. Protein and fat consumption in the pre-training period results in a smaller rise in plasma insulin levels which negates the inhibition of fatty acid mobilization therefore increasing the rate of fat metabolism and slowing the rate of muscle glycogen oxidation during subsequent exercise. The high-intensity nature of football relies on a high rate of glycogenolysis and PCr degradation to support the necessary ATP production. As discussed previously, fat metabolism is insufficient in generating ATP at the rate necessary to support the high-intensity nature of football.

Fluid

Football players experience numerous challenges in regards to thermoregulation and hydration during training. During training camps, practice, and games players may wear full protective equipment (i.e. shoulder pads, helmets, and upper-leg protection) which impairs the players thermoregulatory capacity and may increase sweat rates to offset the impaired heat loss capacity. Additionally, Texas is typically hot during the football season with temperatures reaching over 100° F and some players (especially linemen) are larger, both of which can influence the thermoregulatory response and cause higher than normal sweat rates. Ideally, players arrive at the training facility properly hydrated with access to fluids prior to training may limit the negative performance effects of hypohydration associated with large sweat losses found in football athletes. A more in-depth look at fluid needs of football players can be found in Chapter 6 of this book and this review by Davis et al., (2016).

Other Nutrients to Consider

Collagen

Musculoskeletal soft tissue injuries (such as strains, sprains, and tears) are the most common injuries suffered by players. Nearly 70% of all injuries in football are soft tissue sprains or strains (Feeley et al., 2008) which can limit a players ability to return to play at all levels of competition. Due to the extreme load placed on football players during training and competition, nutritional strategies to optimize tendon and ligament health may aid in reducing the occurrence of such injuries and may potentially reduce the time to return to play. Recent research in tissue-engineered models has suggested that consuming ~15 g gelatin with 50 mg ascorbic acid (vitamin C) can increase blood markers associated with collagen synthesis (Shaw et al., 2017). Although consumption of gelatin may aid in the recovery process of soft tissue tendon breakdown from football training, the available research (although limited, not yet conclusive and rapidly evolving) has suggested that consumption between 30-60 minutes prior to training may help maximize the availability of the amino acid collagen pre-cursors in the blood stream. Collagen is discussed more thoroughly in Chapter 8 of this book.

Caffeine

One of the most widely researched dietary supplements is caffeine. The ergogenic effect of caffeine ingestion has been widely established with benefits found in endurance performance (Peeling et al. 2018) and high-intensity exercise (Astorino & Roberson 2010). A more detailed review of caffeine supplementation and the potential ergogenic benefits can be found in Chapter 7. However, limited research has investigated the effects of caffeine on team sport performance, especially football players.

Beta-alanine

The high-intensity and repeat sprint nature of football can lead to intramuscular hydrogen ion build-up which lowers muscle pH and is associated with muscular fatigue. Reducing this muscular fatigue through beta-alanine supplementation to buffer intracellular hydrogen ions may be of interest to football players. Beta-alanine supplementation may support periods of higher training volumes such as pre-season training camp. Chronic (~30-day) supplementation of 4.5 g/day of beta-alanine has been shown to reduce subjective measures of muscle fatigue during NCAA collegiate football training camp while supporting higher training volume (Hoffman et al., 2008). A more comprehensive review of beta-alanine and the potential benefits of supplementing to support football players can be found in Chapter 7.

NUTRITION TO RECOVER

In the days following a game, rehydrating, replenishing muscle glycogen, and repairing damage to the musculoskeletal system are a priority. Research in high-school and collegiate football players indicates a football game causes reductions in neuromuscular function and an increase in muscle damage (as indicated by elevated creatine kinase (CK) concentrations), stress hormone imbalances (e.g. cortisol), and perceptual fatigue for up to 4 days (Hoffman et al., 2002; Kraemer et al., 2009; Fullagar et al., 2017). However, the effect of a professional football game on these measures is not well established. In our experience anecdotal evidence suggests many NFL players do not “feel normal” for 5-6 days following a game. To adequately replenish muscle glycogen stores and to stimulate the musculoskeletal regenerative process in the recovery period following training, it is important for the players to consume an appropriate amount of dietary carbohydrate, and some protein, which is reflective of the demands (intensity, duration, impact etc.) of the session in question. Unfortunately, energy expenditure during football is poorly understood due to the technical difficulty in obtaining the energy cost of repeated body contact by players through tackling and blocking and is currently mostly based on player’s movements and estimations from intermittent high-intensity running

research. A mixture of anaerobic (mostly during high-intensity sprints, tackles, and blocking) and aerobic (lower intensity running and recovery between plays) energy systems are responsible for energy production during intermittent, team sport activities (Williams & Rollo 2015).

Protein

Dietary protein intake is important during recovery days for muscle repair, muscle remodeling and immune function. A key component of the muscle remodeling process is muscle protein synthesis (MPS) which synthesizes amino acids into functional contractile myofibrillar proteins and energy producing mitochondrial proteins. The MPS response to protein intake can be influenced by body size and exercise type (whole body versus limb specific), protein source, per meal dose, daytime feeding pattern, and intake timing in relation to exercise (Witard et al., 2016). Recommendations for post-training protein consumption are 0.3 g/kg as soon as possible following the training (Macnaughton et al., 2016) and 0.3 g/kg/meal for 4-5 meals spaced evenly across the day (Mamerow et al., 2014). For a 250-pound player, this equates to 35 g protein following the game and another 35 g at each meal thereafter. Consuming leucine-rich rapidly digestible protein sources, such as whey protein, exhibit greater stimulation of MPS during recovery compared to other protein sources of lower leucine composition such as soy, micellar casein (Tang et al., 2009), and wheat (Gorissen et al., 2016). The importance of leucine consumption is linked to directly activating the mechanistic target of rapamycin complex 1 (mTORC1) through the leucine-binding protein sestrin2 which increases MPS (Gai et al., 2016). As long as the optimal protein dosage is consumed, co-ingestion of protein with other nutrients such as carbohydrates offers no additional advantage in terms of muscle remodeling (Koopman et al., 2008; Glynn et al., 2010; Staples et al., 2011). Nevertheless, carbohydrate consumption is important for replenishing glycogen storage which will be discussed in the next section. Therefore, consuming the optimal amount of protein at the right time during the recovery phase may translate to improved recovery from football games as well as during intense training.

Carbohydrates

The acyclic nature of football games including repeated high-intensity bouts of sprints, accelerations, cuts, backpedals, tackles, and collisions requires the use of muscle and liver glycogen to supply the working skeletal muscle the energy necessary for these high-intensity bouts. During short sprints lasting up to 6-s, glycogen accounts for 50% of the ATP production, whereas phosphocreatine (PCr) contributes 48% and remaining 2% is provided by the muscle's store of ATP (Cheetham et al., 1986).

Although there are no studies on football players' glycogen utilization during a game, research in rugby and Australian football games have found that players can utilize up to ~40-65% of their muscle glycogen depending on in-game carbohydrate consumption strategies (Bradley et al., 2016; Routledge et al., 2018). However, differences in rules and styles of play limit the extrapolation of this data to the football player. Although there are similarities in the movement patterns between these sports, the demands a Cowboys player experiences are different than a rugby or Australian footballer. For example, a wide receiver may cover a similar distance during a game as a rugby player (wide receiver: 5531 m vs. rugby back: 6544 m); however, rest periods during games differ drastically as rugby and Australian players play both offense and defense while football athletes only play one side and rest while the other is in play.

Since glycogen utilization is important for training and competition, replenishing depleted glycogen stores following training is of importance. This is because, inadequately replenishing endogenous glycogen and reduced endogenous carbohydrate availability is associated with impaired team sport performance (Krustrup et al., 2011; Gunnarsson et al., 2013). Although football players typically have a full week between games, allowing for plenty of time for glycogen resynthesis, optimal carbohydrate intake during the recovery phase that is flexible, periodized, and personalized can enhance short-term recovery and promote longer term adaptations and health.

Consuming a moderate carbohydrate diet (4-7 g/kg body weight/day) (Holway & Spriet 2011), including 1-1.2 g/kg body weight in the post-game period, will aid in glycogen resynthesis. However, a periodized and personalized approach should be followed, based on the individual player load experienced e.g. a kicker/punter will have experienced a different level of glycogen depletion compared to a defensive back or wide receiver. As such, a diet ensuring appropriate carbohydrate availability aids in supporting daily fueling demands (Burke et al., 2011), mitigation of energy deficit, fatigue, and associated injuries (Balsom et al., 1999), and maintenance of immune function (Meeusen et al., 2013) with higher amounts likely warranted in players who have experienced a higher load. For a 250 pound player, the post-game carbohydrate consumption for recovery could entail up to 135 g carbohydrates as quickly as possible post-game and then another 135 g carbohydrates at regular meals. Carbohydrate from both food and fluids are effective in restoring glycogen, therefore, the preference of the player, practicality, and availability should dictate the consumption method. Late evening games, especially on the road, on Sunday and Monday nights may play large roles in determining the practicality and availability of post-game refueling. The suggested range in carbohydrate intake allows for the likely variations in loads (e.g. rest versus training day) as well as individual player training and body composition goals (Chapter 3).

Fluids

Rehydration is an important part of the post-exercise recovery process. In the post exercise occasion, the ingestion of carbohydrate, fluid and electrolytes are required for replenishing depleted glycogen stores and rehydration, respectively (Shirreffs, Taylor et al. 1996). If players have accrued a body mass (BM) deficit (i.e. hypohydrated), they should aim to completely replace fluid and electrolyte losses prior to the start of the next training session or game. In most cases players can drink according to thirst as there is time to restore fluid balance before the next training sessions.

If hypohydration is severe (>5% of BM) or rapid rehydration is needed (e.g. < 24 h before next training or games or pre-season two-a-day sessions) the replacement of fluid and electrolytes in the post-exercise period takes on greater importance. The main factors influencing the effectiveness of post-exercise rehydration are the volume and composition of the fluid consumed. The recommendation is to drink ~1.5 L of fluid for each 1 kg (~23 oz. per 1 lb) of BM deficit (Shirreffs and Sawka 2011). This is because some of the ingested fluid will be excreted in urine and additional sweat loss, and studies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indicate that ingestion of 150% or more of weight loss is required to achieve euhydration within 6 hours following exercise (Shirreffs and Maughan 2000). In most other situations, water and sodium can be consumed with normal eating and drinking practices with no urgency.

Drinking plain water is not the ideal post-exercise rehydration beverage when rapid and complete restoration of body fluid balance is necessary and where all intake is in liquid form (Snell et al. 2010). Ingestion of water alone in the post-exercise period results in a rapid fall of the plasma sodium concentration and plasma osmolality. These changes have the effect of reducing the stimulation to drink and increasing the urine output, both of which will delay the rehydration process. Plasma volume is more rapidly and completely restored in the post-exercise period if sodium chloride is added to the water consumed (Maughan and Leiper 1995, Snell, Ward et al. 2010).

The rehydration drink should also contain carbohydrate (glucose or glucose polymers) because the presence of glucose will also stimulate fluid absorption in the gut and improve beverage taste. Carbohydrate solutions ranging from 6 to 12% have been shown to promote greater fluid retention compared with electrolyte-matched placebos (Evans, 2009, Evans, 2011, Osterberg et al. 201, Kamijo, 2012). The increased energy density and/or osmolality of highly-concentrated carbohydrate solutions (e.g., 10-12%) could delay gastric emptying or intestinal absorption. In turn, this would slow the appearance of fluid into circulation and attenuate diuresis during rehydration. Following exercise, the uptake of glucose into the muscle for glycogen re-synthesis should also promote intracellular rehydration (Gisolfi et al. 1992, Gisolfi et al. 2001).

Milk, which contains a comparable amount of sodium as sports drinks (~20-30 mmol/L), has also been studied for its efficacy in promoting fluid retention during rehydration. Recent research suggests that milk protein (80% casein, 20% whey) can enhance post-exercise fluid retention compared with traditional sports drinks (i.e., 6-8% carbohydrate-electrolyte solutions) (Shirreffs, Watson et al. 2007/7, Watson 2008, James, Clayton et al. 2011, Desbrow 2014, Volterman KA 2014). However, most studies report that whey protein per se does not confer improved fluid retention compared with water or sports drinks (Seifert, Harmon et al. 2006, James LJ 2012, James LJ 2014, Hobson R 2015).

Other Nutrients to Consider

Omega-3

Recently, there has been increased attention on omega-3 polyunsaturated fatty acids (PUFA) in the context of nutritional support for player recovery (Heaton et al., 2017) due to their role in promoting muscle remodeling, muscle repair, and immune surveillance. A players omega-3 status can be found utilizing the omega-3 Index which is a percentage of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (two of the most bioactive omega-3 PUFA) in total erythrocyte fatty acids (von Schacky et al., 2014). The omega-3 Index zones are established for cardiovascular disease: high risk, <4%: intermediate risk, 4%-8%; and low risk, >8% (Harris & Von Schacky 2004). Based on a small sample of NFL players, GSSI testing has found only 6% of players had a desirable omega-3 Index. The majority of the remaining players (88%) were classified as having an intermediate range, with ~6% displaying an undesirable omega-3 Index range. Although this research is preliminary and omega-3 supplementation is considered a class B supplement by the Australian Institute of Sport, preliminary research has shown that supplementing Rugby Union players with omega-3 PUFA helped maintain explosive power during pre-season training (Black et al., 2018). Additionally, supplementation in recreational athletes and competitive soccer players has shown reductions in inflammation from strenuous eccentric exercise (Jouris et al., 2011; Corder et

al., 2016; Philpott et al., 2018; Tsuchiya et al., 2019) and can aid in attenuating strength loss and improve range of motion (Tsuchiya et al., 2016). Considering a majority of the NFL players tested outside the desirable range for the omega-3 Index, increasing omega-3 PUFA consumption through supplementation or dietary sources such as fish oils, krill oils, cold water fatty fish (like salmon and tuna) may aid in recovery from the physical stresses of an NFL season.

Vitamin D

There is emerging evidence that suggests vitamin D plays a role in the repair of damaged muscle tissue (Owens et al., 2015) . Vitamin D precursors can be obtained through the diet or from sun exposure; however, the amount of vitamin D obtained from sun exposure is highly variable depending on many factors including latitude, environment, season, skin pigmentation, clothing, and sunscreen use (Owens et al., 2018).

Polyphenols

There is growing interest in fruits, vegetables, foods, and spices that contain high amounts of polyphenols due to their antioxidative and anti-inflammatory properties. Consumption of foods such as turmeric (curcumin as the active ingredient), tart cherry, beetroot (dietary nitrates), and quercetin have been investigated for their polyphenolic properties and potential benefit in supporting recovery from strenuous exercise. Preliminary research in these food products is promising but preliminary and not yet football specific; however, tart cherry is the most encouraging in reducing muscle soreness and accelerating recovery (Bell et al., 2016; Vitale et al., 2017). More research should be conducted to determine proper dosage, timing, and efficacy of polyphenolic foods and products in football (see Chapter 7 for more details).

Nutrient	Dosage	Best Sources	Benefits	Strength of evidence
Protein	0.3 g/kg as soon as possible post-training 0.3 g/kg/meal across 4-5 meals	Leucine-rich complete proteins: whey and milk Complete proteins: lean meats, poultry, fish, eggs, milk, yogurt, soy, tofu, quinoa	Support muscle protein synthesis Support muscle repair and muscle remodeling	Good Good
Carbohydrate	1-1.2 g/kg within the first hour post-training 4-7 g/kg/day spread throughout the day	Quickly digested and absorbed: sports drinks, bars, shakes, white bread Whole grains, potatoes, sweet potatoes, brown or wild rice, fruits, vegetables, dairy products	Replenish glycogen Support the demands of training and recovery	Good Good
Fluid	1.0-1.5 L of fluid for each 1-kg body mass lost	Chilled fluid with sodium (20-50 mmol/L)	Restore body fluid balance and plasma volume	Good
Omega-3 PUFA	~3 g/day of EPA/DHA	Cold water fatty fish (tuna, salmon) fish oils, krill oil	Reduce inflammation Support immune function Support muscle repair and remodeling when protein intake is insufficient	Fair
Vitamin D	RDA (adults) 600 IU/day Vitamin D status (blood 250 HD) 20-50 ng/L	Sunlight, supplements, fortified foods, fatty fish, egg yolk	Support muscle repair and recovery	Fair
Gelatin/collagen + vitamin C	≥15 g of collagen hydrolysate with ≥50 mg of vitamin C delivered ~1 h before training	Gelatin, vitamin C rich foods (e.g. oranges, raspberries, grapefruit), dietary supplements	Promote collagen synthesis	Fair
Polyphenols	>1000 mg polyphenols/ day for 3+ days for recovery	Turmeric, tart cherry juice, beetroot, blueberries, blackcurrants, cocoa	Antioxidant and anti-inflammatory to support recovery from muscle damage	Fair

Table 3

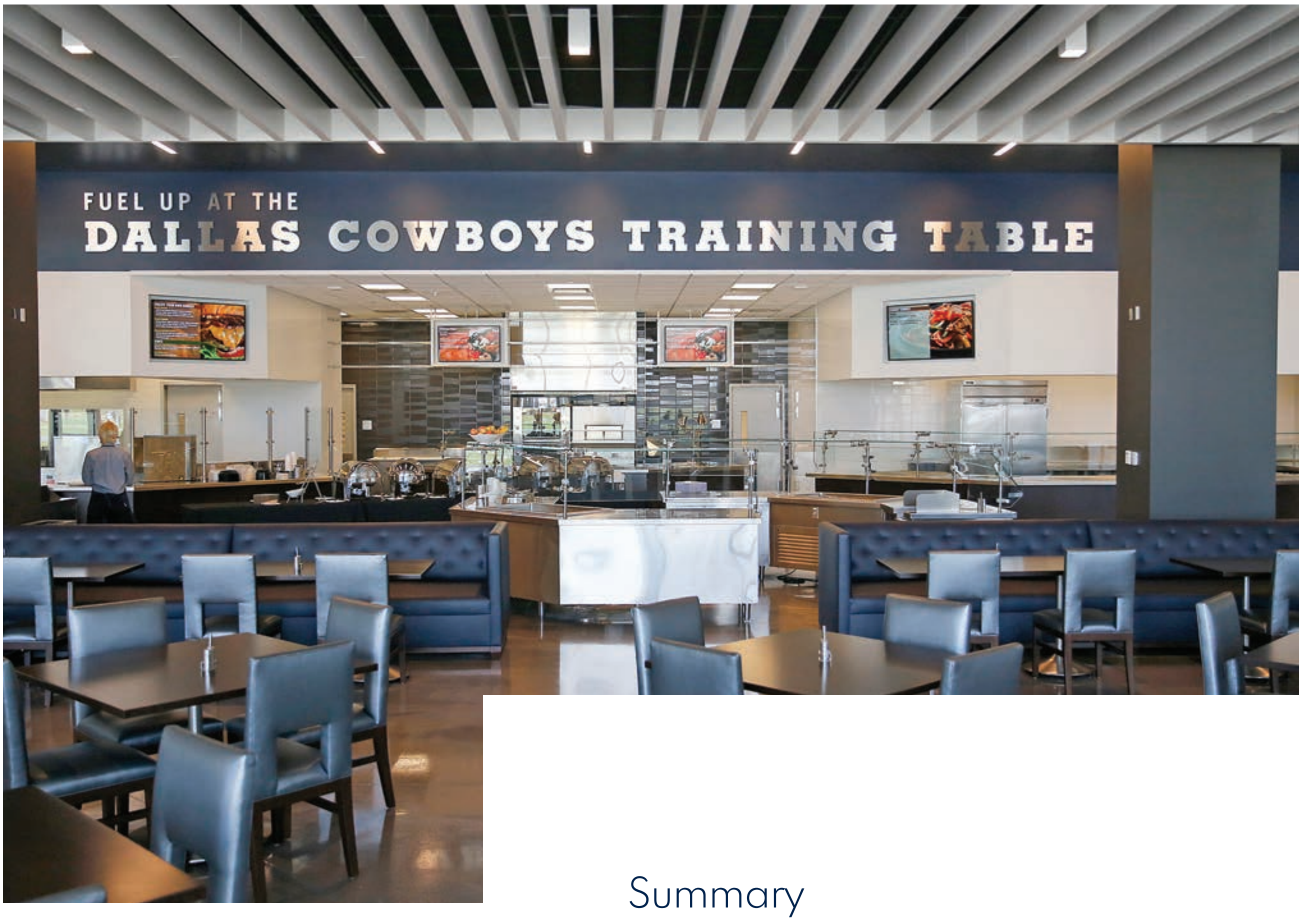
Macronutrients, micronutrients, and supplements to support recovery, including dosage, sourcing, and benefits.

Adapted from (Heaton et al., 2017) DHA: docosahexaenoic acid, EPA: eicosapentaenoic acid, PUFA: polyunsaturated fatty acids, RDA: recommended dietary allowance, 25OHD: 25-hydroxyvitamin D

*Strength of evidence conclusion statements are assigned a grade by the authors based on the systematic analysis and evaluation of the supporting research evidence. Grade I = good; grade II = fair; grade III = limited; grade IV = expert opinion only; and grade V = not assignable (because there is no evidence to support or refute the conclusion). *See grade definitions at andevidencelibrary.com*

TRAINING TABLE

At the center of The Star training facility resides a state-of-the-art dining area called the “Training Table”. This facility has been established to guarantee all players have access and visibility to the proper appropriate nutrition throughout the training week. The significant investment, both in time and finance, to the nutritional landscape and capabilities highlights the Dallas Cowboys appreciation for the importance of Sports Nutrition. The aim of the Training Table is to ensure the players are appropriately fueled, recovered, and ready to perform throughout the entire NFL



season. Collaborations between the sports medicine, strength and conditioning, and the team Sports Dietitian is integral in ensuring player performance is underpinned with the proper knowledge, experience, and application.

Summary

During the NFL season, players are fluctuating between states of recovery and preparation. The sports nutrition strategy must therefore reflect the training phase. The goal is to prepare the player to perform at the highest level for every game across the 17-week season and playoffs. Sports nutrition plays a vital role in supporting the strength, speed, skills, and overall performance development of a player along with promoting recovery from the demands of football training and competition. Consuming a diet ensuring appropriate carbohydrate availability during the training recovery days and preparation days will aid in supporting daily fueling demands, glycogen resynthesis, mitigation of energy deficit, fatigue, and associated injuries, and maintenance of immune function in players (e.g. 5-7 g/kg/day for players whose training/competition load was high). Optimal dietary protein intake is important for recovery for a multitude of reasons including facilitating muscle repair, muscle remodeling, and immune function. Consuming 0.3 g/kg/meal for 4-5 meals spaced evenly across the training days is recommended. Other nutrients, including omega-3, vitamin D, tart cherry, and collagen, may also have the potential to support the players “preparation” or “recovery” training phases and should be considered at an individual level.

Chapter 4: In-Season Sports Nutrition for Training & Practice

SUMMARY

During the NFL season, players fluctuate between states of recovery and preparation. **The sports nutrition strategy must therefore reflect the training phase.**

When training and competition load is high, players should aim to consume **5-7 g/kg/day of carbohydrates** to support daily fueling demands, glycogen resynthesis, mitigation of energy deficit, fatigue, and associated injuries.

Players should aim to consume **0.3 g/kg/meal of protein spaced evenly across 4-5 meals** to ensure appropriate dietary intake to facilitate muscle repair, muscle remodeling, and immune function in support of recovery from training and competition.

The goal of a personalized sports nutrition approach in training is to prepare the player to perform at the highest level for every game across the 17-week season and playoffs.

Nutritional needs of players vary by position, body type, and training demands, highlighting the importance of a **personalized approach to nutrition** recommendations to improve training adaptations, improve performance in games, improve recovery from games, and aid in supporting long-term health.

Other nutrients including

omega-3, vitamin D, tart cherry, and collagen

may also have the potential to support the players "preparation" or "recovery" training phases and should be considered at an individual level.

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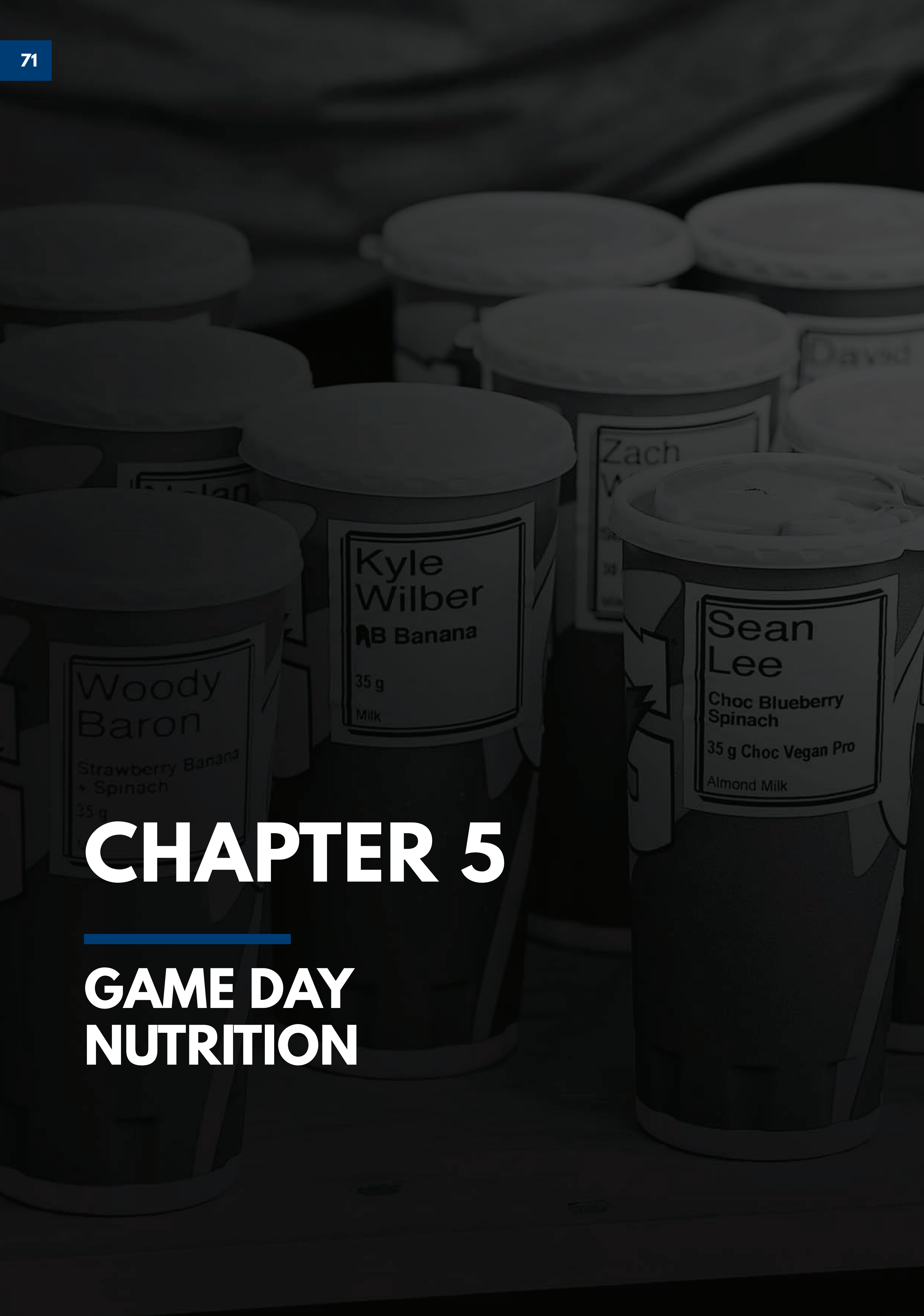
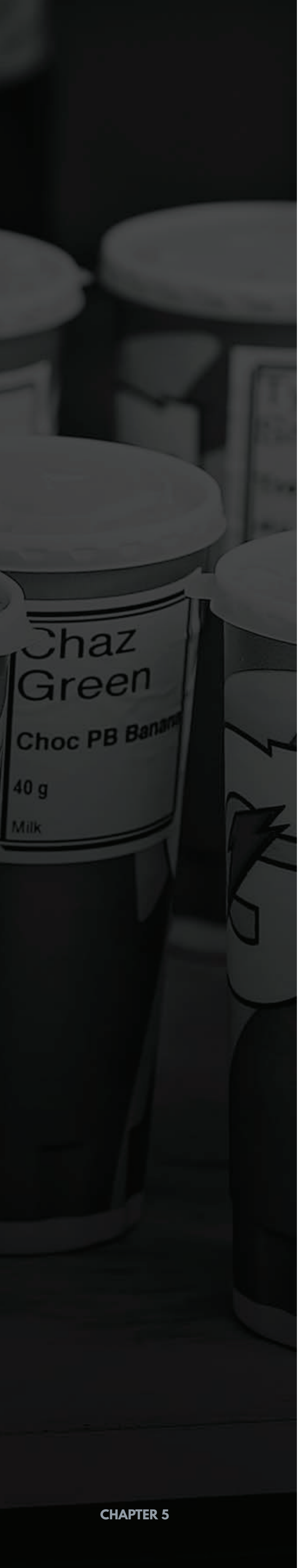


CHAPTER 5

GAME DAY NUTRITION



GAME DAY NUTRITION

Lisa Heaton, Meagan Nielsen and Rebecca Randell

Introduction

The team's success on game day is the overall objective of the player. Understanding the energy systems which underpin player movement, as well as the demands of the players position (Chapter 2), is important when designing a game-day nutrition strategy for a football player. Unfortunately, the impact of nutrition strategies on American football performance has not been extensively studied. Therefore, relevant extrapolations must to be made from existing sports nutrition literature and applied to the football game day occasion. To this end the current chapter provides nutrition recommendation before, during and after the game, to support play preparation, performance and recovery, respectively. Nutrition considerations for specific positions will also be discussed.

Pre-Game Nutrition

Pre-game nutrition objectives:

Player begins the game with adequate carbohydrate stores	Player begins euhydrated	Provide player with confidence and routine

For football players the pre-game fluid and nutrition strategy may begin at least 3-4 hours prior to the game. In the first instance, consuming a pre-game meal and/or snack high in carbohydrate will help to replenish liver glycogen stores and continue to fill muscle glycogen stores. This is especially important if the game is at noon, and players have slept until they are required to arrive to the facility, because liver glycogen stores will be significantly depleted following an overnight fast while sleeping.

The Academy of Nutrition and Dietetics, Dietitians of Canada and American College of Sports Medicine consensus statement recommend the ingestion of a carbohydrate rich meal, consisting of 1-4 g of carbohydrate per kg of body mass (g/kg/bm), 1-4 h before a game (Thomas et al. 2016). This is because the consumption of a meal containing 2.5 g/kg/bm has been shown to increase muscle glycogen by 11-15% and liver glycogen by 33%, following an overnight fast (Wu et al. 2006).

In addition, increasing the players body store of carbohydrate by feeding carbohydrate 3-4 hours prior to exercise, has been found to improve endurance performance (Chryssanthopoulos et al.1997). Therefore, this is of relevance during football games which may last more than 3h, especially in the last quarter.

NFL Game Time	Meal 1	Snack 1	Meal 2	Snack 2	Meal 3	Snack 3	This may end up being Meal 3 for some
12:00pm	Between 8:00am-11:00am	11:00am	Post-game (3:00-3:30pm)*	N/A	7:00pm	Within 1 hour of bedtime	
3:25pm	7:00-9:00am	10:00-11:00am	11:30am-2:00pm	2:00pm	Post-game (6:30-7:00pm)*	Within 1 hour of bedtime	
7:20pm	Within 1 hour of waking	N/A	12:00pm	2-3pm, if needed	3:00-6:00pm	6:00pm* if required	Post-game (10:30-11:00pm)

*Consider carbohydrate mouth rinse or carbohydrate snack as tolerated during game/halftime.

Table 1

Meal timing based on game time.

The precise timing and composition of meals and snacks will vary depending on game start time (Table 1), player preferences, and the gastrointestinal tolerance of each individual player (and, potentially, player position). However, it is advised that players consume easily digestible carbohydrates (foods with a high glycemic index) and avoid high fat and fiber foods (see Table 2 for practical recommendations) as it gets closer to kickoff time. Games that start during the early afternoon timeslot (12 pm) may only allow for one meal and snack to be consumed pre-game. On the other hand, late afternoon and night games (3:25 pm and 7:20 pm) allow more time to focus on multiple meals and snacks throughout the day. Education related to meal timing and basic composition will help the football player prepare for the game.

In addition to food consumption, ingestion of fluid is important before a game. This is because starting exercise in a hypohydrated state may negatively affect performance, especially when exercise lasts >60 min, such as a football game (Shirreffs et al. 2011). To ensure adequate hydration prior to a game, players are advised to drink a volume of fluid specific for their BM. Players should gradually drink 5-7 ml of fluid per kg BM, at least 4 hours before exercise, this equates to 7.5-11 oz for a 220 lb player (Sawka et al. 2007; Shirreffs et al. 2011;Thomas et al. 2016). By drinking approximately four hours before exercise, there is sufficient time for urine output to be expelled before players are expected to perform. In addition, it avoids the situation of players drinking too much fluid immediately before exercise, which increases the risk of the player feeling bloated and experiencing gastrointestinal distress. However, if during the 4 hours pregame, players do not pass urine over that time period, or if the volume is low and dark in color, then a further 3-5 mL/kg bm is recommended (i.e., ~4.5-7.5 oz. total for a 220 lb player). Fluids containing sodium (i.e. sports drinks) or drinking fluids alongside foods containing sodium will help with fluid retention and distribution. It is important to note that fluid intake is of course self-regulated by the player. Therefore, adequate education should be in place so that the player can identify signs of hypohydration (and hyperhydration) themselves and modify their drinking behavior appropriately.

Immediately before the game starts, or before the warmup, players may be recommended to ingest a small bolus (25-30 g) of carbohydrate. The carbohydrate ingested will blunt the output of liver (hepatic) glycogen and in turn spare liver glycogen stores (Howlett 1998). Preserving the limited store of glycogen may delay player fatigue and preserve performance, especially towards the end of the game.

Controversy has surrounded carbohydrate feedings immediately prior to exercise, as it has been assumed that the carbohydrate ingested will cause hypoglycemia (low blood glucose), suppress fat metabolism and accelerate glycogen breakdown (Jeukendrup et al. 2010). However, studies have found that carbohydrate consumption in the hour before exercise has no detrimental effects on performance (Hawley et al. 1997; Jentjens et al. 2003).

It should be noted that the aforementioned negative connotations associated with carbohydrate feeding, in the hour before exercise, can affect a small number of individuals. If these symptoms do occur they may be diminished by consuming; (1) carbohydrate in the 5-10 min before a game, (2) low GI carbohydrates (carbohydrates which take longer to digest in the body) and (3) consuming carbohydrate during the game (Jeukendrup et al.

2010), instead of ingesting carbohydrate in the hour before. As per any nutrition strategy, these recommendations should be practiced in training before being implemented in a game environment.

Supplementation is discussed in chapter 7, but it is important to note that caffeine may be of benefit for football players. The absorption rates of caffeine are detailed in the aforementioned chapter, but it appears that caffeine may be ideal to consume before kickoff with potential ergogenic effects lasting the length of the football game (60 min uninterrupted; 4 h with interruptions).
In conclusion, the aim of the pre-game nutrition strategy must achieve a balance between fueling the player and promoting adequate hydration levels, whilst ensuring gastrointestinal comfort and "readiness" to play. It is important to achieve these goals within the context of the team culture as well as the players habitual routine to which they are accustomed.

Purpose and benefits of a fuelling plan 1-4 hours pre-game

Carbohydrate	• Carbohydrates will provide the energy needed for game play. • Focus on carbohydrates that the player is used to eating before a game. • Choose nutrient-dense carbohydrates (e.g. potatoes vs. potato chips).
Protein	• Choose lean options that are complete proteins (meaning they contain all the essential amino acids) i.e. lean chicken breast, fish, quinoa. • Avoid overindulging on protein before a game, so that there is room on the plate for carbohydrates. • Aids satiety
Fat	• Choosing foods high in fat too close to game time may cause upset stomach. • Choose fats that the player knows they can tolerate close to game time (e.g. they consume these foods close to practice times), or only get fats from protein and carbohydrate choices in this meal.
Fluid	• Starting a game in a hydrated state is important for performance. • Consume fluids containing sodium, or drink fluid alongside sodium containing foods to aid fluid retention. • Alcohol should be avoided prior to a game.

Table 2
Nutrition recommendations for 1-4 h pre-game

During-Game Nutrition

The objectives of in-game nutrition are:

Prevent fatigue	Optimize performance: physical and skill	Prevent significant hypohydration or over drinking	Prevent GI disturbances

Carbohydrate Fueling

Numerous studies have demonstrated that the intake of carbohydrate during prolonged sessions of moderate-intensity or intermittent high-intensity exercise can improve endurance and performance. This enhancement in performance is often attributed to the maintenance of plasma glucose, as well as maintaining high rates of carbohydrate oxidation and preserving muscle and liver glycogen stores. Ingestion of carbohydrate during exercise has also been shown to improve skill execution and decision making (Ali et al. 2009).

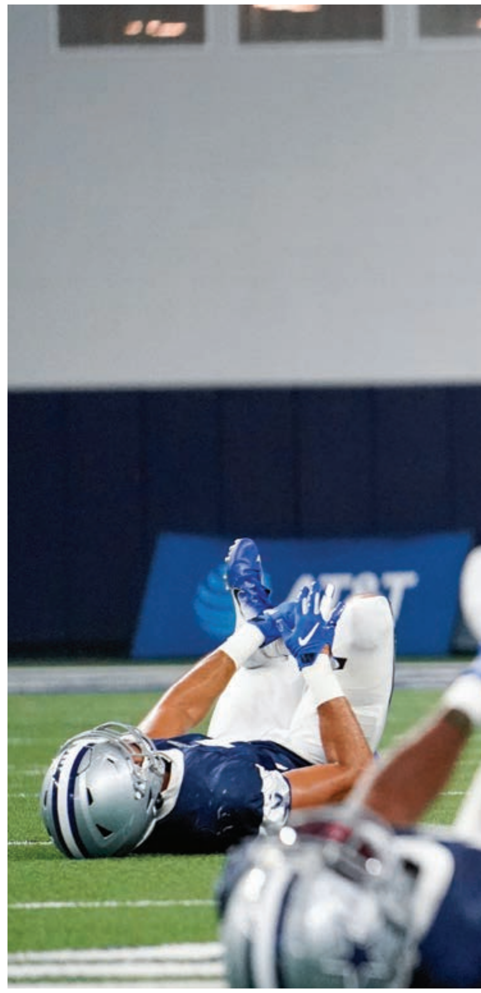
The general fueling recommendation for a team sport player is to consume 30-60 g/h of easily digestible carbohydrate (Thomas et al. 2016). However, the exact amount of carbohydrate a football player should consume per hour will depend upon a variety of factors, including but not limited to playing time, position demands (e.g. sprinting vs. blocking), pre-game nutrition strategy and gastrointestinal tolerance.

Completing repeated plays in football may result in player fatigue (Chapter 2). Thus, it would be intuitive that feeding carbohydrate at recommended rates may attenuate declines in power output.

However, to date only one study has tested the effect of carbohydrate intake during a simulated football game (50-play scrimmage) on sprint performance in football players (Criswell et al. 1991). In this study a 170 mL carbohydrate beverage (7% carbohydrate solution), or placebo, was consumed before warm-up, before the start of the scrimmage, and at 4 separate fluid breaks during the scrimmage (total of 71 g carbohydrate consumed). A test, consisting of eight 40-yd sprints separated by a 40-s jog, was conducted before and after the scrimmage. The authors of this study found no differences in mean or peak sprint velocity between the carbohydrate and placebo condition.

It is important to note that carbohydrate ingestion during exercise has been shown to be consistently associated with improved skill-based performance and decision making (Russell et al. 2014). As these are essential elements to player performance, carbohydrate ingestion during football games should be considered.

As previously mentioned in Chapter 2, field coverage, sprint time, etc. of each position will vary with each team and its style of play. This may even change depending on their opponent's defensive or offensive capability. For example, in some games the quarterback may cover a significant amount of the field sprinting, while in other games the quarterback may be quickly shut down on several plays by the opposing defense. Starters for each position and/or players that play a significant amount of each game have a greater need to focus on recovery nutrition than the players that only come in on a few plays/2nd or 3rd string players that sit the bench in anticipation of needing to provide coverage for starters that get pulled. It is important for the team sports dietitian to educate each individual player on his nutritional needs based not only on body mass, but also on assessment if their activity was low



(did not play or played very little), moderate (played in game, but infrequent and less than 60 minutes of playing time), or high (played a significant portion of the game, >60 minutes of playing time).

The source of carbohydrate ingested can come from a variety of forms, for example: beverages, gels, chews or food, depending upon the preference of the player. A key factor is to focus on high GI carbohydrates to limit the potential for gastrointestinal distress. High GI carbohydrates are digested quickly and are rapidly absorbed. Therefore, these sources can be utilized for quick energy, via the body's energy systems and in turn spare muscle and liver glycogen stores. Some examples of common sports nutrition products, and the approximate amount of carbohydrate, can be found in Table 3. However, it is recommended that the practitioner works with each player to understand everyone's specific needs, preferences and tolerances.

Sometimes players cannot tolerate nutrient consumption in-game due to upset stomach yet need the energy to maintain performance. If a player has consumed adequate nutrients prior to the game, another option is to mouth rinse with a carbohydrate source. Research has found that carbohydrate for energy is not confined to its metabolic advantage, but also is associated with impacting the central nervous system. Due to this, simply rinsing the mouth with a carbohydrate beverage without ingesting it may have a positive impact on athletic performance (Rollo et al. 2011; Rollo et al. 2015).

Source	**Portion**	**Grams of CHO**
Sports Drink - 6% solution	12 fl oz	21 g
Gel	1 gel	20-30 g
Chews	1 sleeve (6 chews)	24 g
Sports Drink	1 pouch	25 g
Banana	1 medium	27 g

Table 3

Common sports nutrition products, and the approximate quantity of carbohydrate.

Hydration

Body water loss during a game is largely a consequence of thermoregulatory sweating i.e. the internal mechanism to cool the body. It is well established that if significant sweat losses occur, resulting in a loss of ≥ 2% body mass (and ≥ 3% in a cold environment), performance can be impaired (Nuccio et al. 2017). In team sports, players sweat losses can be significant due to the repeated nature of high intensity sprints, equipment worn, large body mass and environmental heat stress. On average, sweating rates in football players have been reported as 1.5 L/h, typically ranging from 0.2 to > 2.5 L/h (Barnes et al. 2019). However, rates as high as 5.5 L/h have been reported in a small population (~1%) of football players (Barnes et al. 2019). In the study by Barnes et al, the authors also reported that the average sweat rate of football players was significantly greater than other team sports such as basketball, soccer and baseball. Attention should also be drawn to the individual variation in sweat rates reported above, which provides evidence for a personalized hydration approach.

Sweat rates can be established on a player-by-player basis, see Chapter 6 for a detailed description on how to monitor player fluid balance. Individual fluid balance from sweat testing can help to establish in-game fluid recommendations. It is important to note that some players, when faced with drinking guidelines, may be overwhelmed by the volumes of fluid suggested. If a player's current drinking practices are in stark contrast to recommendations, it is advised to work towards fluid intake goals over time in training (see Chapter 4 & 6 for more information).

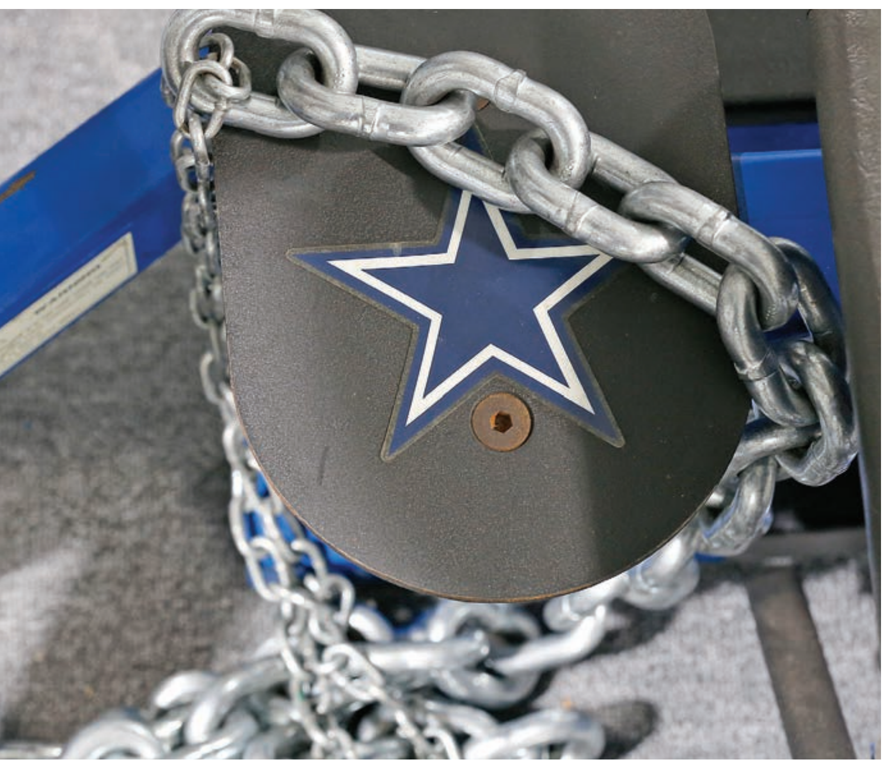
During games, players can utilize the breaks in game play and halftime to consume fluids and refuel. More specifically, during halftime, players may be encouraged to consume carbohydrate, fluids and sodium. High GI carbohydrates are recommended during half time as they are quickly digested and will not only replenish the energy stores needed for the second half of the game, but they also empty from the stomach at faster rates reducing the risk of gastrointestinal discomfort. Data taken from soccer studies have found that a high carbohydrate beverage consumed prior to a simulated soccer game and at half time enhanced skill performance, when compared to placebo (Harper et al. 2017; Rodriguez-Giustiniani et al. 2019). In addition, gastrointestinal comfort was similar in the carbohydrate, placebo and water trials (Harper et al. 2017).

Sports drink, gels, and chews containing electrolytes (including sodium) are a preferred option (Pfeiffer et al. 2012) as they are a source of high GI carbohydrate. In addition to the carbohydrate content, sports drinks help the body to retain fluid (Maughan et al. 2016). It is highly recommended that sports nutrition strategies are practiced in training before being introduced into a game day environment.

Post-Game Nutrition

The priorities for post-game nutrition are:

Refuel muscle (and liver) glycogen stores	Rebuild muscle	Rehydrate fluids lost in-game



Muscle Glycogen Replenishment

Due to the intermittent nature of football, involving high intensity activities, it can be assumed that muscle glycogen will decrease over the game period, even if strict carbohydrate plans are adhered to. Very little data on glycogen depletion have been collected from football players. In reviewing literature on sports of similar intensity level, data collected from professional rugby league players found a 45% decrease in muscle glycogen content from pre to post game (Bradley et al. 2016).

For effective refueling it is advised that players consume 1 g/kg/bm of carbohydrate as close to the end of the game as possible. However, this recommendation is most suited for athletes who have limited time between games/practices (i.e. three games per week). Football teams play one game each week, and typically have >24 hours post game until they will report to the practice field or training room. In this instance, a high carbohydrate diet equating to 5-7 g/kg/bm over the 24 hour period post-game may be sufficient in restoring muscle glycogen concentrations (Parkin 1997).

In addition, it should be noted that muscle glycogen re-synthesis may be slowed following exercise which induces significant muscle damage, like football. Research by Bangsbo et al (2006) found significantly lower muscle glycogen concentrations 48 hours post soccer match, compared to pre-match, despite the ingestion of a high carbohydrate diet (Bangsbo et al. 2006). This highlights the importance of consuming a high carbohydrate diet in the days following a game, in order to achieve optimal glycogen replenishment. During this time foods such as whole-wheat pasta, bread, rice and fruit are recommended. These foods provide a source of high-quality carbohydrate but also micronutrients that are essential for many bodily processes (Dekkers et al. 1996)

Rehydration

Rehydration is another key element to the post-game recovery period. As previously mentioned, significant sweat losses have been observed in football players (Barnes et al. 2019). Therefore, if players have accrued a deficit in body mass, or if there is limited time until the next practice, emphasis should be placed on optimal rehydration. As a general rule, it is recommended to consume 150% of body mass loss within a 6 hour period to achieve optimal hydration (Sheriffs et al. 2000). This amount compensates for any additional body water losses through continued sweating and urination. The type of fluid consumed will influence the effectiveness of water retention. Beverages containing sodium, or drinking water alongside salty foods, will increase the desire to drink and decrease urinary output (Maughan et al. 2016).

To kick start the recovery process immediately post-game it would be recommended for football players to consume a beverage which contains protein, carbohydrate and sodium (i.e. a yogurt-based fruit smoothie, a protein-carbohydrate shake, or milk). Milk contains a comparable amount of sodium as sports drinks (~20-30 mmol/L) and has been studied for its efficacy in promoting fluid retention during rehydration. Research suggests that milk protein (80% casein, 20% whey) can enhance post-exercise fluid retention compared with traditional sports drinks (i.e., 6-8% carbohydrate-electrolyte solutions) (Shirreffs et al. 2007; Watson et al. 2008; James et al. 2011; Desbrow et al. 2014; Volterman et al. 2014). Although, most studies report that whey protein per se does not confer improved fluid retention compared with water or sports drinks (Seifert et al. 2006; James et al. 2014; Hobson et al. 2015).

Football players typically have sufficient time to refuel and rehydrate before the next practice. Therefore, the emphasis should be placed on consuming regular meals throughout the day that include lean protein, carbohydrates, healthy fats, fluids, fruit and vegetables. Building a plate with these foods will provide the macronutrients, micronutrients and overall energy needed to recover and prepare for upcoming practices and games.

Future direction

The current nutrition related published literature within the American football population is very limited. To provide both sport specific and position specific evidence-based recommendations for football players, more research is needed with this population.

Conclusion

In conclusion, following the evidence-based recommendations for pre-game nutrition helps to ensure that the whole team starts hydrated and with the energy to support the demands for each position. Continuing to hydrate and fuel as needed throughout the game will help minimize the risk of performance decrements due to excessive dehydration and/or glycogen depletion. To promote optimal recovery, post-game nutrition strategies should focus on replenishing muscle glycogen, repairing muscle protein and rehydrating. Prior to implementing any changes in the players' routine, the nutrition practices should be tested during practices throughout the week to ensure it is tolerated prior to game time usage.

Chapter 5: Game Day Nutrition

SUMMARY

It is recommended that players should ingest a carbohydrate meal, consisting of **1-4 grams of carbohydrate** per kg of body mass (g/kg/bm), 1-4 h before a game.

Drinking **5-7 mL of fluid** per kg/bm in the lead up to the game will ensure that players start in a euhydrated state.

The carbohydrate recommendations during a game is **30-60 g/h of easily digestible carbohydrates** such as sports drink, gels, and chews containing electrolytes.

Fluid intake during a game should be individualized to the players sweat rate.

Players should make the most of gaps in play and half-time to take on board fluids and carbohydrates.

The **post-game nutrition priorities** are: refuel muscle (and liver) glycogen stores, rebuild muscle and rehydrate.

Football players typically have **sufficient time to refuel and rehydrate before the next practice.** The emphasis should be placed on consuming regular meals throughout the day that include lean protein, carbohydrates, healthy fats, vegetables, and fluids.

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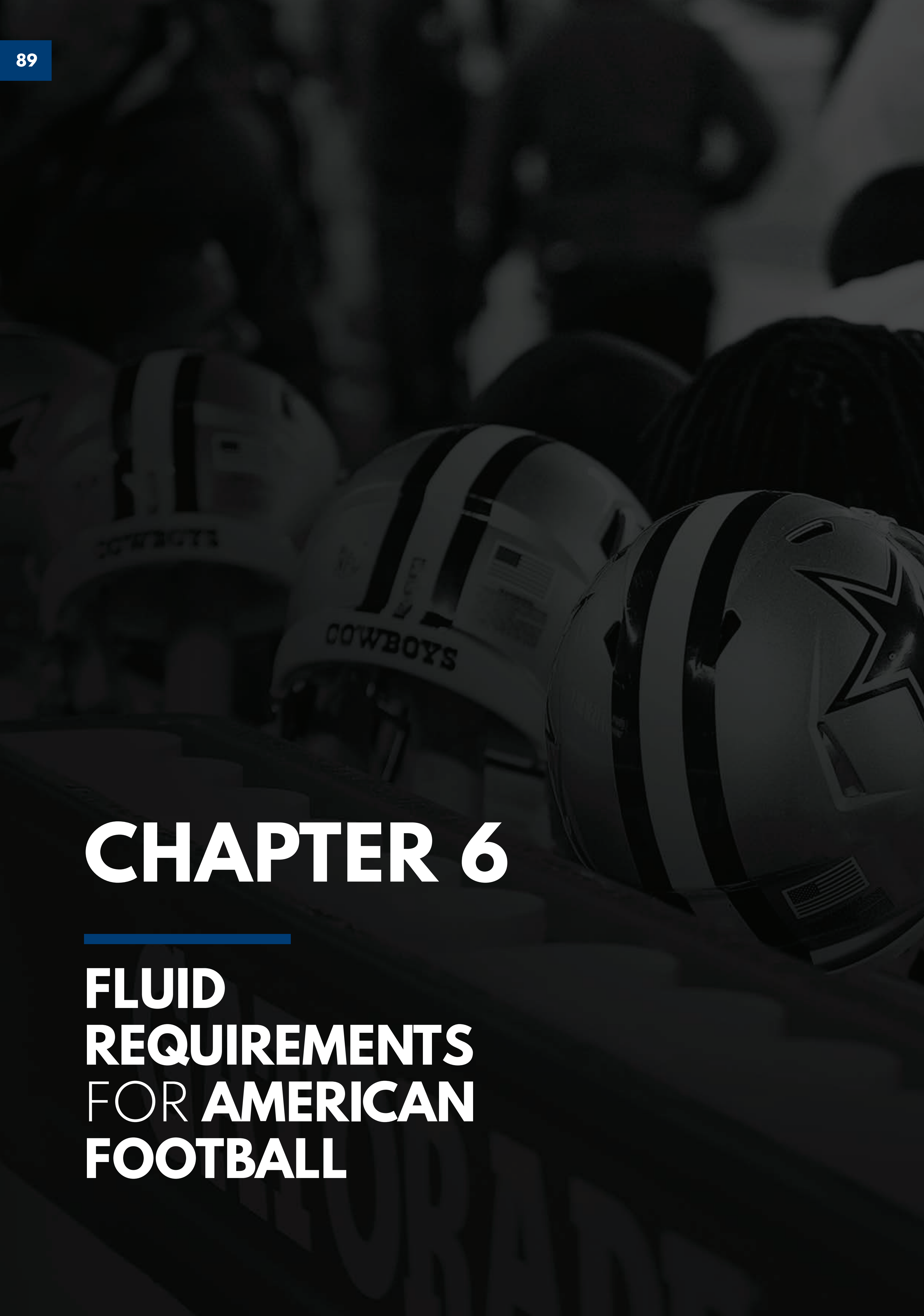
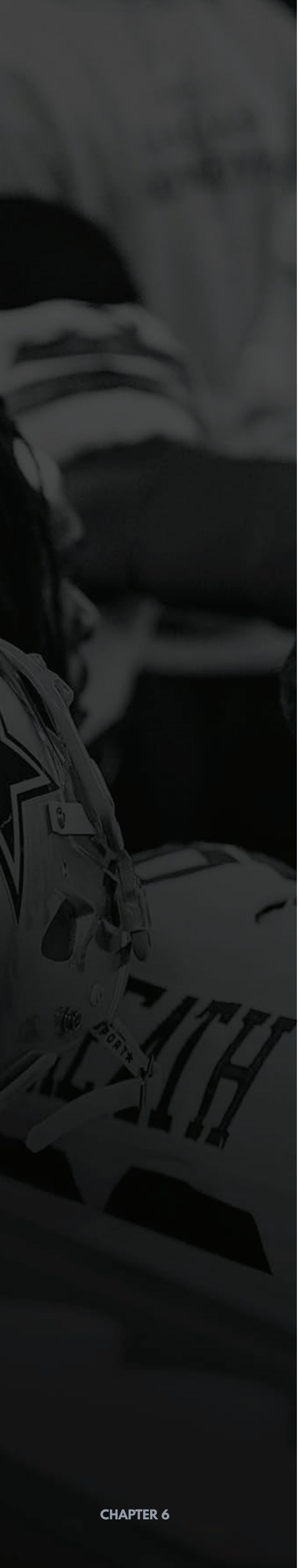


CHAPTER 6

FLUID REQUIREMENTS FOR AMERICAN FOOTBALL



FLUID REQUIREMENTS FOR AMERICAN FOOTBALL

Anthony Wolfe and Ian Rollo

Introduction

Water accounts for approximately 55-60% of a football player's body mass (BM), equating to approximately 16-18 gallons (61-67 liters) (Chapter 3). Every day, water is gained by the ingestion of foods and fluid in the players' diet whilst water is lost from the players' body in the form of sweat, urine and respiratory losses. The player's kidneys regulate water balance by adjusting the output of urine. Although the total body water content is remarkably constant, water turnover can be very high in some conditions such as when players train or play games in hot environments. In order to maintain fluid balance, water intake should be adjusted to fluid losses on a daily basis (Armstrong et al., 1998; Kavouras et al., 2012; Cheuvront & Kenefick 2014).

Intense exercise is associated with a high level of metabolic heat production (Davis et al., 2016). For each liter of oxygen consumed during exercise approximately 16 kJ (4 kcal) of heat is produced and only 4 kJ (1 kcal) is actually used to perform mechanical work. During football specific exercise (Chapter 2) some of this heat is stored and results in an elevation of core temperature (38–40 °C; 100.4–104 °F). This effect is amplified in football players particularly when wearing full pads (Hitchcock et al., 2007; Armstrong et al., 2010) and when playing in hot environments during training camp (Yeargin et al., 2006; Deren et al., 2012; Cooper et al., 2016). If this heat is not dissipated, players soon "overheat" and cease to exercise (Yeargin et al., 2006; Armstrong et al., 2010).

The rise in a player's body temperature is sensed by central and peripheral (skin) thermoreceptors. This sensory information is processed by the players' brain (hypothalamus) to trigger appropriate effector responses (Gleeson 1998). There are several mechanisms to dissipate heat and to maintain body core temperature in a relatively narrow range, both at rest (36-38 °C; 96.8–100.4 °F) and during exercise (38-40 °C; 100.4–104 °F). Although radiation and convection contribute, it is the increased skin blood flow and evaporation of sweat which are the most effective mechanisms to dissipate heat from the body (Armstrong et al., 1997; Cheuvront & Kenefick 2014). Sweat must evaporate from the body surface in order to exert a cooling effect, with the evaporation of 1 L (~32 oz.) of sweat from the skin removing 2.4 MJ of heat from the body. Although sweating is a very effective way to dissipate heat, it poses a challenge for football players due to the small surface area of skin exposed to the environment, as a result of the required clothing (Chapter 2). Sweating may also cause hypohydration if sweat losses are not replenished (Cheuvront et al., 2013; Cheuvront & Kenefick 2014).

Terminology

Dehydration is the process of fluid loss	**Hypohydration** is the resulting state

>2% BM LOSS = Potential Performance Implication

- Physical ability
- Technical Skill
- Perception of effort
- Decision making

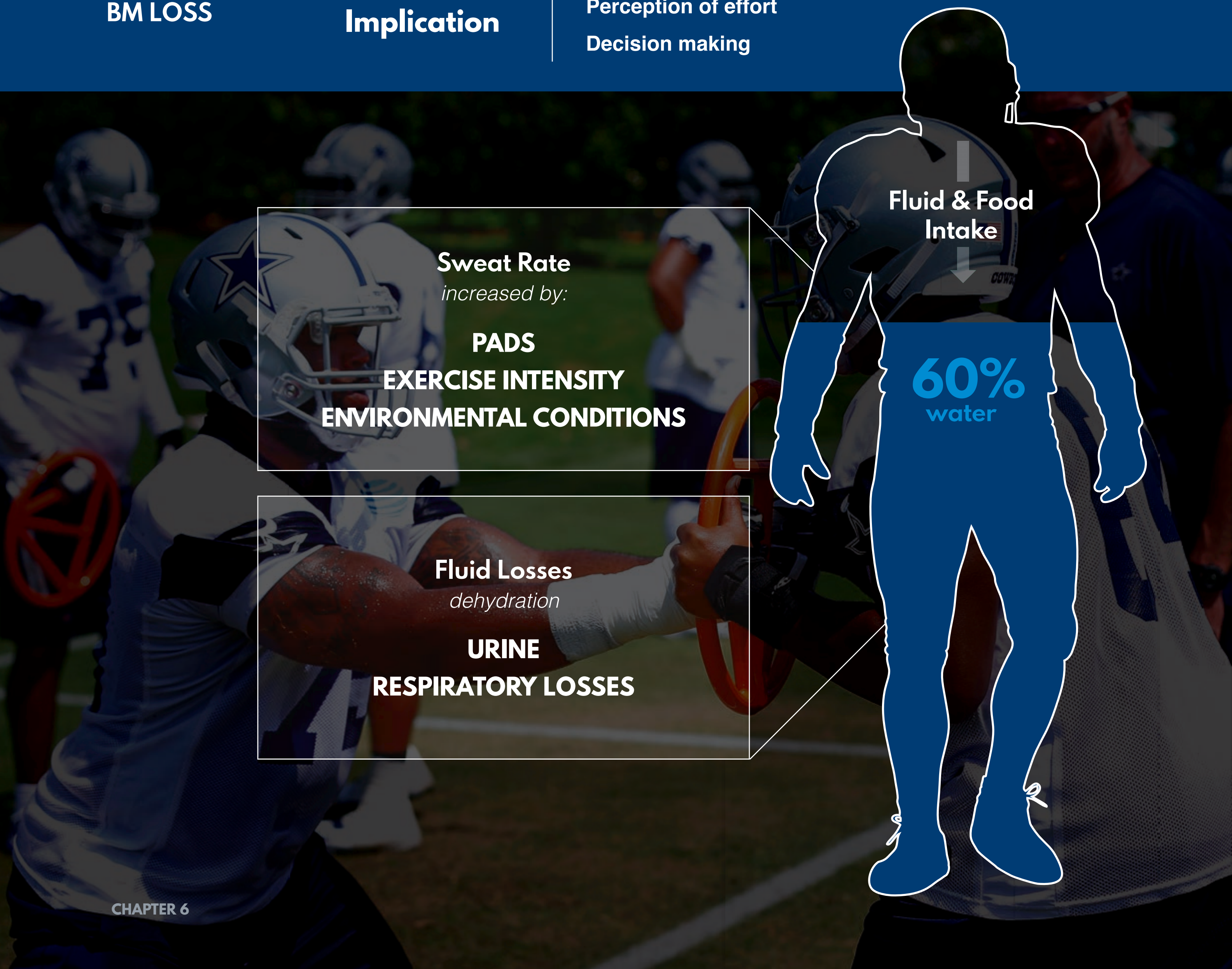
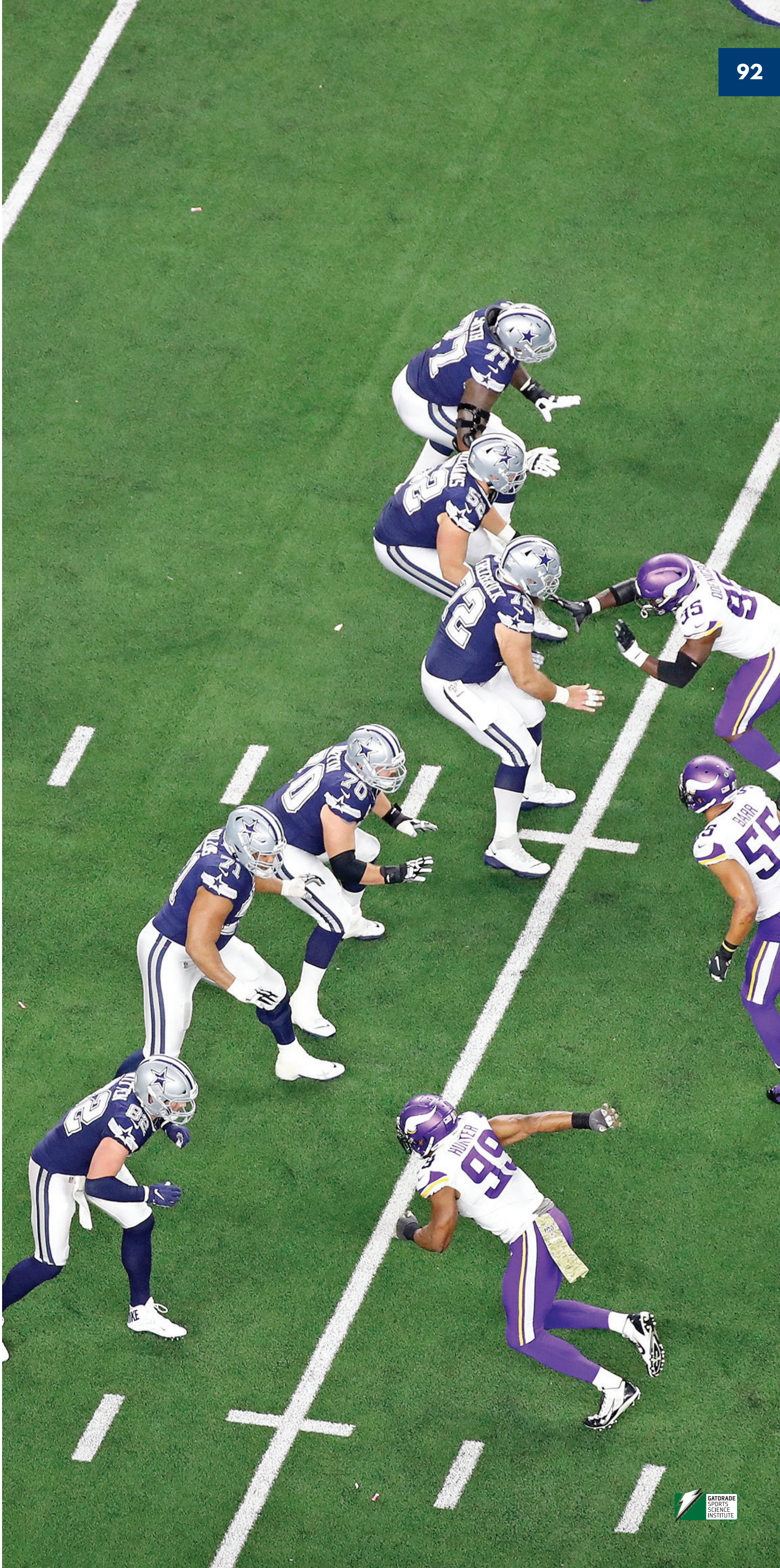


Table 1

Fluid balance and potential performance implications for players.



HYPOHYDRATION AND EXERCISE PERFORMANCE

As players become hypohydrated, a reduction in skin blood flow and sweat rate may occur, impairing the player's ability to regulate their body temperature (Kenefick et al., 2010). Numerous studies have shown that mild hypohydration at the level of 2% reduction in BM can be sufficient to impair exercise performance (Nuccio et al., 2017). Significantly, it has been shown that greater losses in BM may result in greater deficits in physical performance (Baker et al., 2007; Sawka et al., 2012), as well as cognitive impairments (D'Anci K et al., 2009), especially in hot environments (Nuccio et al., 2017).

Although hypohydration has detrimental effects, especially on performance in hot conditions, such effects have also been observed in cool conditions. Others have argued that performance may not be affected by mild hypohydration. It is possible that individuals may be more or less sensitive to hypohydration. The magnitude of the "fatigue/response" to exercise-heat stress has high inter-individual variation due to training and acclimation status, which are influenced by genetic/phenotypic variations of favorable traits associated with innate thermal tolerance and its attainment (Horowitz 2014; Nybo et al., 2014). Higher muscle temperatures within the quadriceps and elevated core temperatures have been reported when competing in the heat, compared to temperate environments (Mohr & Krustrup 2013). Well-trained individuals seem to tolerate higher core temperatures (39.2 °C and 40.3 °C) better than less trained individuals, and this coincides with prolonged time to exhaustion during constant paced exercise (Cheung 2010; Sawka et al., 2011). One theory is that the degree of hypohydration which can be tolerated by the player may be a result of the degree of hypohydration which the player has become accustomed to or routinely experiences. Research in cycling demonstrated that as little as four sessions, designed to habituate the individual with the dehydrating protocol, attenuated the performance decrement observed when 2.4% hypohydrated (Fleming & James 2014). Nevertheless, it is important to note that performance following habituation was still lower than when exercise was completed hydrated. Therefore, given the performance decrement still present and the higher risk of exertional heat illness, players and coaches should not allow hypohydration to become the “norm” and become accustomed to consistent sub-optimal performance. To this end, the discussion about the acceptable level of hypohydration in football players should be based at the individual level. Monitoring of the players BM and an accurate measurement of sweat rate and sweat sodium loss can help to understand each player’s individual fluid balance needs.

Hypohydration can impair the ability of the body to lose heat. As a consequence body temperature rises faster during exercise when the body is dehydrated and this is commonly accompanied by a higher heart rate during exercise (Montain & Coyle 1992; Coyle & Gonzalez-Alonso 2001). The larger rise in core temperature during exercise in the hypohydrated state is also associated with an increased rate of muscle glycogen breakdown (Hargreaves et al., 1996; Logan-Sprenger et al., 2015). Depletion of muscle glycogen stores could also result in premature fatigue, increasing the risk of reduced sprint performance as well as injury, especially in the fourth quarter.

Most relevant to football, hypohydration is likely to be associated with decrements in muscle endurance, strength and anaerobic power (Savoie et al., 2015). It has previously been suggested that a reduction in BM may be advantageous to sprint performance (force production) and therefore may theoretically benefit the player (Judelson et al., 2007; Judelson et al., 2007). Indeed it is possible that body water loss (~3% BM) may improve exercise tasks such as vertical jumping ability (Savoie et al., 2015). However, when considering the demands of football, peak power in both the upper and lower body has been reported to decrease by an average of 16% when subjects were hypohydrated to 3% BM loss during non-weight bearing exercise (Jones et al., 2008). Considering BM loss at a position level it would seem disadvantageous for specific players to lose significant BM during training or games. For example, given the combative nature of linemen duties relies heavily on the ability to hold off opponents, a decline in BM may reduce the players inertia and put them at a disadvantage.

Each down both the offensive and defensive player is tasked with identifying one another’s plays and adjusting accordingly at the line of scrimmage. Making the correct decision quickly is imperative to the outcome of every play. Therefore, cognitive function/processing is a key quality for football. In a study including collegiate players, players underwent 60-75 minutes of high intensity practice before completing a battery of cognitive tests. Players either received no fluid intake or drank water to maintain intake to euhydration. In the no fluid trial, players that lost >1.8% BM were shown to have 3-4% impairment in vigilance and higher negative mood ratings in comparison to those players who had access to water (D’Anci K et al., 2009). It is important to note that the results in this study included data from both male and female athletes and that several cognitive measures were not impacted by hypohydration.

Baker et al. (2007) found that after exercising in the heat basketball athletes who were hypohydrated made significantly more errors and had slower response times to an attention task, compared with when they were euhydrated (Baker et al., 2007). Furthermore, hypohydration may also effect time components of decision making as 2% hypohydration was associated with a 7% reduction in time taken to perform a field hockey skill (MacLeod & Sunderland 2012). To support these observations Bandelow et al. (2010) also found mean time to complete a working memory test was slower when soccer players were 2% hypohydrated. In addition to hydration status, it is important to remember that other factors such as blood glucose levels and a stable core temperature will also have important roles in determining both accuracy and speed during cognitively challenging tests (Bandelow et al., 2010). Hypohydration is also associated with an increase perception of effort during exercise and impaired co-ordination (Baker et al., 2007; Logan-Sprenger et al., 2015). This is likely to impact on a players skill and decision making process, which may be particularly evident during the final quarter of a game (Nuccio et al., 2017).

TYPES OF FLUID

Numerous studies have shown that "regular" water intake during prolonged exercise is effective in maintaining performance. However, fluid intake during training and games also offers the opportunity to provide some fuel in the form of carbohydrate. The type and composition of drink consumed during exercise should be specific to the exercise session, as well as the goals of each individual player (Jeukendrup 2014; Impey et al., 2016). Thus, during occasions where "performance" is the objective, the addition of carbohydrate to beverages consumed will have an additive and independent effect in comparison to water on exercise performance (Below et al., 1995; Nicholas et al., 1995; Williams & Rollo 2015).

As a guide, beverages for fluid and energy replacement during training and games should; 1) taste good, 2) not cause gastrointestinal discomfort, 3) be rapidly emptied from the stomach and absorbed in the intestine, 4) provide energy in the form of carbohydrate and 5) contain a source of electrolytes. It is for this reason that sports drinks typically have three main ingredients: water, carbohydrate and sodium. The water and carbohydrate provide fluid and energy respectively, while sodium is included to aid water absorption and retention (Maughan & Murray 2001).

Both carbohydrate and fluid are important. Supply of a concentrated form of carbohydrate may slow gastric emptying and reduce water absorption. Therefore, it is usually recommended to combine the ingestion of gels, chews and other solids with water. If stomach contents are too concentrated water may be drawn out of the interstitial fluid and plasma and into the lumen of the small intestine by osmosis and fluid delivery will be less effective (Gisolfi et al., 1992). Whether this is a problem depends on the goals for hydration and carbohydrate delivery. It must be emphasized here that the addition of sodium to sports drinks is to increase palatability, maintain thirst (and therefore stimulate drinking), and promote fluid retention and distribution into the vascular space. The replenishment of electrolytes lost in sweat can be achieved in post-exercise recovery period (Chapter 4, 5), unless the player is a particularly heavy and salty sweater and/or the game/training duration is prolonged (2 h +) and in warm conditions (Baker et al., 2016). Specific fluid intake guidelines for training and game day are detailed in Chapters 4 and 5.

METHODS TO MONITOR PLAYER FLUID BALANCE

Measuring the fluid balance of players across training and games will help inform the individual players of their fluid needs during exercise. This method also helps inform the coaches, training staff and dietitians to the degree of hypohydration being experienced by the player, as well as identifies those players most at risk of experiencing significant dehydration. Specifically, fluid intake and losses can be recorded and used to calculate the players sweat rate (Baker 2016).

It is important to note that body water gain also occurs through metabolic water production via the dissociation of water from glycogen and substrate oxidation. It is generally accepted that water lost from the lungs through respiration (evaporative losses) is negligible and can be disregarded (Maughan et al., 2005). For practical purposes, it is assumed that 1 kg of BM loss represents approximately 1 L of water loss (Maughan et al., 2007; Maughan et al., 2007). Therefore, sweat loss can calculated from the change in player BM during either training or games, following the correction for fluid intake and urine/stool loss. The method to measure fluid balance during exercise is displayed in Figure 2 and described below:

Collect a pre-exercise urine sample from the players. Despite limitations (Cheuvront et al., 2015), these samples can be used as an indicator of the players' hydration status, either through analysis of urine specific gravity/ osmolality or more simply by analysis of volume and color.

Before the first BM measurement encourage players to void their bladder. Record the players' BM (kg). This can be completed by players wearing minimal clothing (i.e. underwear) or nude if privacy is possible.

Allocate each player a drinks bottle, which should be weighed before and after exercise. Changes in the bottle weight in grams, represents the volume of fluid ingested in mL. Advise the player to only drink from their bottle and to avoid squeezing water onto their faces for cooling purposes.

During exercise, record the duration of exercise and the environmental conditions and collect, measure and record any urine which may be passed by the player.

After exercise, ensure the player is dry before the final BM measurement is recorded (kg). A change in BM of 1 kg is the equivalent of 1 L of fluid loss.

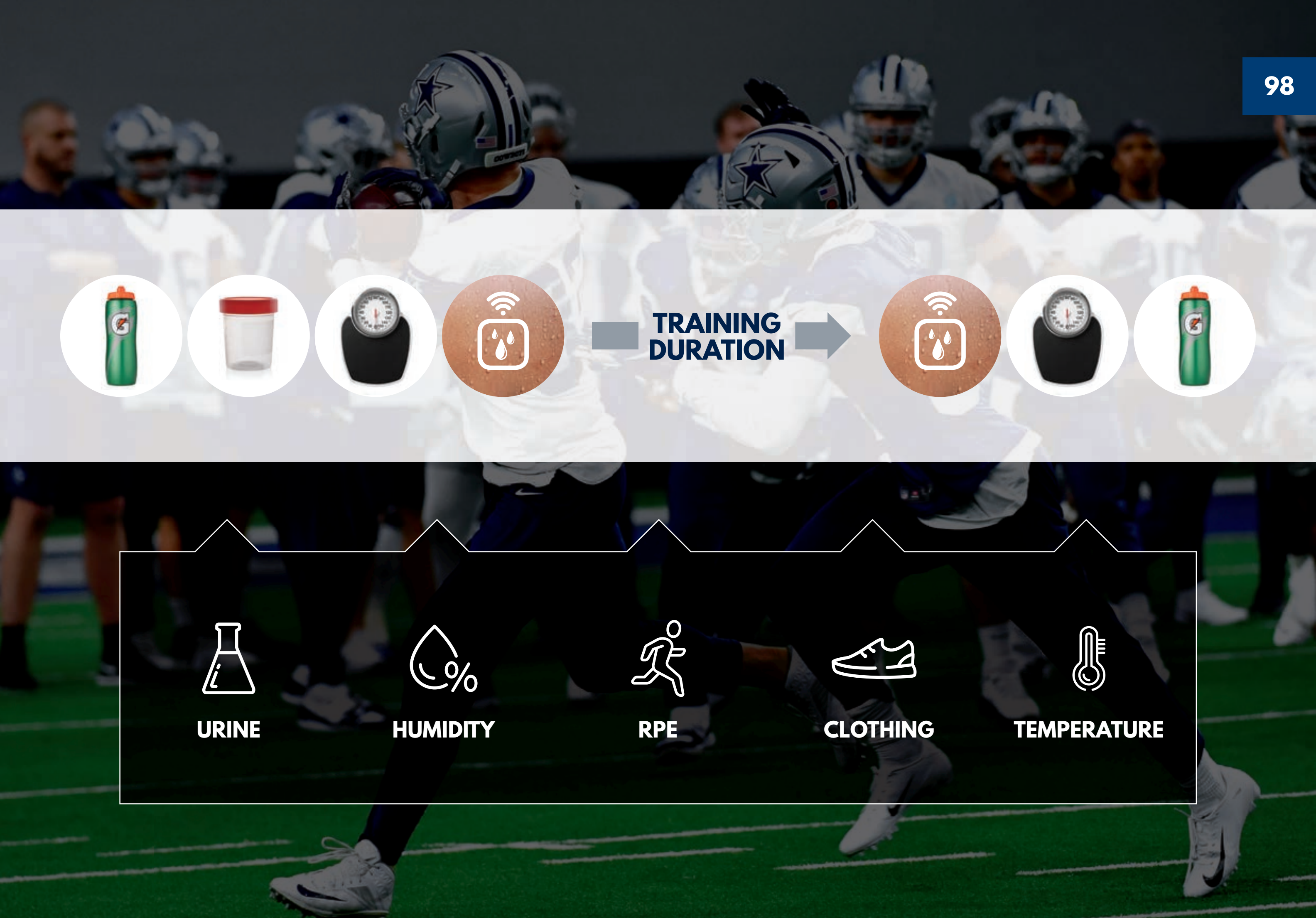


Figure 2
Fluid balance method

Sweat loss (L) =
BODY MASS LOSS (kg) + FLUID INTAKE – URINE VOLUME

Sweat rate (L/h) =
SWEAT LOSS (L) / DURATION (HOURS)

Sweat loss (L) =
BODY MASS LOSS (kg) + FLUID INTAKE – URINE VOLUME

1.5 kg + 500 ml /1000 – 0 ml /1000 = *2.0 L*

Sweat rate (L/h) =
SWEAT LOSS (L) ÷ DURATION (HOURS)

2.0 L ÷ 1.5 (90 min) = *~1.3 L/h*

Figure 3
Example of sweat rate calculation

SWEAT ANALYSIS

Sweat is mainly water (hypotonic) but also contains electrolytes. An electrolyte is a molecule or ion which has a positive or negative charge when dissolved in fluid. The major electrolytes found in sweat are sodium (Na^+) and chloride (Cl^-); collectively these ions form the salt sodium chloride. Analysis of sweat composition allows for the amount of sodium chloride lost during exercise to be determined and differences between individual players to be measured. The replenishment of sodium chloride post exercise is important for complete and rapid rehydration (Chapter 5) (Shirreffs et al., 1996). Full details of the sweat collection and analysis protocol have been described in detail (Baker et al., 2009). However, in summary, absorbent patches are covered with an adhesive film that holds the patch in place and prevents sweat evaporation. The patches should be placed on the skin surface following washing with deionized water and/or alcohol swabs and drying

with sterile gauze. Patches remain in place for the duration of exercise and are removed immediately after exercise or sooner to avoid patch saturation.

Historically sweat electrolyte composition analysis has been laboratory based, relatively slow and expensive (Baker et al., 2009). Recently, a field method has been validated against reference laboratory techniques which allows rapid analysis of sweat composition (Baker et al., 2014). After removal from the skin, patches can be immediately placed inside the barrel of a 5-mL syringe using sterile tweezers. The syringe plunger is then depressed to compress the patch and the expelled sweat collected into a sterile tube. Sweat samples can be analyzed immediately using a compact wireless analyzer that uses ion-selective electrode technology (Horiba B-722) to derive measures of sodium concentration (Baker et al., 2014; Baker et al., 2016).

FLUID LOSS

The commonly cited range in sweat rate across a large population during exercise is 0.5-2.0 liters per hour (L/h) (Sawka et al., 2007). However, this range is subject to a large amount of inter-person variability, as well as intra-person variability under specific circumstances such as environmental temperature, exercise intensity and layers of clothing worn. More specifically, in football players, who wear protective clothing and equipment, many investigations have reported elevated sweating rates including means of ~1.5 L/h (Barnes et al., 2019) all the way to the extremes of 3.0 L/h (Godek et al., 2010; Baker et al., 2016). Much of the inter-person variation can be described by the impact of body size on thermoregulation (Godek et al., 2008; McDermott et al., 2009; Godek et al., 2010), and by extension can be extrapolated out to position. Given the impact of body size, it is not surprising that linemen have higher sweating rates than backs (Godek et al., 2005; Godek et al., 2010).

The uniform requirements appears to cause greater rises in core temperature, reported in both field (Godek et al., 2005) and lab (Armstrong et al., 2010) studies, compared to when players wear shorts, socks, and sneakers only. Specifically, wearing full and half pads (no helmet or should pads) impairs heat loss capacity and leads to increased thermal strain (Armstrong et al., 2010; McLellan et al., 2013) and metabolic heat gain (Mathews et al., 1969). This results in significantly higher core temperature and energy cost, particularly in linemen (Hitchcock et al., 2007).

FLUID INTAKE

Despite the large sweating rates, football players generally do a sufficient job of drinking enough to prevent body mass loses in excess of 2% (Godek et al., 2006; Godek et al., 2008; Godek et al., 2010). Only one study has reported pre- to post-practice losses of >2% BM. It is important to note that this study took place in the southeastern United States (known for high humidity) and described some of the highest levels of heat stress (WBGT 29.4-32.2 °C) found among field studies (Horswill et al., 2009). Furthermore, when tracked over the course of pre-season practices only mild BM deficits were accrued from baseline, that is to say fluid intake between practice sessions was apparently sufficient to avoid cumulative hypohydration (Godek et al., 2005).

As mentioned earlier, fluid balance is the combination of sweat output and fluid intake and so far we have only discussed when output is greater than intake. A potential concern for players is when intake is greater than output (i.e., overdrinking). When players overdrink relative to their sweat losses, they increase the risk for exercise-associated hyponatremia (i.e., a dilution of blood sodium levels) (Hew-Butler et al., 2015). Hyponatremia is a serious and dangerous condition and has been previously reported in football (Herfel et al., 1998; Dimeff 2006). Therefore, education and behavior monitoring should be aimed at preventing significant fluid imbalances, including both over- and under-drinking. Knowledge of individual player sweat rates in various environmental conditions in combination with BM changes and thirst levels can help to personalize fluid replacement strategies. Given the structure of football games and practices (e.g. timeouts and quarterly stoppages) combined with the fact that most players are limited to one side of the ball, players should have sufficient opportunity to consume the appropriate amount and type of fluid (Chapters 5&6).

Full fluid guidelines for training and games can be found in chapter 4 and chapter 5, respectively. In summary, players should aim to minimize fluid losses during exercise of an hour or more to ≤ 2% of starting BM (assuming the player started in a euhydrated state). This goal becomes even more important when playing in the heat or in extended gameplay, i.e. overtime scenarios or two-a-day practices often found in preseason (Shirreffs & Sawka 2011). Preseason training camps often begin in the summer and continue through the hottest and most humid portions of the year when player heat tolerance is sub-optimal. A common issue faced during particularly hot periods is exertional heat illness (EHI). During a single collegiate football season in the Southeast 139 cases of EHI were reported, with the risk being highest when temperatures exceeded 27.8°C (82°F) (Cooper et al., 2016). Numerous factors affect heat tolerance and subsequently EHI, including environmental conditions, heat acclimation status, fitness, clothing, and fluid consumption (Casa et al., 2015). Given that training camp and preseason is when players face both heat acclimation and increasing their fitness level, ensuring adequate hydration is as an appropriate way to reduce the risk of exertional heat illness (McDermott et al., 2017). It is important to note that ensuring players are well-trained and heat acclimated are the most effective ways to reduce the risk of EHI. Thus it is advised that coaches coaches and training staff acknowledge the importance of easing players into workouts in the first few days of camp.

Furthermore, maintaining euhydration is a greater challenge for players during two-a-day sessions (Godek et al., 2005; Godek et al., 2006). Therefore, when there is little time in between two training sessions or when temperatures are higher than average (e.g., training camp), an individualized drinking plan can be employed to optimize player hydration and rehydration (Table 1).

Occasion	Targets	Principal
Daily Intake	Adjust to daily levels of physical activity	Fluid can be ingested via beverages, fruits and vegetables.
Prior to Exercise	2-3 ml /lb BM (5-7 ml/kg) 18-26 oz. total (550-780 ml)	Drink 3-4 h before exercise
During Exercise	Routine ingestion of fluid	Base intake on individual fluid losses and adjust for exercise intensity and environmental conditions
Post Exercise	If rapid rehydration is required drink 150% of BM losses in the 5 h after the game Avoid alcohol (no more than 1 unit)	Replace fluid losses as a consequence of sweating during exercise. The addition of sodium to the recovery beverage will help with fluid retention and maintain the drive to drink.

Table 1

Fluid intake guidelines. Fluid recommendations should be refined with individual sweat rates, specific training intensities and environmental conditions. Feedback from training / competition performance is required. Fluid needs will increase during training and games in warmer environments. Total amounts calculated for the average player weight (245 lbs).

Chapter 6: Fluid Requirements for American Football

SUMMARY

Water accounts for **approximately 55-60% of a player's body mass (BM),** equating to approximately 16-18 gallons (61-67 liters).

Hypohydration of >2% BM, is likely to impair aspects of performance relevant to football, such as muscle endurance, strength and anaerobic power, as well as cognitive function.

Rises in body temperature and heat stress are exacerbated when wearing both full and half pads.

Extra attention should be given when in uniform. Sweat rate and sweat electrolyte loss is highly specific to each individual and, as such, personalized drinking plans based on fluid balance (sweat) analysis and personal preference can be beneficial.

Players should be educated on how to assess their hydration status and modify the intake of fluid depending on the demands of the exercise and environmental conditions.

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CHAPTER 7

DIETARY SUPPLEMENTATION FOR AMERICAN FOOTBALL

DIETARY SUPPLEMENTATION FOR AMERICAN FOOTBALL

Steven Basham and Rebecca Randell

Introduction

As defined by the International Olympic Committee consensus statement a dietary supplement is defined as "A food, food component, nutrient, or nonfood compound that is purposefully ingested in addition to the habitually consumed diet, with the aim of achieving a specific health and/or performance benefit" (Maughan, Burke et al. 2018). In context to football there are dietary supplements that may help performance or recovery but, in any case, they should be consumed to complement adequate training and nutrition and not be used as a substitute. In addition, players are advised to consult with their certified dietician or performance staff before consuming any dietary supplements, as well as to perform a cost/ benefit analysis (Maughan, Shirreffs et al. 2018). To that end, this chapter will review the available scientific literature and highlight the potential dietary supplements which may be efficacious for enhancing athletic performance and recovery in players.

CAFFEINE

Caffeine is a substance which can be found in a variety of food and beverages such as coffee, tea, soda and chocolate. Caffeine is one of the most widely researched dietary supplements as it is purported to have ergogenic effects. For example, numerous studies have found anhydrous (pure) caffeine supplementation to improve endurance capacity and enhance short-duration high intensity exercise (Peeling, Binnie et al. 2018). Furthermore, a review on the effects of caffeine on high intensity exercise reported that > 50% of studies found positive outcomes on performance (Astorino and Roberson 2010).

When compared to endurance sports, studies which have investigated the effects of caffeine on team sport performance are limited; however, some studies have indicated beneficial effects from caffeine supplementation. For example, Stuart et al (2005) gave elite rugby players 6 mg per kg of body mass (mg/kg/bm) of caffeine 70 min prior to performing a series of performance related tasks. The authors found caffeine to improve 20 and 30 m sprint speeds and tackling speed compared to placebo. Additionally, there was a 10% improvement in ball-passing accuracy in the caffeine trial (Stuart, Hopkins et al. 2005). Similar effects have also been reported in soccer players, who enhanced ball-passing accuracy and response to visual and audible stimuli following caffeine ingestion (6 mg/kg/bm) (Foskett, Ali et al. 2009). Recently a systematic review has been completed on acute caffeine ingestion on team sport performance (Salinero, Lara et al. 2019). On balance, this review reported that moderate caffeine ingestion (3 – 6 mg/kg/bm) has a small but significant effect on improving several aspects of sports performance, such as increasing total running distance and distance covered at sprint velocity (Salinero, Lara et al. 2019).

Regarding the effect caffeine ingestion on muscular strength and endurance, the available research is equivocal, with some studies reporting positive effects (Beck, Housh et al. 2006;Woolf, Bidwell et al. 2008) and others demonstrating no benefit (Astorino, Rohmann et al. 2008;Woolf, Bidwell et al. 2009). More specific to football, a study, which investigated the effects of caffeine on American college football players, found no benefits in bench press performance when 5 mg/kg/bm caffeine was consumed 60 min before testing (Woolf, Bidwell et al. 2009). However, a review of studies in this area (total of 34 studies) concluded that caffeine does exert a small beneficial effect on both muscular strength and endurance (Warren, Park et al. 2010).

The exact mechanism in which caffeine exerts a performance enhancing effects is still to be fully determined and may be multifactorial. There is some evidence to suggest that caffeine may increase calcium release, resulting in quicker initiation of calcium to the cross bridge kinetics of the actin binding sites, which in turn may increase maximal muscle output (Weber 1968). However, it appears that caffeine exerts its main effect on the central nervous system (CNS). In more detail, caffeine

can cross the blood-brain barrier and as such act as an adenosine receptor antagonist. This in turn increases the release of certain neurotransmitters such as dopamine. An increase in dopamine is associated with alterations in mood, perception of effort, pain, and motor control. In fact, there are several reports which have found positive effects of caffeine on mood as well as cognitive performance (for a detailed meta-analysis see (Doherty and Smith 2005). In more detail, Duncan and Oxford found higher scores for vigor and lower fatigue scores, in resistance trained men performing bench press exercises to failure, after consuming 5 mg/kg/bm (Duncan and Oxford 2011). Additional information can be gleaned from studies conducted in military personnel, and the general population, in which positive effects on mood and cognitive function have been consistently reported (Lieberman 2003).

Practical Recommendations

Once caffeine is consumed it is quickly absorbed, appearing in the blood within 5-15 min with peak concentrations reached between 40-80 min after consumption. Caffeine also has a long-lasting half-life, reported to be between 3-5 h (Spriet 2014). With these fast absorbing and slow metabolizing characteristics, caffeine may be ideal to consume before kickoff with potential ergogenic effects lasting the length of the football game (60 min uninterrupted; 4 h with interruptions). In contrast to the use of caffeine on game days, caffeine ingestion may also be beneficial when consumed prior to training sessions, when the aim of the session is focused on muscular strength and endurance.

Importantly, the type, form and amount of caffeine should be considered. Typically, studies investigating the ergogenic effects of caffeine use anhydrous (pure) caffeine, in the form of a drink or gel. However, a relatively recent study by Hodgson et al (2013) found the same endurance performance benefits when coffee was consumed to that of anhydrous caffeine (Hodgson, Randell et al. 2013). This is the only study to date which has compared coffee to caffeine, and as such, this data has not been replicated on team sport performance.

Lastly, the majority of studies reporting ergogenic effects have used a caffeine dose of 6 mg/kg/bm. However, recent research has shown that lower doses (i.e. < 3 mg/kg) can be beneficial when provided before and during exercise/competition (Spriet 2014). It is important to highlight that larger doses of caffeine may evoke several adverse effects such as insomnia, gastrointestinal distress, jitteriness and tremor, headaches, increased heart rate, confusion and shortness of breath (Maughan, Greenhaff et al. 2011). Therefore, some players may benefit from ingesting smaller doses and have an additional top-up dose during halftime. However, as with all nutritional strategies, players that wish to use caffeine should first practice different caffeine doses in training before implementing it on game day.

BETA-ALANINE

Beta-alanine, found in skeletal muscle, combines with the amino acid L-histidine to produce carnosine. Carnosine acts as an intracellular buffer for hydrogen ions to maintain the muscle pH level, which can lower during repeated sprints and is associated with fatigue. The high-intensity and repetitive nature of football, may result in muscle fatigue through reduced power output during a competitive football game (Hoffman, Maresh et al. 2002). Thus, dietary supplementation with beta-alanine may offset the early onset of fatigue.

The majority of the literature has found positive effects of beta-alanine supplementation on improving exercise capacity lasting from 60 – 240 s (Saunders, Elliott-Sale et al. 2017). With evidence also indicating benefits for exercise lasting as short as 30 s and long as 600 s (e.g. 10 min), in events such as rowing and swimming (Hobson, Saunders et al. 2012). However, the favorable outcomes are often observed through exercise capacity tests, rather than performance tests (Lancha Junior, Painelli Vde et al. 2015), limiting the application of these findings to football players.

There is some, albeit limited, data on beta-alanine supplementation and team sport athletes. One study supplemented soccer players with 3.2 g/day of beta-alanine for 12 weeks. In this study the supplemented players covered more distance in the intermittent Yo-Yo recovery test, compared to those players who were in the placebo trial (Saunders, Sunderland et al. 2012). However, the same researchers failed to replicate these findings when the supplementation period was shorter (4 weeks) but the daily dose was higher (6.4 g/day) (Saunders, Sale et al. 2012).

Moreover, few studies have examined beta-alanine supplementation in football players. Hoffman and colleagues examined chronic beta-alanine supplementation (e.g. 4.5 g/day for 30 days) in college football players before and after a pre-season football camp. Although no differences were reported for anaerobic power measures, the authors

found elevated work capacity (represented through higher training volumes) in the beta-alanine group. In addition, subjective measures of muscle fatigue tended to be lower in the beta-alanine group compared to placebo (Hoffman, Ratamess et al. 2008). The same researchers also reported elevated training volumes and increased strength in college football players following a longer dosing protocol (i.e. 10 weeks), albeit, with lower dosages of beta-alanine (3.2 g/day) in combination with creatine (Hoffman, Ratamess et al. 2006). Changes in lean body mass were also observed in the beta-alanine + creatine group, which could be attributed to the increased training volume. Whether the benefits were attributed, in part, to the beta-alanine, the creatine or the combination, could not be ascertained.

Practical Recommendations

Recommendations of beta-alanine supplementation for football players may be two-fold. The aforementioned evidence suggests that supplementation may be of interest during the off-season when training volumes are high, and strength and power adaptations are relevant.

However, dietary supplementation throughout the season may be considered, especially for teams that consistently utilize an up-tempo offense or for particular players who are required to perform repeated bouts of high-intensity sprints, especially during the last two minutes of the half (where most teams implement a hurry-up offense, attempting to score before the half). In these situations, beta-alanine may be advantageous to mitigate fatigue during limited to no rest between plays.

Regarding the amount and duration of supplementation the majority of studies have used a daily dose of 3.2 - 6.4 g/d. More recently Stellingwerff et al. (2012) observed that four-weeks of 3.2 g/d significantly increased muscle carnosine levels to a greater extent when compared to 1.6 g/d (Stellingwerff, Anwander et al. 2012). Additionally, these researchers found that a dose of 1.6 g/d, following the 4-week supplementation of 3.2 g/d, further increased muscle carnosine levels (Stellingwerff, Anwander et al. 2012). However, it is important to note that high levels of beta-alanine (typically > 10 mg/kg/bm which equates to 1 g for a 220 lb player) may be associated with adverse effects, such as flushing of skin and a tingling sensation. Therefore, lower doses, ingested over a longer duration, may be suitable if adverse effects are experienced.

SODIUM BICARBONATE

Similar to beta-alanine, the potential buffering capacity of sodium bicarbonate has been extensively researched. However, while beta-alanine acts as an intracellular buffer (in the muscle), sodium bicarbonate has the potential to act as an extracellular buffer (in the blood). Therefore during high intensity exercise, a situation that increases hydrogen ions and subsequently reduces blood pH, supplementation of sodium bicarbonate may also be warranted. In fact, a review of the literature suggested that athletes competing in high-intensity sports, where a relatively large muscle mass is recruited (synonymous with football players), may benefit from bicarbonate supplementation (Requena, Zabala et al. 2005)

However, the majority of research in this area has investigated the effect of sodium bicarbonate on short duration (30 – 150s) high intensity exercise, in sports such as swimming, running and cycling. Data from a recent systematic review stated that twelve out of eighteen studies (~ 67%) found a positive effect of acute sodium bicarbonate ingestion on a variety of exercise performance tasks, lasting ≤ 4 min (Hadzic, Eckstein et al. 2019). However, in two studies the sodium bicarbonate was ingested with another supplement, and it should not be overlooked that the additional five studies found no performance enhancements (Hadzic, Eckstein et al. 2019).

In team sport athletes, when the exercise duration is > 4 min, the evidence is largely equivocal. Sodium bicarbonate ingestion has been found to improve performance of the Yo-Yo test, in trained athletes, by 14% (Krustrup, Ermidis et al. 2015) and 23% (Marriott, Krustrup et al. 2015). However, a study in rugby union players found no effect of acute sodium bicarbonate supplementation on rugby specific sprint tests (Cameron, McLay-Cooke et al. 2010). Furthermore, sodium bicarbonate ingestion failed to improve performance in basketball players (Afman, Garside et al. 2014). Therefore the efficacy for sodium bicarbonate on teams sport performance, and specifically for football performance, is unclear.

Practical Recommendations

Horswill et al. (1988) failed to find improvements in sprint performance following ingestion of bicarbonate ranging from 0.1 – 0.2 g/kg/bm (Horswill, Costill et al. 1988). Therefore, recommended bicarbonate “loading” strategy, which has been used in the majority of research, is a dose of 0.3 g/kg BM. This dose has been shown to increase extracellular bicarbonate levels from ~25 mmol/L to ~30 mmol/L (Marx, Gordon et al. 2002). In addition, because bicarbonate ingestion is known to temporarily increase blood concentration, an acute dose is often recommended typically in the 60 – 120 min period prior to competition.

However, it is important to note that bicarbonate supplementation is associated with major gastrointestinal side effects such as, diarrhea, stomach pain and vomiting. These side-effects can have significant implications for athletes and are not conducive for optimal performance. Strategies to overcome this may include spreading out the consumption of bicarbonate before the start of exercise, consuming it alongside a small carbohydrate snack and practicing the optimal loading strategy in training.

NITRATE

Over recent years nitric oxide (NO) has been found to affect a variety of physiological functions including, but not limited to, regulating blood flow and glucose metabolism. (Jones 2014). Nitric oxide is synthesized in the body via the rate limiting enzyme, nitric oxide synthase (NOS) and until late has been thought to only be produced endogenously (i.e. in the body), through the L-arginine-NOS-NO pathway. More recently it has been found that NO can be metabolized via dietary intake of inorganic nitrate (NO3-). As such, this has led to an increased interest in the investigation of inorganic nitrate supplementation on exercise physiology and exercise performance.

High levels of NO3- can be found in foods such as dark leafy green vegetables and roots, such as spinach and beetroot respectively. However, in order to provide a high dose of NO3- researchers have typically used concentrated beetroot juice. In fact, Bailey et al (2009) was the first to report significantly elevated plasma NO3- levels following consumption of 0.5 L of concentrated beetroot juice (containing ~11 mmol nitrate) for 6 days. In addition, the authors also reported improved endurance capacity (during high intensity exercise) in the beetroot juice trial compared to placebo. These performance enhancements were attributed to the 4% reduction in oxygen cost, at a given exercise intensity, which was observed (Bailey, Winyard et al. 2009). These initial study findings have been supported by additional experiments which have reported reductions in blood pressure, lowering of oxygen consumption for a given workload and improvements in exercise capacity following acute and chronic beetroot juice supplementation (Vanhatalo 2010, Lansley 2011, Cermak 2012).

In the context of team sports, and the relevance for NO3- ingestion in football players, Thompson et al (2016) supplemented team sport athletes with beetroot juice (6.4 mmol nitrate) for 5 days and on the last day of supplementation subjects completed a series of 20 m sprints followed by a Yo-Yo test. Compared to a placebo trial, beetroot juice improved both sprint split times and total distance covered in the Yo-Yo test (Thompson, Vanhatalo et al. 2016). Similar results have also been observed following acute supplementation. For example, Wylie et al. (2013) gave subjects 0.5 L of beetroot

juice in the 30-h preceding a Yo-Yo intermittent test. Interestingly, performance in the Yo-Yo test was 4.2% greater in the beetroot juice condition compared to placebo.

Furthermore, it has been speculated that NO3- supplementation may be particularly effective at augmenting physiological responses specifically in Type II (fast twitch) muscle fibers. In a study by Breese et al (2013), participants underwent two exercise protocols, one where predominantly Type I muscle fibers were recruited (low intensity exercise) and another which predominantly recruited Type II fibers (high intensity exercise). Both of these tests were completed after NO3- supplementation in the form of beetroot juice (~8 mmol nitrates for 6 days). Compared to placebo, NO3- supplementation resulted in faster muscle oxygen kinetics and increased exercise tolerance by 22% in the high intensity trial, but not the low intensity trial. Although highly speculative this suggests that dietary nitrate has a greater effect when Type II muscle fibers are recruited. This is of particular relevance to football players as the majority of football type actions are high intensity and explosive in nature.

Practical Recommendations

NO3- supplementation may provide some benefit for football players to enhance game day performance. The optimal strategy for NO3- supplementation in elite team sports athletes is still largely unknown. Nevertheless, it appears that for acute (2.5 h prior to exercise) ingestion of NO3- containing 8.4 mmol is just as effective at improving exercise capacity as 16.8 mmol, however both doses are more efficacious than a lower dose of 4.2 mmol. Regarding the time course of supplementation, the study by Wylie et al (2013) observed significant improvements in distance covered in a sprint test when beetroot juice was ingested 30 h prior to the exercise task. Therefore, a 2-day pre-load of nitrates, plus an additional dose ~2 hours prior to the start of a game, is recommended. In addition, to further enhance the effectiveness of nitrate supplementation players are advised to avoid antibacterial mouthwash and chewing gum. Dietary nitrate side effects are minimal; that said, discoloration of stools and urine (‘beeturia’) is a common occurrence and athletes should be made aware of this likelihood before supplementation.

CREATINE

Creatine has been widely researched within the sporting context for both enhancing performance and aiding recovery (Branch 2003;Volek and Rawson 2004;Rawson and Persky 2007;Gualano, Roschel et al. 2012;Roberts, Fox et al. 2016). Creatine is produced endogenously (in the body) at about 1 g/d, but can also be consumed in the diet through ingestion of fish and red meat (Cooper, Naclerio et al. 2012). The main stores of creatine are found in the skeletal muscle, in the form of phosphocreatine (PCr) and the primary role of creatine is to resynthesize adenosine triphosphate (ATP) following high intensity bouts of exercise (Buford, Kreider et al. 2007;Rawson and Persky 2007). Therefore, creatine supplementation may increase skeletal muscle stores and mitigate the rapid decline in stored PCr following high intensity exercise, thus improving recovery time between plays.

There are many studies which have found creatine supplementation to improve repeated sprint performance, during both short and prolonged protocols performed on a bike (Birch, Noble et al. 1994;Balsom, Soderlund et al. 1995). The research on creatine supplementation on team sport performance is limited. However, Mujika et al (2000) investigated the effects of creatine ingestion on a variety of high-intensity activities in soccer players. Interestingly, after 6-days of creatine supplementation (4 x 5 g per day) the authors found faster 5 and 15 m sprint time, compared to placebo. In addition, countermovement jump recovery time was maintained in the creatine group but decreased in the placebo group. Specifically to football, Stone et al (1999) supplemented 42 players with creatine for 5 weeks (0.22 g/kg/bm = ~20 g/d), during which the normal training schedule continued. After the supplementation period, the players in the creatine group had a significantly greater squat and bench press 1 rep max (RM) as well as greater vertical jump power output, compared to placebo (Stone, Sanborn et al. 1999). It could be speculated that findings were a result of increasing resting PCr stores as well as greater PCr resynthesis, resulting in more work completed during training. This is because players in the creatine group also displayed greater increases in lean body mass (Stone, Sanborn et al. 1999). However, it should be highlighted that the authors did not measure muscle PCr levels, therefore it is difficult to attribute the findings solely to the creatine supplementation per se.

Although creatine supplementation is unlikely to exert a favorable effect on muscle protein breakdown/ synthesis, there is some evidence to suggest that creatine may amplify training adaptations, through increased activation/gene expression of growth factors, subsequently increasing overall muscle strength and power (for review see (Rawson, Miles et al. 2018). Increasing muscle mass is advantageous for football players due to the physical nature of the game. In addition, increasing muscle mass may aid in reducing the risk of skeletal muscle and/or soft tissue injury (Baht and Krosshaug 2005) (Chapter 8).

Creatine supplementation has also been attributed to enhancing certain aspects of recovery. There is convincing evidence reporting a link between creatine supplementation and increases in muscle glycogen content at rest ((Harris, Soderlund et al. 1992;Nelson, Arnall et al. 2001). More recently, Roberts et al (2016) investigated the effects of creatine supplementation (20 g/day) on the rate of muscle glycogen replenishment, following an exhaustive exercise test. Over a 6-day period creatine supplementation increased muscle creatine and PCr content compared to placebo. Furthermore, creatine supplementation significantly increased muscle glycogen after 1 day of supplementation, compared to placebo, which was sustained thereafter (Roberts et al., 2016) . It is important to note that higher doses of creatine may be needed to elicit a supercompensation effect on muscle glycogen. This is evidenced by Van Loon et al (2004) who found an 18% increase in muscle glycogen content during a creatine "loading phase" (20 g/day). However, this phenomenon was not maintained when participants transitioned to the "maintenance phase". As muscle glycogen replenishment is essential for recovery (Chapter 4 & 5), the evidence points towards the notion that creatine supplementation may be of benefit during periods of intense training.

It is also prudent to mention that brain creatine levels can also be increased with creatine supplementation. There is evidence, albeit limited in athletes, that creatine supplementation can improve cognition (for a detailed review see (Dolan, Gualano et al. 2019)). Cook et al. (2011) found acute creatine supplementation maintained rugby performance however, this was in tested in a sleep deprivation situation (Cook, Crewther et al. 2011). Furthermore, there is emerging evidence that creatine may reduce the severity of mild brain injury. In two studies, Sakellaris et al found creatine supplementation to improve symptoms in patients that had experienced a traumatic brain injury (Sakellaris, Kotsiou et al. 2006;Sakellaris, Nasis et al. 2008). Although this may be advantageous for football players, where the incidence of mild brain trauma (i.e. concussion) is high, there is currently no data on creatine supplementation on improving symptoms of a mild brain trauma in athletes.

Practical Recommendations

In order to increase skeletal muscle creatine and PCr stores it has been suggested that creatine supplementation should involve a "loading phase", consisting of 20 g/d (divided in 4 equal daily doses of 5 g) for the first 5-7 day, followed by a "maintenance phase" of 3-5 g/d (Harris, Soderlund et al. 1992;Hultman, Soderlund et al. 1996). However, sufficient muscle creatine levels can be also be attained, without a "loading phase", if smaller doses (about 3 g) are taken for a longer period (1 month) (Hultman, Soderlund et al. 1996). It should be mentioned that creatine supplementation is associated with increased water retention (Buford, Kreider et al. 2007) and associated with a perception of feeling heavy or slow, therefore supplementation may not be relevant for players that rely on speed (See Chapter 2 for physical demands of the game) (Peeling, Binnie et al. 2018).

Accordingly, creatine supplementation should be strategically planned at specific times during the year (i.e. in-season, off-season) to maximize the benefits: for performance, training adaptations or for recovery depending on the players individual needs. Furthermore, the bioavailability of creatine supplementation may be enhanced when consumed with other macro-nutrients (i.e. protein and carbohydrates) (Steenge, Simpson et al. 2000;Maughan, Burke et al. 2018). Therefore, players should work with a dietician to ensure appropriate supplementation of creatine, timing, source and duration.

OMEGA-3 POLY-UNSATURATED FATTY ACIDS

Omega-3 polyunsaturated fatty acids are essential fatty acids which are not synthesized in the body and therefore must be consumed in the diet. The main dietary sources of omega-3 fatty acids are, but not limited to, oily fish (such as tuna, mackerel and salmon) flax seeds, chia seeds and walnuts. In addition, omega-3 supplements can be consumed in the form of fish oil, krill oil or capsules. The most bioavailable sources of omega-3s are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) and ingestion is most commonly associated with cardiovascular health benefits. However, and of relevance to this chapter, it is the research investigating the relationship between omega-3 consumption and muscle protein synthesis (MPS) that will be covered in the following sections.

Under resting conditions Smith et al (2011) found favorable effects on MPS, following 8 weeks of omega-3 supplementation in healthy adults, both younger and older. However, these anabolic effects were only observed under hyperinsulinemic-hyperaminoacidemic conditions (Smith et al. 2011). In an exercise situation, Rodacki et al (2012) found greater increases in skeletal muscle strength, in elderly females, when fish oil (2 g/d) was consumed during a 12 weeks strength training program compared to a training only group (Rodacki et al. 2012). To test this theory in an athletic population, McGlory et al (2016) supplemented resistance-trained males with fish oil (5 g/d), or a control, for 8 weeks. Following the supplementation period subjects completed a bout of resistance type exercise, after which MPS was measured. Unfortunately, the authors found no effect of fish oil supplementation on MPS. Furthermore, 4 weeks of fish oil supplementation failed to enhance strength, power or speed in soccer players (Gravina, Brown et al. 2017). Therefore, to date, there is currently

Table 1

The purported effects and practical recommendations of dietary supplements which may have beneficial effects for football players.

limited evidence of omega-3 supplementation on augmenting MPS in healthy males.

However, there is new research to suggest that omega-3 may be of benefit for the injured athlete. McGlory et al (2019) supplemented participants with omega-3 (5 g/d) for 4 weeks. During this period subjects underwent 2 weeks of limb immobilization, followed by two weeks of return to normal activity, a protocol which is comparable to that of an athlete who has experienced a minor muscle injury. Interestingly, McGlory and colleagues found a greater decline in muscle volume in the control group, compared to the omega-3 group. Furthermore, omega-3 ingestion maintained muscle mass during the immobilization period, attributed to the higher MPS rates observed. However, it should be highlighted that this research was performed on female subjects. Thus, these findings should be extrapolated to male athletes with caution, especially players who have a larger body and muscle mass. Finally, Jouris et al. (2011) found a 15% decrease in muscle soreness following eccentric arm curl exercise when omega-3s had been ingested for 7 days. Therefore, and although the evidence remains in relative infancy, omega-3 ingestion may have anti-inflammatory properties and be beneficial in supporting player recovery.

Practical Recommendations

Omega-3 supplementation could provide benefits to football players when undergoing periods of heavy training and or rehabilitation. The optimal dosage is not known however, the aforementioned studies have used 5 g/d This dosage may be difficult to achieve through dietary means alone, especially for vegetarian or vegan players. Finally, omega-3 oils are difficult to batch test so caution should be advised to select reputable suppliers with the appropriate third party certification.

Dietary Supplement	Purported effect	Practical Recommendations	Sources
Caffeine	Improved high-intensity and endurance type exercise. Improved cognition and mood	Consume ~ 1 h prior to a game Consume 3 – 5 mg/kg/bm	Chewing gum, coffee, caffeine capsules
Beta-Alanine	Improved high-intensity and intermittent type exercise.	Consume 3 – 6 g daily for four-weeks, followed by a maintenance daily dose of ~2 g	Capsules or powder (from a reputable source)
Sodium Bicarbonate	Improved high-intensity and intermittent type exercise.	Consume 0.3 g/kg/bm 1-2 hours prior to game	Capsules or powder (from a reputable source)
Nitrate	Enhanced endurance and intermittent type exercise	Consume 8 mmol nitrate at least 2 days prior to a game plus an additional dose ~2.5 h before kick off	Concentrated beetroot juice, root vegetables: rhubarb, rocket leaves,
Creatine monohydrate	Improved high-intensity exercise and muscle strength. Enhanced muscle glycogen resynthesis and training adaptation.	Consume 20 g/d (4 x 5 g) for 5-7 days, followed by a maintenance dose of 3 – 5 g/d	Powder (from a reputable source)
Omega-3 Fatty Acids	Maintained muscle mass during periods of muscle immobilization	Consume 5 g/d for 4 weeks (or throughout the whole duration of limb immobilization)	Omega-3 capsules, oily fish, nuts, flaxseeds, chia seeds
		Polyphenols	
Curcumin	Reduced muscle damage, inflammation and muscle soreness	Consume an enhanced bioavailable form of curcumin	Curcumin capsules (from a reputable source)
Quercetin	Reduced muscle damage, inflammation and muscle soreness	Consume 1000 mg/d	Quercetin capsules (from a reputable source), tea, onions, apples, peppers and dark green vegetables
Tart Cherry	Improved muscle recovery and reductions in inflammation	Consume for 3-7 days (twice a day) prior to and immediately after muscle damaging exercise Consume 1200 mg polyphenols/day	Concentrated tart cherry juice
Beetroot Juice	Improved muscle recovery	Consume immediately after and 24 h post muscle damaging exercise	Concentrated beetroot juice

ANTIOXIDANTS

Polyphenols are known to possess antioxidative/ anti-inflammatory properties. Therefore, there is a growing interest in fruits, foods and spices which have a high content of polyphenols. These foods include, but are not limited to, curcumin, tart cherry and beetroot and are often referred to as "functional foods".

Curcumin, the active component in the spice, turmeric, has been linked to reducing inflammation, ameliorate muscle damage, mitigate oxidative stress, and alleviate delayed onset of muscle soreness (DOMS) (Takahashi, Suzuki et al. 2014;Nicol, Rowlands et al. 2015;McFarlin, Venable et al. 2016;Delecroix, Abaidia et al. 2017). For instance, one study reported reduced TNF-α, interleukin-8 (IL-8) (markers of inflammation) and muscle damage following 6 days of supplementation with 400 mg/ day, but failed to reported any reductions in DOMS (McFarlin, Venable et al. 2016). While another study reported reduced muscle damage and DOMS, but no effects on inflammatory markers, following 28 days of curcumin supplementation (Basham, Waldman et al. 2019). Ambiguity in the findings may result from differentiating methods employed to induce muscle damage, along with varying training status of subjects, inconsistent dosing protocols, and curcumin formulations.

In addition, due to the limited bioavailability of curcumin, the aforementioned studies use a wide range of bioavailable curcumin formulas and dosages. Dosing ranges from 400 mg/day to 5 g/day (Nicol, Rowlands et al. 2015;McFarlin, Venable et al. 2016). However, it is recommended to supplement with an enhanced bioavailable form of curcumin in order to attain advantageous results (McFarlin, Venable et al. 2016).

Quercetin is another polyphenol which has received interest as a potential antioxidant and anti-inflammatory supplement. High quantities of quercetin can be found in food sources such as tea, onions, apples, peppers and dark green vegetables, accumulating mostly in the skin and leaves. Nieman et al. (2007) investigated the anti-inflammatory effects of chronic (3 wk) quercetin supplementation (1000 mg/d). Following three consecutive days of cycling the authors found an attenuation of specific blood proinflammatory cytokines (interleukin (IL)-8 and IL-10) mRNA. However, quercetin failed to attenuate any of the measured muscle inflammatory markers (Nieman, Henson et al. 2007). In two follow up studies, using the same supplementation protocol (3 wk 1000 mg/d), quercetin failed to attenuate any inflammatory makers following intensive running and cycling exercise (Nieman, Henson et al. 2007;Nieman, Henson et al. 2007). Furthermore, Konrad et al. (2011) reported that ingestion of a quercetin-based supplement (1000 mg) 15 min before the 2 hours of treadmill run did not attenuate exercise-induced inflammation or immune changes or improve performance (Konrad, Nieman et al. 2011). Taken together the available data on the anti-inflammatory/ antioxidant effect of quercetin is questionable. There is some data to suggest that quercetin may have a performance enhancing effect. A meta-analysis reported that the potential endurance performance effect on trained individuals is trivial (Pelletier, Lacerte et al. 2013).

In 2006 tart cherry was reported to speed recovery by lessening the decline in maximal voluntary contractions, following an eccentric-induced muscle damaging protocol (Connolly, McHugh et al. 2006). This study lead to subsequent research examining the efficacy of tart cherry juice on biomarkers of muscle damage (i.e. creatine kinase, lactate dehydrogenase and muscle soreness) following resistance type and endurance type exercise ((Howatson, McHugh et al. 2010;Bowtell, Sumners et al. 2011). Of the available laboratory-based literature >50% of studies have found ingestion of tart cherry to enhance recovery of muscle function (Bowtell and Kelly 2019). However, a recent field based study, which provided elite soccer players with tart cherry juice before and after a 90 min match, found no beneficial effects on muscle recovery (measured by countermovement jump reactive strength index, subjective well-being and muscle soreness), when compared to placebo (Abbott, Brashill et al. 2019). However, this study only provided the supplement immediately before and in the recovery period after the match. Studies which have found a beneficial effect typically provided tart cherry for at least 3 days (every morning and evening) prior to the exercise and provided at least 1200 mg polyphenols/day.

In addition to the high concentration of nitrate in beetroot (see above), beetroot also contains high quantities of polyphenols. Therefore, Clifford et al. (2016) investigated the effects of beetroot supplementation on muscle recovery following severe muscle damaging exercise. In more detail, subjects consumed beetroot juice in the recovery period (immediately post, 24 h and 48 h post) following 100 drop jumps. Countermovement jump height (indicative of muscle recovery) recovered quicker in the beetroot juice trial. However, markers of muscle damage were unaffected (Clifford, Bell et al. 2016). In addition, the same authors conducted a study investigating the effects of beetroot juice on muscle recovery between two repeated-sprint tests (Clifford, Berntzen et al. 2016). Following the first sprint test team sport athletes consumed beetroot juice for 3 days (2 x 250 mL/d), before replicating the same sprint task. In line with the previous finding countermovement jump height recovered quicker in the beetroot juice trial. However, performance outputs, such as mean sprint time or fatigue index, did not differ compared to placebo (Clifford, Berntzen et al. 2016).

Practical Recommendations

Dietary anti-oxidants may be beneficial in supporting player recovery. The use of antioxidants should be periodized during the season when the demands of the training and game schedule is high. High quantities of antioxidants should be avoided during periods of the season (i.e. pre-season) when promoting training adaptations is the priority. This is because certain antioxidants (namely vitamin C and E) have been found to blunt training adaptations (Morrison, Hughes et al. 2015) however, this blunting effect has not been found in the functional foods mentioned herein. Finally, individual players may respond differently to dietary supplementation based upon the anti-oxidant content of their habitual diet.

Summary

In summary, professional players undergo prolonged training sessions, to promote football-specific fitness, and skill as well as gym sessions in order to increase muscle strength and power. Furthermore, a football game is a high impact game and involves periods of high-intensity type activity. Football players must ensure that daily energy intake is sufficient in both macro- and micronutrient quantities to support training adaptations, performance and recovery. There is evidence to suggest that some supplements, reviewed herein and summarized in Table 1, may be beneficial for football players. However, most of the evidence is derived from endurance-type or high-intensity exercise protocols as opposed to football specific activity. Therefore, there is a definite need for further research to be conducted utilizing highly trained football players and employing football specific exercise protocols. When deciding if a player should take a supplement a cost-benefit analysis must occur, and players should experiment with supplement strategies in training or simulated games first before implementing during competition. Additionally, players should work closely with a health professional (e.g. a registered dietitian) to ensure supplements consumed are from a reliable source and that supplementation, in the first instance, is required.

SUMMARY

Supplements are a food, food component, nutrient, or nonfood compound that is purposefully ingested in addition to the habitually consumed diet, with the aim of achieving a specific health and/or performance benefit.

Supplements, such as caffeine, beta-alanine, sodium bicarbonate, nitrate and creatine may help **improve high-intensity type exercise.**

Ingestion of creatine may also enhance certain aspects of recovery as well as training adaptations.

Dietary antioxidants such as,

curcumin, quercetin, tart cherry and beetroot juice,

may be beneficial in supporting player recovery. However, The use of antioxidants should be periodized during the season when the demands of the training and game schedule is high.

Some supplements may cause adverse effects therefore players should work with a health professional, and experiment with supplement strategies in training or simulated games, before implementing during game day.

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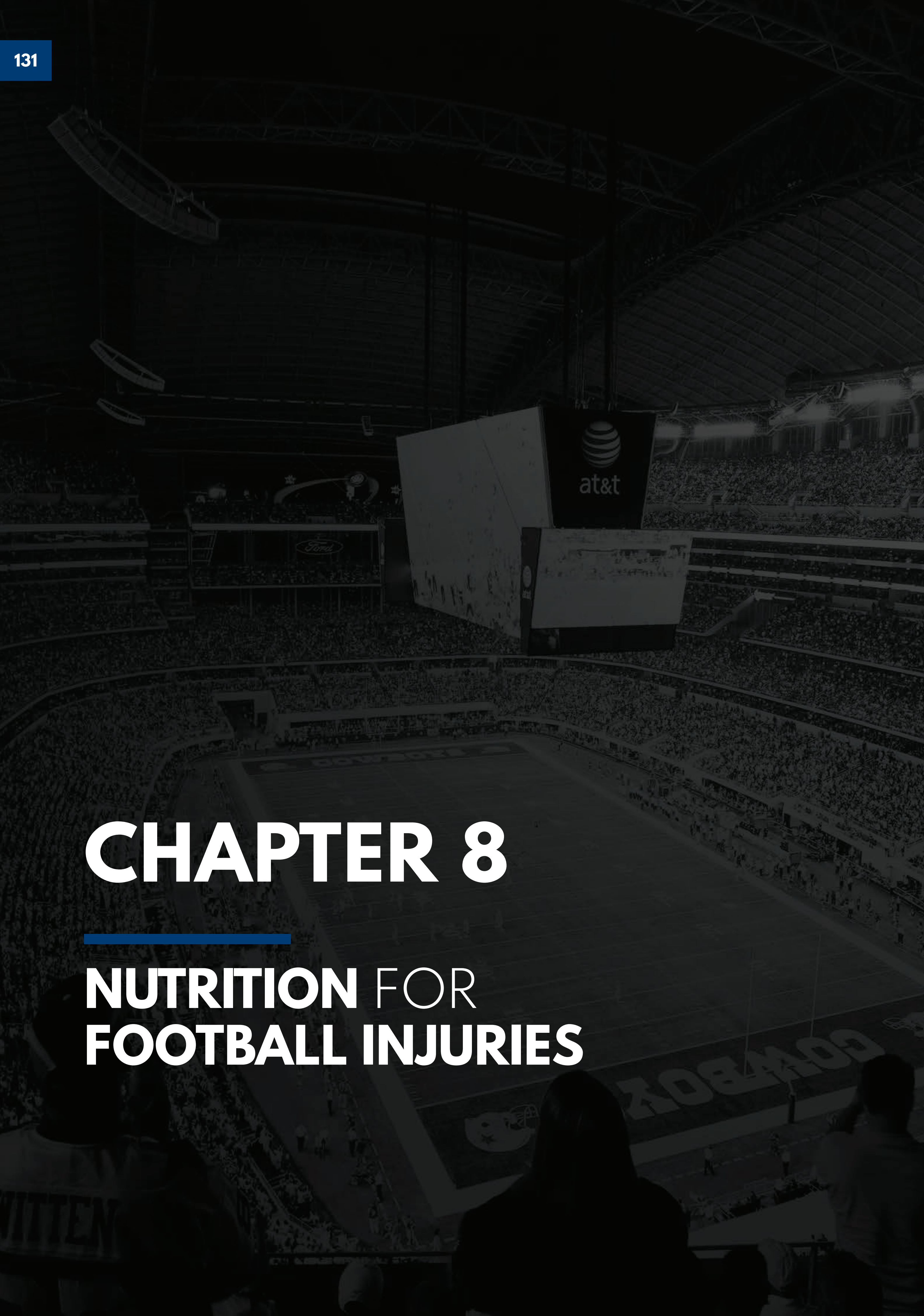
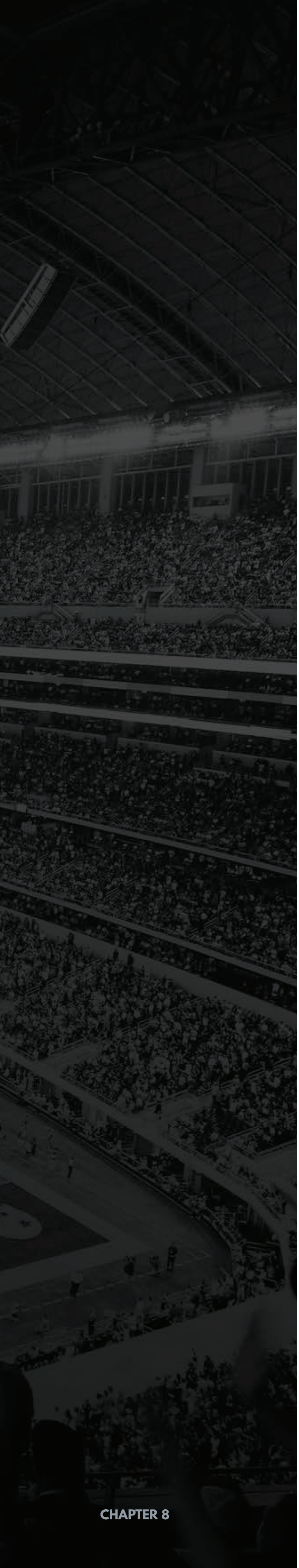


CHAPTER 8

NUTRITION FOR **FOOTBALL INJURIES**



NUTRITION FOR **FOOTBALL INJURIES**

Ian Rollo and Eric Freese

Introduction

Approximately 1.5 million players participate in American football in the United States. As football is a contact sport (Chapter 2) injuries can be an unfortunate consequence of participation. It has been estimated that 1.2 million football-related injuries are sustained annually (Saal 1991). In a recent injury surveillance program commissioned by the National Football League (NFL), an injury was defined as one that resulted in a players removal from participation and inability to take full part in football activities following the injury (Dreyer et al., 2019). The process and duration required to return a player to training and ultimately competition following injury is complex and will depend on the severity and classification of injury (Rae & Orchard 2007). It is important to recognize that there are multiple negative consequences of injury including those related to the players' financial situation, psychological and physical long-term health. However, these issues are beyond the scope of the current chapter. Instead, the purpose of this chapter is to discuss common injuries in football and the corresponding nutrition interventions to be considered alongside the appropriate physical rehabilitation programs. This is because nutrition is one method to counter the negative impact of an exercise-induced injury (Tipton 2010; Wall et al., 2015).

Injuries In American Football

Epidemiological studies tabulating data from the 1970s to early 2005 reported that the risk of injury increases as the football player progresses through their career. Specifically, the incidence of injury increases with the level of play, player age, and player experience (Stuart 2005). During the season approximately half of injuries occur at training, whereas the other half in games. During training players risk of injury was increased by 4.7 times by completing contact sessions in comparison to controlled non-contact sessions (Saal 1991). During pre-season training camps the incidence of season-ending injuries was higher during games (5.4/1000 player exposures) than training (0.4/1000 player exposures) (Feeley et al., 2008).

Historical data suggests that lower extremity injuries are prevalent in American football. Knee injuries, typically damage to the anterior cruciate ligament (ACL) and medial cruciate ligament (MCL), account for up to 36% of injuries (Saal 1991). Data collected from 2285 NFL combine players between 2009 and 2015 revealed over half had a history of ankle injuries (Mulcahey et al., 2018). Out of the reported injuries approximately 80% were unilateral injuries and 20% bilateral injuries. Running backs (61.9%), offensive linemen (60.3%), and tight ends (59.4%)

had the highest reported incidents of ankle injuries in comparison to kickers/punters (23.3%) and long snappers (37.5%) who had the lowest (Mulcahey et al., 2018).

Upper extremity injuries account for approximately 30% of all injuries, of which the shoulder appears to be a vulnerable joint. Despite protective padding, injuries to the shoulder girdle are common at all levels of competitive football (Gibbs et al., 2015). Fractures of the players' clavicle are also a common upper extremity injury (Morgan et al., 2010; Jack et al., 2017). Other upper extremity injuries of note include those to the players hands (thumb collateral ligament injuries occur frequently in the NFL (Werner et al., 2017)) and head (brain), i.e. concussion (Pellman et al., 2006; Maroon & Bost 2011).

It is important to note that cervical spine injuries have the potential to be fatal. As a result of rule changes to tackling and blocking techniques, as well as improved fitness, equipment and coaching, the incidence of these injuries declined dramatically between 1975 to 1984 (Saal 1991). Since 2012, the NFL have commissioned an independent third-party company to compile and analyze injury data on American football players. Tables 1,2 and 3 tabulate the incidence of injuries from 2012-2018 (NFL 2018).

TENDON AND LIGAMENT INJURIES

American football is associated with the highest rates of ACL injury in comparison to other National Collegiate Athletic Association sports (Agel et al., 2016). Based on injury surveillance data (Table 1) it appears that the incidence of ACL injury is fairly consistent, with an average of 57 ACL injuries per year between 2012 and 2018. For an ACL injury NFL physicians advise a period of six to nine months before returning to play (Erickson et al., 2014). A single injury may result in both an ACL and MCL tear. Analysis of both these injuries are included in table 1 and 2. The incidence of MCL injury is over double that of an ACL injury (Table 2). In a review of 260 ACL injuries in NFL players it was found that playing on synthetic turf was associated with a 16% increase in lower extremity injuries per play than that on natural turf (Mack et al., 2019)

In comparison to muscle, there are few studies investigating the impact of nutrition interventions on ligament function and recovery (Baar 2015). Ligaments have limited blood flow, and are dependent on nutrient delivery though bulk fluid flow (Baar 2015). Therefore, the physiology of ligaments is different to that of muscle and as such require a different nutrition approach (Kjaer et al., 2009).

> "Ligaments get their nutrients though bulk fluid flow. Here, think of a sponge that gets wrung out and put into a liquid. As the sponge expands, it draws fluid in. The same is true for soft tissues" (Baar 2017).

The most abundant protein in ligaments is collagen (type I collagen), forming the mechanical backbone of the intramuscular connective tissue and of tendons and ligaments. Thus, in part, the strength and stiffness of the player's ligaments will be determined by the quantity of collagen they contain. The main components of collagen are the amino acids glycine, proline, lysine,

Preseason				Regular Season				Preseason + Regular Season			
Year	Practice	Game	Total	Year	Practice	Game	Total	Year	Practice	Game	Total
2012	13	16	**29**	2012	5	28	**33**	2012	18	44	**62**
2013	15	10	**25**	2013	3	33	**36**	2013	18	43	**61**
2014	12	10	**22**	2014	0	27	**27**	2014	12	37	**49**
2015	13	16	**29**	2015	5	25	**30**	2015	18	41	**59**
2016	9	11	**20**	2016	7	29	**36**	2016	16	40	**56**
2017	15	16	**31**	2017	2	21	**23**	2017	17	37	**54**
2018	10	18	**28**	2018	5	24	**29**	2018	15	42	**57**

Table 1
Incidence of ACL tears 2012-2018. Includes ACL tears as primary, secondary or tertiary (NFL 2018).

Preseason				Regular Season				Preseason + Regular Season			
Year	Practice	Game	Total	Year	Practice	Game	Total	Year	Practice	Game	Total
2012	19	26	**45**	2012	9	77	**86**	2012	28	103	**131**
2013	20	25	**45**	2013	4	85	**89**	2013	24	110	**134**
2014	16	23	**39**	2014	3	98	**101**	2014	19	121	**140**
2015	12	38	**50**	2015	6	102	**108**	2015	18	140	**158**
2016	15	21	**36**	2016	3	86	**89**	2016	18	107	**125**
2017	17	20	**37**	2017	9	97	**106**	2017	26	117	**143**
2018	13	23	**36**	2018	1	94	**95**	2018	14	117	**131**

Table 2
Incidence of MCL tears 2012-2018. Includes MCL tears as primary, secondary or tertiary.
A single injury may result in both a ACL and MCL tear (NFL 2018)

hydroxylysine and hydroxyproline. Initial studies performed in vitro reported that providing the amino acid proline with vitamin C was associated with improved collagen synthesis (Paxton et al., 2010).

Interestingly, from a nutrition perspective the amino acids (glycine, proline, lysine, hydroxylysine and hydroxyproline) found in collagen, are abundant in the food gelatin. Gelatin is typically produced from the skin and connective tissues of cows and pigs. Early studies in healthy male subjects have reported positive responses with regard to collagen production in response to gelatin feedings. Therefore, this nutrition intervention, is worthy of consideration during the rehabilitation process following injury. Specifically, the ingestion of gelatin has been reported to be effective in increasing circulating concentrations of the amino acids glycine, proline, hydroxyproline, and hydroxylysine (Shaw et al., 2016). Furthermore, the ingestion of gelatin (15 g ingested with 50 mg vitamin C) 1 h prior to exercise increased blood markers (amino-terminal propeptide of collagen I) related to increased collagen synthesis (Shaw et al., 2016).

Although further research is required, the ingestion of gelatin is a promising nutritional intervention for football. The ingestion of gelatin may be considered prior to training and games for both "healthy" players, as well as those players with a history of ligament injury. Gelatin ingestion may also be a potent strategy to integrate into a players physical rehabilitation program following injury to facilitate the ligament remodelling (Baar 2017).

CONCUSSION

A concussion is characterized by any alteration in cerebral function caused by a direct or indirect force transmitted to the head (Delaney & Frankovich 2005; Delaney et al., 2014; Partridge 2014). It is important for players and staff to recognize the symptoms of concussion, as well be aware of appropriate concussion assessments to facilitate the accuracy of identification, treatment and reporting of incidents (Alosco et al., 2017). A full pathology of concussion is beyond the scope of this chapter. In summary, concussion symptoms include: a brief loss of consciousness, light-headedness, cognitive and memory dysfunction, vertigo, tinnitus, blurred vision, difficulty concentrating, amnesia, headache, nausea, vomiting, photophobia and/or a balance disturbance. Delayed symptoms may also be evident through fatigue, personality changes, depression, lethargy and sleep irregularities (Aubry et al., 2002; Delaney & Frankovich 2005).

There is considerable awareness of concussion (traumatic brain injury) in football (Alosco et al., 2017). This is due, in part, to those institutes dedicated to understanding, preventing and treating concussion (for example: Sports Legacy institute 2007, Boston University; Azheimer's Disease Center), reports by popular media, as well as on-going preventative measures being introduced by the NFL. A retrospective study demonstrated that in general, NFL players who sustain concussion experience a higher rate of franchise release as well as a shorter career span (Navarro et al., 2017). The short-term implications of concussion have been reported to be a reduction in career longevity and salary (Navarro et al., 2017). Reduced physical and subsequent game performance is also reported following concussion. However, the primary concern is the players' short and long term health.

Scientific studies have tabulated data from a public broadcasting service (PBS) "FRONTLINE" to investigate the incidence of concussion. In one study 960 NFL games (excluding self-reported concussion injuries sustained during training) were analyzed during four consecutive seasons (2012-2015). During this period, 411 (42%) of games experienced a concussion and 549 (57%) of games were concussion free (Haider et al., 2018).

This same data set has also been combined

with game characteristic variables (ESPN data) to investigate the association between playing position (Chapter 2) and the incidence and severity of concussion (Dai et al., 2018). It was found that the characteristics of games and player position had the potential to influence the incidence of concussion. Specifically, away teams and losing teams demonstrated a significantly greater concussion incidence per game than home teams and winning teams. Within individual playing positions, significantly higher concussion incidence was associated with tight ends, running backs, wide receivers and cornerbacks (Dai et al., 2018). Furthermore, passing positions had significantly higher concussion incidence in comparison to running positions (Dai et al., 2018). The recent introduction of "unconventional" NFL game schedules i.e. Thursday games and overseas games raised concerns as to increasing the risk of concussion. However, to date, both these game fixtures have been reported to not further increase the risk of concussion (Teramoto et al., 2017).

There has been a number of studies with regard to nutrition and the prevention and treatment of concussion (Ashbaugh & McGrew 2016). To date, recommendations are based on results from rodent studies which have provided antioxidant and anti-inflammatory compounds (Mills et al., 2011; Tipton 2015) as well as recent studies in humans investigating the remodelling and restorative processes of long term cognitive function (Pu et al., 2016). Thus, based on the available literature firm nutritional guidelines are difficult to prescribe.

Nevertheless, there are two main dietary supplements which, so far, offer encouraging results and therefore may be considered relevant in football. The main compounds currently under investigation are omega-3 fatty acids (Docosahexaenoic acid) and creatine (Ashbaugh & McGrew 2016). This is because the ingestion of high dosages of omega-3 fatty acids may improve the short term outcomes following concussion (Lewis 2016). This may be achieved via neurite growth, increased neurite branching, and subsequent synaptogenesis, resulting in enhanced synaptic function and improved neuronal repair after head injury (Kim & Spector 2013). Furthermore, supplementation with omega-3 fatty acids prior to sustaining a concussion may protect against reduced plasticity of neurons and impaired learning (Wu et al., 2011). The ingestion of omega-3 fatty acids has also been reported to normalize levels of proteins associated with neuronal circuit function and locomotor control after sustaining a concussion (Wu et al., 2011).

In a study performed with football players, omega-3 ingestion has been reported to attenuate axonal damage which is a characteristic of mild traumatic brain injury (Oliver et al., 2016). In this study a benefit was reported independent of the dose provided to the player i.e. either 2 g, 4 g or 6 g per day. Given the potential additional benefit of omega-3 supplementation on muscle, discussed next, it would be prudent to recommend players ingest omega-3 (2 g) daily during the competitive season and increase this to 5 g per day following head (or immobilization) injury. Position specific recommendations may also be considered for those with an increased risk of concussion. However, further football specific research is required to refine recommendations (Zetterberg et al., 2013; Oliver et al., 2018).

Creatine is synthesised in the players' body mainly by the kidneys, liver and pancreas. Creatine is combined with a molecule of phosphate and stored in tissues such as the muscle and brain as Phosphocreatine (also known as creatine phosphate). It functions as an energy system to rapidly resynthesize ATP (energy) in cells. Creatine may also be provided to the player via foods such as meat and fish in their diet (Greenhaff 2001).

Preseason

Year	Practice	Game	Total
2012	42	43	**85**
2013	39	38	**77**
2014	42	41	**83**
2015	29	54	**83**
2016	26	45	**71**
2017	45	46	**91**
2018	45	34	**79**

Regular Season

Year	Practice	Game	Total
2012	3	173	**176**
2013	4	148	**152**
2014	8	115	**123**
2015	9	183	**192**
2016	6	166	**172**
2017	12	178	**190**
2018	8	127	**135**

Preseason + Regular Season

Year	Practice	Game	Total
2012	45	216	**261**
2013	43	186	**229**
2014	50	156	**206**
2015	38	237	**275**
2016	32	211	**243**
2017	57	224	**281**
2018	53	161	**214**

Tables 3A

Incidence of concussion 2012-2018 (NFL 2018).

Regular Season Games

Impact Source for Helmet	2012	2013	2014	2015
Another Helmet	91	72	58	92
Shoulder	25	11	7	23
Forearm / Elbom	4	4	7	1
Thigh	9	3	0	2
Knee	13	15	15	12
Foot	2	0	2	6
Body, Location Unknown	1	3	2	4
Playing Surface	15	25	16	29
AT selected "Unknown"	9	10	6	13
AT did not select a source	4	5	2	0
Total	**173**	**148**	**115**	**182**

Table 3B

Source of impact 2012-2015 (NFL 2018).

Following a sport-related concussion a decrease in total brain phosphocreatine has been reported, the degree of which may be dependent on the severity of the injury (Vagnozzi et al., 2013).

To this end, football players may benefit from additional intake of creatine. Whilst creatine can be ingested via food, a practical and rapid method is to provide creatine monohydrate as a dietary supplement (Chapter 7). Traditional loading protocols have focused on increasing phosphocreatine concentrations in skeletal muscle. Effective loading regimes include ingesting 20 g a day for 5 days or the ingestion of 3 g a day for 30 days (Hultman et al., 1996). However, similar dietary supplementation protocols are also associated with increased concentrations in the brain. Increases in brain creatine concentrations were observed when healthy young males were fed 20 g of creatine monohydrate either in a single bolus or spread out into 4 x 5 g doses per day for four weeks (Dechent et al., 1999). The relative increases in concentrations varied between individuals and were dependant on initial concentrations.

Interestingly, a single 20 g bolus of creatine was sufficient to increase the total brain creatine pool (Dechent et al., 1999). Thus, and although ingesting creatine for a longer period of time is associated with larger increases, acute ingestion may be considered immediately following concussion. Creatine supplementation may improve the players' cerebral energetics (Pan & Takahashi 2007; Turner et al., 2015). This may result in improved cognition, communication, self-care, personality, and behaviour (Sakellaris et al., 2006). In addition, supplementation may significantly reduce the magnitude of concussion symptoms such as headaches, dizziness and fatigue (Sakellaris et al., 2008). However, further research is needed to investigate the impact that supplementing the players diet with creatine has on concussion in football (and other sports).

MUSCLE

Muscle injury accounts for about one-third of sports-related injuries. Muscle injuries continue to be an on-going concern in football because of the time loss in training and games as well as a relatively high rate of recurrence (Valle et al., 2016). The lower limb muscles have one of the highest incidence of injury in the NFL. The most common muscle group injured are the hamstrings, followed by the quadriceps (Kumaravel et al., 2018). The time required to return to play will depend, in part, on the classification and severity of the muscle injury (Kumaravel et al., 2018). The risk of muscle injury is increased during the execution of football specific activities (Chapter 2). Players risk of muscle injury will be increased as players experience transient fatigue during activity and with increasing number of impacts/collisions with the opposition. The risk of muscle injury may be exacerbated by a combination of other factors including: dehydration (Chapter 6), glycogen depletion (Chapters 4 and 5), muscle damage and neuromuscular fatigue (van Beijsterveldt et al., 2013) (Chapter 9).

As well as muscle injury per se, the consequence of other football related injuries discussed in this chapter may result in player inactivity (Tyler et al., 2004). Either a decrease in muscle activation or, in more severe cases, limb immobilization may result in significant loss in muscle mass. Muscle strength loss and atrophy are evident within five days of immobilization. This is due to a rapid increase in muscle protein breakdown followed by a decrease in muscle protein synthesis. Approximately 150 g of muscle mass can be lost per day, equivalent to 1 kg/week. Of particular relevance to the American football player, type II muscle fibers are the most susceptible to atrophy (Wall & van Loon, 2013). Should immobilization/inactivity continue (ten days or more) muscle loss is predominantly caused by an inhibition of muscle protein synthesis, basal and post-prandial, causing atrophy and subsequent functional loss.

During the acute phase of injury players will experience inflammation and, depending on the injury, differing extents of immobilization, reduced weight bearing and rest. The temptation is to dramatically reduce the daily energy intake of the player based on the reduced activity (Chapter 3). However, it is important to note that some metabolic stress injuries will increase the energy requirements, such as bone fractures or walking with crutches. Those studies which have reduced energy intake during this period have shown a large loss of muscle mass. Thus, it is suggested that a slight increase in body fat would be preferential and lost more rapidly in comparison to a loss in muscle mass, which takes longer to regain (Milsom et al., 2014). To this end, low energy diets should be avoided.

The priority following injury appears to be muscle activation, since anabolic resistance will remain as long as muscle stimulation is lacking. Of note are methods such as percutaneous electro-stimulation and training the uninjured limb or other muscle groups that can exert some cross effect to diminish the anabolic resistance (Farthing et al., 2009).

The use of electro-stimulation may be considered prior to bed time protein feedings to increase the incorporation of amino acids into the activated muscle (Dirks et al., 2016).

During the acute injury phase, it is recommended to maintain or increase protein intake to 2 g / kg BM per day (Tipton 2010). This may be achieved by either ingesting food or supplements containing protein of high biological value routinely throughout the day (25-30 g) (Res 2014). One strategy is to ingest high quality protein sources, rich in leucine, between meals at mid-morning and mid-afternoon. Beside whey protein, this can also be achieved by ingesting a variety of protein sources, for example fish and plant based proteins (Dort et al., 2012; Dort et al., 2013; van Vliet et al., 2015). Protein intake prior to sleep is also recommended; in this instance 30-40 g of the slow-release protein casein is a good choice (Trommelen et al., 2016; Trommelen & van Loon 2016).

The essential amino acid leucine may play an important role during injury by attenuating the decrease in muscle protein synthesis through the activation of anabolic pathways (van Loon 2012). Leucine is found in greater amounts in proteins of high biological value (i.e. whey protein). Food also offers a good source of leucine; for example, 3 g of leucine can be found in 25-30 g of whey protein, 140 g of chicken or 170 g of fish. The catabolite of leucine, beta-hydroxy beta-methylbutyrate (HMB) ingested at 3 grams per day has also been reported to be an effective dietary supplement in the activation of muscle protein synthesis (Molfino et al., 2013). If injury results in obligatory bed rest, the ingestion of HMB in similar quantities has been reported to reduce the degree of muscle loss. Therefore, HMB ingestion may be considered in the preservation of muscle mass in the injured player (Wu et al., 2015).

Although non-essential amino acids are not generally believed to be important for the regulation of protein synthesis, studies have indicated that some of these amino acids can manipulate muscle protein metabolism during conditions of (chronic low-grade) inflammation or oxidative stress (Domingues-Faria et al., 2016). For example, the amino acid glycine is thought to modulate the production of inflammatory cytokines; thereby reducing the negative impact of these cytokines on protein metabolism (Wheeler et al., 1999; Roth et al., 2003). Thus, players should be aware to maintain total daily protein intake during rehabilitation.

Unfavorable lipid profiles (pro-inflammatory) due to excesses in the diet of trans-fat, saturated fat and excessive omega-6 fat from vegetable oils should be avoided. Instead, players are encouraged to regularly eat foods, such as oily fish, for a source of omega-3 (Simopoulos, 2007). Furthermore, the daily ingestion of 4-5 g of fish oil has been reported to improve muscle sensitivity to anabolic stimuli, resistance exercise and protein. Specifically, the ingestion of 5 g of fish oil supplements daily (providing 3 g , eicosapentaenoic acid and 2 g docosahexaenoic acid) has been shown to prevent muscle atrophy during limb immobilization in active females through increases in myofibrillar muscle protein synthesis (McGlory et al., 2019). Therefore, the ingestion of omega-3, in combination with the ingestion of protein and HMB may be effective in maintaining muscle mass (Smith et al., 2011; Smith et al., 2011; McGlory et al., 2016), especially in the immobilized player (Zwart et al., 2010).

The ingestion of 5 g of omega-3 is not realistic to achieve in the players standard dietary intake. Therefore, supplementation is warranted with due consideration given to supplement safety and appropriate batch testing for contaminants (Chapter 7). If players are not already ingesting omega-3, it would be recommended that this strategy begin immediately following the injury. In addition, players may consider supplementation if opting for elective surgery. In this case ingestion protocols should begin two weeks in advance of immobilization, as this may be the time required for the omega-3 to be incorporated into the muscle cell membranes (McGlory et al., 2016).

The functional recovery phase is characterized by progressive hypertrophy and functional rehabilitation exercises. This phase involves a progressive return of the player to training and ultimately games. The return to play criteria includes but is not limited to: full range of motion; normal strength; normal neurological evaluation; no joint swelling or instability; ability to run and sustain contact without pain; no intake of pain medication; player education about preventive measures and future risks. It is suggested that these criteria should be led by the teams' medical physician and interdisciplinary team responsible for the players recovery.

An increase in energy expenditure, as training volume and intensity is progressed, should be married with an increase in daily carbohydrate intake (Chapters 4 and 5). Appropriately formulated carbohydrate sports beverages are typically ingested during and after exercise to help meet player fuel and fluid requirements (Rollo 2014). In the functional recovery phase recommendations consistent with optimal nutrition practice for the player should be modified to ensure, and help support, full recovery (Chapters 3-7).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BODY COMPOSITION

The routine assessment of player body composition (Chapter 3) can identify injury risk factors such as muscle imbalances, especially in the lower limbs. Improved symmetry between the left and right legs may reduce the risk of injury and may also benefit performance (Rahnama et al., 2005; Hart et al., 2014). Accurate and routine assessment of body composition provides baseline/target numbers for the player to achieve during the rehabilitation process. These targets can be used for goal setting and player motivation. Body composition should therefore be assessed at the time of injury, specifically the quantification total body mass, lean mass and fat mass (Chapter 3). Changes in body composition during injury typically involve increased body fat and decreased lean mass from an early stage (Wall et al., 2013; Wall et al., 2015). These changes are not always reflected in body mass, as body mass may increase, decrease or stay relatively constant depending on the ratio of lean- and fat mass change (Peterson et al., 2011).

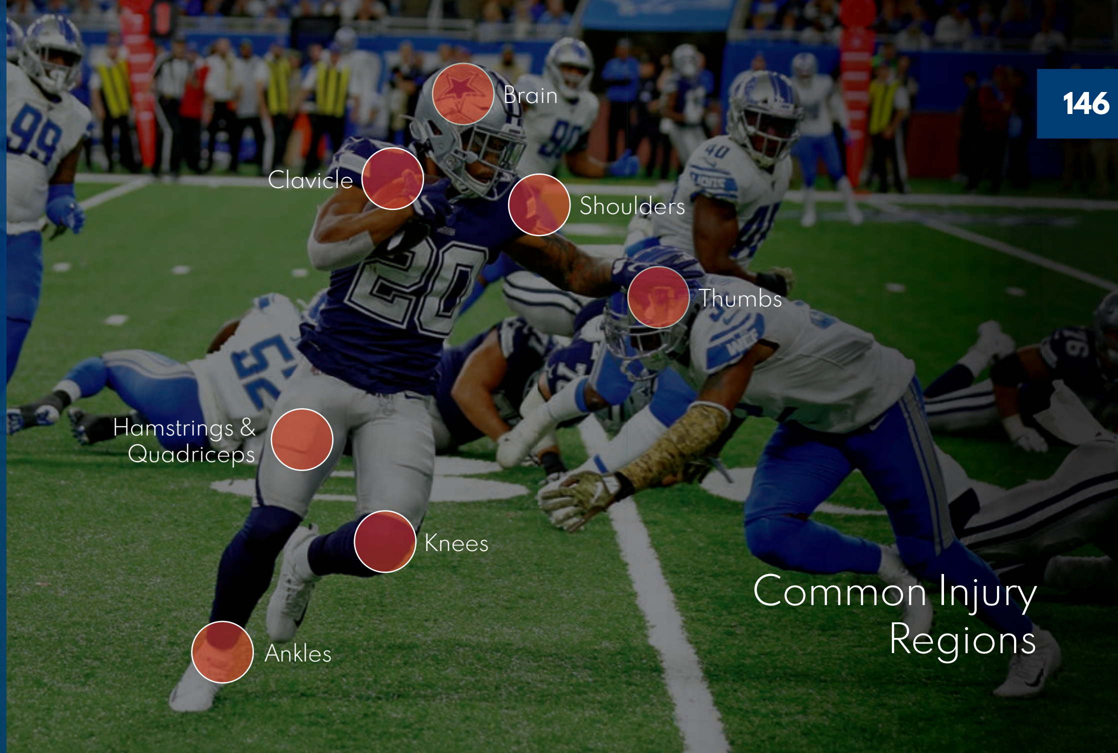
Injury Risk Factors

Playing Position

Playing surface

Poor nutrition

Muscle imbalance



Nutrition

Daily diet

Maintain Energy Intake

Hydration / meal
5-7 ml/kg BM

Protein
20-30 g/meal
4-6 meals/day
30-40 g before sleep

Dietary Supplementation

Omega-3 : fish oils
(5 g/day)

Creatine
(20 g/d x 5 d, 5 g/d)

Figure 1

Injury risk factors, common injuries and nutritional considerations for injuries in football. Common injury regions below the neck can be unilateral and/or bilateral.

Additional Considerations

Nutritional compounds to stimulate muscle growth and or prevent muscle loss continue to be investigated, these include, amongst others, curcumin (Drobnic et al., 2014; Franceschi et al., 2016). However, these compounds are typically investigated in clinical or elderly populations. More research is required and case studies complied on the use of novel “bioactive” compounds before recommendations can be provided with confidence to football players.

A practical consideration may be to use appropriate methods to routinely assess the players vitamin D status throughout the season (Owens et al., 2018). This is because both in vitro and in vivo studies have shown muscle regeneration is attenuated with low vitamin D concentrations (Owens et al., 2015). In the case of deficiency players may consider the daily ingestion of 2000 iU of vitamin D, until a concentration of 75 nmol/L is achieved (Close et al., 2013). Though thresholds of Vitamin D deficiency, assessment protocols and ingestion protocols continue to be debated.

It is also important to advise players on what to avoid during injury. Beyond both excessive and low energy intake, alcohol ingestion may also be discouraged. This is because players may ingest excessive alcohol if unmotivated or seeking distraction from not being involved in the daily demands of football (Tipton 2015). Alcohol intake after training and games is likely to reduce rates of muscle protein synthesis, even if co-ingested with protein (Parr et al., 2014). Therefore, routine or excessive alcohol ingestion will be unfavourable to the desired adaptations sought during the rehabilitation program of the injured player.

Summary

Football may be considered a "high risk" sport with regard to injury. Since 2012, the NFL have commissioned an independent third-party company to compile and analyze injury data on football players. Common upper body injuries include those to the head, shoulders and hands. Common lower body injuries include those to the knees (ACL/ MCL) and ankles. Both muscle and connective tissue injuries can be positively influenced by appropriate nutrition strategies. Further research is required to determine impact of nutrition on short and long term consequences of concussion. Following injury, an interdisciplinary approach, which includes nutrition, is required for the clinical care and support of injured players.

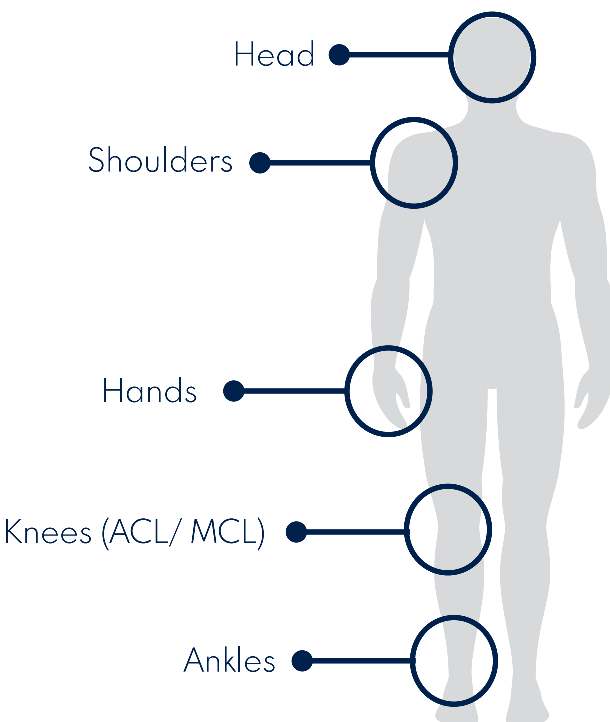
Chapter 8: Nutrition for Football Injuries

SUMMARY

Football may be considered a **"high risk"** sport with regard to injury.

Since 2012, the NFL have commissioned an independent third-party company to compile and analyze **injury data on football players.**

COMMON INJURIES



NUTRITION CONSIDERATIONS FOLLOWING INJURY

- Energy intake modification
- Protein
- Collagen
- Omega-3

Following injury, an interdisciplinary approach, which includes nutrition, is required for the clinical care and support of injured players.

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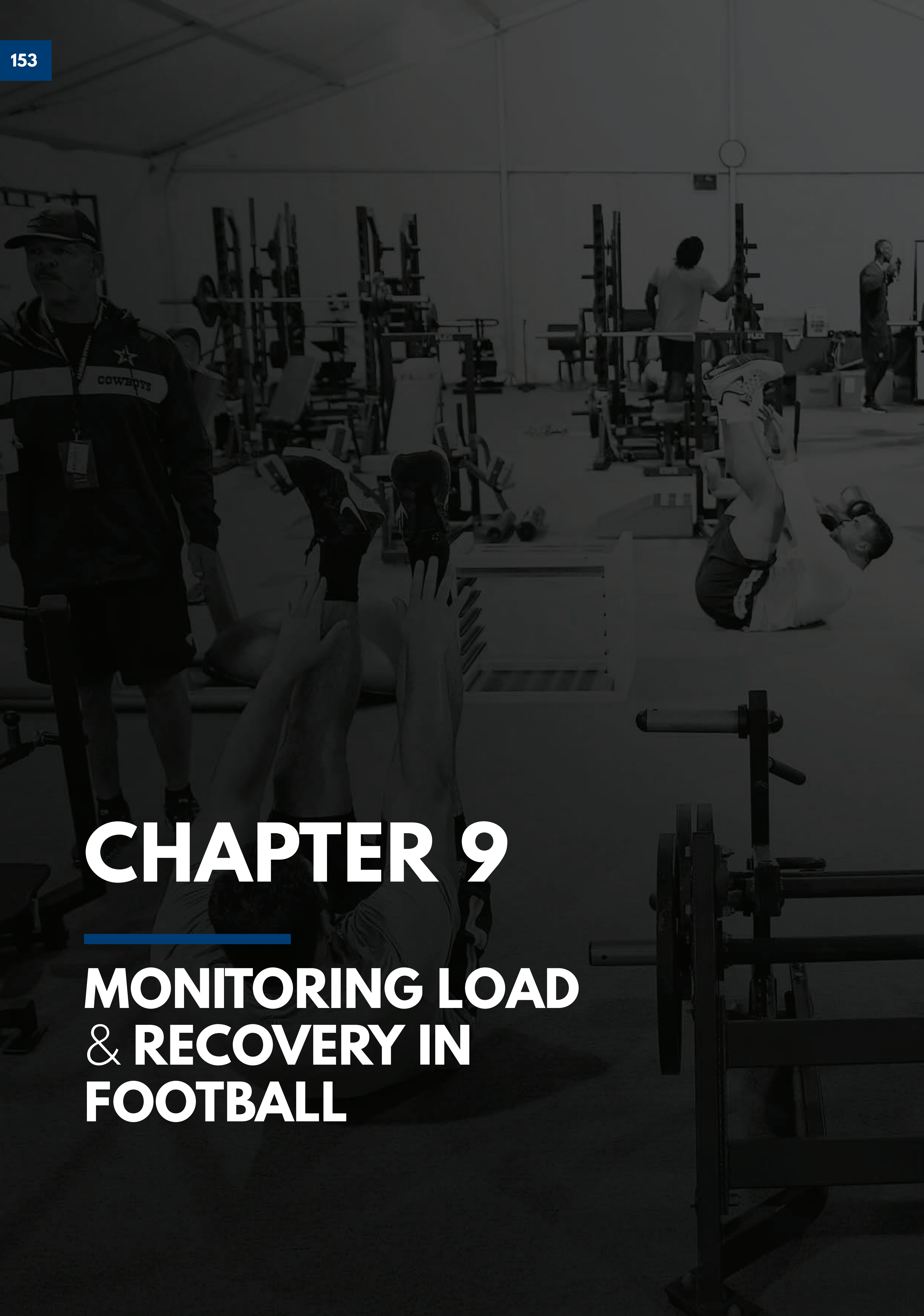


CHAPTER 9

MONITORING LOAD & RECOVERY IN FOOTBALL

MONITORING LOAD & RECOVERY IN FOOTBALL

Eric C. Freese and Bridget C. Sopeña

Introduction

In an ideal world, football players arrive at each day of practice and competition feeling rested, powerful, and ready to compete at their best. In reality, players exhibit both highs and lows in terms of psychological and physiological levels of preparedness, both for training and games. The goal of this chapter is to define player monitoring by first discussing the different parameters of external and internal load assessment in football before discussing tools to monitor the player's recovery. Key applications specific to the football player will be shared with the aim of optimizing both their health and performance.

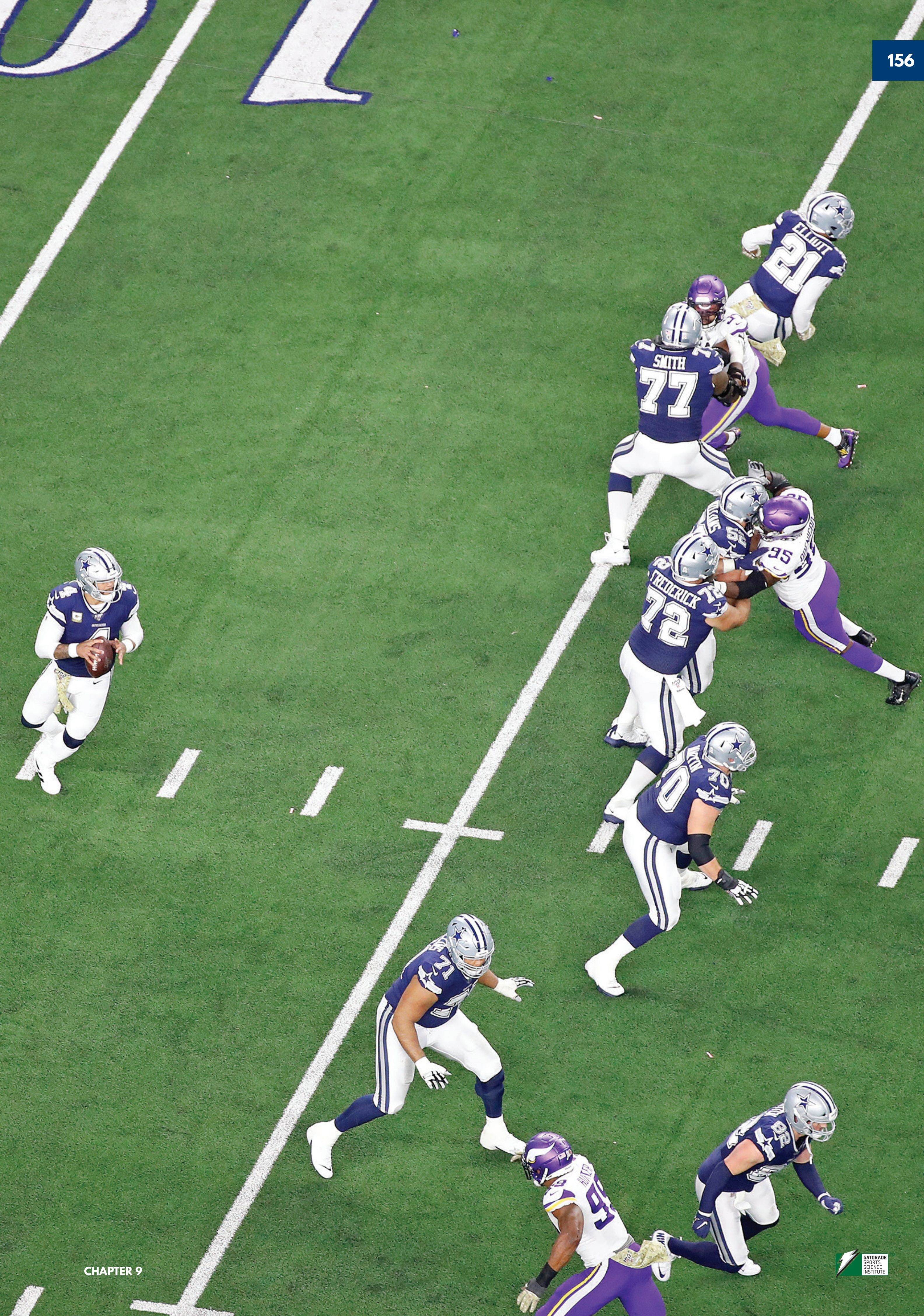
Monitoring and Recovery Landscape

Load during activity may be defined as a stimulus experienced and responded to by an individual before, during, or after participation in exercise (Team Physician Consensus Statement, 2019). Football training load can be described as the input variable that is manipulated to elicit a desired training response and level of preparedness for the rigors of the NFL season (Impellizzeri et al., 2005; Halson 2014; Gabbett et al., 2017; Impellizzeri et al., 2019). External load is the prescribed work the player completes during training, practice, and games while internal load is the player's psychological and physiological responses that occur while completing the external load. Typically, both psychological and physiological fatigue associated with the stressors of training, practice, and competition can be compensated with recovery. Although the term “recovery” is often used in football, identifying a common consensus or appropriate integration of the term is often elusive. Recovery is defined by the Oxford dictionary as ‘A return to a normal state of health, mind, or strength.’ Therefore, recovery is a multifaceted restorative process necessary to return a player to physiological and psychological balance. In football recovery can be used as an umbrella term referring to different behaviors (i.e. sleep and nutrition) and modalities (i.e. hydrotherapy, compression, massage, neuromuscular stimulation, and many more) to restore/enhance player ‘readiness’ before training sessions and/or games.

For example, the time course of neuromuscular function and perceptual assessments varies considerably between 24-120 h post-game depending on the sport (rugby, Australian football, and soccer), position, and competitive level of the athlete (Cormack et al., 2008; Twist & Highton 2013; Thorpe 2018). As a consequence of a football game, players experience muscle damage (as measured by creatine kinase in the blood) (Kraemer et al., 2009), stress (as indicated by plasma cortisol concentrations) (Hoffman et al., 2002), and perceptual fatigue (Fullagar et al., 2017). Additionally, perceptions of wellness, including soreness, sleep, and energy, have been shown to take longer than four days to return to pre-game levels in D1 NCAA football players (Fullagar et al., 2017). Although the specific time course of neuromuscular function recovery following a football game has not been established to date, it is reasonable to assume this will be influenced by playing position, playing time and number of impacts experienced (Chapter 2).

The practical implementation of player monitoring poses a challenge in football due to the multidimensional and complex structure of training and the game, the busy training (strength and conditioning as well as practice) and competition schedules, along with logistical issues such as the large number of players on the 53-man roster. The current literature that has assessed psychological and physiological responses to football has focused primarily on college players (Hoffman et al., 2002; Kraemer et al., 2009; Kraemer et al., 2013; Sterczala et al., 2014; Fullagar et al., 2017) with no research to date on professional football players. Our hypothesis is that mitigating psychophysiological disturbances are also relevant during the professional season, in maintaining performance, health and general player wellbeing.

The external load applied to a player during training and throughout the season is designed to elicit a desired effect on player performance and well-being, culminating in high-level athletic performances across the NFL season and into the playoffs. The external load the player has completed (i.e. strength and conditioning, practice, training, and games) induces varying degrees of physiological and psychological fatigue. In general, the greater the fatigue experienced, the greater the “recovery” required. This load and recovery continuum will depend on the activity and the individual responses. Therefore, characterizing the external load imposed on a player is important to understand the stressors of the NFL season while monitoring the individual internal load helps identify how an athlete is coping with those stressors. Improper recovery may lead to reduced performance and ultimately impaired player health. Performance, physiological, biochemical, and subjective measures are all options for player monitoring. Nevertheless, understanding which measures are most appropriate in any given football-specific circumstance remains to be determined (Cormack 2014; Saw et al., 2016).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TERMINOLOGY

Fatigue can be defined as a 'failure to maintain the required or expected force (or power output)'

(Edwards 1983).

Player Monitoring Tools in Football

External Load

External loads are those factors that causes a player physical stress. From a football perspective, these are activities performed during training and games. There are two types of physical stressors, external load and internal load. External load can be divided into controllable (training, practice, etc.) and the uncontrollable (games) variables. This measurement is the foundation of any player monitoring program and should be conducted independently of the players internal load characteristics and performance/subjective assessments (Halson 2014).

In principle, for a coach to prescribe an appropriate external load, they should understand the current workload the player is exposed to during practice and games (Gabbett et al., 2017). The type of external load measurement chosen needs to be specific to the individual as certain measurements may not apply to every position on the football field. For instance, monitoring throw count would not be appropriate for a lineman considering their position does not require that type of movement or workload. Instead, choosing position specific metrics for the lineman, such as contacts (hits) and/or contact load (G-forces (Gs), will provide more appropriate) and meaningful information. It is important to note that markers of external load should be monitored against position specific and individual performance indicators. This will allow the evaluation of how the "load" is impacting upon performance, which can then be modified accordingly. How the load is managed will depend on many factors including the players individual goals, injury history and time of the season.

Internal Load

The internal load represents the relative physiological and psychological stress experienced as a result of practice and games (Halson 2014). This measurement is important in order to understand how the player responds to the external load as well as training load and subsequent adaptation (Halson 2014). Therefore, internal load is most valuable when it is paired with external load. This allows staff to accurately recognize and intervene when players are fatigued or not coping with the demands of training and games. Monitoring both the internal load and external load between players also makes it possible to separate the fresh versus fatigued football players on a team (Halson 2014). For example, identical external training loads could elicit different internal loads in two different players even with similar physical characteristics. The following section will discuss internal load variables that are applicable to football.

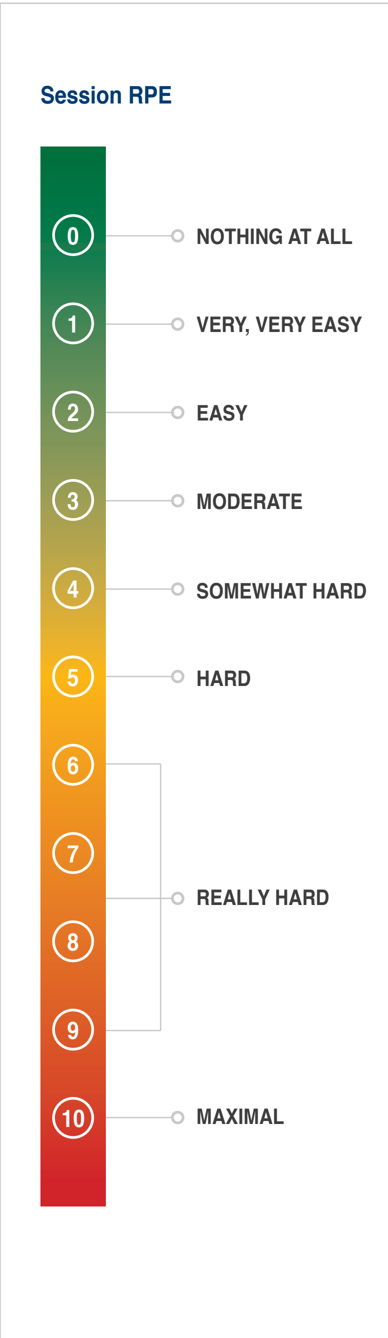


Figure 1
The modified CR-10 scale by Foster et al. (2001).

Rating of Perceived Exertion

The rating of perceived exertion (RPE), initially created by Gunnar Borg (Borg 1962), can be used to determine the perceived effort during or after training, based on the notion that the player can monitor their own physiological stress due to afferent and efferent sensory signals. In 2001, Foster and colleagues proposed a method to monitor training load through a combined subjective and objective methodology, known as session rating of perceived exertion (sRPE) (Foster et al., 2001). The sRPE assesses the internal load of the player by subjectively classifying the intensity of the entire training session or practice. Thus, following the completion of training, practice, or a game a player can rate 'how hard the session was' on a scale from 0-10 (see figure 1; Borg CR-10 scale). This value is then multiplied by the duration of the session in minutes. For example, if practice lasted 120 minutes and the player rated the practice a 5, the sRPE training load is calculated as follows:

Training Load (A.U.) = 5 (RPE) x 120 (duration) = 600 A.U.

Two recent reviews sought to determine the validity and ecological validity of utilizing sRPE to monitor training load (Haddad et al., 2017; McLaren et al., 2018). The reviews confirmed the validity, reliability, and internal consistency of sRPE across several sport domains and populations (men, women, children, adolescents, adults, elite athletes, etc.). The meta-analytic review by McLaren et al., (2018) identified 10,418 individual session observations across varying team-sports and found correlation coefficients between sRPE and total distance, accelerometer load, and collision impacts to be r = 0.79, 0.63, and 0.57, respectively. The validity of sRPE as a monitoring tool has been established in soccer (Impellizzeri et al., 2004; Alexiou & Coutts 2008), rugby (Lovell et al., 2013), Canadian football (Clarke et al., 2013), Australian Rules football (Scott et al., 2013), resistance training (Day et al., 2004), interval training (Minganti et al., 2011), and conditioning (Alexiou & Coutts 2008; Lovell et al., 2013). However, to date, the validity and reliability of sRPE has not been established in football.

Given the low cost, ease of administration, lack of time commitment from individual players, and previously established validity and reliability across sports and training domains, it is reasonable to suggest sRPE would be a reliable internal load monitoring tool for football and further research now needs to confirm this. Until this research is completed, it is suggested that sRPE could be paired with other physiological parameters, such as heart rate, to provide a well-rounded and meaningful internal training load monitoring program for football.

Heart Rate

Monitoring heart rate (HR) is one of the most common methods of assessing internal load in athletes. A linear relationship between HR and the rate of oxygen consumption during steady state exercise provides the basis for utilizing HR as a valid means to understand the cardiovascular stress (i.e. internal load) endured by the athlete during exercise (Hopkins 1991). Specifically, the HR response is directly associated with exercise intensity. It is important to consider and control for factors such as hydration, environment, and medication when using HR as a means of monitoring internal load (Bagger et al., 2003). Nevertheless, through consistent measurement, a players HR can provide an insight into their training status. For example, during standardized exercise protocols an "uncharacteristic" high HR may indicate an impaired training status or a state of under-recovery. Therefore, obtaining and understanding the baseline HR profile of the player is critical for subsequent internal load interpretation, as is annual measurement of a true HR maximum (versus prediction from 220-age).

Heart Rate Variability

Resting heart rate variability (HRV) is a metric gaining popularity to monitor recovery status in team sports. Resting HRV is a noninvasive indicator of autonomic modulation of the heart, reflecting cardiovascular recovery after a training session (Stanley et al., 2013) and which has been suggested to indicate both positive and negative adaptations to training (Plews et al., 2013). Appropriate methodological approaches to monitoring, including longitudinal tracking of responses to training, taper, and competition, are critical (Halson 2014) due to the high day-to-day variability caused by environmental and homeostatic factors. While studies have interpreted the HRV data differently, Plews et al., (2013) suggests the use of the natural logarithm of the square root of the mean sum of the squared differences between R-R intervals (ln rMSSD). In addition, weekly averages can be used to improve validity in comparison to single-day measurements (Plews et al., 2012).

Flatt et al., (2018) utilized HRV to determine positional differences in recovery from consecutive-day training sessions in elite NCAA football players. In this study it was concluded that the ~20-hour recovery time between the end of training session 1 and the onset of training session 2 was not sufficient for cardiac-parasympathetic activity to return to baseline in linemen. However, receivers, defensive backs, linebackers, running backs, and tight-ends had all recovered to near baseline values. This finding aligns with a systematic review that determined the HRV recovery from exercise is slower in individuals with lower aerobic fitness and is attenuated for longer durations after high-intensity, anaerobic exercise (Stanley et al., 2013). The combination of higher cardiac strain, lower aerobic fitness, and increased anaerobic workload (e.g. repeated blocking, tackling, and short sprints) for linemen increase the possibility of reduced cardiac-parasympathetic recovery following training sessions (Deren et al., 2012; Deren et al., 2014).

Measuring HRV should be completed in a rested state either at the training facility prior to training or at home. Measurements obtained at home after waking can be more challenging but may be mitigated by utilizing inexpensive smartphone applications that have been validated (Flatt & Esco 2013; Esco et al., 2017). However, further research is required to determine specific guidelines for football players.

Biomarkers

The use of various biomarkers has become a routine tool used in monitoring elite football players. Blood collection and muscle biopsies, both invasive in nature, are considered the gold standard for the analysis of biomarkers in exercise science (Lindsay & Costello 2017). However, due to obvious practicalities, other non-invasive methods using urine and saliva have emerged preferred options for biomarker assessment. Not all markers can be measured accurately in all bodily fluids; therefore, the biomarker of interest will dictate the type of specimen collected, and ease/frequency of collection. The use of saliva in relation to biomarker monitoring is discussed below.

Stress & Recovery

In football, measuring the hormones testosterone and cortisol may assist in monitoring recovery. Both markers have been used to establish a player's adaptability to a training stimulus, overall stress, and the ability to recover from muscle damage. Testosterone has been associated with increased performance, aggression, and drive to win (Wood & Stanton 2012). Whereas cortisol may negatively modulate the players immune function leading to compromised cell repair (Malm 2001; Tidball 2002). Furthermore, cortisol may act to inhibit testosterone mediated muscle repair and muscle protein synthesis (Kraemer & Ratamess 2005). The hormones are typically assessed in concert and expressed as a testosterone: cortisol (T:C) ratio. The majority of studies to date have revealed little to no change in testosterone or cortisol throughout a football season or following a competitive game (Hoffman et al., 2005; Kraemer et al., 2009; Sterczala et al., 2014). Nevertheless, recent evidence has reported acute changes in the T:C ratio following a game (Stone et al., 2019). Given the advances in analysis methods, monitoring the T:C ratio may offer a valuable insight into the players "readiness" to perform (Fry et al., 1994; Kraemer & Ratamess 2005).

Both cortisol and testosterone can be accurately determined in serum and saliva, giving the practitioner flexibility in their collection methods. The most important factor to consider when collecting hormones is consistency in the protocol. Both cortisol and testosterone follow diurnal rhythms, with concentrations peaking in the morning and declining throughout the afternoon and evening (Smyth et al., 1997). Therefore, collecting morning samples and then maintaining that collection time throughout the season is recommended.

Immunity

The relationship between physical activity and the suppression of the immune system is not fully understood, but it is known that moderate intensity exercise can improve immune defenses, while extreme effort can reduce them by creating an increased risk of upper respiratory tract infection (URTI) (Trochimiak & Hubner-Wozniak 2012), Monitoring load and maintaining an appropriate balance between exercise and recovery may reduce the risk of suppressed immunity and decrease the frequency of URTI. Furthermore, monitoring changes in immunity can help in preventing potential illnesses that are well correlated with changes in training and

load. Salivary immunoglobulins are the most well studied markers of the mucosal immune system due to their relative ease of collection and extensively investigated response in relation to exercise (Lindsay & Costello 2017).

One study found that a normal season of extensive training in football resulted in a significant decrease in both the concentration and secretion rate of immunoglobulin A (IgA), as well as an increase in the incidence of URTI (Fahlman & Engels 2005). Although data are limited in American football, many studies in European soccer, Australian Football League, and rugby have found similar results determining that excessive, prolonged physical exertion in team sports resulted in suppressed immunity, increasing the susceptibility to infections (Owen et al., 2014); (Moreira et al., 2011); (Coad et al., 2015).

Analysis of saliva for specific biomarkers, including IgA, offers several key advantages when comparing against blood. The non-invasive nature of salivary collection allows for greater personalized timing of sample collection, rapid sample collection, and does not require specific professionals to collect.

Muscle Damage

The players skeletal muscle experiences damage from high-velocity eccentric loading (Dick et al., 2007; Shankar et al., 2007; Feeley et al., 2008), rapid acceleration and deceleration forces, and blunt force trauma. Muscle damage results in elevations of creatine kinase (CK) (Kraemer et al., 1990; Malm 2001; Kraemer et al., 2013). In football, changes in CK over the course of a season are minimal, yet large individual variations can be observed (Kraemer, Looney et al. 2013). The individual variation is likely to be due to “starters” versus “non-starters” (Stone et al., 2019). Starters will experience more game time and consequently more muscle damage over the season.

Of interest is that monitoring CK can inform strength and conditioning programs (Kraemer et al., 2013). Therefore, monitoring CK may be a valuable internal load measure in football to inform players recovery strategies and “readiness” to perform.
At present, CK should be measured in serum, however, future research is needed to determine if saliva is a truly valid alternative. Much of the research in salivary-CK is clinical in nature, focusing primarily on patients with myocardial infarctions (Mirzaii-Dizgah et al., 2012). Although this may transfer to monitoring post exercise, further research is required before applying in football settings (Barranco et al., 2018).

Neuromuscular Fatigue

The result of football-specific fatigue on neuromuscular performance and the time course of recovery has received very little attention in the literature. Although data are limited in football, there are simple, practical, and reliable measures of lower body power that can be used to monitor neuromuscular fatigue, the countermovement jump (CMJ) and isometric-midthigh pull (IMTP) (Hughes et al., 2019).

The CMJ provides single-point concentric variables, such as peak power, force, and height. The CMJ has been reported to be a suitable athlete-monitoring method for neuromuscular fatigue (Gathercole et al., 2015). Moreover, this assessment has been shown to be the most reliable measure of lower-body power in comparison to other popular jump tests (Markovic et al., 2004). The IMTP is a reliable and valid test for measuring maximum strength, providing practitioners valuable information on peak force (McGuigan & Winchester 2008) and rate of force development (RFD) as well as fatigue in football players (De Witt (De Witt et al., 2018).

For both the CMJ and IMTP, practitioners should be consistent in their methods to avoid error and reliability issues. In our experience, standardizing warmups, hand placement, squat depth, timing of assessment (pre/post game/exercise, days following games, etc.), and encouraging/ensuring maximal player effort will all influence the quality of the results. Establishing a protocol at the beginning of the season will reduce the variability in the data and allow for better interpretation and identification of neuromuscular fatigue.

Sleep

Sleep is one of the body's most important biological functions with roles in performance, cognition, learning and development, as well as in mental and physical health (Halson 2014). In addition to being an imperative part of the recovery and adaptive process, evidence proposes that increased sleep duration and better sleep quality are associated with increased performance and decreased risk of injury (Watson 2017). Despite this, studies have found that athletes fail to obtain the recommended amount and quality of sleep, affecting both performance and health. For example, Fullagar and colleagues found that post game, college football players took up to 96 hours for their perceptual sleep quality to return to baseline during a competitive season (Fullagar et al., 2017). A number of obstacles can reduce the likelihood of football players obtaining proper sleep, such as training and competition schedules, travel, stress, and additional under recovery. For instance, Leduc, et. al found that in international rugby players, sleep quantity and quality seemed to deteriorate during higher loads of training, highlighting the necessity to monitor and explore strategies to improve sleep in and around such training periods (Leduc et al., 2019).

In the applied setting, practitioners can monitor sleep quantity and quality through actigraphy and/or sleep diaries (Halson 2013) and screening surveys (Bender et al., 2018). Actigraphy is a method that requires the athlete to wear a wrist activity watch (which has preferably been individually calibrated) for an extended period of time, while it continuously monitors movement (Halson 2013). Sleep diaries involve simply recording the start and stop time

of sleep periods (night-time sleeps and daytime naps) to monitor trends in sleep quantity. While there is uncertainty in the literature on the efficacy of sleep screening questionnaires as a tool to identify which athletes may benefit from additional sleep monitoring, recently Bender et. al clinically validated the Athlete Sleep Screening Questionnaire (ASSQ) as a valid method in detecting meaningful sleep disturbances in an elite athlete population (Bender et al., 2018). Utilizing sleep monitoring/screening tools and implementing the recommendations to improve sleep may help maintain/improve performance over the course of a competitive season.

Subjective Wellness

There are a wide variety of questionnaires that have been identified in the literature as well as being utilized by high-performance sport teams (Taylor K 2012) including, but not limited to: the Profile of Mood States (POMS) (Morgan et al., 1987); the Daily Analysis of Life Demands for Athletes (DALDA) (Rushall 1990); the Recovery-Stress Questionnaire for athletes (REST-Q-Sport) (Kellman & Kallus 2001); and the Total Recovery Scale (TQR) (Kentta & Hassmen 1998).

Subjectively assessing a player's perceived physical or psychological well-being through questionnaires or diaries is a relatively cheap and simple means of determining training load and the player's subsequent responses.

Saw et al., (2016) systematically reviewed objective and subjective measures of athlete well-being and evaluated those against their response to acute and chronic training load, finding that subjective measures reflected acute and chronic training loads with superior sensitivity and consistency than objective measures. The findings from 56 original studies found a general impairment of subjective well-being with increases in acute and chronic training loads while an acute decrease in training load improved subjective well-being. These finding support the use of subjective measures to monitor player well-being in response to increases in training load, such as might be exhibited during training camp for example.

To date, there has been no published literature in professional football players investigating the effectiveness of subjectively assessing player wellness. Bespoke subjective measures that are simplified beyond POMS, DALDA, and REST-Q-Sport questionnaires have become more common in elite sport in recent years due to logistical challenges associated with longer questionnaires (Taylor 2012; Twist & Highton 2013; Wellman et al., 2019). Two recent studies in NCAA football players utilized customized wellness questionnaires comprised of 5-point Likert-scale questions, including a combination of fatigue, sleep quality, general soreness, stress levels, mood, sleep quantity, and energy questions (an example of these Likert-scale questions can be found in Figure 2) (Fullagar et al., 2017; Wellman et al., 2019). The number of questions, when those questions should be asked (return to training day, game day +X, etc), and the exact scale dimensions (5-point vs. 10-point) in order to effectively determine recovery status of the football player has yet to be established. Wellman et al., (2019) utilized six Likert-scale questions while Fullagar et al., (2017) utilized three Likert-scale questions. Both studies found evidence to support the use of subjective wellness questionnaires to monitor perceived wellness in NCAA football players. Fullagar et al., (2017) sought to determine the time course of perceptual recovery markers after football games in NCAA football players and found that perceptual markers of soreness, energy, and overall wellness were impaired 96 hours post-game.

Given the potential turnaround for some games are shorter than others in the NFL (96 hours from Sunday to Thursday), it is important to consider the perceptual recovery of the players and training load during short weeks to ensure the players are ready to compete on game days. Further research is necessary to determine the time course of recovery in professional football players and identify interventions (nutritional or otherwise) that can positively impact the time course of recovery.

DAILY WELLNESS SURVEY

How Much Energy Do You Have?

0 1 2 3 4 5 6 7 8 9 10

LOW ENERGY — MODERATE ENERGY — HIGH ENERGY

How Motivated Are You To Train/Practice Today?

0 1 2 3 4 5 6 7 8 9 10

LOW MOTIVATION — MODERATE MOTIVATION — HIGH MOTIVATION

How Much Muscle Soreness Do You Have?

0 1 2 3 4 5 6 7 8 9 10

NO SORENESS — MODERATE SORENESS — VERY SORE

How Much Non-training/Practice Stress Do You Have?

0 1 2 3 4 5 6 7 8 9 10

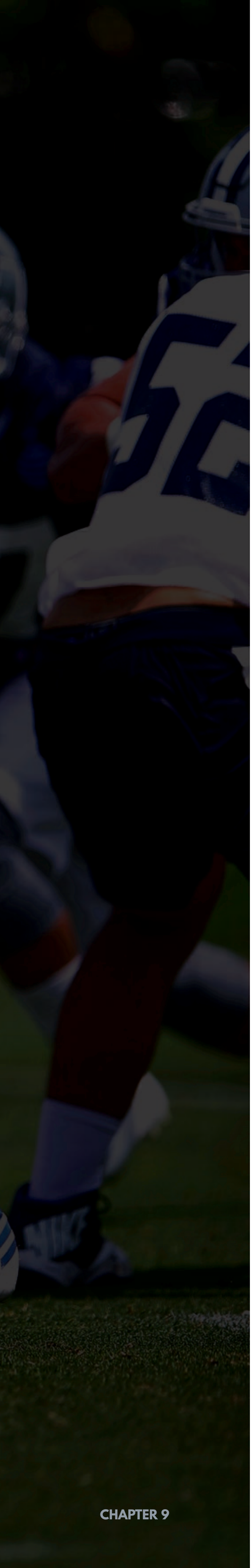
LOW STRESS — MODERATE STRESS — HIGH STRESS

How Many Hours Of Sleep Did You Get Last Night?

1 2 3 4 5 6 7 8 9 10 11+

What Was Your Sleep Quality?

GOOD — AVERAGE — POOR



Summary

In summary, football load during training and throughout the season is designed to elicit a desired training response on player performance, well-being, and level of preparedness for the rigors of the NFL season. An appropriate player monitoring strategy aims to elevate the player's responses to training and practice to elicit performance maintenance across the NFL season. Identifying an appropriate player monitoring strategy may help optimize external load prescription and/or moderate player recovery behaviors which may lead to sustained performance, reduced injuries, and a more successful player. Alignment and effective communication between the players and the interdisciplinary sports performance team is paramount in successfully executing a player monitoring program.

Chapter 9: Monitoring Load & Recovery in Football

SUMMARY

Football training load can be described as the input variable that is manipulated to elicit a desired training response and level of preparedness for the rigors of the NFL season.

EXTERNAL LOAD

the work completed during training, practice, and games

INTERNAL LOAD

the player's psychological and physiological responses that occur while completing the external load.

Monitoring both the internal load and external load between players makes it possible to separate the fresh versus fatigued football players on a team.

Typically, both psychological and physiological fatigue associated with the stressors of training, practice, and competition can be compensated with recovery.

Identifying an appropriate player monitoring strategy may help optimize external load prescription and/or moderate player recovery behaviors which may lead to sustained performance, reduced injuries, and a more successful player.

In football, **recovery can be used as an umbrella term** referring to different behaviors (i.e. sleep and nutrition) and modalities (i.e. hydrotherapy, compression, massage, neuromuscular stimulation, and many more) to restore/enhance player 'readiness' before training sessions and/or games.

Alignment and effective communication

between the players and the interdisciplinary sports performance team is paramount in successfully executing a player monitoring program.

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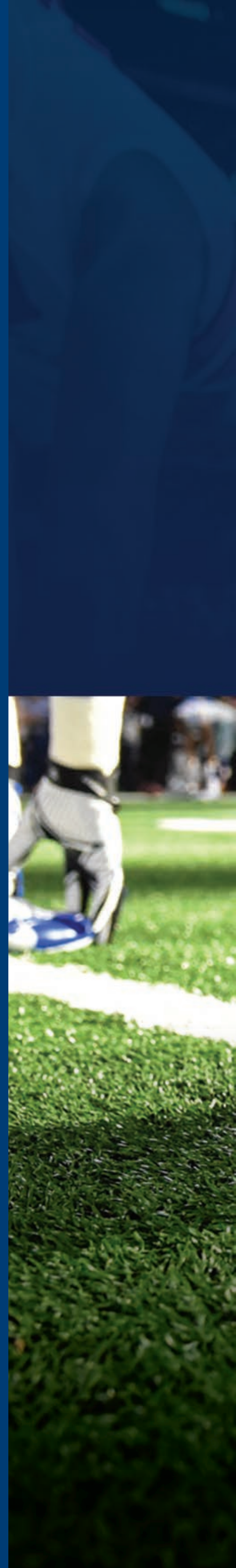

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