1.1 Physical demands of football

Introduction

Understanding the physical demands of playing football and the corresponding energy systems, which power the movement of the football player, are fundamentally important for sports nutrition. Understanding how the player's body responds to meet the challenge of football-specific exercise, provides the basis to inform nutrition recommendations. In this unit, we will aim to classify and quantify the physical demands of football. With this knowledge, it is possible to design football-specific nutrition strategies to enhance the development of players and allow them to adequately cope with the physical demands football places on them. The game of football will be introduced before covering how player specific activity has been studied. The key variables, which influence the player's physical workload, will be covered to allow you to identify when changes to the nutrition strategies may be required. Unit 2 will discuss how the player's body responds to meet the physical demands of football activity.

Overview of football

A football team is composed of eleven players including one goalkeeper and ten outfield players. Although, rules may vary between competitions, since the year 2020 teams have been permitted to make five substitutions during a 90 min match. If a match goes to extra time, an additional substitution can be made. Therefore, a total of six players out of 11 players can be changed.

An important update to the substitution rule is that teams are now allowed to use a maximum of two concussion substitutions in a match. In situations where there are clear symptoms of concussion (head injury), teams are permitted to replace the player with a permanent concussion substitution. These substitutions can be made in addition to the normal substitutions.

Substitutions are an important consideration for sports nutrition, as they create a break in play as players exit and enter the pitch. Therefore, each substitution represents an opportunity for players on the pitch to take on fluids and energy, which will be covered in detail in later modules.

For the purpose of this course, we will focus on the outfield players. Nevertheless, general principles of sports nutrition can also be applied to goalkeepers. Football is a match of two 45-minute halves separated by a 15-minute half-time interval (figure 1). Two opposing teams compete for possession of a single ball. The objective of the team is to pass or shoot

the ball into the opponent goal, whilst preventing the opposing team from completing the same objective. The team's score is a product of the number of goals they have achieved. The match score is a product of the number of goals scored/conceded by both teams. A football match may result in a win, where more goals have been scored than the opponent, a draw where both teams score the same amount of goals or no goals during the match or a loss where the opponent scores more goals. In league competitions, "3" points are awarded to the team for a win, "1" point for a draw and "0" points for a loss.
For cup competitions, in the event of a draw, the game may be extended into extra time involving an additional two 15-minute periods. Should there be no result following extra time, the result of the match is decided by both teams completing a penalty shoot-out. In this situation five players from each team are selected to take a penalty. A penalty kick involves placing the ball on a penalty spot marked 12 yards (11 m) from the goal line and striking the static ball towards the goal. The goal is defended only by the opposition goalkeeper. After five penalties, the team with the most goals wins the match. In the event of an equal amount of goals being scored, the teams continue to take penalties consecutively until one team outscores the other. The full laws of the match as directed by Fédération Internationale de Football Association (FIFA) can be downloaded here:

https://digitalhub.fifa.com/m/3f3e15cc1ab8977b/original/datdz0pms85gbnqy4j3k-pdf.pdf

Did you know?

Significant dates in football history

1849: First written rules of a non-handling form of football produced at Eton School, England.

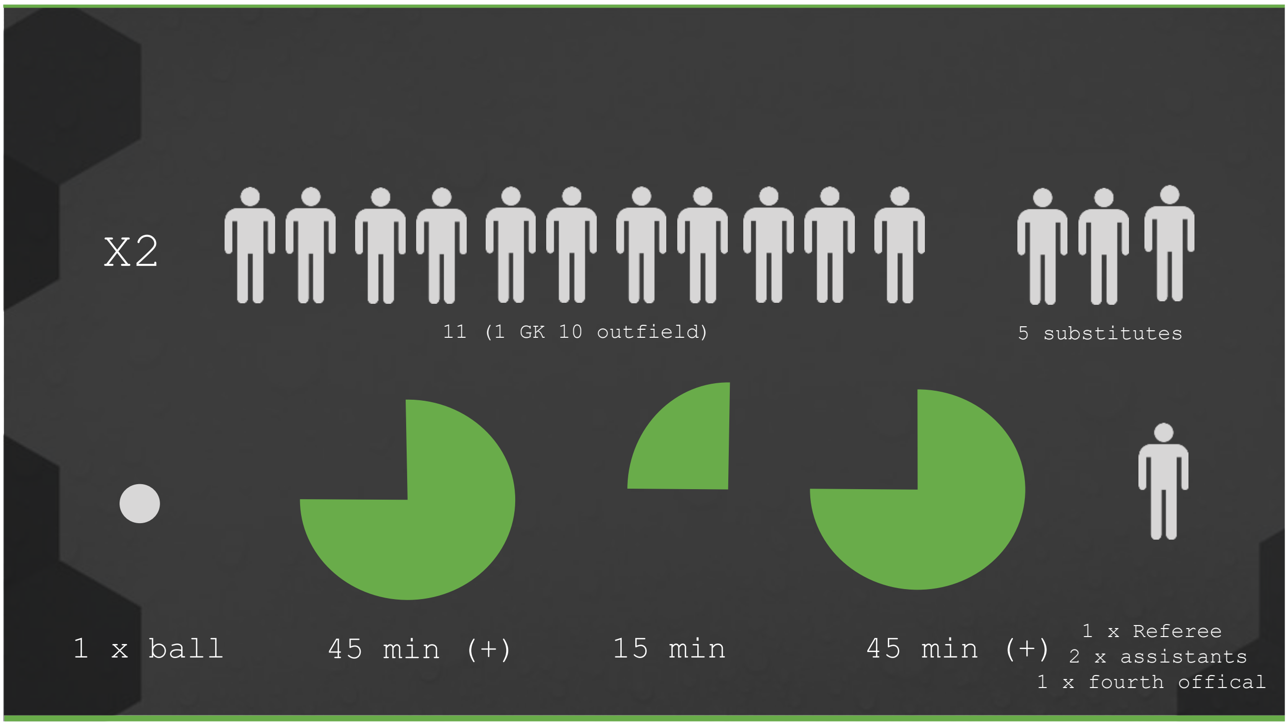
1863: Formation of the Football Association, England.

1899: FC Barcelona founded by Joan Gamper.

1906: Formation of FIFA.

1930: Inauguration of the World Cup.

Figure 1. Number of players required and duration of a standard football match



Source: own elaboration.

Did you know?

The ball used in professional leagues and international competitions is a "size 5." The specifications of an official size 5 ball are the following: circumference 27 to 28 inches (69 to 71 cm); weight 14 to 16 oz (400 to 450 grams), pressure between 8.5 to 15.6 PSI.

Match analysis

There are many challenges a football player must face during a match. In addition to the physical demands, the player must cope with psychological stress, tactical awareness, skill execution, crowd support/hostility and social interaction with team members/opposition. This unit will concentrate on the physical demands of football. The assessment of the physical demands can be achieved through the analysis of player movement patterns and quantifying specific football activities.

The energy expended during football is primarily a product of the total distance covered and speed at which that distance was covered (Reilly, 1997). The first studies to perform match analysis to determine the physical demands of football were performed in Sweden in the late 1960s. These early studies used video analysis of short filmed sequences of the football players during a match. The video analysis approach was further developed in England and later in Denmark. By the early 1990s, scientific data was available on the differences in physical demands among players, in different playing positions (Bangsbo, 2014). Following these early studies, much of our understanding on the physical demands of football is owed to the work of Professor Jens Bangsbo and his research group at the August Krogh Institute, Copenhagen, Denmark, and Professor Thomas Reilly and colleagues at Liverpool John Moores University, UK. In more recent research, many methods of monitoring player movement during competition are used including tape-recorded commentaries, video recordings, film analysis, synchronized and computer-aided video analysis. It is important to note that whichever method is adopted, it must comply with quality control criteria and provide valid, objective and reliable observations (Reilly, 1997). Common methods used to capture match activities and classify movements/activity intensity include video-based technologies, global positioning satellite (GPS), automated systems and subjective scales. Each of these techniques are described below in more detail.

Video-based technologies

The gold standard of capturing physical activities during a match are video-based technologies. Video-based technologies are considered the most accurate systems and use multiple-camera methods developed by companies such as Amisco and Prozone. Such systems use high-speed cameras installed at the stadium to film different sections of the field for post-match analysis. Separate from tactical analysis, these systems also provide detailed information on characteristics of the physical work that occurred during the match. These physical characteristics, captured via time motion analysis, include running intensity, acceleration/deceleration rates, total distances covered and distances covered at different intensities (Bangsbo, 2014). These systems can generate information of every outfield player. More than 2500 codes (see match activity classification below) for a single match are recorded, which can result in more than 3.5 million data points (Bangsbo, 2014).

Historically, these systems were only able to accurately measure approximately 60 % of a players' activity, with the remaining 40 % requiring manual input to prevent inaccuracies. As a result, data from semi-automatic systems (such as video analysis) was delayed to approximately 24 to 48 hours after the match. In addition to the physical activity profile, video filming can also be used to quantify other important match metrics such as the direction and success rate of passing, tackles and ball interceptions, number of shots and success.

Global positioning satellite

Global positioning satellite (GPS) systems and GPS-based technologies do not require manual intervention to analyse the activity profiles of the player. Such systems work by players wearing GPS devices, typically in vests worn under training or football shirts during training and/or matches. In general, the outputs (velocities, distances, accelerations, decelerations) generated by GPS systems are determined via mathematical algorithms. A main issue with these systems is that they fail to provide context, such as insight into the opposition or the 'skills' completed by the player (Castellano et al., 2011). The use of GPS-based technology has become a common method to assess the physical demands of football, both in training and matches. A key benefit of GPS technology is that it permits real time or deferred analysis of the data. In addition, there is no need for third party assistance, thus the individual club coaches, sports science departments or statisticians can rapidly interpreted data generated.

Automated systems

Over the last decade, there has been an influx of computer-based technologies to assess movement in football. These technological advances have included automated multiple-camera systems, which allow the real time measurement of speed. These systems use cameras that are usually permanently installed in stadiums. Players are tracked in real time by recognition algorithms, capturing the positional data (co-ordinates) from the players' bodies. Importantly, real time automated systems demonstrate good validity over a range of soccer specific movements and speeds, up to and including sprinting (Redwood-Brown et al., 2012). Automated player tracking systems are installed in many professional clubs. For example, these systems have been used to measure the metabolic power and energy expenditure in the German Bundesliga (Venzke et al., 2023).

Subjective scales

Questionnaire and/or "paper/pen" (more recently electronic tablet) based data collection is common in professional clubs. Although this method does not provide any information on the physical activities *per se* (such as distance covered) the overall intensity of the training or match can be determined by asking players to rate their perceived exertion following exercise. Typically, clubs adopt the Borg 1-20 rating of perceived exertion (RPE) scale or a modified 1-10 rating scale (Borg, 1982). The Borg scale has been shown to be an accurate and reliable instrument to measure perceived exertion across multiple sports and is a universally adopted method in exercise physiology studies. The RPE of a player can accurately reflect exercise intensity as well as some physiological features of fatigue. The RPE has been reported as a tool sensitive enough to dictate training intensity (Impellizzeri et al., 2004) as well as detect changes in training load in professional players (Gaudino, 2015).

Did you know?

FIFA allowed the use of GPS devices during competitive matches in 2015.

Match activity classification

In football, movement activities during matches are generally "coded" according to the intensity i.e. determined by the speed of action (table 1). When evaluating a players' match performance, the frequency of each type of movement and the time spent or distance covered in each movement can be analysed. The main physical activity categories used to analyse football work rate are standing, walking, jogging, low speed running, moderate speed running (cruising/striding), high speed running and sprinting. These categories have recently been extended to include other activities such as skipping, jockeying and shuffling. Most activities in football are carried out at submaximal intensities and levels of exertion (figure 2). Analysis of football matches allow those activities (beyond football specific movements: pass, control, shots, headers) to be classified as detailed in table 1. However, it is important to note that ideally individual player or team specific thresholds can also be set (Carling et al., 2008; Carling et al., 2016). For example, the high-speed running velocities may be significantly different between players.

Table 1. Example of match coded activities and the associated velocities to classify movements

Coded activity	~ Velocity km/h
Standing	0
Walking	0-6
Jogging	6-8
Low speed run	8-12
Moderate speed run	12-15
High speed run	15-18
Sprinting	18 – 30 +
Backward running	0-10

Source: own elaboration.

Did you know ?

The fastest sprint recorded in the English Premier League during the 2023/2024 season was 36.93 km/h

Quantifying physical demands

During a 90-minute match, the distance covered by a top-level outfield player typically ranges between 10 km and 13 km (Bangsbo, 1994a; Mohr et al., 2003; Bangsbo et al., 2006; Di Mascio and Bradley, 2013). The majority (>80 %) of the distance is covered by walking and low to moderate intensity running (figure 2). Tabulated data from elite footballers allow either individual or team physical demand standards to be established. These metrics may act as a benchmark from which to inform the recruitment of new players or maintain performance standards (table 2).

However, it is the high-intensity exercise periods, which are associated with critical moments during a football match (Gregson et al., 2010). This is because the key actions in a match (i.e. goal being scored/conceded) are in general, preceded by a high intensity effort. Therefore, it is reasonable to suggest that the ability to maintain high intensity efforts for the duration of 90-minutes is a critically important performance consideration. This observation has significant implications for the nutrition of the player, which will be discussed in later modules (Filter et al., 2023).

The sprints or "all out efforts" in football are rarely longer than 2–4 seconds covering average distances of 10-15 meters. Sprints typically occur every 90 seconds, followed by several seconds of recovery, before players are in action again (Reilly, 1997). Longer duration sprints will require greater recovery times. There are two main types of sprint in football: an explosive sprint, defined as attainment of sprint speed preceded by rapid acceleration (from low or moderate speed) reaching the high-speed zone within less than 0.5 seconds and a leading sprint which is characterized by gradual acceleration from low to moderate to high speed (Bangsbo, 2014).

The common pattern of play in football can be described as 'stop and go', i.e. where players perform repeated bouts of brief high-intensity exercise interspersed by periods of lower intensity activity (Williams and Rollo, 2015).

This is observed during match play when a player sprints to tackle an opponent (or gain possession of the ball), followed by dribbling the ball, passing it and then jogging into position to support an attack or defence. During a match, a player responds approximately every 3-5 seconds to around 1200 unpredictable changes in activity, instigated by either their own team or their opponents. Analysis of the English Premier League (first division) has shown that physical demands of match play have intensified (Bush et al., 2015). Physical performances during matches (analysed using a video tracking system), were collected across seven consecutive seasons (2006-07 to 2012-13). The total distance covered remained relatively unchanged (10679 ± 956 vs. 10881 ± 885 m) between 2006 and 2013. However, it was found that high-intensity running distance increased (+0.4 km) in the final season in comparison to the first season in all playing positions. Specifically, high-intensity running distance and high-intensity actions increased by ~30 % (890 ± 299 vs. 1151 ± 337m) and ~50 % (118 ± 36 vs. 176 ± 46), respectively. Sprint distance and number of sprints rose by ~35 % (232 ± 114 vs. 350 ± 139m) and ~85 % (31 ± 14 vs. 57 ± 20), respectively. Importantly, this trend was observed in all outfield positions (central defenders, fullbacks, central midfielders, wide midfielders and attackers). In addition, players were also found to be more skilfully proficient. Modern players are required to make more passes (35 ± 17 vs. 25 ± 13), with a higher success rate (83 % ± 10 % vs. 76 ± 13 %).

More recent analysis of professional football has reported the physical-tactical profiles of elite teams and individual players according to final league rankings (Ju et al., 2023). In this study, 100 English Premier League match and 583 player observations were analysed by coding the player's physical-tactical actions through synchronising tracking data and video. Teams were categorised into tiers based on their final league rankings: (A) 1st–5th ranking (n = 25), (B) 6th–10th ranking (n = 26), (C) 11th–15th ranking (n = 26), and (D) 16th–20th ranking (n = 23). This approach of combining physical and technical profiles is important in football as it highlights the need to contextualise the high intensity running that is completed in a match. Specifically the tier A teams performed high speed runs to "receive/exploit space" and "run with the ball", as well as better technical skills (greater number of shots on target, number and successful passes) compared to those in lower tiers. Regarding positional trends, central defensive players and wide defensive players in tier A covered more distance (65–550 %) at high-intensity to "move to receive/exploit space" in comparison to other tiers (Ju et al., 2023).

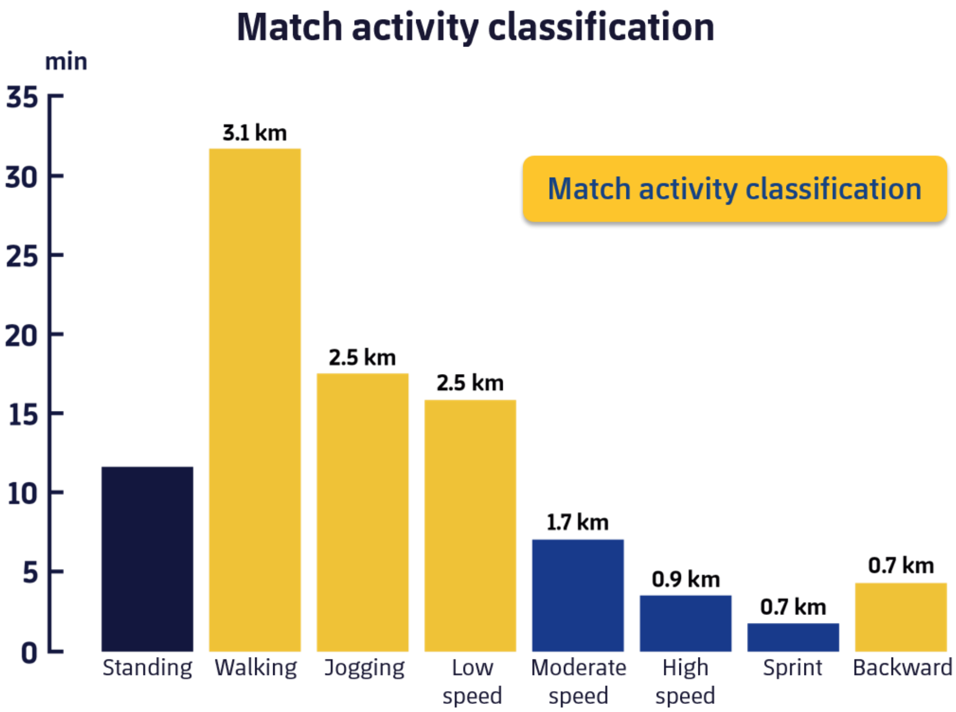
For international football, the contextualised physical demands of positional roles were analysed for the FIFA World Cup in Qatar 2022, using a multi-camera computerised tracking systems (Bradley, 2024). During a match, defensive and central midfielders covered 8-19 % more total distance than other positional roles. The distances covered at higher intensities (→20 and →25 km/h) were 16-92 % and 36-138 % higher for wide midfielders and wide forwards compared to central defenders, defensive and central midfielders as well as centre forwards. Importantly, from a nutrition perspective, all positional roles demonstrated a significant reduction in second half-total distance covered compared to the first half. A decline between halves for the distances covered at higher intensities (→20 and →25 km/h) were more evident in attacking midfielders, wide defenders and midfielders than for other positional roles.

Thus, the preservation of skill as well as high intensity running are key requirements for domestic professional and international football. These key observations highlight the importance of effective nutritional strategies to support player performance.

Key point

The common pattern of play in football can be described as 'stop and go'.

Figure 2. Classification of football activities by the amount of time spent in each activity



Source: Bangsbo et al., 1994a, https://lc.cx/ifA_hw

Table 2. Example of elite standards of physical performance*

	Elite individual standards	Elite team standards
Overall distance covered	~12 km	~120 km
Distance covered in sprints	~0.6 km	~3.6 km
Distance covered in high speed runs	~1.6 km	~8.5 km
Number of sprints	~90	-
Top speed	~9.5 m/s	~9.5 m/s
Average recovery time	~30 s	~35 s
Number of interceptions	~15	-
Number of tackles	~10	-
Change of activity	~1350/match every 4-6 sec	-

Other activities	Heading, passing, dribbling, shooting	-
Penalty area entries	-	~40 +
Final third entries	-	~80 +
Crosses	-	~30 +

Source: own elaboration.

*Metrics of football specific activities, shots per match, interceptions, tackles won can also be included and modified to be relevant to the specific position.

Other physically demanding activities during match play

Football also involves other energy-demanding activities such as alterations in pace, decelerations, changes in direction, execution of specific match skills, heading, tackles, jumps, physical contact for possession of the ball and tracking opponents (Carling et al., 2008). The data presented on high-intensity running for example does not include a number of other energy-intensive activities, such as short accelerations, turns, actions with the ball, tackles and jumps. Most maximal accelerations are not performed at speeds associated with high-intensity running, but are still metabolically taxing (Osgnach et al., 2010). It has been reported that players in the FA Premier League make about 700 turns in a match, with around 600 of them being 0–90 degrees and are also involved in about 110 actions with the ball, with marked variation between players (Bloomfield et al., 2007; Bangsbo, 2014).

At the top level of the sport, the number of tackles and jumps have been shown to vary from 3–27 and 1–36 per match, respectively (Mohr et al., 2003). However, this depends on the individual playing style and position in the team. Regarding headers, central defenders head the ball most frequently, data from the Spanish League and English League suggest that these players head the ball 5-15 times during a match (Bangsbo, 2014).

Finally, attacking players and defenders frequently fall to the ground in match-play, with the emphasis usually on defenders to get-up quickly. Thus, repeatedly regaining a standing position from lying on the floor is another physically demanding activity for players during football-specific activity.

Did you know?

> An objective of a "tackle" in football is to dispossess an opposing player of the ball or to prevent the opposing player from completing an activity that they intend to complete.

On the ball activities

A review by Bloomfield et al. (2007) investigated ball interactions by players during competitive matches (figure 3). Although there was variation between playing position, there was no significant difference found in the number of ball interactions. In general, a player will interact with the ball between 90 and 140 times in a match; however, the average time of interaction is extremely short. The typical interaction is a one-touch pass or a control-pass. Players, especially at the elite level, will usually receive the ball within 1 to 5 meters of space between them and an opponent. Consequently, a player usually has less than a second "on the ball" to execute a skill. On the appropriate occasions, a player may control and dribble the ball leading to rare situations of up to 4 seconds of possession. On average, over an entire 90-minute match, a player will typically have up to 60 to 90 seconds of ball time. Thus, players have ~1 % of the total playing time to impact the match through "on the ball" interaction.

Figure 3. Frequency of 'on the ball' activity within total match-play performed by players of different positions. Data are means (+-SD)

Variables	Position				H_2	*p*
	Striker (n=19)	Midfielder (n=18)	Defender (n=18)	All (n=55)		
Pass long air (right foot)	1.3 (2.5) *	7.0 (6.9)	9.7 (6.9)	5.9 (6.7)	15.6	<.001
Pass short air (header)	8.8 (9.2)	5.0 (6.6)	7.0 (6.9)	7.0 (7.7)	2.2	.325
Pass short ground (right foot)	13.9 (9.6)	27.3 (28.8) †	9.0 (7.8) †	16.7 (19.3)	6.1	.046
Receive (right foot)	14.8 (11.2)	22.7 (20.4)	11.7 (12.1)	16.4 (15.5)	4.3	.118
Receive (left foot)	6.3 (7.6)	11.0 (10.3)	5.0 (8.0)	7.4 (8.9)	5.6	.061
Dribble	18.0 (13.4)	22.7 (24.3)	12.0 (12.5)	17.6 (17.7)	3.6	.152
Total	102.3 (51.1)	139.7 (111.1)	90.3 (47.6)	110.6 (76.9)	2.9	.234
Follow up Mann Whitney U tests: * significantly different to both other positions, † pair of positions annotated is significantly different.						

Source: Bloomfield et al., 2007, https://lc.cx/jsrs6_

Factors that influence physical demands of football

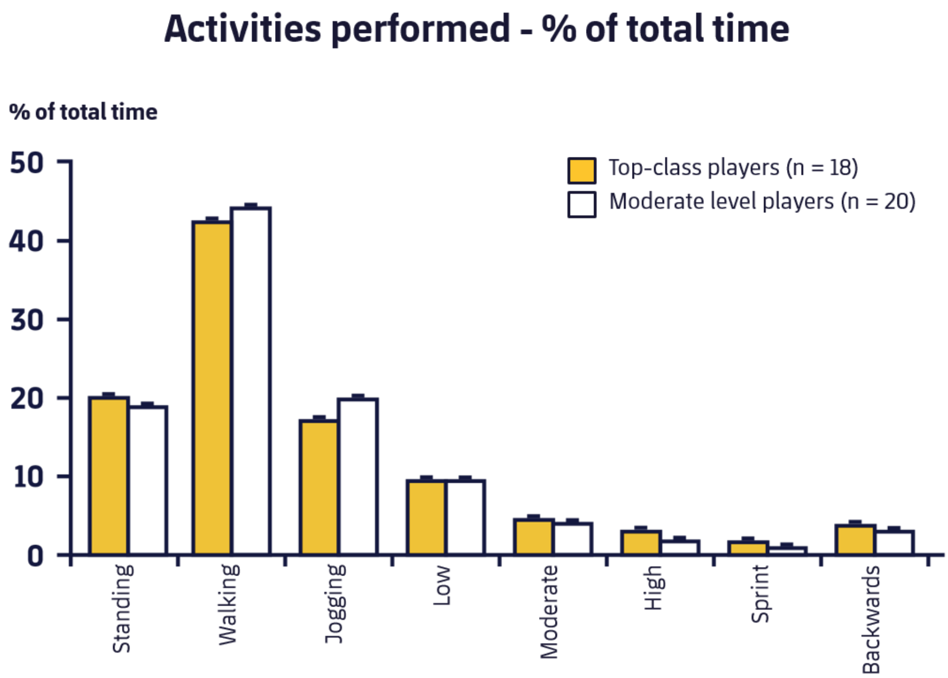
i) Standard of play

As previously mentioned, players typically spend approximately 80 % of the match engaged in low-intensity and walking activities (figure 2). Of interest, is that this pattern

does not appear to change between moderate level and top-class level professional players (figure 4). Instead, the amount of high-speed running may be a distinguishing factor between top-class and moderate-level professional players from those players who complete at a lower standard (figure 5). For example, a review by Bangsbo (2014) explained how international top-class players performed 28 % more high-intensity running (2.43 vs. 1.90 km) and 58 % more sprinting (650 vs. 410 m) than professional players at a lower level (Mohr et al., 2003). Furthermore, Ingebrigtsen et al. (2012) found that players in the top teams (top half) in the Danish League covered 30–40 % more high-speed running distance compared to the middle and bottom ranked teams (Ingebrigtsen et al., 2012). Conversely, some studies observed that English Championship players (second league) covered greater overall distance and performed more high-speed running and sprinting than players in the English Premier League (top league) (Di Salvo et al., 2013). Although these changes were reported to be statistically different, the actual differences (~0.2 km) were negligible in practical terms (Di Salvo et al., 2009; Di Salvo et al., 2013).
A similar study, comparing the match performance of players in the top three competitive standards of english football, found that players in the second (Championship) and third (League 1) leagues performed more high-speed running (>19 km/h) than those in the Premier League (top league) (803, 881 and 681 m, respectively), which was also the case for sprinting (308, 360 and 248 m, respectively) (Bradley et al., 2013). This observation was consistent for all outfield players (Bangsbo, 2014). In addition, players (n=20) who changed teams, moving down from the Premier League to the Championship League, were found to cover more distance with high-intensity running (1103 vs. 995 m), whereas no difference was observed for players moving up from Championship to Premier League (945 vs. 1021 m). Nevertheless, when comparing higher and lower standard footballers, no difference in the Yo-Yo Intermittent Endurance Test Level 2 was observed (see "Physical capacity" section). This would suggest that the difference between the top and second tier players were not due to differences in the players physical fitness (Bradley et al., 2013).

Interestingly, it has been reported that successful (winning) teams in the Italian Serie A league (first division) appear to cover less (4–12 %) high-intensity running distance compared to unsuccessful teams, but more distance while in possession of the ball (Rampinini et al., 2009). In addition, players cover more ground with high intensity running when playing against higher in comparison to lower quality opponents (Rampinini et al., 2007, Castellano et al. 2011; Castellano et al., 2012). Playing against strong opponents has been found to be associated with lower ball possession (Bloomfield et al., 2005). It is possible that lower-standard players must cover greater distances in an attempt to "close down" players and regain possession. It may also be that higher-standard players are more selective about their high-intensity efforts (Bangsbo, 2014). Differences in match demands between higher and lower league players may also be related to playing style. For example, higher level teams may aim for possession tactics, rather than the long ball or direct tactic typically associated with lower standards of play.

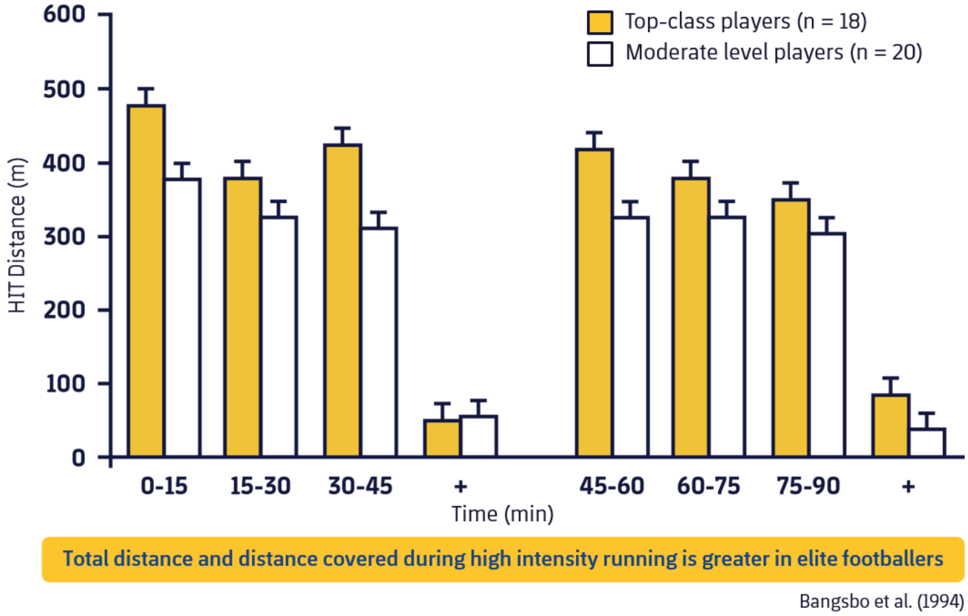
Figure 4. Activities performed in percentage of total time are not different between top-class and moderate level players*



*Data tabulated from the English, Danish and Swedish leagues.

Source: own elaboration.

Figure 5. Total distance and distance covered during high intensity running is greater in elite footballers



Source: Bangsbo, J. (1994a). https://doi.org/10.1080/02640414.1994.12059272

ii) Influence of team tactics on physical demands

The distance covered and intensity of activities performed by a player during a match will be heavily influenced by the coaches' tactical requests and team system. A study investigated the effect of playing formation on high-intensity running and technical performance of English Premier League teams (Bradley et al., 2011). Bradley et al. (2011), found no differences in total distance covered or high-intensity running between the 4-4-2, 4-3-3 and 4-5-1 formations. However, players in a 4-5-1 formation performed less very high-intensity running when their team was in possession and more when their team was not in possession, compared to the 4-4-2 and 4-3-3 formations. These differences may be related to the attacking and defensive characteristics inherent to these playing formations, as a 4-5-1 formation is considered more defensive than a 4-4-2 or 4-3-3, due to the reinforcement of the midfield areas at the expense of forward players (Bangsbo, 2014). Although few differences in physical demands were observed between formations on an individual player basis, formation did impact the physical demands of attacking players. In a 4-3-3 formation, forward players performed approximately 30 % more high-intensity running than forwards in the 4-4-2 and 4-5-1 formation (Bradley et al., 2011). It was also observed that attacking players in a 4-5-1 formation had a significant decline in high-intensity running in the second half, which was not observed in the other systems. This could be explained because the 4-5-1 formation requires the single attacking player to pressure the defenders when not in possession of the ball (Bangsbo, 2014). Overall, ball possession does not seem to differ between the 4-4-2, 4-3-3 and 4-5-1 formations, but the number of passes and the proportion of successful passes are found to be higher in a 4-4-2 compared with 4-3-3 and 4-5-1 formations.

In general, the available data suggest that playing formation *per se* does not influence the overall activity profiles of players (Bangsbo, 2014). Instead, it is the playing position within the formation that governs the differences in physical demands. For example, analysis of positional data regarding physical demands across formations, showed differences in forwards and central midfielders (Arjol-Serrano et al. 2021). Thus, it could be suggested that "additional" consideration be paid to the nutritional preparations of the central midfield and attacking players in the 4-5-1 and 4-3-3 formations. Especially if the player is inexperienced in the system, they are at greater risk of premature fatigue (Bloomfield et al., 2007; Bangsbo, 2014).

Did you know?

The sequence of numbers in a team's "formation" refers to the number of players moving from defensive to attacking positions. For example, 4-4-2; 4 defenders, 4 midfield players and 2 attacking players. The goal keeper is not included in the "formation" information.

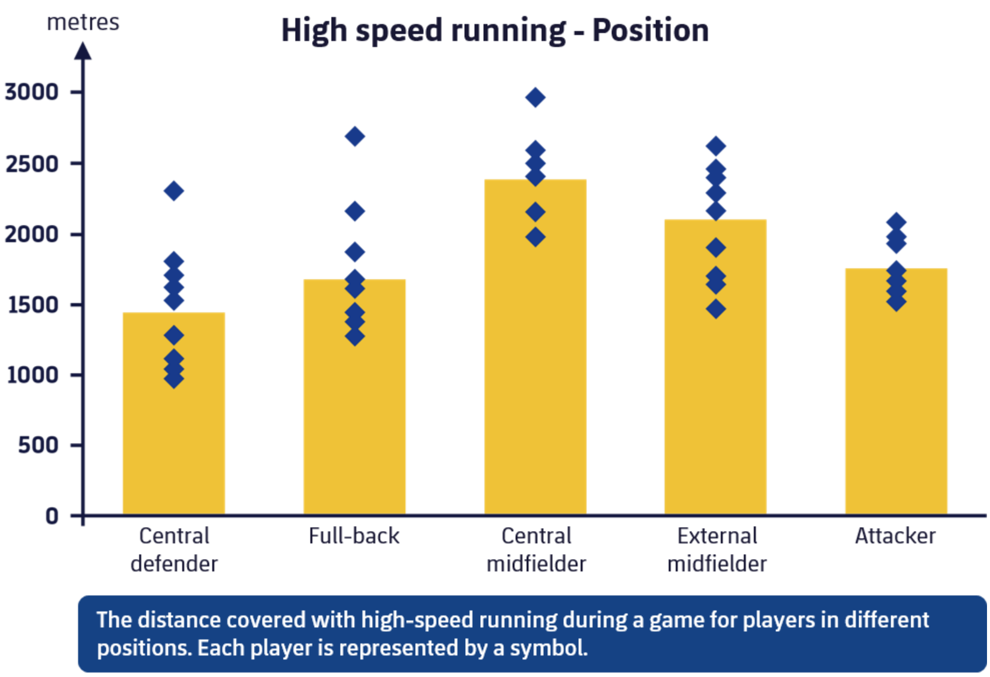
iii) Positional differences

The activity profile and demands on a player are determined by his/her positional role in the team (Reilly, 1997). Mohr et al. (2003) studied top-class players and found that central defenders covered less total distance and engaged in less high-intensity running than players in the other positions, which is probably linked to their tactical roles and lower physical capacity (Bangsbo, 2014 Mohr et al., 2003). On the other hand, midfielders typically cover the greatest distances. However, there are marked differences between players within the same position (figure 6) (Bangsbo, 2014). Differences in distance covered has also been reported to differ between players in the same position, this may be related to playing style and could explain contrasting results between studies.

Data from the English Premier League has shown that defenders and central midfielders performed fewer leading sprints compared to other positions (Bloomfield et al., 2007). In general, data from top English and Spanish leagues suggests that central defenders and central defensive midfield players cover the least high-speed running and sprinting distances, whereas forwards cover the greatest high-speed running distances (Bangsbo, 2014). Central defensive midfield players cover a greater distance than central attacking midfielders (Dellal et al., 2011) and external/wide midfield players cover the most high-intensity running distance (Carling et al., 2008). Finally, central attacking and wide midfielders also cover the most distance in high-speed running when their team has possession of the ball (Bradley et al., 2013).

Therefore, it is important to consider the team formation and track trends in formation of national professional football leagues. As tactical formations continue to evolve it will be important to understand how they influence the physical demands placed on football players (González-Rodenas et al., 2023).

Figure 6. Position specific demands of the match in different football leagues



Source: Bangsbo et al., 2014, https://lc.cx/sOJp9K

iv) Physical capacity

To manage and perform football specific exercise, the physical capacity of the player should also be considered. The physical capacity of a player has a great influence on work rate during a match. Differences in physical capacity exist among top-class players even within the same position, which to some extent can explain the differences observed in high-speed running during the match (Bangsbo, 2014). Differences in a players physical capacity can be determined using the Yo-Yo Intermittent Recovery Level 1 (Yo-Yo IR1) and Level 2 (Yo-Yo IR2) Tests (figure 7) (Bangsbo et al., 2008).

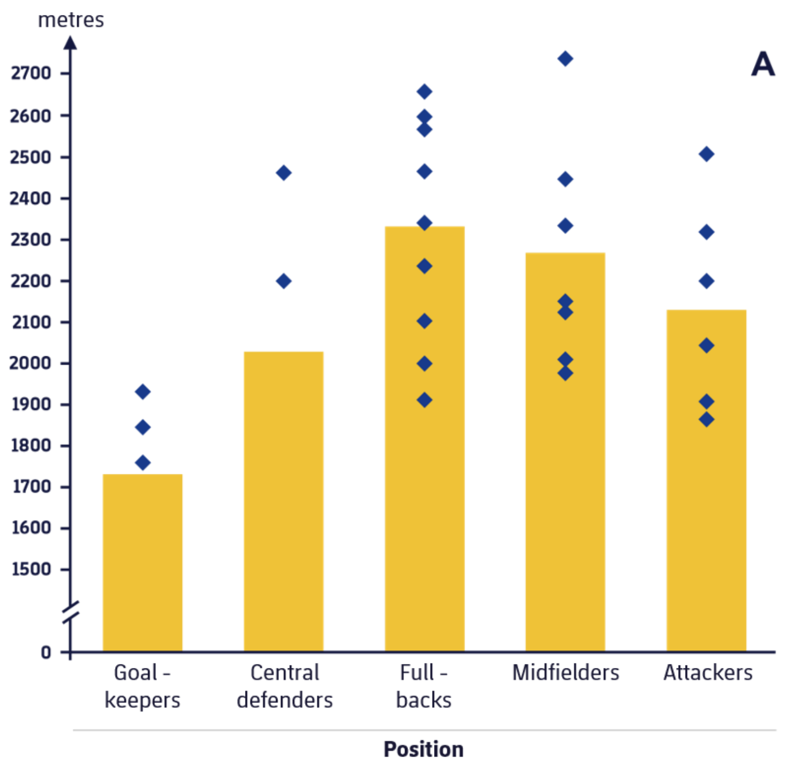
The two Yo-Yo intermittent recovery (IR) tests evaluate an individual's ability to repeatedly perform intense exercise. The Yo-Yo IR1 test focuses on the capacity to carry out intermittent exercise leading to a maximal activation of the aerobic system, whereas Yo-Yo IR2 determines an individual's ability to recover from repeated exercise with a high contribution from the anaerobic system (Bangsbo, 2014).

On average, central defenders had lower Yo-Yo IR1 test scores than players in other positions. Whereas no differences were observed in the Yo-Yo IR2 test, showing that on the whole central defenders had lower intense endurance capacity, but the same ability to recover (Krustrup et al., 2006a).

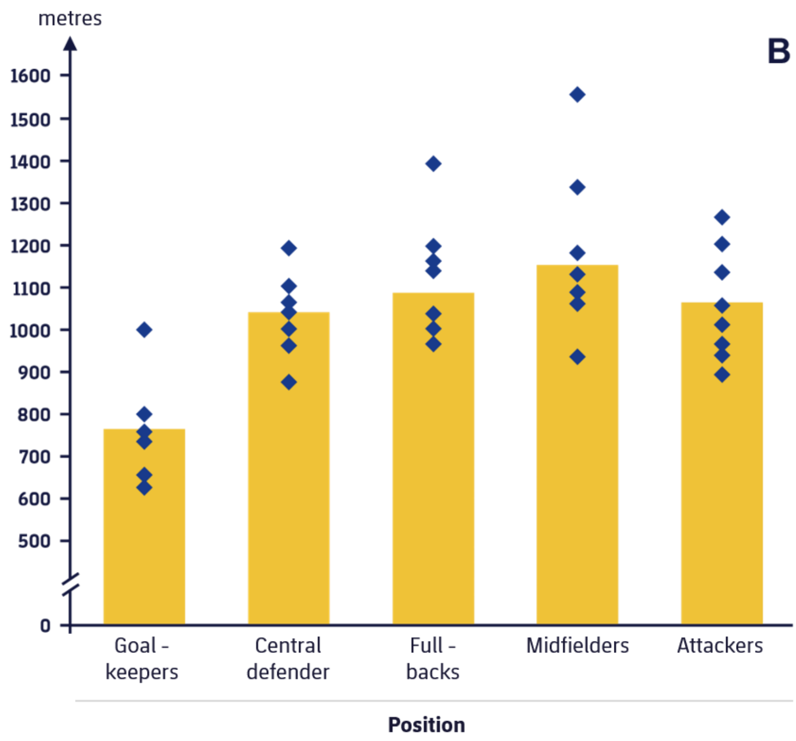
Physical capacity is highly related to the training load accumulated by the player. For example, trained football players have been reported to have 67 % improved Yo-Yo scores in comparison to untrained individuals (Krustrup et al., 2015). Interestingly, more successful teams have been reported to have superior physical capacities measured by Yo-Yo score (Mohr and Krustrup, 2014). The detailed discussion for training a football player is beyond the scope of this unit. Specific nutrition strategies to support football training are covered in later modules. To summarise, the exercise volume that the player completes is typically referred to and subdivided into “external” and “internal” load. External load refers to parameters such as time, distance, speed, and number of repetitions of each activity performed by the player. Internal load refers to the physiological response to the external load. The internal response relates to specific demands placed on the physiological systems such as the cardiovascular system (Unit 2).

Figure 7. Yo-Yo intermittent recovery level 1 and level 2 in relation to playing position. Each player is represented by a symbol

Yo-Yo Intermittent recorevy level 1 - Performance



Yo-Yo Intermittent recorevy level 2 - Performance



Source: Bangsbo, 2014, https://lc.cx/sOJp9K

v) Gender

The studies described in this unit (Unit 1) have in general, examined male players, but female players have also been evaluated (Bradley et al., 2014). The amount of high-intensity running in elite women's football has been shown to be approximately 30 % lower than in male elite football (Krustrup et al., 2005). This has been confirmed in studies of top-class females competing in the European Champions League, showing that they cover less high-speed running distance than their male counterparts (Bangsbo, 2014). One of the major reasons is that female players possess lower physical capacity than male players across a range of aerobic and anaerobic fitness tests (Krustrup et al., 2010; Bradley et al., 2014).

vi) Pitch size

Small-sided games are widely used by coaches to develop technical and tactical skills as well as to improve the endurance of football players. In this sense, several studies have investigated the effects of altering different variables or match rules, including the duration of the match formats and pitch size. During training, the size of the pitch can be constantly modified to manipulate the intensity or focus of the session. Some studies have found that small-sided matches played on larger pitches are more intense than those played on smaller ones (Rampinini et al., 2007) whereas other studies have found opposite results. In any case, it is important to recognize that modifying the size of the pitch may change the physical demands placed on a player during training and matches.

Did you know?

The dimensions of a professional football pitch can vary significantly. The length of a pitch can range between 100 yards (90m) and 130 yards (120m) and the width can range between 50 yards (45m) and 100 yards (90m).

vii) Heat and hypoxia

Players may be expected to play in temperatures >30 °C during early and later stages of the season. The potential for matches to be played in extreme temperatures was also highlighted in the last International Federation of Association Football (FIFA) World Cup played in Qatar, 2022. Within both competitive and non-competitive football matches, studies have reported a reduction ranging from 2.6 to 57 % in total distances players achieved at high intensity in hot conditions (Mohr et al., 2003; Buchheit et al., 2011, Mohr and Krustrup, 2013). Exertional heat stress elicits substantial decrements upon football-specific performance, due to increasing body temperatures amongst other multi-factorial mechanisms accelerating fatigue (Mohr et al., 2010; Nybo et al., 2014). Thus, high environmental temperatures can influence the completion of football-specific activities (Mohr and Krustrup 2013).

Total distances players achieved at high intensity are known to reduce between 3 and 20 % in hypoxic environments (McSharry, 2007). Elite clubs playing in the Union of European Football Associations (UEFA) Champions and Europa leagues could play in altitudes as high as 1000 meters above sea level. However, "low altitudes" classified as 500 meters – 2000 meters are sufficient to produce minor impairments in aerobic performance, due to a reduction in partial pressure of oxygen (Gore et al., 2013). A reduction in maximum oxygen uptake will inhibit recovery from repeated sprint activities and inhibit total distances covered within a match (Taylor and Rollo 2014). As such, players usually have more time on the ball and may be perceived as more technically proficient.

It is important to recognize the influence that environmental extremes may have on the physical performance of players and subsequent match outcome. Appropriate nutrition strategies to combat these extreme environments will be covered later in the course (Nutrition Considerations in Football).

Did you know?

Professor Tom Reilly (1941 – 2009) pioneered applied practice in the football world. This early work on notational analysis and work rate profiles has paved the way for generations of sports science graduates to apply their knowledge and expertise in the football industry.
To know more about Professor Reilly, visit the following link:
https://www.ljmu.ac.uk/about-us/bicentenary/our-people/professor-tom-reilly/professor-tom-reilly-profile

Unit 1. Summary

- The physical demands on a football player during a match can be determined from the analysis of match activities using time motion analysis.

- The typical total distance covered by a top-level outfield male player during a match is approximately 10–13 km.

- High intensity running/activities/sprints precede key events in a match.

- Players perform approximately 1200 unpredictable changes in activity, every 3-5 seconds.

- Countless factors influence the physical demands placed on players during a match including, but not limited to:

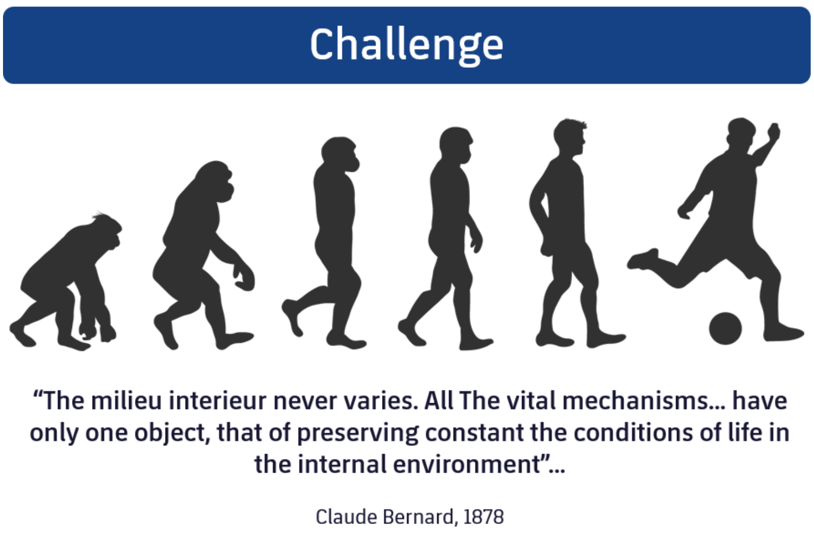
    - standard of play
    - playing position
    - tactical formation
    - gender
    - pitch size
    - environmental factors

Unit 2. Physiological response to football activity

Unit 1 outlined the physical demands of football. Now, it is important to describe the physiological responses to football exercise. This information not only provides understanding of how the players' body responds to meet the energy demands, but also provides the rationale for appropriate sports nutrition strategies. It is also important to understand what causes a player to fatigue. This is because understanding fatigue will inform the players' daily diet as well as acute sports nutrition strategies to preserve running and skill performance. As demonstrated in the previous unit, many studies have analysed football match activities. However, studies investigating the physiological demands during match play are less prevalent.

Homeostasis is the ability to maintain a stable internal environment of the body. Physiological variables such as body temperature and fluid balance are kept within narrow limits. Thus, to maintain a stable internal environment the body must continuously adjust to changes created by either the internal and/or external environment. The participation in football poses a great challenge to the internal environment of the player's body. Luckily, humans have evolved over millions of years to cope with the demands of exercise. Specifically, humans have evolved to cover great distances on foot but maintain the capacity for bursts of short fast movements. Therefore, it could be argued that humans have, in fact, evolved to play football.

Figure 8. **Humans have evolved to cope with the physical demands of football**



Source: own elaboration.

Physiological responses

As a player initiates in football exercise there is an immediate increase in the demand for energy by the contracting muscles, to perform the movements classified in Unit 1. Providing energy, via the aerobic energy system, is dependent upon the availability of fat, carbohydrate and oxygen to the working muscle. The bi-product of aerobic metabolism, carbon dioxide, must be removed simultaneously. These key processes of oxygen delivery and carbon dioxide removal during football are achieved by the respiratory and cardiovascular systems.

Did you know?

The composition of atmospheric air is approximately 21 % oxygen, 78.0 % nitrogen and 0.04 % carbon dioxide.

The role of the respiratory system

Gaseous exchange occurs in the lungs, where the gases (oxygen and carbon dioxide) move by diffusion from areas of high concentration to low concentrations. As such, oxygen diffuses from the atmospheric air in the lung (alveoli) into the blood, and carbon dioxide diffuses from the blood into the lung and is subsequently expelled from the body.

Oxygen is bound in the blood by the protein haemoglobin (found in red blood cells, which gives blood its red colour), to form oxyhaemoglobin. Ingesting sufficient iron in the diet is required for the formation of haemoglobin (covered in detail in Nutrition Considerations in Football course). The oxygenated blood from the lungs returns to the heart to be pumped to the working muscles, via the circulatory system to the working muscles. A 75 kg male adult footballer will have approximately 5 L of blood. Just under half of the blood composition will consist of red blood cells with the remaining volume of blood (~55 %) consisting of plasma (a watery solution that suspends the blood cells and serves as an essential solvent for the transport of nutrients, electrolytes, proteins and gases).

In response to increased football intensity, the player increases both the depth (tidal volume) and frequency of their breathing, with the aim of matching breathing to the oxygen demand of the football exercise. The mechanism on how ventilation is increased during exercise is likely due to the respiratory centres in the brain being stimulated (Ursino and Magosso, 2004). This stimulation is likely in response to specialised receptors (chemoreceptors) detecting changes in the blood chemistry, such as an increase in carbon dioxide that results from increased energy production in the muscle.

The role of the cardiovascular system

Football activity also causes a rapid increase in the blood flow to the working muscles, caused by repeated muscle contractions. The redistribution of blood, from central organs to the contracting muscle provides the oxygen and nutrients required for energy production, whilst also facilitating the removal of heat and carbon dioxide. The brain registers this disturbance and compensates by increasing the heart rate (the number of heart beats per minute) and stroke volume (the volume of blood pumped out per heart beat). Both these factors combined increases the total volume of blood being pumped by the heart per minute (cardiac output) as well as blood pressure at the onset of exercise. A football player's heart rate during football exercise is largely determined by the intensity of the match or training session. The relative exercise intensity is usually expressed as a percentage of a player's maximal heart rate. Ideally, maximal heart rate should be determined through a graded maximal exercise test, alternatively it may be estimated by subtracting a player's age from 220, though significant variation will exist. Though beyond the scope of this course, cardiac screening (using electrocardiography and echocardiography) is now performed annually on all professional players (Berge et al., 2019).

Did you know?

The player's heart works constantly without ever pausing to rest. It is made of cardiac muscle that never gets tired. It has a dual function: to pump oxygen-rich blood to the player's body and oxygen-poor blood to the player's lungs.

The combined ability of the cardiovascular system to deliver oxygen to the working muscle and the muscle's capacity to use the oxygen will determine the maximal rate of energy generation via aerobic metabolism. Maximal oxygen uptake ($\dot{V}O_{2max}$) is the common measure of aerobic fitness and relative intensities of exercise can also be expressed as a percentage of this value. The $\dot{V}O_{2max}$ will differ among players, dependent upon playing position, body composition and training status. Those players with higher $\dot{V}O_{2max}$ values have been reported to perform better at football-specific tasks such as the Yo-Yo test and cover greater distances during a football match (Krustrup et al., 2015).

Physiological demands of football

Research studies have shown that football is an intermittent sport in which the aerobic energy system is highly taxed. During a match, the average oxygen uptake is around 70 % $\dot{V}O_{2max,}$ with mean and peak heart rates reported to be approximately 85 % and 98 % of maximal values, respectively (Reilly and Thomas, 1979; Bangsbo, 1994a; Bangsbo, 1994b). These values were determined by indirect measurements. Specifically, heart rate values were recorded during a football match and extrapolated to those gathered during an incremental treadmill running test measuring both heart rate and oxygen uptake (Bangsbo, 1994a). Later studies validated these observations by directly measuring heart rate and oxygen uptake (using mobile oxygen update devices) during football drills. Interestingly, these studies reported similar heart rates for a given oxygen uptake during football training to those values found during treadmill running (Reilly, 1997; Wong del, Carling et al., 2011). It is important to note that heart rate values recorded during a match may overestimate the oxygen uptake of the player. This is because several factors such as hypohydration, psychological stress, and increased core temperature may increase the heart rate without affecting oxygen uptake in the muscle.

A player's heart rate during a match is rarely below 65 % of their maximal value. This suggests that blood flow to the exercising muscles is continuously higher than at rest, which also means that oxygen delivery is high (Bangsbo, 2014). This is visually evident during matches, as the player's breathing frequency is notably increased to meet the oxygen demand. The rapid change in oxygen uptake kinetics, required during a football match to change from low to high intensity running, appear to be dependent upon, but not limited to, the oxidative capacity of the contracting muscles (Nyberg et al., 2010). Players can enhance their muscles oxidative capacity by aerobic and or intense interval training (Iaia et al., 2009).

Metabolic heat production is a consequence of metabolism in the muscle. The heat is dissipated by the body through a thermoregulatory process, but some of the heat is stored by the body causing a gradual rise in core temperature. As such, core temperature can be used as another indirect measurement of energy production during exercise. A linear relationship has been reported between the rectal temperature (method to measure core temp) and relative work intensity during continuous cycling exercise (Saltin and Hermansen, 1966). Interestingly, core temperature has been reported to be approximately 0.3 °C higher during intermittent exercise in comparison to continuous exercise at the same relative intensity (Ekblom et al., 1971). From a football perspective, core temperatures recorded during a match have been reported to reach 39-40 °C. Reassuringly these values signify a mean aerobic load to that reported previously i.e. approximately 70 % $\dot{V}O_{2max}$ (Smodlaka, 1978; Mohr and Krustrup, 2012).

Did you know?

Muscle covers the player skeleton, giving the players body its shape. Muscle is attached to the skeleton by tendons. Every movement the player makes is a consequence of skeletal muscle contraction that is under the voluntary control of the player.

Fatigue during a football match

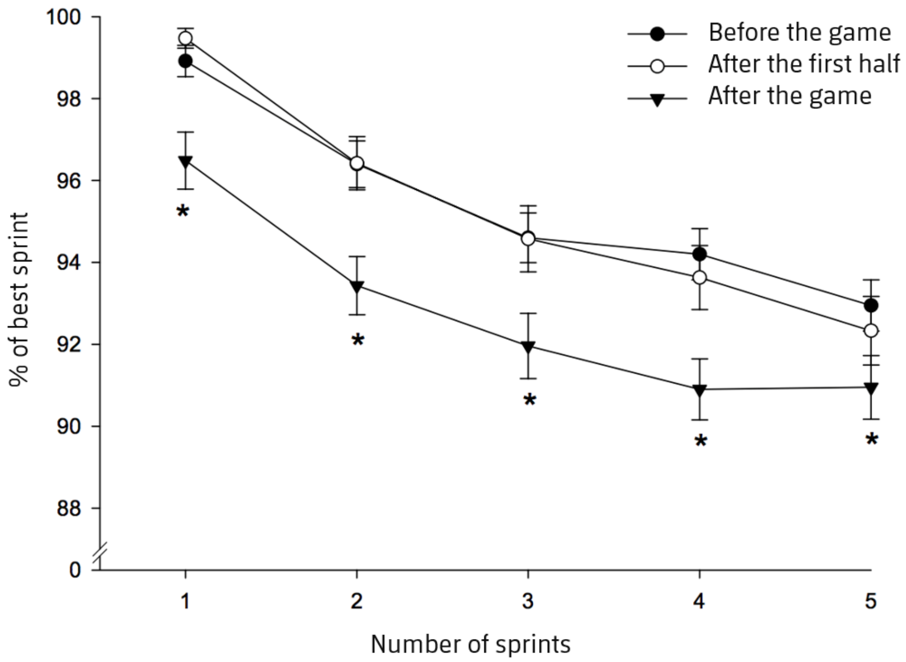
The aim of the player is to maintain their running and technical performance for the duration of match play. However, research studies have shown that the players' ability to perform high-intensity exercise is reduced towards the end of matches in both elite and sub-elite football players (Mohr et al., 2005). In the absence of appropriate nutrition strategies, the volume of sprinting, high-intensity running, and distance covered are generally lower in the second half than in the first half of a match (Bangsbo et al., 1991; Reilly, 1997).

Notably, it is the high-speed running in the second half, which is reduced. The degree of the reduction in the high intensity running is likely to be influenced by the activities performed in the first half. For example, those players who play in the most physically demanding roles (Unit 1; full-backs, central and external midfield players) have been reported to experience the greatest reductions in running performance in the second half (Bradley et al., 2013). In general, over 90 minutes, the volume of high intensity running is reduced in the final 15-minute period, even in a professional match (Mohr et al., 2003; Bradley, 2024).

It has also been suggested that reductions in match running performance could be a result of conscious or subconscious pacing strategies. A change in pacing strategies would theoretically adjust the players running speeds so that they have enough "energy" to complete the match. However, it is important to note that the player's activity will be largely dictated "externally" by the activities of teammates and the opposition. Therefore, it is difficult for players to dictate the intensity of exercise. Furthermore, the player's ability to perform jumps and repeated sprints (figure 9) is significantly reduced at 90 minutes compared to pre-match performance scores (Mohr et al., 2005; Rebelo et al., 2014). This would suggest that the fatigue experienced is due to physiological consequences of playing football, rather than pacing strategies *per se*.

It is important to note that not all studies report reductions in performance during a match. For example, one study observing elite french teams reported that players were generally able to maintain their skill-related performance throughout a match (Carling and Dupont, 2011). Nevertheless, most studies indicate that physiological mechanisms are responsible for reductions in physical performance and technical abilities, especially in the final 15 minutes of a match. As reductions in player performance are likely a consequence of player fatigue, discrepancies between research studies and observations in matches could reflect the standard of player used (professional versus non-professional players) or level of competition (tier 1 versus tier 2 leagues). This is because matches failing to induce sufficient fatigue are unlikely to influence player physical performance or technical skill.

Figure 9. Multiple sprint performance during a match (a)*



Source: Bangsbo et al., 2006, https://lc.cx/tQWL0C

*Sprint time (% of the best sprint) of five 30-m sprints separated by a 25-s period of recovery. Before the match (filled circles), after the first (open circles) and second (filled triangles) half. Data are means±SEM.

Causes of fatigue

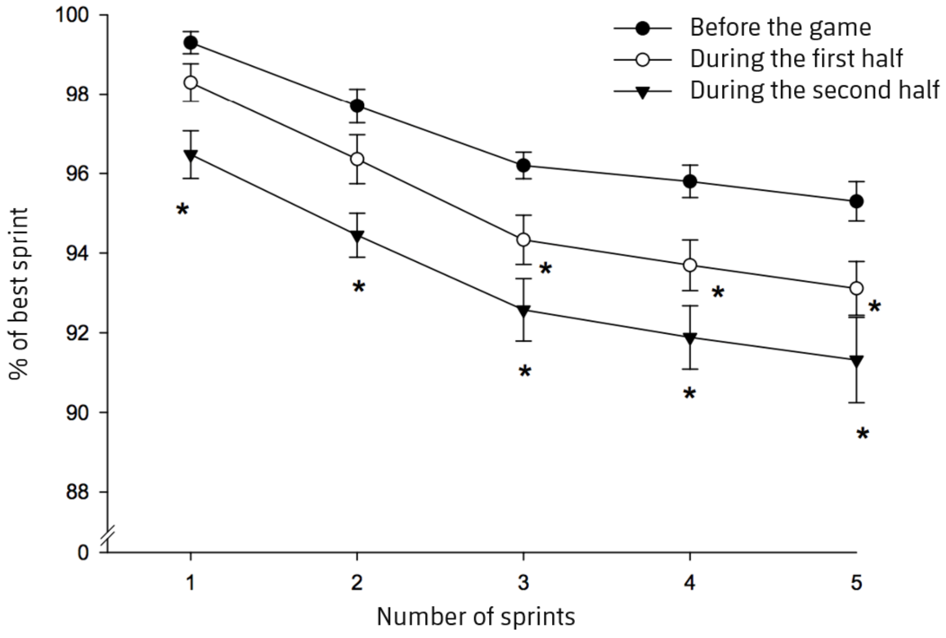
The physiology of fatigue has been extensively studied (Enoka et al., 2011). Fatigue is considered a psychophysiological condition. Playing football results in players experiencing "temporary fatigue" during a match and more "permanent fatigue" towards the latter stages of a match. The causes of fatigue during a football match are multifactorial with no single factor responsible for any decline in physical or skill performance (Behrens et al. 2022). The exact underlying mechanism(s) responsible for football induced fatigue are still under investigation. For sports nutrition it is important to understand and be able to identify "temporary", "permanent" and "mental" fatigue as explained below.

Temporary fatigue

Players experience temporary fatigue during a match. Temporary fatigue can be identified by a reduction in high-intensity exercise, below match average, in the five-minute period following the most intense periods of the match (Mohr et al., 2003). Indeed, decrements in physical performance follow peak 1-minute, 2-minute and 5-minute periods of high speed running during a match (Leifsson et al., 2024). When independently assessed, repeated sprint performance is significantly reduced after an intense period during the match (as well as at the end of each half) (figure 10) (Krustrup et al., 2006a). Thus, it would appear that the temporary fatigue players experience during training and matches is a result of physiological mechanisms.

It is important to consider that fluctuations in physical performance after an intense period of play could be a consequence of the natural "flow" in match intensity. For example, two players may sprint to contest for a ball, with the result being a corner kick. In this situation, a period of lower intensity running is typically observed as both attacking and defending teams take their tactical positions. Nevertheless, for well-motivated players, the cause of temporary fatigue is associated with peripheral disturbances (within the muscle) which ultimately result in impaired physical performance (Bigland-Ritchie et al., 1986).

Figure 10. Multiple sprint performance during a match (b)*



Source: Bangsbo et al., 2006, https://lc.cx/tQWL0C

*Sprint time (% of the best sprint) of five 30-m sprints separated by a 25-s period of recovery. Before the match (filled circles), after an intense period in the first (open circles) and second half (filled triangles). Data are means±SEM

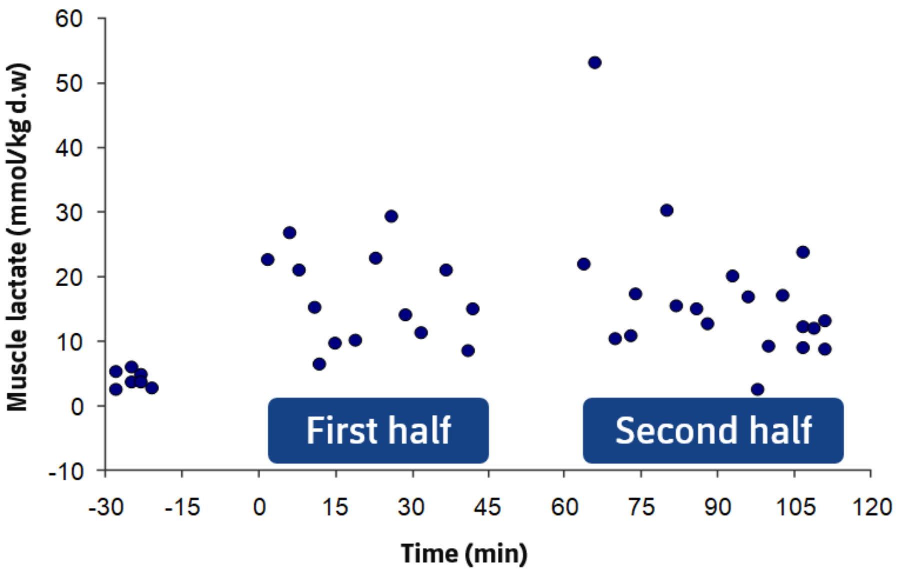
Coaches and players commonly blame "lactate" or "lactic acid" accumulation on fatigue. This is potentially because reductions in performance during a match or training have been previously associated with moderate increases in muscle or blood lactate concentrations (figure 4). However, this terminology is not accurate because there is little evidence to support that elevated lactate is the cause of temporary fatigue during a football match, nor limiting to high intensity intermittent performance *per se* (Bangsbo et al., 1992a). Instead, it is highly likely that lactate is serving as (i) an energy source, (ii) a gluconeogenic precursor, (iii) a signalling molecule (Brooks, 2018; Brooks et al., 2023).

Elevated lactate concentrations can result in an increase in hydrogen ions within the muscle. If hydrogen ions accumulate, the muscle becomes more acidic and the contractile properties of muscle are impaired (Bangsbo et al., 1992a). However, the degree of muscle acidity reported during a football match is only mild (pH ~6.8) and to date is not considered as the direct cause of reduced football performance (Krustrup et al., 2006a).

Did you know?

Gluconeogenesis is a pathway of reactions that generate glucose from non-carbohydrate substrates, occurring primarily in the liver.

Figure 11. Muscle lactate production during a football match



Source: Krustrup et al., 2006a, https://lc.cx/seH0PJ

Did you know?

pH is a measure of the degree to which a solution is acidic or alkaline. The more acidic a solution the greater the hydrogen ion concentration. A pH of 7.0 is an indicator of neutrality, a pH of more than 7 indicates alkalinity and a pH of less than 7 is an indicator of acidity. The pH of the player's blood is approximately 7.4.

Other potential causes of fatigue may be due to low muscle phosphocreatine concentrations. This mechanism of fatigue is supported by studies which report improved performance during intense intermittent exercise following dietary supplementation of creatine monohydrate (Football Nutrition Skills).

Phosphocreatine concentrations have been reported to be almost depleted in individual fibres at the point of fatigue, after intense exercise (Soderlund and Hultman, 1991). However, in football, muscle phosphocreatine concentrations are only 25 % lower than resting concentrations after the intense periods in a match (Krustrup et al., 2006a). This relatively small reduction in muscle phosphocreatine observed during football is likely a consequence of the fast recovery of phosphocreatine that would have occurred within the 15-30 second delay in the preparation and collection of muscle biopsies. This may also account for the absence of change in muscle phosphocreatine reported in the final stages of the Yo-Yo IRT at the point of exhaustion (Krustrup et al., 2003).

Did you know?

A muscle biopsy is a procedure that removes a small sample of muscle tissue. The muscle sample is freeze dried and later analysed in a laboratory.

To date, the best candidate for the development of temporary fatigue during high-intensity exercise is related to an accumulation of potassium in the muscle interstitium and the associated electrical disturbances in the muscle cell (Juel et al., 1990; Nielsen et al., 2004; Street et al., 2005). Prior to contraction, the muscle must be innervated by its motor neuron. Neurons send messages electrochemically (using sodium and potassium) to cause an electrical impulse. The accumulation of potassium in the muscle interstitium may impair the impulse to the muscle and subsequent recruitment of the muscle. This hypothesis is supported by studies that have reported the muscle interstitial potassium concentrations to be higher than 11 mmol/L during exhaustive exercise (Nielsen et al., 2004), which according to in vitro studies is sufficient to depolarize the muscle membrane potential and reduce force development (Cairns and Dulhunty, 1995).

During a football match, venous plasma potassium concentration taken from the arm have been reported to be 5 mmol/L, values only slightly lower than values observed after exhaustive incremental intermittent exercise (Krustrup et al., 2003). However, these plasma values do not provide a clear picture of the concentrations around the contracting leg muscles engaged during football. Thus, further research is needed and studies continue to improve our understanding of transient fatigue during football exercise (Mohr et al., 2005).

Did you know?

A motor neuron is a nerve cell that conveys impulses from the player's central nervous system to a muscle that is required for contraction.

Permanent fatigue

Muscle glycogen

The development of fatigue during prolonged intermittent exercise has long been associated with low glycogen availability in the muscle (Bergstrom et al., 1967). Studies have demonstrated that elevating muscle glycogen prior to football exercise, through a high carbohydrate diet, results in enhanced high intensity intermittent running performance (Bangsbo et al., 1992, Balsom et al., 1999). Failure to increase pre-exercise muscle glycogen concentrations or provide carbohydrate during exercise may result in muscle glycogen levels falling below the concentration required to maintain maximal glycolytic rate (~200 mmol/kg d.w.) (Bangsbo et al., 1992a). Analysis of individual muscle fibres revealed that approximately half of both type 1 and type 2 were almost depleted or fully depleted of glycogen at the end of a 90-minute match (Krustrup et al., 2006a). This reduction was associated with a decrease in sprint speed during a sprint test performed immediately after the match. Therefore, the depletion of glycogen in muscle fibres may prevent a maximal effort in single and/or repeated sprints and be responsible for the "permanent fatigue" towards the end of a match (figure 2).

Furthermore, low glycogen concentrations are likely to inhibit the electro-chemical chain of events between the brain and skeletal muscle contraction (Rollo and Williams, 2023). Therefore, low carbohydrate availability and "permanent" fatigue is likely to be detrimental to coordinated skill performance also.

Hypohydration and hyperthermia

Other factors that contribute to the onset of fatigue in the latter period (final 15 minutes) of a match include hypohydration and hyperthermia Nutrition Considerations in Football) (Reilly, 1997). The fluid losses in football players are highly varied between individuals, even in response to the same training session or match (Baker et al., 2016). It has been reported that football players lose 1-3 litres of fluid during matches in thermoneutral environments, and fluid losses may exceed 3 L in hot and humid environments (Laitano et al., 2014). High fluid losses are of importance because hypohydration equivalent to 2 % body mass losses have been reported to impair football skill performance (McGregor et al., 1999). In other intermittent running sports such as tennis, greater fluid deficits equating to 2.7 % body mass loss have been reported to reduce five and ten meter sprint performance (Magal et al., 2003). In football, even modest fluid losses (approximately 1 % of the players body mass) have been reported to result in significant reductions in sprint performance, despite having no effect on core temperature (Mohr et al., 2004; Mohr et al., 2005). Thus, it appears that fluid loss is also a contributing factor to impaired performance at the end of a match. This is of great relevance to sports nutrition for football, because fluid replacement strategies can be personalised to support individual player training and match requirements.

Did you know?

Thermoneutral environments cover a range of temperatures that allows a player to maintain a body temperature (~37 °C) without regulatory changes in metabolic heat production or evaporative heat loss. Many factors will influence the range of "thermoneutral" temperatures, such as the players body composition and the clothing (kit) worn during training and matches.

Fixture congestion

A relevant question in professional football is whether “chronic” fatigue may manifest because multiple matches are played within a short period of time. For example, players are often required to play 2-3 matches a week during specific stages of the season. To date, no differences in either skill or physical performance were observed when three matches were played within seven days (Carling and Dupont, 2011). However, players' ability to sprint, jump and perform repeated intense exercise has been reported to be impaired when playing two competitive matches a week over a six week period (Rollo et al., 2014). To this end, a nutritionist must modify the nutrition plan for the team and individual players based on both the “single” match demands and in context of the “overall” fixture schedule. Emphasis during these busy stages of the season should focus on appropriate fuelling and recovery strategies between matches.

Mental fatigue

Mental fatigue is defined as a psychobiological state that arises during prolonged demanding cognitive activity and results in an acute feeling of tiredness and a decreased cognitive ability as well as mood changes (Habay et al., 2021). Mental fatigue can reduce physical capacity and increase ratings of perceived exertion. Relevant for football, mental fatigue has been shown to fluctuate throughout a competitive season (Russell et al., 2022). This is important as mental fatigue has been reported, in one review, to have a negative influence on 37 % of soccer specific skills (n.=92) (Habay et al., 2021).

Thus, mental fatigue has been recognised as a key consideration in football, due to the associated negative impact on physical, technical, decision-making, and tactical performance (Smith et al., 2018). Contributing factors to mental fatigue in team sport environments include but are not limited to prolonged cognitive demands, team meetings, travel, and the inability to “switch off” (Smith et al., 2018). These factors are of interest, as there are occasions which can be influenced by the sports nutritionist.

Unit 2. Summary

- The players body responds rapidly to the energy demands of football exercise.
- The aerobic energy system is highly taxed during a football match, with average and peak heart rates around 85 % and 98 % of maximal values, respectively, corresponding to average oxygen uptake of around 70 % of maximum.

- Playing football results in players experiencing "temporary" fatigue during a match, most likely due to an accumulation of potassium in the muscle interstitium.

- The "permanent fatigue" towards the latter stages of a match is associated with a reduction in muscle glycogen and significant hypohydration.

- Mental fatigue fluctuates over the season.

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