

# Module 1. Physiology of the Female Football Player and Factors Predisposing to Injury

## Locomotor and Mechanical Demands in Women's Football

In recent years, scientific evidence regarding the analysis of kinematic demands in women's football has increased, although the first descriptive studies were conducted in the 1980s. The review by Davis and Brewer in 1993 showed that, in the analysed matches using video analysis of 7 players from the Swedish national team, an average distance of approximately  $8471 \pm 2200$  m was covered, with a low sprint distance of  $14.9 \pm 5.6$  m (Davis & Brewer, 1993). In 2005, the group from the University of Copenhagen led by Bangsbo published an analysis of the kinematic demands achieved in 4 matches involving 14 elite players from the Danish league. This analysis showed that the average number of activity changes during the match was 1459 (range: 1336-1529), which corresponds to an activity change every 4 seconds (Krustrup et al., 2005). The total distance covered during the game was 10.3 km (range: 9.7-11.3), from which 9 km (range: 8.4-9.8) were run under 15 km/h, 1.31 km (range: 0.71-1.70) was between 15-18 km/h and sprint distance (between 18 and 25 km/h) was 0.16 km (range: 0.05-0.28). In this study, the authors found a direct positive relationship between high intensity running (>15 km/h) and variables such as oxygen consumption, running speed at aerobic threshold, time in maximal incremental test, and yo-yo test (Krustrup et al., 2005).

This same research group published in 2008 a comparison of kinematic demands between elite players (n=19) and high-level players (n=15) in the Danish league. The total covered distance did not show significant differences. However, the distance covered at high intensity and during sprints was significantly greater for elite players compared to high-level players (Mohr et al., 2008).

In 2014, through the FAiM (Female Athletes in Motion) project, the first analysis of match demands using GPS technology was conducted. It involved 89 players from three categories (U15 n=11; U16 n=63; U17 n=15), including 8 forwards, 25 midfielders, and 56 defenders (Vescovi & Favero, 2014). Regarding the total distance covered, there was a significant increase by category (U15:  $6961 \pm 238$ ; U16:  $8024 \pm 101$ ; U17:  $8558 \pm 223$  m). In terms of intensity ranges, it was observed that each category demanded more effort in all variables, with the distances covered at higher intensity and during sprints showing the greatest increases (Vescovi & Favero, 2014).

It is in more recent studies where data on the neuromuscular load associated with



competition are shown, specifically in terms of the number of accelerations and decelerations (Mara, Thompson, Pumpa, & Morgan, 2017; Ramos et al., 2019). This variable also highlights the actions in which, as we will see later, the risk of injury increases. Ramos et al. presents data by category (senior, U20, U17) and position on the field (defenders, midfielders, forwards), with values showing a significant increase as we move up the categories (Ramos et al., 2019). The latest study, and the only one known as of the writing of this module, that thoroughly analyses accelerations and decelerations in women's football reports a total of 23 ( $\pm 126$ ) accelerations ( $\rightarrow 2 \text{ m/s}^2$ ) and 430 ( $\pm 125$ ) decelerations ( $\leftarrow -2 \text{ m/s}^2$ ) per match. The time between efforts of this nature varied between 11-16 s, and the maximum time observed, with fluctuations during the match, was 74-105 s between accelerations and 70-101 s between decelerations (Mara et al., 2017). This type of mechanical load in competition has been studied more in men than in women, but it is interesting to note that research in male competition accounts for these actions as 18% of the total (Akenhead, Hayes, Thompson, & French, 2013), resulting in a 25% increase for accelerations and up to 65% for decelerations (Dalen et al., 2016).

Recently, data on training and competition from a club in the Spanish first division have been published, showing that in matches, the total distance covered is approximately  $9046 \pm 938$  m, and the distance covered at high intensity (HSR:  $>15 \text{ km/h}$ ) is  $1108 \pm 294$  m (Romero-Moraleda et al., 2021). However, all these studies present the average and standard deviation for each of the analysed variables. Considering the intermittent and anarchic nature of our sport, it is ideal to know the scenarios of maximum demand for both locomotor variables (total distance, high-intensity distance, sprint distance) and mechanical variables (high-intensity accelerations and decelerations).

In this regard, a recent publication shows the highest value for each external load variable measured through GPS in 1-minute windows (González-García et al., 2022). The following table shows the data of maximum demand in minutes:

**Table 1: Scenario of Maximum Demand in Women's Football Competition**

	1-Minute windows		
	Mean	Deviation standard	Coefficient of variation
<b>Total distance (m/min)</b>	167.80	16.00	9.5
<b>High-intensity distance (<math>&gt;15 \text{ km/h}</math>) (m/min)</b>	47.12	14.30	30.4

<b>Very high intensity distance (&gt;18 km/h) (m/min)</b>	30.54	12.98	42.5
<b>Sprint distance (&gt;21 km/h) (m/min)</b>	19.06	11.86	62.2
<b>Low intensity acceleration distance (&lt; 3 m/s<sup>2</sup>) (m/min)</b>	99.34	28.71	28.9
<b>High intensity acceleration distance (&gt; 3 m/s<sup>2</sup>) (m/min)</b>	31.55	11.96	37.9
<b>Low intensity deceleration distance (&lt; 3m/s<sup>2</sup>) (m/min)</b>	12.47	3.76	30.1
<b>High intensity deceleration distance (&gt; 3 m/s<sup>2</sup>) (m/min)</b>	3.65	1.45	39.8
<b>Player Load (A.U/min)</b>	4.61	2.18	47.3

Source: own adaptation based on González-García et al., 2022.

These data are of utmost importance for designing training tasks that reach these demands and achieve adaptations based on these intensity thresholds.

### **Epidemiology of Injuries in Women's Football**

To specifically understand injuries in women's football, we found a cohort study conducted by the FIFA medical team published in 2012 (Junge, 2015). It analysed the incidence of injuries in international competitions from 1998 to 2012. In this study, any injury that required medical attention and resulted in missing training or matches was considered. The injury ratio per match ranged from 1.9 to 2.8. The severity of injuries based on time loss was over 30 days in 1-3% of cases, 8-29 days in 4% of cases, 1-7 days in 24-38% of cases, and the rest represented contusions treated during the match without the need of time off (Junge & Dvorak, 2013). Regarding the description of injuries occurring in competition, this study highlighted that 58% of cases were lower limb injuries, with the knee (13%) and ankle (15%) being the most affected areas. Among the injuries recorded in FIFA women's tournaments, 83% resulted from contact, and 35% of them were sanctioned.

### **Table 2: Injury Data in Different Competitions and Categories by Location, Type, and Mechanism**



		FIFA World Cups	Olympic Games	FIFA World Cups U19/20	FIFA World Cups U17
		N=220	N=208	N=447	N=223
Location	Head/neck	48 (21 %)	36 (17 %)	74 (17 %)	33 (15 %)
	Upper limb	22 (10 %)	20 (9 %)	34 (8 %)	13 (6 %)
	Trunk	15 (7 %)	15 (7 %)	51 (12 %)	19 (9 %)
	Hips	3 (1 %)	5 (2 %)	12 (3 %)	7 (3 %)
	Thigh	22 (10 %)	30 (14 %)	39 (9 %)	15 (7 %)
	Knee	30 (13 %)	23 (11 %)	57 (13 %)	28 (13 %)
	Leg	33 (15 %)	26 (12 %)	56 (13 %)	46 (21 %)
	Ankle	34 (15 %)	46 (22 %)	104 (24 %)	39 (17 %)
	Foot	13 (6 %)	7 (3 %)	20 (4 %)	23 (10 %)
		N= 222	N=202	N=446	N=219
Type	Concussion	7 (3 %)	11 (5 %)	10 (2 %)	5 (2 %)
	Fracture	9 (4 %)	3 (1 %)	8 (2 %)	3 (1 %)
	Tendon or ligament rupture	7 (3 %)	3 (1 %)	8 (2 %)	3 (1 %)
	Sprain	35 (16 %)	52 (25 %)	96 (22 %)	43 (20 %)
	Overload	20 (9 %)	17 (8 %)	25 (6 %)	23 (11 %)
	Concussion	108 (50 %)	93 (46 %)	242 (57 %)	116 (53 %)
	Skin injury	18 (8 %)	6 (3 %)	19 (4 %)	5 (2 %)
	Other	20 (9 %)	16 (7 %)	26 (6 %)	20 (9 %)
Mech	Without contact	39 out of 224* (17 %)	50 out of 204 (25 %)	58 out of 446 (13 %)	54 out of 217 (25 %)

anism	With contact	185 out of 224*(83 %)	154 out of 204 (75 %)	338 out of 446 (87 %)	163 out of 217 (75 %)
	Contact foul	54 out of 156* (35 %)	39 out of 107* (36 %)	165 out of 355 (46 %)	47 out of 161 (29 %)
*No information documented about time loss in the tournament (1998/1999).					

Source: own creation based on Junge and Dvroak, 2013.

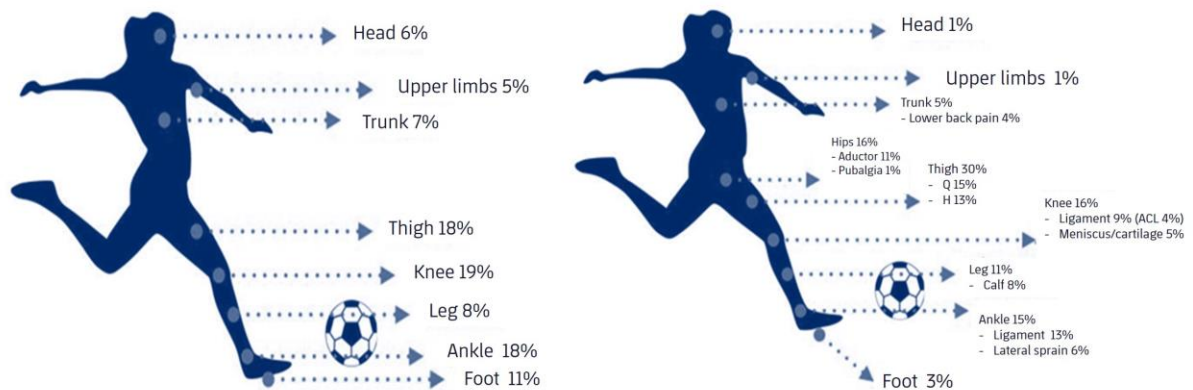
In the FIFA report published at the end of 2015, an epidemiological study was conducted on 9 teams from the German first division, including 165 players with an average age of  $22.4 \pm 5$ . The number of injured players throughout the season was 115 (70%), resulting in a total of 241 injuries (Junge, 2015). Of these, 16% were due to overuse, while 84% were traumatic, with 58% occurring in competition and 42% in training.

Regarding the severity of the injuries, 51% were classified as minor, 36% as moderate, and 13% as acute. 50% of the acute injuries were anterior cruciate ligament (ACL) tears.

Regarding injuries in the Spanish women's first division, a recent study published in the *Scandinavian Journal of Medicine and Science in Sports* compared the epidemiology of injuries between the professional male and female teams over 5 seasons (Larruskain et al., 2018). In the women's team, there were 160 injuries, with 50% occurring in matches and 47% in training. Only 19% of the injuries were caused by contact, while 78% were non-contact injuries. 78% of the injuries were first-time occurrences, while 22% were recurrent injuries. Out of the 160 recorded injuries, 23% were classified as acute (absence from play for more than 8 weeks). The women's team reported 6 anterior cruciate ligament (ACL) tears, averaging more than one per season. In the graph presented below, we can see the percentage of injuries by location. For further details, please refer to Table 4 of the mentioned article (Larruskain et al., 2017), where you can observe that the percentage of days lost was 28% for muscle injuries, with a higher prevalence of quadriceps tendon ruptures compared to hamstring injuries, and 69% for ligament injuries.



**Image 1: Comparison of Injury Locations in the German League (left) (FIFA Report, 2015) and the Spanish League (right)**



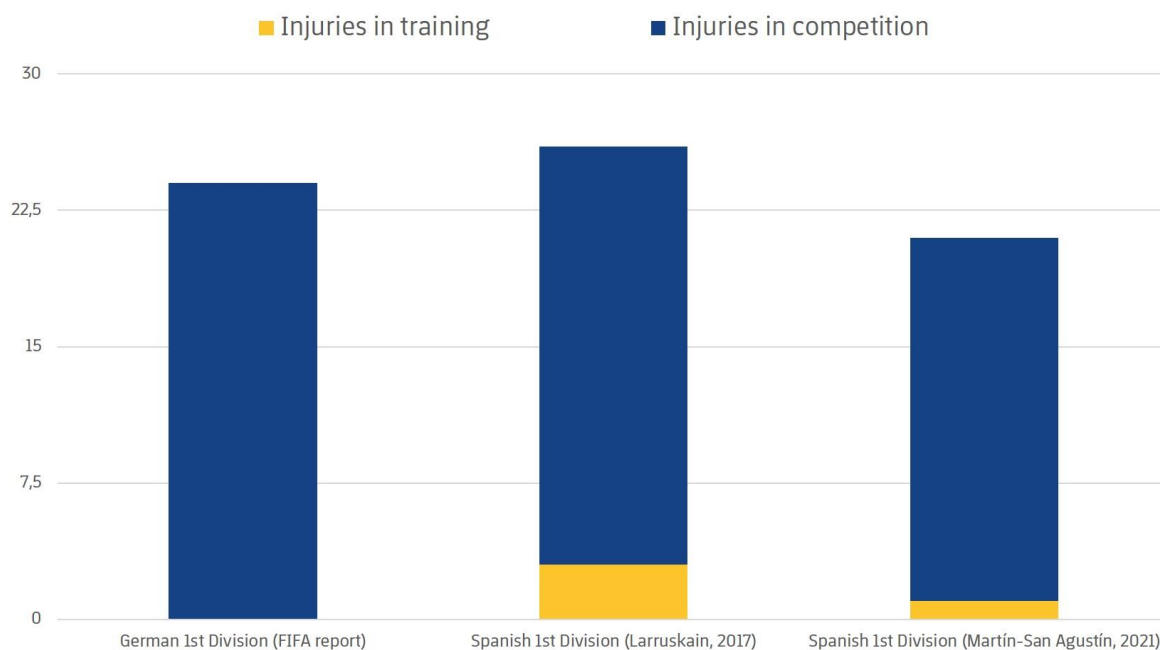
Source: own creation based on Larruskain et al., 2017.

Cabeza	Head
MMSS	Upper limbs
Tronco	Trunk
Muslo	Thigh
Rodilla	Knee
Pierna	Leg
Tobillo	Ankle
Pie	Foot
Dolor lumbar	Lower back pain
Cadera	Hips
Abductor	Abductor

Pubalgia	Pubalgia
Lig 9% (ACL 4%)	Ligament 9% (ACL 4%)
Menisco/cart.	Meniscus/cartilage
Gemelo	Calf
Esguince Lat	Lateral sprain

Lastly, a recent study published in 2021 shows that the incidence of injuries in our first division remains very high, with a ratio of 1.70 injuries/1000 training hours and 19.2 injuries/1000 competition hours (Martín San-Agustín et al., 2021). (Martín San-Agustín et al., 2021).

**Image 2: Injuries in Training and Injuries in Competition**



Source: own creation based on Larruskain, 2017 and Martin- San Agustín, 2021.

Lesiones en entrenamiento	Injuries in training
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Lesiones en competición	Injuries in competition
1 div Alemana (informe FIFA)	German 1st Division (FIFA report)
1 div Española	Spanish 1st Division

Therefore, we must highlight the higher frequency of joint injuries found in women compared to men. The anterior cruciate ligament (ACL) injury has received significant attention in recent years due to the increasing number of cases. Various epidemiological studies alert us to the fact that ligament injuries in women have a prevalence 4 to 6 times higher than in men (Joseph et al., 2013). Furthermore, the work of Beynnon et al. (2014) indicates that specifically, ACL tear in women has a 2 to 8 times higher ratio than in men in the same sport and competitive level (Beynnon et al., 2014). This study also informs us that the ratio of ruptures in competition is 20.8 times higher than in training.

### **Biomechanical Risks**

The epidemiology of injuries in women's football, with a predominance of ligamentous injuries, among others, can be attributed to physiological and anthropometric characteristics of women. A more specific analysis of the female gender in these aspects will allow us to approach the recovery and prevention processes with a better perspective. Therefore, in addition to the anatomical and biological differences that will be discussed later, we want to emphasise the importance of biomechanical, kinetic, and kinematic alterations. These areas offer the greatest potential for positive intervention by fitness coaches, rehabilitation specialists, physiotherapists, and others in order to reduce the risk of injury.

- Biomechanical Differences between Men and Women:

The study by Landry et al. (2007) shed light on the biomechanical differences between men and women in basic and specialised motor patterns. In this study, kinetic variables, and muscle activation during change of direction (COD) and jump landing were compared between male and female football players (Landry et al., 2007)

- Key Kinematic Findings in Women:
  - Higher hip adduction moment during COD.
  - Higher knee adduction (valgus) moment.
  - Greater ankle eversion angle.

- Less hip-knee-ankle flexion, indicating less vertical displacement of the centre of mass and, consequently, less force absorption in the muscles and more absorption in passive joint structures.
- Key Muscle Activation Findings in Women during COD:
  - Increased activation of the rectus femoris.
  - Decreased activation of the hamstring muscles.
  - Decreased activation of the hip abductor muscles.

These findings provide clues for setting objectives in injury risk reduction planning. Therefore, it is crucial to focus on increasing strength levels in the hip abductor/external rotator muscles, posterior chain muscles, plantar flexors, and the core muscles (including pelvic and scapular girdle muscles).

In line with this, the study by Sighard, Pollard, and Powers (2012) shows that when comparing jump landing mechanics in different groups of sexual maturation (pre-puberty, during puberty, and post-puberty), biomechanical differences arise during sexual maturation. It was observed that women land with greater knee valgus and less vertical displacement of the centre of gravity, which increases the risk of joint injuries (Sighard, Pollard, & Powers, 2012). These findings are further supported by more recent studies analysing drop jumps and change of direction in different stages of sexual maturation (Westbrook et al., 2020). Additionally, mechanics of landing, deceleration, and force absorption are further altered with fatigue (Fidai et al., 2020), highlighting the importance of training these movements under fatigue conditions.

Other factors that also affect the biomechanics of female football players and make them more vulnerable to injury include the following (Hewett et al., 2010; Smith et al., 2012):

- Lower hamstring-to-quadriceps (H: Q) strength ratio, with a quadriceps dominance. This is related to reduced knee flexion during landing and decreased activation of posterior muscles (hamstrings, popliteus, gastrocnemius) in knee stabilisation to prevent anterior displacement of the tibia.
- Lower quadriceps and hamstring strength, resulting in insufficient muscle capacity to absorb forces, leading to increased knee valgus and anterior tibial translation.
- Lower stiffness in the hamstrings.
- Lower limbs activation asymmetry: lower muscle activation and motor control in the non-dominant leg, leading to weight shift to the dominant leg and lateral trunk tilt.



- Longer reaction and processing time to stimuli; and reduced verbal and visual memory.
- Insufficient or delayed activation of the lumbopelvic muscles. Reduced lumbopelvic stability results in lower knee stabilisation capacity.

### **Influence of Fluctuations in Sex Hormones during the Menstrual Cycle and Risk of Injury**

This is one of the most controversial topics, as there are studies that do not show a higher frequency of injuries in one phase of the menstrual cycle compared to another, while other studies highlight a specific phase as more predisposing to injury. The study by Wojtys, Huston, Lindenfeld, Hewett, and Greenfield (1998) examines the menstrual cycle phase of 40 athletes who recently suffered ACL injuries and correlates it with the timing of the injury. The results show significant differences between menstrual cycle phases, with a higher number of injuries occurring during the ovulatory phase (days 10 to 14) and fewer injuries during the follicular phase (days 1 to 9) (Wojtys et al., 1998). In line with this, Shultz et al. (2005) studied ACL laxity in different menstrual cycle phases and demonstrated that ACL laxity is hormone-dependent, increasing with higher concentrations of oestradiol, which are present during the ovulatory phase (Shultz et al., 2005). These findings align with the higher prevalence of injuries during a specific phase of the menstrual cycle (ovulatory phase) reported in the descriptive study by Wojtys et al. (1998). However, reviews published on this topic (Balachandar, 2017; Hewett et al., 2007) include studies showing a higher prevalence of ACL injuries in the days preceding ovulation. Some studies even show a higher frequency of injuries during the days of menstruation, while others find no differences between menstrual cycle phases. It is important to highlight that the afferent sensory property of ligaments for stabilisation does not vary throughout the menstrual cycle (Wolf et al., 2013).

In conclusion, further research is needed in this area to provide clear answers regarding whether the risk of injury can increase due to fluctuations in sex hormones. Therefore, it is important not to convey to female athletes that there is a higher risk in one phase compared to another, as it has not been proven, and doing so may lead to avoidance behaviours during that particular phase of the menstrual cycle when engaging in sports activities.

### **What Differentiates Us from Men from a Physiological Standpoint**

The anatomical, physiological, and biomechanical differences between men and women determine variations in performance. Increasing knowledge about the biological factors that can determine differences in sports performance can provide training professionals with more tools for optimising women's performance. In the 19th century, some essays were published on the physiological functions of the menstrual cycle, considering it as a

pathology (Hirt, 1873). Progress over the decades has allowed for an increased scientific understanding of women's physiological responses to exercise. However, despite this evolution, there is still a significant disparity between the number of studies conducted on men and women, with a ratio of approximately 4:1 (Beery & Zucker, 2011). Nonetheless, the evidence found regarding the different physiological responses of women to training compared to men highlights the importance of considering sex as a biological variable for optimal exercise prescription (Ansdell et al., 2020). Many studies demonstrate how acute exercise imposes stress on physiological systems, triggering a cascade of molecular responses that, when repeated and progressed through a training program, lead to physiological adaptations that improve exercise capacity. However, the distinct response of women to fatigue underscores the importance of understanding the appropriate dosage needed to elicit adaptations (Hunter, 2016b).

## **Sexual Differences by Physiological Systems**

### **1. Muscular System**

The contractile fibres of the motor system are ultimately responsible for force generation and movement (Dulhunty, 2006). Reduced skeletal muscle capacity to produce force is a signal of fatigue and limits the ability to maintain exercise intensity (Brownstein et al., 2021). An obvious difference between men and women is that men possess a higher amount of muscle mass (~12%), which contributes to a greater capacity for generating force. The phenotypic expression of sex-related gene expression leads to considerable differences in the morphological composition of skeletal muscle. Muscle biopsy studies have shown that the vastus lateralis of women has 7 to 23% more type I fibres compared to men (Roepstorff et al., 2006; Simoneau & Bouchard, 1989; Staron et al., 2000). This higher percentage of type I fibres in women has relevant consequences in metabolic response, mechanical force generation, and post-high-intensity exercise recovery. At a metabolic level, women oxidise more fats and fewer carbohydrates and amino acids than men (Tarnopolsky, 2008), also showing greater  $VO_2$  kinetics during moderate-intensity activities (Beltrame, Villar, & Hughson, 2017). This is also attributable to men having greater glycolytic capacity while women have greater oxidative capacity (Esbjörnsson-Liljedahl et al., 1999). Similarly, these studies suggest that women have a lesser decrease in ATP concentrations and an increase in ATP metabolism by products after maximal exercise (Esbjörnsson-Liljedahl et al., 1999). Regarding mitochondrial oxidation rate, women exhibit about one-third higher mitochondrial respiration than men, measured through high-resolution respirometry following muscle biopsy (Cardinale et al., 2018). These findings indicate that female skeletal muscle metabolism is better suited for ATP resynthesis through oxidative phosphorylation during exercise.

The proportional difference in fibre type between men and women also influences the contractile properties of the skeletal muscle. Male skeletal muscle exhibits faster relaxation rates compared to female muscle (Hunter, 2009). Type I fibres also display



slower  $\text{Ca}^{2+}$  kinetics, lower energy generation, and slower shortening and relaxation velocities than type II fibres (Schiaffino & Reggiani, 2011). In fact, muscle biopsy results have shown that women have a lower rate of maximum activity of sarcoplasmic reticulum  $\text{Ca}^{2+}$ -ATP compared to men (Harmer et al., 2014). These findings have suggested that differences in ionic regulation of muscle contraction contribute to greater fatigue resistance in female muscle during exercise (Hunter, 2016a, 2018).

Lastly, hemodynamic and muscle perfusion properties also differ between sexes, which can affect oxygen supply during exercise (Beltrame et al., 2017). The vasodilatory response of arteries in target muscles during exercise is greater in women. For example, the femoral artery exhibits higher vascular conductance and blood flow during incremental exercise (Parker et al., 2007). This vasodilatory response difference could promote greater muscle perfusion during exercise (although this also depends on muscle capillarization). In line with this, muscle biopsy analysis has shown a higher capillary density per unit of skeletal muscle in women compared to men in the vastus lateralis (Roepstorff et al., 2006). In summary, evidence suggests that the metabolic, contractile, and hemodynamic properties of skeletal muscle differ between men and women, which directly influence their response to the same exercise stimulus.

## 2. Respiratory System

Like the muscular system, differences between men and women in the respiratory system are also well established. Like skeletal muscle, women tend to have smaller lungs than men (even when matched for height) (Schwartz et al., 1988), smaller airways (Dominelli et al., 2018), and different pulmonary geometry (Torres-Tamayo et al., 2018). These morphological differences influence factors such as respiratory work (the product of pressure and volume for each breath,  $W_b$ ), respiratory efficiency, and susceptibility to arterial hypoxemia (reduced oxygen concentration in arterial blood), which can be a central limitation for exercise in women. Regarding minute ventilation (the volume of gas expired per minute,  $\dot{V}_E$ ), women demonstrate greater mechanical respiratory work ( $W_b$ ), regardless of age (Molgat-Seon et al., 2018) or fitness level (Guenette et al., 2007). This response is due to the smaller size of the airways, as the phenomenon becomes evident only with elevated  $\dot{V}_E$  (Dominelli & Sheel, 2019). Dominelli and Sheel (2019) also demonstrated lower respiratory efficiency (the ratio of respiratory work to absolute  $\dot{V}O_2$  of respiratory muscles,  $\dot{V}O_{2RM}$ ) for women compared to men at a given  $\dot{V}_E$ . When  $\dot{V}O_{2RM}$  is expressed as a fraction of whole-body  $\dot{V}O_2$ , women typically allocate ~14% of total  $\dot{V}O_2$  at maximal exercise intensities, while men allocate only ~9% (Dominelli et al., 2015). If the  $\dot{V}O_2$  of a muscle is directly proportional to blood flow in the Fick equation, it is likely that respiratory muscles require a greater fraction of cardiac output for women (Dominelli & Sheel, 2019). This study suggested that women may be more prone to exercise-induced arterial hypoxemia than men due to their smaller lung volumes, smaller airways, and fewer alveoli (Dominelli & Sheel, 2019).

Despite these potentially more limiting morphologies within the female respiratory system compared to males, certain functional aspects may counteract any central limitation in exercise response. It has been found that the diaphragm is more fatigue-resistant in women than in men (Guenette et al., 2007). Additionally, women seem to recruit extra diaphragmatic accessory muscles at elevated V<sub>E</sub>, which could also delay diaphragm fatigue (Mitchell et al., 2018). Despite this greater respiratory muscle fatigue resistance, evidence regarding sex differences within the respiratory system suggests that there is a central limitation for high-intensity resistance performance, particularly in women.

Sexual differences directly influence fatigue tolerance, resulting in women having a higher tolerance for strength exercise compared to men and a lower tolerance for cardiovascular exercise (Ansdell et al., 2020). Furthermore, differences in fibre typology and metabolism in women enable them to tolerate a higher frequency of strength training sessions, recovering faster than men (Hunter, 2016b). All of the considerations mentioned above are necessary to prescribe the appropriate exercise dosage that sufficiently stimulates female football players. For example, in upper limb strength training, where there are fewer anabolic receptors, a higher training volume is required for an equivalent response compared to lower limb training.

### **The Menstrual Cycle in Female Football players**

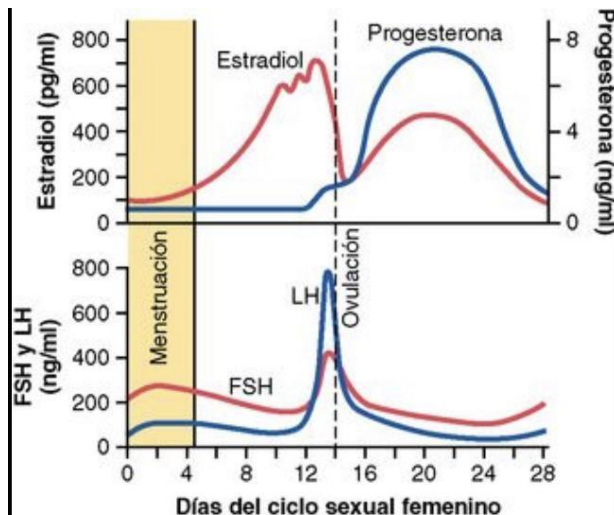
The female hormonal system, like that of males, consists of three groups of hormones that function in a cascade (Guyton, Hall, & Moreno, 1997):

1. A hormone released by the hypothalamus: gonadotropin-releasing hormone (GnRH).
2. Hormones released by the adenohipophysis: follicle-stimulating hormone (FSH) and luteinizing hormone (LH), both secreted in response to GnRH.
3. Ovarian hormones, oestrogens (oestradiol, estrone, estriol), and progesterone, secreted by the ovaries in response to the adeno-hypophyseal sex hormones.

This cascade mechanism is known as the hypothalamic-pituitary-ovarian axis, which is responsible for controlling the stimulation and inhibition of the mentioned hormones. Throughout the monthly female sexual cycle, commonly known as the menstrual cycle, these hormones are secreted at varying rhythms, marking the different phases of the menstrual cycle.



Image 3: Menstrual Cycle



Source: Guyton, Hall, and Moreno, 1997.

Estradiol	Oestradiol
FSH y LH	FSH and LH
Estradiol	Oestradiol
Progesterona	Progesterone
Ovulación	Ovulation
LH	LH
FSH	FSH
Días del ciclo sexual femenino	Days of the menstrual cycle

In the lower part of Image 3, we can observe the approximate changes in the concentration of the adeno-hypophyseal hormones, FSH and LH, and in the upper part, the changes in ovarian hormones, oestradiol (oestrogen), and progesterone. In contrast, the GnRH released by the hypothalamus increases and decreases in a much less noticeable manner during the menstrual cycle. The average duration of this cycle is 28 days, with also shorter cycles (around 22 days) and longer cycles (exceeding 36 days) observed. Oligomenorrhea is considered when cycles last more than 36 days, while

amenorrhea is defined as the absence of menstruation over 180 days. As seen in Image 3, the menstrual cycle is divided into two phases separated by **ovulation: the follicular phase and the luteal phase**. The first day of bleeding (menstruation) coincides with day 1 of the **follicular phase**, which lasts approximately 14 days and is subdivided into two phases: **early follicular phase and late follicular phase**. The first 6-10 days are characterised by low concentrations of ovarian hormones (oestrogens and progesterone), which is identified as the early follicular phase. In the late follicular phase (which, in an ideal 28-day cycle, can range from days 6 to 13), due to an increase in FSH, there is a rise in oestrogens for follicle formation, reaching the maximum peak just before ovulation, which occurs in the middle of the cycle (day 14). The increase in oestrogens in the late follicular phase greatly enhances the pituitary sensitivity to GnRH, leading to a sudden increase in LH. This LH surge triggers the successful development of the dominant follicle, which is completed during ovulation (the process of releasing the oocyte from the follicle and the formation of the corpus luteum, which lasts 36 to 42 hours). The **luteal phase** corresponds to the following 14 days after ovulation until the next menstruation. During this phase, the corpus luteum is formed, activated, and grows. The corpus luteum stimulates the secretion of oestrogens and, especially, progesterone, reaching its peak around the eighth day (day 21-22 of the cycle), and it prepares the uterus for the potential implantation of the embryo. If fertilisation does not occur, the corpus luteum degenerates, causing a decline in oestrogens and progesterone, and ultimately initiates a new cycle with menstruation.

### **Relationship between the Menstrual Cycle and Sports Performance**

In recent years, there has been an increasing scientific interest in the following question: Can the menstrual cycle affect performance? However, although it may seem like a trendy topic nowadays, in 1939, renowned physiologist Hans Selye received the Nobel Prize in endocrinology for his theory on the "general adaptation syndrome," reporting through his animal experiments that a sudden increase in exercise volume and intensity can cause irregularities in the menstrual cycle in women (Selye, 1939). In 1953, we find the first article where the authors, Devi and Reddy, observe a reduction in muscular performance during menstruation (Devi & Reddy, 1953). Delving into the scientific literature, the following are the main areas of performance studied, and I can already tell you that in all the capacities studied, we find studies with results pointing in different directions:

- Cardiovascular endurance: two recent studies reported lower cardiorespiratory efficiency and a higher perception of fatigue during the mid-luteal phase compared to the early and late follicular phases (Barba-Moreno et al., 2019; Freemans et al., 2020).

One physiological response supporting this finding is that during the luteal phase, there is an increase in basal body temperature by 0.3 to 0.5 °C for the formation



and development of the corpus luteum, which can affect thermoregulation mechanisms and decrease performance.

- Variation in cortisol concentration throughout the menstrual cycle: the meta-analysis by Hamidovic et al. (2020) reported that cortisol concentration is higher during the follicular phase, which may lead to a greater stress response during this phase.
- Muscle damage and recovery measured through creatine kinase (CK) and interleukin-6 (IL-6): different studies have not found an association between oestrogen levels and lower muscle damage measured by creatine kinase (CK) concentration (Clarkson & Hubal, 2001; Romero-Parra et al., 2020). However, previous works, such as the review by Kendall and Eston (2002) and the descriptive study by Hackney, Kallman, and Aǧgön (2019), have shown the potential protective role of oestrogen against muscle damage.
- Muscle stiffness or the ability of a tissue to resist deformation: in a recent study that measured 37 women using elastography, it was observed that during muscle contraction, there is lower stiffness in the ovulatory phase in different lower limb muscles (rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius) (Ham et al., 2020).
- Cognition: previous studies have observed improvements in executive tasks (perception and memory) when oestrogen concentration is higher (late follicular phase) (Le, Thomas, & Gurvich, 2020), although these findings are not consistent.
- Risk of injury: a systematic review (Shultz, 2016) that included 9 studies analysing the frequency of injuries in different phases of the menstrual cycle found that in 3 of the studies, there was a higher frequency of injury in the late follicular phase, while the remaining 6 studies did not report a higher frequency of injury in any of the menstrual cycle phases. Therefore, we cannot state that there is a greater predisposition to injury in a specific phase.
- Strength and neuromuscular performance: this can be the hottest topic in recent years. In summary and in line with the previous information, there are studies showing an increase in strength performance in some phases of the menstrual cycle, such as the studies by Bambiaichi et al. (2004) and Sarwar Niclos and Rutherford (1996), which reflect better strength performance in the late follicular phase (Bambiaichi et al., 2004; Sarwar et al., 1996). Similarly, there are also studies whose results show no changes in strength performance across different phases of the menstrual cycle (García-Pinillos et al., 2020; Romero-Moraleda et al., 2019).

In summary, and in line with the two most recent reviews and meta-analyses (McNulty et al., 2020; Thompson et al., 2020), performance can be trivially affected during the early follicular phase in women who experience menstrual symptoms. In the study by Armour et al. (2020), 82% of the women reported that experiencing premenstrual or menstrual pain increased their perception of fatigue and could decrease their performance. However, the lack of methodological rigor in the included studies prevents drawing consistent conclusions.

### **Consideration of the Menstrual Cycle in Sports Planning and the Hypothalamic Adaptive Response**

At this point, a new question arises: Should we consider the menstrual cycle when planning training for women? To address this question, let's go back to the physiological basis. As mentioned at the beginning of this module, the menstrual cycle is regulated by a triple cascade axis: the hypothalamic-pituitary-ovarian axis. The hypothalamus acts as a central hub that receives a lot of information, both internal and external, to maintain homeostasis and control the secretion of numerous pituitary hormones. Hypothalamic adaptation directly influences ovulatory (reproductive) function, and there are many factors that can influence this hypothalamic response, such as energy changes, environment, temperature, psychological stress, or physical stress (sudden increases in training intensity and/or volume). The adaptive response of the hypothalamus to training, which directly affects ovulatory/menstrual function, is to provoke a shorter luteal phase and a decrease in progesterone levels, while oestradiol levels remain stable. In the face of any stressor, the hypothalamic response tends to be **conservative** to ensure the proper functioning of survival and homeostatic maintenance functions. Therefore, if our female athlete experiences alterations in the menstrual cycle or ovulatory function (long cycles, anovulatory cycles, amenorrhea, etc.), it is a consequence of a stress factor that exceeds proper adaptation and, if prolonged, can jeopardise her health (Constantini & Hackney, 2013; Hackney, 2017). Hence, it is essential to understand the **individual response** of our athlete to menstrual hormone fluctuations, as well as the adaptive response to training stimuli.

Merely knowing the length of the cycle does not allow us to determine if there are hormonal irregularities such as anovulatory cycles, where the egg is not released from the ovary due to a lack of LH surge. However, tracking the length of the cycle, which can be easily done through various applications, does allow us to assess cycle regularity and educate the athlete to avoid giving the menstrual cycle a negative connotation. It is important to avoid statements such as "in this phase, you may have lower performance or a higher risk of injury," etc. because performance during different phases of the menstrual cycle is highly individual and should be known and evaluated for each athlete.

### **Practical Applications for Strength Training**



Well, despite the inconclusive results from scientific studies, have any practical tools for strength training planning based on the knowledge of the menstrual cycle of our athletes been obtained?

Starting with the fact that each individual responds to training in a highly individual manner, in recent years, several studies have revealed that there are different adaptations in strength gains depending on the phase of the menstrual cycle in which training is focused. Sung et al. (2014) conducted a clinical trial in which 20 women performed 8 strength training sessions with one leg during the follicular phase and 2 sessions during the luteal phase, while with the other leg, they performed 8 training sessions during the luteal phase and 2 during the follicular phase. After three complete menstrual cycles, the leg that received more strength training during the follicular phase showed improvements in maximal strength and diameter of fast-twitch fibres (Sung et al., 2014).

Similarly, another study showed that after four months of strength training, the group of women who trained 5 times per week during the first two weeks of the cycle (more training in the follicular phase) and once a week during the last two weeks achieved a greater increase in squat strength, jump performance, and peak values of the hamstrings compared to the group that trained once a week during the first two weeks of the cycle and 5 times per week during the last two weeks (more training in the luteal phase) (Wikström-Frisén, Boraxbekk, & Henriksson-Larsén, 2017). Therefore, the practical recommendation derived from these findings is that fitness coaches and coaches could optimise strength gains in women by incorporating higher frequency and load of strength training **in the first two weeks of the cycle (follicular phase)** compared to the last two weeks.

We must not forget that the response and time of hormonal action vary greatly among different hormones. For example, adrenaline and noradrenaline are secreted within seconds after gland stimulation and exert their action within a few seconds, while others, such as growth hormone, can take months to exert their full effect (Guyton, Hall, & Moreno, 1997). Thus, the onset and duration of action differ for each hormone and depend on its specific control function. Ovarian hormones (oestradiol and progesterone) do not have an immediate time of action, so their influence on performance within a training session is limited, which is why many studies comparing performance during different phases of the menstrual cycle do not find significant differences.

There is still much to be researched in this field, as well as a need to standardise methodologies for identifying phases of the menstrual cycle and develop non-invasive and low-cost hormonal measurement tools that are accessible to all. While this happens, monitoring and understanding the characteristics of your athlete's menstrual cycle through questionnaires will allow you to make informed decisions within the training plan. And something very important is **not** to give a negative connotation to the

menstrual cycle, that is, not to influence our athlete with phrases like: "there is a performance decline in this phase," "there is a higher risk of injury in these days," "we can't include plyometrics here in case you get injured," etc. Because, as Anthony Hackney, one of the world's leading menstrual cycle experts, says: "gold medals have been won and world records set at all different phases of the menstrual cycle" (2020, p. 285).

In summary, this module analysed the competition demands in women's football, along with the epidemiology of the most common injuries, particularly joint injuries. Based on this knowledge, the possible causes of the higher injury ratio in women compared to men were addressed, with a strong emphasis on biomechanical factors, which are modifiable to reduce the risk of injury. The module also reviewed the scientific literature on the risk of injury and the menstrual cycle, leading to an extensive section that explains the biological differences between men and women and the role of the menstrual cycle in performance.

These insights can provide tools for planning training loads and content in women's football.

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