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Comparison of Hamstrings and Quadriceps Muscle Activation in Male and Female Professional Soccer Players

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Featured Application: Surface electromyography is a valid and useful tool to assess quadriceps and hamstring muscle activation in professional male and female soccer teams. This methodology can be used in hamstring and knee injury prevention and rehabilitation programs.

Abstract: (1) Background: this study aimed to determine if there are differences in quadriceps and hamstring muscle activation in professional male and female soccer players. (2) Methods: muscle activation was recorded by surface electromyography in 27 professional soccer players (19 male and 8 female). The players performed the Bulgarian squat and lunge exercises. Vastus medialis, vastus lateralis, rectus femoris, semitendinosus, and biceps femoris were the muscles analyzed. (3) Results: The statistical analysis of the hamstring:quadriceps ratio showed no significant differences ($p > 0.05$). Significant differences were found in the vastus medialis:vastus lateralis ratio for both the lunge exercise ($t_{20} = 3.35$; $p = 0.001$; d = 1.42) and the Bulgarian squat ($t_{23} = 4.15$; $p < 0.001$; d = 1.76). For the intragroup muscular pattern in the lunge and Bulgarian squat exercises, the female players showed higher activation for the vastus lateralis muscle ($p < 0.001$) than the male players and lower muscle activation in the vastus medialis. No significant differences were found in the rectus femoris, biceps remoris, and semitendinosus muscles ($p > 0.05$). (4) Conclusions: Differences were found in the medial ratio (vastus medialis: vastus lateralis). Moreover, regarding the intramuscular pattern, very consistent patterns have been found. In the quadriceps muscle: VM>VL>RF; in the hamstring muscle: ST>BF. These patterns could be very useful in the recovery process from an injury to return players to their highest performance.

Keywords: electromyography; ratio; prevention; injury

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1. Introduction

There have been numerous epidemiological studies in soccer for estimating that hamstring strain injuries (HSI) in soccer represent 10–12% of all injuries [1], which indicates five to six injuries per team per season [1]. The cost per injury is estimated to €6355 [2], of which 46% of the players are from relapse [3].

In turn, hamstring breaks have been significantly associated with a low hamstring: quadriceps (H:Q) ratio [4,5]. In soccer, quadriceps injury represents 19% of total injuries and approximately 16% of hamstring injuries [6]. To date, the main risk factors reported for HSI in soccer are previous injuries [7–9], muscle power imbalance [5,10], neuromuscular disorders [11], and fatigue [12–14]. Focusing on soccer, male soccer players get 1.9 times more hamstring injuries than female soccer players, with a 12% absence rate in the season compared to an absence of 6% for female counterparts [15]. Moreover, female soccer players have two times more quadriceps injuries than male soccer players, with an 8% absence rate compared to 3% for males [8].

Another important injury in soccer is the anterior cruciate ligament (ACL), which affects 2–9 times more females than males [16,17]. If we focus on knee injury and specifically ACL injury, noncontact ACL injury in athletes has a multifactorial etiology [18]. The factors reported as important are hamstring muscle weakness, excessive quadriceps strength, medial and lateral imbalances, and age [19,20]. In addition, muscular fatigue may increase the risk of the noncontact ACL [18]. In addition, Wojtys and Huston [21] reported that female athletes have a slower response of hamstring activation to anterior stress on the ACL (using anterior tibia translation tests) compared to male athletes in a physical examination. Cowling and Steele [22] reported sex differences in muscle activation strategies of the hamstrings musculature that do not coincide with the findings of [21], who found no significant differences in either segmental alignment or temporal characteristics of the quadriceps muscles shown by males and females on landing. The inter-limb differences in muscle recruitment patterns, muscle strength, and muscle flexibility tend to be greater in females than in males [23].

There are differences between the competition of males and females, and therefore, the incidence of injuries is not the same between the two groups. For males, the most frequent injury is a minor one (65%), while for females the most frequent injury is a moderate one (51%) [12]. Generally speaking, more injuries occur in male's soccer, but it is in female soccer players that the most serious injuries occur [24]. It has been established that the H:Q ratio not only helps to prevent damage to the posterior thigh muscles but also helps to reduce the stress on the ACL of the knee [25]. To help reduce stress on the knee, not only is the H:Q ratio important, but also how each of the quadriceps and the hamstrings muscles are activated, which is called the activation pattern [26].

If attention is paid to the muscle imbalance factor, isokinetic machines have mainly been used to evaluate the relationship between the quadriceps and the hamstrings [27]. These machines measure the maximum total flexor and extensor strength of the knee but do not take into account the participation of each muscle group separately [28]. Another disadvantage of isokinetic machines is that they produce a lot of fatigue in the athlete, which makes it difficult to use them during moments of the season with a lot of intensity of training and official matches [29]. Another tool that has been used to evaluate the muscle activation between the quadriceps and the hamstrings is surface electromyography (sEMG) has also been used as a tool to evaluate muscle activation between the quadriceps and the hamstrings [30–32]. In sEMG studies, basic movements (e.g., forward lunge, Bulgarian squat, and lateral step-ups) are often used to make them easily reproducible [33,34], and these exercises do not cause excessive fatigue, allowing soccer teams to use them at any time during the season. These are simple exercises used to strengthen the hamstring and quadriceps muscles, and their study can provide information on the activation of the different muscles of these muscle groups and see the differences in activation in the phases of exercise [30]. These exercises can be decisive for soccer players, taking into account the muscle group they are targeting, since recording the electrical activity of each of the muscular bellies would help reduce the time in the process of recovery from an injury and also help in its prevention [30].

Exercises with higher H:Q activation ratios may be preferred during early rehabilitation after injury [35]. Previous studies have suggested that the H:Q force ratio should be at least 0.6 to prevent injuries to both the hamstrings and the knee [36]; however, this has been studied using isokinetic machines rather than sEMG. With the use of sEMG, some studies have been carried out with soccer players, most of them males, reporting H:Q ratios from 0.21 to 0.81 [31,32,37] and few studies have compared the ratio of males to females and with a non-soccer specific sample [37,38].

Therefore, the main objective of this study was to determine if there are differences in muscle activation patterns between female and male soccer players for better understanding and application. The following hypotheses were formulated: (1) the H:Q ratio will be different between male and female soccer players; (2) the vastus medialis (VM):vastus lateralis (VL) ratio will be different between male and female soccer players; and (3) there would be a different pattern of intra-hamstrings and intra-quadriceps muscle group coactivation between male and female soccer players.

2. Materials and Methods

2.1. Ethical Considerations

All athletes signed the informed consent form before the study. The study followed the guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of the Universidad Politécnica de Madrid (Spain).

2.2. Participants

Twenty-seven (19 male and 8 female) professional soccer players conducted the study. The male group was made up of players from the Atletico de Madrid youth soccer team. The team was composed of 24 players at the time of data collection, but 5 of them could not perform the test because they were injured and did not have the authorization of the medical staff. The female group was made up of players of the First and Second Spanish Soccer Divisions (Liga Iberdrola and Reto Iberbrola, respectively). All players had medical clearance to conduct the study and were completely healthy and uninjured at the time of data collection. The male soccer team completed the test in the 2015–2016 season. On the other hand, the data collection with female athletes was carried out in the 2018–2019 season. The players who participated in the study were both regular starters and substitutes. However, all players had the same training load, which was 5 days a week plus a regular league match. Both male and female football players had strength training throughout the season, although its frequency varied depending on the time of the season and physical condition to regulate their load control. Inclusion criteria were shown as follows: (1) having medical clearance to conduct the study; (2) not having suffered a musculoskeletal injury one year prior to the date of the protocol (i.e., checked through a previous exclusion questionnaire); (3) presenting neither any cardiovascular, musculoskeletal, and/or neurological disease nor previous ones that could affect participation in the study.

2.3. Study Design

A descriptive study was conducted in the sports biomechanics laboratory, where players had to perform two exercises while quadriceps and hamstring muscle activation was recorded.

Lunge: The starting position was one leg forward and the other leg backward. The knee and the hip were at 90 degrees, both in the front and back legs. The Lafayette Gollehon (Lafayette Instrument Company; Lafayette, IN, USA) goniometer was used in our study to determine degrees. Before starting the exercise, the starting position was established and the distance between each player's feet was measured and marked on the ground. From the starting position, the athletes had to bend the forward leg while keeping their backward leg straight at all times. It is important to note that in our study, we performed the lunge exercise, not the front lunge.

Bulgarian squat: The starting position was one leg forward and the other leg backward placed on a raised surface. As in the lunge exercise, the Lafayette Gollehon goniometer (Lafayette Instrument Company; Lafayette, IN, USA) was used to determine the 90 degrees of the knee and hip. From the initial position, the athletes had to bend the forward leg while keeping their backward leg straight at all times.

2.4. Procedure

The athletes, once they arrived at the laboratory, were measured and weighed only in their underwear. Later, always guided by the club's physical trainer, the players performed a warm-up consisting of a continuous run, followed by joint mobility and core work. The warm-up consisted of a continuous run for 7 min, followed by joint mobility exercises for

3 min and light dynamic stretching. To warm up the central area of the body, the players performed core planks (3 repetitions) for 30 s with 15 s breaks between each plank. After warming up, sEMG sensors were placed on both thighs, on the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST), and biceps femoris (BF). The areas where the sensors were going to be placed were shaved and cleaned with alcohol. The physical trainer was responsible for always placing the sensors on the athletes. For the placement of the sensors, the guidelines of the Seniam protocol were followed [39]. sEMG data were recorded using Trigno^{TM} Wireless System (Delsys, Inc., Boston, MA, USA). Data were captured at 1500 Hz.

The players had to repeat the exercise 5 times (Figure 1) with a rhythm of execution of each of the phases (descent, isometric, and ascent phase) of 2 s. The exercises were performed with an external load of 30% of each player's weight.

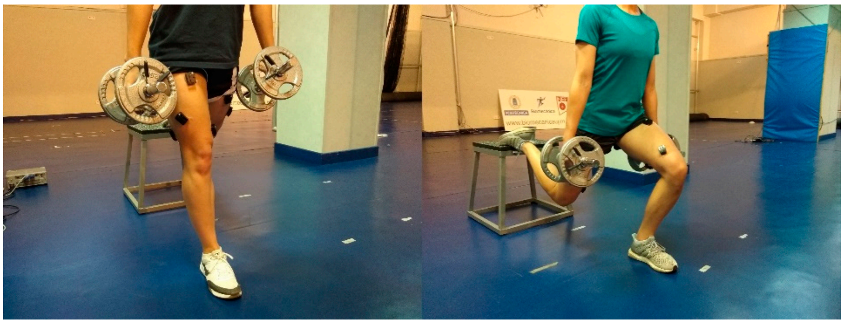

Figure 1. Starting position (**left**) and execution (**right**) of the Bulgarian squat exercise.

2.5. Data Processing

The processing of the data was carried out with EMGWORKS® software (Version 4, Delsys, Inc., Boston, MA, USA). Signal filtering was the first step in data processing using a 2nd-order bandpass Butterworth filter [40] with an attenuation of 40 dB and a cutoff frequency between 20 and 300 Hz [41]. A root mean square (RMS) [42] with a window width of 0.05 s and a window overlap of 0.025 s was later applied to the filtered signal, and the signal offset was removed.

2.6. Statistical Analysis

Dependent variables were calculated following the procedures based on the normalization without the maximum voluntary isometric contraction (MVIC) [32]. A total of seven dependent variables were compared between male and female soccer players in both exercises, H:Q and VM:VL ratios and intragroup muscular ratio. The H:Q ratio was calculated by dividing the mean activity (RMS) of the hamstring muscles by the mean activity of the quadriceps muscles measured in this study. The VM:VL ratio was calculated by dividing the mean activity (RMS) of the VM by the mean activity of the VL. The intragroup muscular pattern expressed the activation of each muscle with respect to the total surface activity of the muscle group. To calculate the intragroup pattern, the activation of each muscle (RMS) was normalized by dividing it by the total activity of the muscle group written as: $\%RF = RF/RF + VM + VL \times 100$. The muscle activity selected to calculate the ratio was the mean of the concentric, isometric, and eccentric phases of the 3 central repetitions, following procedures similar to other authors [33].

To compare the differences between the male and female soccer players in H:Q ratios, VM:VL ratios, and intramuscular activations in both exercises, *t*-tests for independent measures were performed for each variable.

The SPSS software 23.0 (Armonk, NY, USA: IBM Corp) was used to perform the statistical analyses. The significance level was set at 0.05, and effect sizes were determined using Cohen's D [43]. Microsoft Excel (Version 2019, Microsoft Corporation, Redmond, WA, USA) was used to calculate Cohen's D using the means and standard deviation of the samples.

3. Results

The male group was composed of 19 players (age = 19.2 ± 0.5 years, height = 179.7 ± 5.3 cm, weight = 71.0 ± 5.9 kg), and the female group had 8 players (age = 27.3 ± 6.5 years, height = 161.0 ± 0.6 cm, weight = 56.7 ± 4.9 kg). Differences were found between groups in age ($t_{25} = 5.55$; $p < 0.001$; d = 2.33), weight ($t_{25} = 6.02$; $p < 0.001$; d = 2.54), and height ($t_{25} = 9.84$; $p < 0.001$; d = 4.15).

The statistical analysis of the H:Q ratio showed no significant differences (Table 1) between the female and male soccer players in both the lunge and Bulgarian squat exercises ($p > 0.05$).

Table 1. Hamstring: quadriceps (H:Q) ratio (mean ± SD).

	Female Players		Male Players		Significance	Effect Size (d)
	Mean	SD	Mean	SD		
H:Q ratio in the lunge exercise	0.25	0.18	0.18	0.10	$p > 0.05$	-
H:Q ratio in the Bulgarian squat exercise	0.24	0.16	0.18	0.06	$p > 0.05$	-

Significant differences were found in the VM:VL ratio (Table 2) for both the lunge exercise ($t_{20} = 3.35$; $p = 0.001$; d = 1.42) and the Bulgarian squat ($t_{23} = 4.15$; $p < 0.001$; d = 1.76).

Table 2. VM:VL ratio (mean ± SD).

	Female Players		Male Players		Significance	Effect Size (d)
	Mean	SD	Mean	SD		
VM:VL ratio in the lunge exercise	1.12	0.36	2.64	1.88	$p = 0.001$	1.42
VM:VL ratio in the Bulgarian squat exercise	1.10	1.88	2.04	0.72	$p < 0.001$	1.76

For the intragroup muscular pattern in the lunge exercise (Figure 2), the female group showed higher activation for the VL muscle ($t_{23} = 4.1$; $p < 0.001$; d = 1.75) than the male group and lower muscle activation in the VM (Table 3) ($t_{23} = -3.8$; $p = 0.001$; d = 1.62) compared to the male group. No significant differences were found in the RF, BF, and ST muscles ($p > 0.05$). Similarly, in the Bulgarian squat exercise (Table 3 and Figure 3), the females also showed higher VL activation ($t_{23} = 3$; $p = 0.006$; d = 1.29) and lower muscle activation in the VM ($t_{23} = -3.9$; $p = 0.001$; d = 1.67). In the same way, no significant differences were found in the RF, BF, and ST muscles ($p > 0.05$).

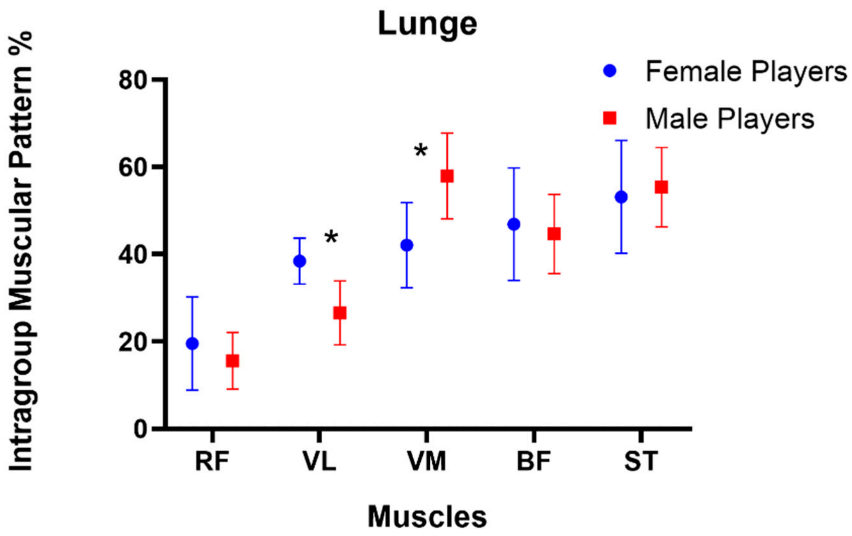

Figure 2. Intragroup muscular pattern (mean ± SD) in percentage. The intragroup muscular pattern expresses the activation of each muscle belly in relation to the total muscle (quadriceps and hamstrings). The asterisk (*) shows that there is a significant difference.

Table 3. Intragroup muscular pattern in percentage.

Exercise	Muscle	Female Players		Male Players		Significance	Effect Size (d)
		Mean (%)	SD (%)	Mean (%)	SD (%)		
Lunge	RF	19.52	10.69	15.54	6.47	$p > 0.05$	-
	VL	38.42	5.29	26.53	7.33	$p < 0.001$	1.75
	VM	42.07	9.75	57.93	9.82	$p = 0.001$	1.62
	BF	46.87	12.92	44.64	9.08	$p > 0.05$	-
	ST	53.13	12.92	55.36	9.08	$p > 0.05$	-
Bulgarian squat	RF	21.70	10.16	15.90	6.32	$p > 0.05$	-
	VL	36.99	5.57	28.87	6.57	$p = 0.006$	1.29
	VM	41.31	8.91	55.23	8.08	$p = 0.001$	1.67
	BF	49.92	1.57	44.64	9.08	$p > 0.05$	-
	ST	50.08	13.57	55.36	9.08	$p > 0.05$	-

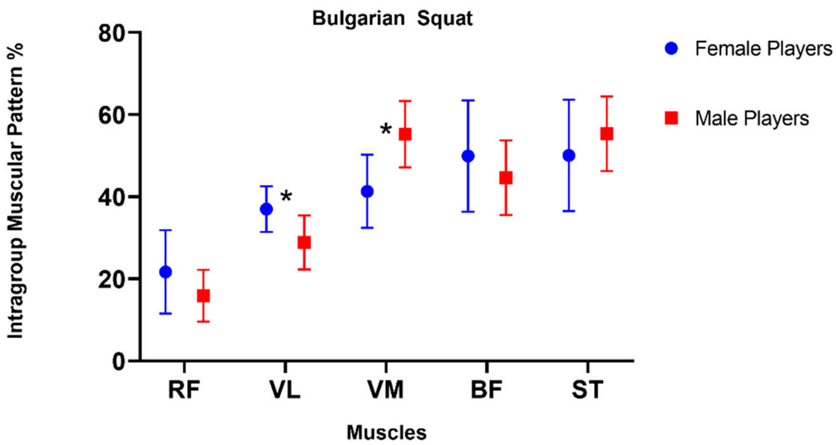

Figure 3. Intragroup muscular pattern (mean ± SD) in percentage. The intragroup muscular pattern expresses the activation of each muscle belly in relation to the total muscle (quadriceps and hamstrings). The asterisk (*) shows that there is a significant difference.

To calculate the intragroup pattern, the activation of each muscle (RMS) was normalized by dividing it by the total activity of the muscle group.

4. Discussion

In the present work, an analysis of the muscular activity in different exercises used in both prevention and rehabilitation was carried out with the aim of finding differences between the male and female professional soccer players. The main objective of this study was to determine if there were differences in muscle activation patterns between female and male soccer players for better understanding and application; however, no significant differences were found. Significant differences in the medial ratio (VM:VL ratio) between the two groups were found for the two exercises. Significant differences were found between both groups for VM and VL activations.

4.1. H:Q Ratio

The results showed no significant differences (Table 1) between the female and male soccer players' H:Q ratios in the lunge and Bulgarian squat exercises. This is perhaps due to the good training and prevention of this muscle in both sexes. Similar studies have been carried out with a team of only males and similar exercises [31]. They carried out the same exercises to professional players and obtained similar results to ours; in the case of those authors, the Bulgarian squat promoted a higher H:Q ratio. Navarro, Chorro, Torres, Navandar, Rueda and Veiga [31] used another type of signal normalization (MVIC) so a possible comparison of results must be done with caution. In our case, the ratios (lunge: female group 0.25; male group 0.18. Bulgarian squat: female group 0.24; male group: 0.18) were slightly lower than those reported by them. Authors, such as McCurdy, et al. [44], set the ideal H:Q ratio in sEMG at 1.67 (unnormalized results). Likewise and more specifically, they concluded that to consider a greater strength of the hamstring with respect to the quadriceps and its decompensation, in females, it should be equal to or greater than 0.71, where our players, neither males nor females, presented such a strength. More recent studies [45] determine the optimum H:Q ratio between 55% and 64% (0.55 and 0.64), and an alteration in the H:Q ratio when there is a difference equal to or greater than 10% between these muscle groups. However, Ruas, Pinto, Haff, Lima, Pinto and Brown [36] reported an H:Q ratio of 0.6 with a range of 0.45–0.59. The results in both studies were too high for our sample. Even so, Ruas, Pinto, Haff, Lima, Pinto and Brown [36] provided insufficient scientific evidence and standardization in this respect, and these ratios mentioned above are not reliable to be used since the methodology in the different studies varied considerably, leading to significantly different results. In addition to the controversy over the ideal H:Q ratio, there is also a controversy over the standardization of electromyographic data [46,47]. The most commonly used signal normalization method is the MVIC [48]. Some studies did not normalize [44] or did so by expressing themselves as a percentage contribution to the total electrical activity of all the muscles tested [30]. Other studies used the highest integrated EMG value among the concentric and eccentric contractions of all exercises, noting that the normalized peak EMG data follow a trend similar to the integrated data [49]. Other authors have used the total activity of each of the muscles (total activity of the quadriceps and the hamstrings) to normalize the signal from each muscular belly [30]. This type of normalization gives us information on how the total workload is distributed on the synergies that occur in the muscle. Another advantage is that this type of normalization can be used at any time during the season. In our case, we considered that not using MVIC has benefits when the sample is elite-professional or when there are injured players.

Studies, such as that of El-Ashker, et al. [50], with isokinetic and sEMG machines, concluded that the functional H:Q ratio was significantly lower in female groups compared to male groups, regardless of the velocity of momentum and the angle of the joint. [51] reported, in the analysis by gender, female soccer players produced lower peak torque H:Q ratios than males involved in the same sport at low speeds. However, at high speeds, there was no difference between the sexes. Different from most of the results presented so far by different authors, Kong and Burns [52] concluded that neither isometric nor isokinetic H:Q ratios differed between males and females, and they pointed out that other characteristics of the subject, such as age and training, may be more relevant.

On the other hand, Gobbi, et al. [53] compared the isokinetic strength between males and females operated on the ACL with two different surgical techniques (i.e., ST and gracilis tendons, or bone-patellar tendon-bone). The authors found that those females who obtained a goosefoot graft (i.e., ST and gracilis tendons) showed worse results in terms of isokinetic forces of knee flexors and extenders than males. No significant differences were found, when the patellar tendon was used as a graft. There are some results presented by various authors that differ from those of the present study; however, it is necessary to point out that the methodology used in all of them is through an isokinetic evaluation.

Electromyographical studies have demonstrated that females may have sex-related differences in the muscle onset time during athletic movement [21,54]. Furthermore, unbalanced medial-to-lateral muscle activations have been associated with increased knee valgus in the frontal plane [54].

4.2. VM:VL Ratio

Studies with female soccer players point out that disproportionate increases in activation of the VL may also result in a low quadriceps medial-to-lateral ratio and an increase in the anterior shear force and the load on the ACL [55]. Considering that the ideal VM:VL ratio is higher than one, our results (Table 2) showed a significantly better VM:VL ratio in male soccer players than in female soccer players. This suggests that the female in our study may be more predisposed to ACL injury.

Deficient motor control, meaning the distribution of electrical activity within the muscles between each of the muscular bellies and also the moment of activation, is problematic, because it affects the load carried by the joints [56]. The activation balance between the medial and lateral parts of the quadriceps is also very important to prevent patellofemoral pain syndrome (PFPS). The stability of the knee is maintained by the dynamic balance between the two muscles [57]. A greater predominance of one of the muscles means that the patella is not aligned and does not make a correct movement. Most problems in the patella arise, when the VM is unable to counteract the activation of the VL. In our case, on the basis of the results, females may be at greater risk of suffering PFPS than males in line with other authors [58]. Although a VM:VL ratio greater than one could be beneficial in reducing joint problems, most studies have reported values slightly below or slightly above one, in both females and males; however, the sample used had a very low sporting level [59,60].

4.3. Intragroup Muscular Pattern

The same intramuscular pattern was repeated in both the lunge and Bulgarian squat. The muscle with the highest weight within the total activation of the quadriceps was the VM, followed by the VL and finally the RF. Similarly, the pattern was repeated in the hamstrings for both exercises, with a higher percentage for ST than for BF. The results are in line with those obtained by other researchers for both the lunge [32,34] and the Bulgarian squat [30,31].

Activation patterns have been used in soccer as a tool in the process of recovery from an injury. One of the ways that were used was to compare the injured leg with the uninjured one, and it was established that when the differences were less than 10–15%, the subject had already recovered from the injury [61,62]. In addition, the activation pattern can be used after an injury as a way to quantify when the player has regained his initial form, so it is important that EMG tests are performed at different times during the season. This can be applied in the case of recurrent pain at the patellar tendon level, where the activation of the vast medialis is the main goal in the early stages of recovery [63].

Other studies have been carried out with female athletes having more analytical exercises, such as quadriceps extension. Those studies give percentages similar to ours (RF: 20–30%; VM: 40–50%; BF: 45–50%; ST: 50–60%), with the only difference being that the VL played a greater role in the total activation when compared to our results (VL: 40–45%) [42]. Other authors, however, point out that it is not correct to establish a relationship between electrical activity and force production in biarticular muscles [64,65]. In short, their results seem to indicate that there are normal activation patterns in the female soccer population. These intramuscular ratios allow both the knee joint and the hamstring muscles to develop their normal activity.

The results obtained for male players are in line with those obtained by other authors [30,34,65,66], with the activation in the order of the VM > VL > RF patterns. In the hamstrings, the ST was more active than the BF. When we compared the data of females and males, we observed that, although they had similar patterns, significant differences were found in the VM and the VL.

Differences in the activation of VM and VL may mainly affect the knee joint, as these muscles are intensively involved in its proper functioning. These differences in magnitude are related to the different compositions of muscle fibers between females and males and their physiological differences [56]. Evidence shows that females have a higher proportion of slow fibers than males [66], which could lead to a change in the activation pattern with a different electromyographic signal distribution than males. It could be expected that the differences between males and females would be greater than those obtained in the study. One of the explanations for these small differences could be that the exercises and loads proposed were of moderate intensity, and in these ranges of effort, no great differences were shown. The greater differences at higher intensity are due, among other things, to the proportion of fast fibers in males [56]. One of the biggest problems when trying to compare the EMG data between males and females is the type of signal normalization. Generally, the MVIC has been used for signal normalization; however, this type of normalization has some problems. The biggest one is its requirement, as it cannot be used with players who are recently injured or at critical times of the season (e.g., near an important match). Another problem is that females sometimes show higher percentages than males in this type of normalization, because the contribution to this specific slow fiber test is greater in females than in males, resulting in data that are difficult to compare between the sexes. That is why many authors are starting to use the same kind of signal normalization [30,32] as we have done in the present study.

The same differences between the male and female groups were observed in the Bulgarian squat exercise (Figure 3), with differences found in VM and VL. Differences in the activation patterns between VM and VL are important primarily to reduce the risk of knee injury. A change in both the activation pattern and the intensity of the quadriceps contraction could increase the stress supported by the ACL [67]. The greater weight in the total activation of the quadriceps by the VM could be good for the stabilization of the knee [67]. Therefore, in both lunge and Bulgarian squat, the patterns found are ideal in a rehabilitation work plan.

The results of our study are in line with other studies [68], although there are differences in the type of normalization and exercises, as most studies use highly analytical exercises, such as isometric tests or quadriceps extension.

In both males and females, the patterns were repeated in the hamstrings, with a greater weight in the total activation by the ST [31,32,69] The increased activation of the ST relative to that of the BF may help to reduce the stress of the latter and reduce its potential for injury, as most hamstring injuries are caused in the BF [70]. The increased activation of the ST may be due to the fact that in both the lunge and Bulgarian squat exercises, the ST is activated to reduce the external rotation of the tibia. In view of the results, both the Bulgarian squat and lunge can be good exercises to implement for both injury prevention and rehabilitation for injured players.

5. Conclusions

The sEMG H:Q ratios in the lunge and Bulgarian squat exercises between professional male and female soccer players did not show differences. However, we observed significant differences between sex in the medial ratio (VM:VL ratio). Moreover, regarding the intramuscular pattern, very consistent patterns have been found with differences in VM and VL between males and females. In this sense, the female group showed higher activation in the VL muscle and lower activation in the VM muscle than the male group, without significant differences in the RF, BF, and ST muscles. These patterns could be very useful in the recovery process from an injury to return players to their highest performance.

To generalize our conclusions, future research with a higher sample size, composed of high-level and recreationally trained athletes from different sport modalities and both sexes, is needed.

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