Original Article

Electromyographic activity of quadriceps and hamstrings of a professional football team during Bulgarian Squat and Lunge exercises

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ABSTRACT

The aim of this study was to analyse the quadriceps-hamstring coactivation in the lunge and Bulgarian squat exercises. A cross-sectional study design was applied to seventeen healthy professional football players. Muscular activity was measured using wireless surface electromyography (sEMG). The Maximum Voluntary Isometric Contraction was used to normalize the data. The muscle activation of each muscle belly was significantly different between the two exercises ($F_{4.24}$ = 28.076, $p < .001$, partial $\eta^2 = .72$). Activity in individual muscles varied in both the lunge ($F_{4,24}$ = 49.315, $p < .001$,partial $\eta^2 = .89$), and the Bulgarian squat ($F_{4,24}$ = 28,076, $p < .001$,partial $\eta^2 = .82$). The results showed no significant differences between the preferred and non-preferred legs of the participants ($p > .05$). In both the lunge and the Bulgarian squat, a significantly greater activation of the vastus medialis (VM) and the vastus lateralis (VL) muscles were found compared to the rectus femoris (RF) and biceps femoris (BF) and semitendinosus (ST). Muscles showed a greater activation during the Bulgarian squat compared to the lunge, but the hamstrings to quadriceps ratio was similar in both exercises ($p > .05$). The present work shows that the Bulgarian Squat exercise produces greater muscle activation than the Lunge exercise, whereas in both exercises there is a similar pattern of muscle activation. No differences were found between legs. If one wants to work specifically on strength development, the Bulgarian Squat would be a better option, as would be the case if one were to focus on synergistic work on the quadriceps and hamstrings, as the Bulgarian Squat exercise shows a higher H:Q ratio.
Keywords: Biomechanics; Therapeutic exercises; Hamstring strain injury.

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INTRODUCTION

Football performance is influenced by numerous factors, including strength (Gardasevic, Bjelica, Milasinovic, & Vasiljevic, 2016; Newman, Tarpenning, & Marino, 2004). Strength is not only important for performance, but also plays a fundamental role in injury prevention (Cameron, Adams, & Maher, 2003). Performance and injury prevention are not isolated fields, and the presence of an injury can influence on-field performance. The assessment of players' muscle capacity is an important factor in predicting the player's functional ability (Daneshjoo, Rahnama, Mokhtar, & Yusof, 2013).

Numerous epidemiological studies have been conducted in football estimating that hamstring strain injuries in football (HSIs) account for 10-12% of all injuries (Ekstrand, Waldén, & Hägglund, 2016; Hägglund, Waldén, & Ekstrand, 2013) indicating five to six injuries per team per season (Ekstrand et al., 2016). To date, the main reported risk factors for HSIs in football are (McCall et al., 2015; Navarro et al., 2015) having suffered a previous injury (Engebretsen, Myklebust, Holme, Engebretsen, & Bahr, 2010) muscular strength imbalance (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008; Fousekis, Tsepis, Poulmedis, Athanasopoulos, & Vagenas, 2011); neuromuscular alterations (Cameron et al., 2003) and fatigue (Greco, Silva, Camarda, & Denadai, 2013).

If one were to pay attention to the factor of muscular imbalance, most studies have used isokinetic machines to measure the relationship between hamstrings and quadriceps (Van Dyk et al., 2016). However, surface electromyography (sEMG) has recently been used as a tool to assess muscle activation between quadriceps and hamstrings (Caterisano et al., 2002; McCurdy et al., 2010). Such comparative studies have been carried out in youth football players as well (Wright, Ball, & Wood, 2009). sEMG allows the quantification of the activation not only of the entire muscle group, but also of each muscular belly, thus giving more information. Muscular asymmetry in football players could be offset with proper exercise prescription, which facilitates improvements in musculoskeletal function by addressing the specific needs of the subject as an integral part of any rehabilitative, preventive, or maintenance program (LaPrade et al., 2014). Other researchers have used sEMG to assess inter-limb differences (Mondal, Chhangte, & Guyan, 2014; Rouissi et al., 2016).

Muscular activity has been studied using sEMG in injured hamstring players and differences have been found with respect to uninjured players (Sole, Milosavljevic, Nicholson, & Sullivan, 2012). The researchers suggest that there are neuromuscular changes that affect the performance of players, such changes can be recorded and quantified in recovery processes (Sole, Milosavljevic, Nicholson, & Sullivan, 2011). Authors suggest that decreases in quadriceps and hamstrings muscle activity may influence the functioning of other surrounding muscles and that an increase in muscle activity may mean a reduction in the risk of injury (Schuermans, Danneels, Van Tiggelen, Palmans, & Witvrouw, 2017).

The heterogeneity of activation pattern of different exercises must be taken into consideration when developing hamstring strength (Bourne et al., 2017). Published prevention programs are composed of diverse tasks including bilateral open chain exercises as: Nordic Hamstring Curl (Shield & Bourne, 2018; Van der Horst, Smits, Petersen, Goedhart, & Backx, 2015),Yo-yo flywheel (Askling, Karlsson, & Thorstensson, 2003; Brukner, Nealon, Morgan, Burgess, & Dunn, 2014), leg curl (Bourne et al., 2017); bilateral closed chain exercises such as: hip flexion-extension (Brughelli & Cronin, 2008; Tsaklis et al., 2015) and unilateral closed chain exercises such as: forward lunge (Brukner et al., 2014), unilateral squat (Brughelli & Cronin, 2008). In rehabilitation, researchers also recommended exercises working on eccentric hamstring strength with great elongations at submaximal loads (Askling, Tengvar, & Thorstensson, 2013; Brukner, 2015; Brukner et al., 2014; Navandar, Veiga, Torres, Chorro, & Navarro, 2018).

The closed kinetic chain (CKC) exercise, which is defined as having the foot fixed against the ground, has been considered a good method to facilitate strengthening while minimizing the load on the ACL. The nature of CKC exercises allows for a lesser anterior displacement of the tibia, thereby reducing the impact on the knee (Beynnon et al., 1997). Unilateral exercises can be considered more functional for daily activities and more specific for the sport, such as in football (Santana, 2001). The lunge and the Bulgarian squat have been considered good therapeutic exercise for developing the hamstrings: quadriceps (H:Q) balance during anterior cruciate ligament rehabilitation (Harput, Soylu, Ertan, Ergun, & Mattacola, 2014; Mauntel, Frank, Begalle, Blackburn, & Padua, 2014), patellofemoral pain syndrome (Irish, Millward, Wride, Haas, & Shum, 2010) or lower extremity strengthening (Farrokhi et al., 2008). Although the activation of the hamstrings has been analysed in these exercises in relation with HSIs (Orishimo & McHugh, 2015; Tsaklis et al., 2015), the activation patterns for the quadriceps nor the hamstring: quadriceps coactivation were recorded in this sense.

Knowledge of the H:Q activation ratios may be important for injury prevention in rehabilitation and sports performance. It is important to know the activation ratios of H:Q for rehabilitation and sports performance. Exercises with higher H:Q activation ratios may be preferred during early rehabilitation after an injury (Santana, 2001). Previous studies have suggested that the H:Q strength ratio should be at least 0.6 to prevent injury to both the hamstrings and the knee (Holcomb, Rubley, Lee, & Guadagnoli, 2007), however this has been studied using isokinetic machines and not with sEMG.

Therefore, the main objective is to analyse quadriceps-hamstring coactivation in two prevention and rehabilitation exercises (the lunge and the Bulgarian squat). The hypotheses were: 1) the activation patterns differ across exercises. 2) The individual muscles will present relevant differences of activation; and 3) the muscle activation will differ bilaterally.

MATERIALS AND METHODS

Participants

The sample was composed of seventeen (18.3 – 24.1 years) healthy (no previous injury in the last six months) elite football players (age = 20.6 ± 1.5 years, weight = 69.3 ± 7.1 kg, height = 177.5 ± 5.1 cm) of the second division of the Spanish football league during the 2013-2014 season. All players belonged to the same football team. Informed consent was obtained from all participants in accordance with the code of ethics of the World Medical Association (Declaration of Helsinki); the study was approved by the Ethics Committee of the Technical University of Madrid (UPM). Weight and height were measured with the players barefoot in club attire. The inclusion criteria were to be contracted into the team at the time of data collection. The criteria for exclusion from the study were having an injury in the last six months, or not having the consent of medical services at the time of the test.

Procedures

Data were collected in the Sports Biomechanics Laboratory of the Faculty of Sports Sciences of the Technical University of Madrid (UPM) over four days. Testing was performed in the presence of the strength and conditioning coach of the club. Prior to testing, participants performed some warm-up exercises led by the club's strength and conditioning coach. Warm-up involved a seven-minute run followed by joint mobility exercises. Electromyographic activity was measured during Bulgarian squat and the lunge. The Bulgarian squat was performed with the participants getting into a lunge position with their rear foot elevated on a platform at a height of 50 cm and lowering their body by flexing their front knee with the trunk in an upright position. Participants performed the lunge by separating their feet such that one foot was in front of the other, and then they lowered themselves by bending the two knees without touching the ground and keeping their knees over the toes with the trunk in an upright position. Five repetitions were performed per exercise per leg and an external load of 30% of body weight. Players were accustomed to using these exercises and loads in training. For the external load two dumbbells were used. The first and last repetition was excluded from calculation of the mean. The exercises were paced such that the participants took two seconds on the way down, followed by sustaining the isometric position for two seconds and took two seconds on the way up. A five-minute rest was allowed between exercises. Quadriceps extension against manual resistance and hamstring curls were performed for five seconds to determine maximal voluntary isometric contraction (MVIC). MVIC data were subsequently used to normalize sEMG data and calculate ratios.

EMG activity was measured in five muscles, namely: *rectus femoris* (RF), *vastus medialis* (VM), *vastus lateralis* (VL), *biceps femoris* (BF) and *semitendinosus* (ST). Measurements were made using Trigno™ Wireless System (Delsys, Inc.® Massachusetts, U.S.A). This system is based on wireless sensors that allow subjects move freely. Data recording frequency was set at 1500 Hz. Sensors were placed following SENIAM protocol. Before sensors were positioned, the skin was shaved and cleaned with alcohol. An accelerometer was placed at the level of the first sacral vertebra, which served as a reference to identify the different phases of motion.

Data were processed using EMGWORKS® (Delsys, Inc. Massachusetts, U.S.A). First, signal filtering was performed by a 2nd-order bandpass Butterworth filter with a normalized cut-off frequency of 20 to 300 Hz and a stopband attenuation of 40 dB. Next, the root mean square (RMS) of the filtered signal was calculated with a window amplitude of 0.05 seconds and a window overlap of 0.025 seconds thereby eliminating signal offset. Mean RMS was calculated for each muscle from the start to the completion of the motion (as detected by the signal of the accelerometer) in the target exercises. Mean RMS was calculated for three seconds neglecting the first and the last second during MVIC exercises. Normalized MVIC activity (RMS%) was calculated by dividing the mean RMS of each exercise by the mean RMS of MVIC. RMS% was obtained for each muscle group by calculating the mean RMS% for each muscle (RF, VM, and VL of the quadriceps, and BF and ST of the hamstrings). The RMS% of hamstrings was divided by the RMS% of the quadriceps to calculate EMG H:Q ratios.

Statistical analysis

Comparation of dependent variables RMS% and the H:Q ratio due to the effects of individual muscles and muscle groups, exercise and legs (preferred versus non-preferred) of independent variables exercise, muscle, leg was carried out throughout three different ANOVAs where muscle and exercise was considered as intra-subject effects and legs as inter-subjects: exercise (2) x muscle (5) x leg (2), exercise (2) x muscle group (2) x leg (2) and exercise (2) x leg (2). The effect size of main effects was analysed using square eta with the threshold values for small, medium and large effects being .01, .06 and .14 respectively (Cohen, 1992). Two-way multiple comparisons were performed posteriori using Bonferroni's correction. All the statistical analyses were carried out on SPSS (v 20.0, IBM Technologies, USA). Statistical significance was set at .05.

RESULTS

Significant differences were found between the activation of each muscle belly in the two exercises ($p < .05$). Inside each exercise, the activity of each muscle belly was also different ($p < .05$).The leg effect on muscles groups (quadriceps and hamstring) and H:Q ratio were also not significant ($p > .05$). Therefore, for the successive comparisons the mean activation between the two legs was used as the dependent variable.

Effect of exercise

The muscular activation of individual muscles across the two exercises (Table 1) large differences were observed between them ($F_{4,24}$ = 28.076, p < .001, partial η^2 = .72). All muscles, except the RF, showed a significantly greater activation during the Bulgarian squat than during the lunge (Table 1). Comparing muscle groups, large differences were seen in both the quadriceps ($F_{1,27}$ = 22.0, p < .001, partial η^2 = .449) and the hamstrings ($F_{1,27}$ = 11.883, p < .001, partial η^2 = .398); however, the H:Q ratio was similar between exercises (p > .05), 0.43 ± 0.05 in Lunge and 0.50 ± 0.06 in the Bulgarian Squat exercise (Table 2).

Table 1. Mean, standard error, and 95% confidence interval (CI) of the RMS% of muscle activation of different muscles normalized to their Maximum Voluntary Isometric Contraction.

Exercise	Muscle	RMS%			
		Mean	Standard Error	CI	
Lunge	Rectus Femoris	23.02	3.03	16.80	29.25
	Vastus Medialis	81.04	8.17	64.28	97.81
	Vastus Lateralis	56.59	5.99	44.29	68.89
	Biceps Femoris	14.58	1.51	11.48	17.67
	Semitendinosus	23.22	1.97	19.18	27.26
Bulgarian Squat	Rectus Femoris	26.98	3.31	20.19	33.77
	Vastus Medialis	94.90	9.20	76.03	113.77
	Vastus Lateralis	68.57	7.04	54.13	83.01
	Biceps Femoris	21.00	2.09	16.70	25.29
	Semitendinosus	30.96	2.56	25.71	36.21

Table 2. Mean, standard error, and 95% confidence interval of RMS% of muscle activation, normalized to the Maximum Voluntary Isometric Contraction, in the quadriceps and hamstring muscle groups and Hamstring to Quadriceps (H:Q) ratio.

Exercise	Muscle Group	RMS%			
		Mean	Standard Error	Confidence Interval	
Lunge	Quadriceps	53.55	4.98	43.34	63.77
	Hamstrings	18.90	1.43	15.96	21.84
	H:Q ratio	0.43	0.05	0.33	0.54
Bulgarian Squat	Quadriceps	63.48	5.30	52.61	74.36
	Hamstrings	25.98	1.97	21.94	30.02
	H:Q ratio	0.50	0.06	0.37	0.62

Effect of muscle

Activity in individual muscles varied in both the lunge ($F_{4,24}$ = 49.315, p < .001,partial η^2 = .89), and the Bulgarian squat ($F_{4,24}$ = 28.076, p < .001,partial η^2 = .82). In the lunge (Table 1), activity in RF (23.03 ± 3.03%) was lower (p < .05) than in VM (81.04 ± 8.17%) and VL (56.59 ± 5.99%). There were no differences between RF and the hamstring muscles, BF (14.58 ± 1.51%) and ST (23.22 ± 1.97%). The electrical activity of VM and VL was significantly larger than the RF and the hamstring muscles (24.45%; p = .023). Interestingly BF had 8.64% lesser activation (p < .005) than the ST in lunge. The pattern of EMG activity of muscles during the Bulgarian squat exercise, was the same than that of lunge but the differences between VM and VL (26.33%) were not significant (p = .05).

When the activation of muscles was analysed joining the muscles in the quadriceps (RF + VM + VL) and the hamstrings (BF + ST) during lunge, quadriceps (53.55 ± 4.98%) activated significantly more than hamstring (18.90 ± 1.43%), leading to an H:Q ratio of 0.43 ± 0.05. In the Bulgarian Squat, the activation of quadriceps (RF + VM + VL) was 63.48 ± 5.30% and the hamstrings activation (BF + ST) was 25.98 ± 1.97% being this one a significant difference ($p < .05$), giving an H:Q ratio of 0.50 ± 0.06. (Table 2).

DISCUSSION

The purpose of this study was to examine hamstrings and quadriceps coactivation during two exercises commonly included in prevention and rehabilitation programs. Surface electromyography was used to measure the activation of quadriceps and hamstrings of Spanish league football players. Based on the results of our study, the Bulgarian Squat exercise would be the best option for strengthening the thigh muscles, as it activates the quadriceps and hamstrings more than the lunge. The Bulgarian Squat also causes a better working synergy between the anterior and posterior muscles, as it has a higher H:Q ratio than the lunge. The activity of each muscle belly was recorded in both the Bulgarian squat and lunge exercises. The MVIC was used to normalize the data. Based on these results, hypotheses 1 is partially confirmed since muscle activation is significantly different between the lunge and the Bulgarian Squat, except for the RF. Hypothesis 2 is confirmed, because muscle activation differs between muscles. However, hypothesis 3 is rejected, because no significant differences were found between legs.

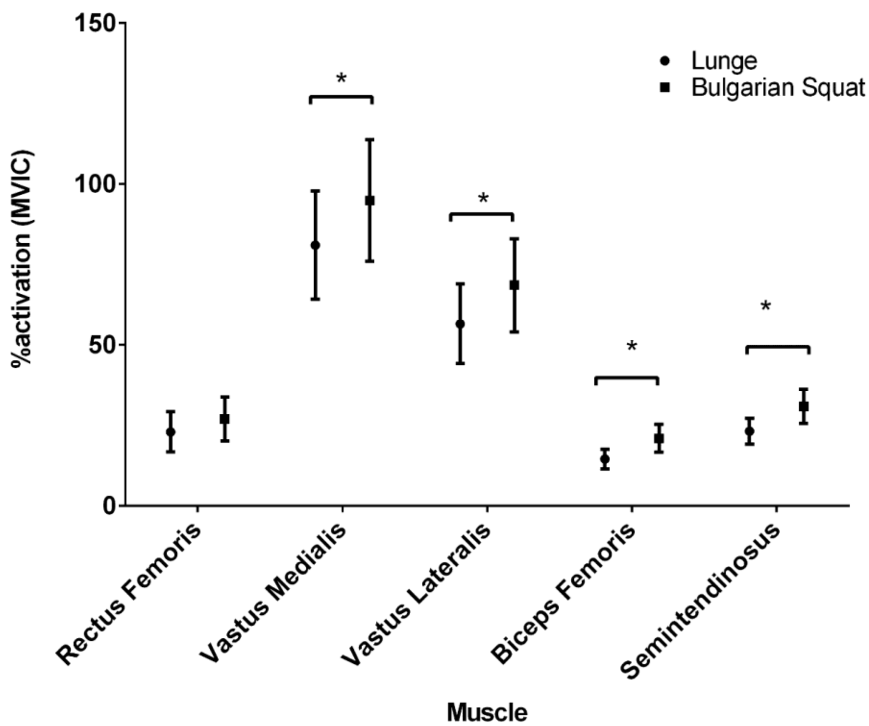

Figure 1. RMS % of muscle activation of different muscles normalized to their Maximum Voluntary Isometric Contraction.

All muscles but the RF showed greater activation in the Bulgarian Squat than in the Lunge (Figure 1). Muscle activation can be categorized according to its MVIC in 4 categories: low level (0-20% MVIC); moderate level (24-40% MVIC); High level (41-60% MVIC) and very high (> 60% MVIC) (DiGiovine, Jobe, Pink, and Perry

(1992); Krause et al. (2018)). Authors suggest that for optimal strength gain, muscles should be activated at 50% or more of their MVIC (Ayotte, Stetts, Keenan, & Greenway, 2007). The results of this study seem to indicate that the Bulgarian squat exercise is better for achieving strength gain, because for both the quadriceps and the hamstrings, they had a higher percentage of activation. However, in the case of the RF, no differences were obtained between exercises. This could be due to the fact that the RF work similarly to control the hip and the knee, a finding previously reported (Krause et al., 2018). Another important finding was that although the quadriceps were activated above 50% of their MVIC, the hamstring activation was below 30%. The lower activation of the posterior muscles could be explained by the fact that, theoretically, the hamstrings work eccentrically to control the hip in the descent phase (knee flexion). This can be confirmed by future studies comparing the muscle activation patterns in the different phases of the exercise.

Looking at muscle groups specifically, the muscle within the quadriceps with the greatest activity was the VM followed by the VL and the RF. In the hamstrings, the BF showed a significantly lower activation than the ST. The results were similar to those previously obtained for the lunge (Pincivero, Aldworth, Dickerson, Petry, & Shultz, 2000) and the Bulgarian squat (Caterisano et al., 2002; Schwanbeck, Chilibeck, & Binsted, 2009) in amateur athletes. However, it remains to be seen if these differences between individual muscles is seen in the different phases of the exercise. If this is true, this could indicate the presence of an activation patterns, and as a consequence similar synergies between muscles (Housh et al., 1995).

In the Lunge exercise, the activation of the VM (81.04%MVIC) was higher than the activation of the VL (56.59%MVIC) and RF (23.02%MVIC),these values being similar to previously reported values (VM: 63%, VL: 45.6%-55%, BF:11.9%) (Farrokhi et al., 2008; Irish et al., 2010). Specifically, in the case of the lunge, comparison with other studies should be done with caution, as muscle activity strongly depends on how the exercises are performed, the sample employed, and the load used. According to Farrokhi et al. (2008), EMG activity during forward lunge depends on the position of the trunk with respect to the vertical; when the trunk is flexed, hamstring activity increases. It is evident that the use of a load during lunge can substantially increase the activation of the muscle. Begalle, DiStefano, Blackburn, and Padua (2012) analysed a sample physically active mean and women volunteers obtaining that activity in the quadriceps (average VL and VM) during forward lunge was 128% of their MVIC, which largely exceeds the RMS% values obtained in this study. It is worth mentioning that values of quadriceps obtained were averaging the RMS% of VM, and VL and subjects performed a forward lunge, not a lunge where the main difference between both exercises is that in the lunge, both legs remain in contact with the ground at all times, the athlete starts from a position of extended hips and knees, followed by placing one leg forward and then flexing both knees, thus lowering the body. In the forward lunge exercise, the athlete starts from a position with the hips as wide as the shoulders, and from that position the athlete places one leg forward, and knee flexion begins once the front foot is supported on the ground, thus lowering the body.

The higher activation of the ST (23.22%) compared to the BF (14.58) could be because ST is activated to minimize the external rotation of the leg. Recently, Bourne et al. (2017) analysed the concentric and eccentric phases of a 12RM (12 Repetition Maximum) lunge finding that the BF and the ST were both activated to 20% of their MVIC approximately. Other researchers Tsaklis et al. (2015) analysing a set of hamstrings conditioning exercises obtained RMS% activations of BF and ST of 18% and 20% respectively during the eccentric phase of lunge with a non-reported load, a finding which is in accordance with the data of this study. Thus, the lunge and the forward lunge can be good choices for low intensity conditioning of hamstring (Brughelli & Cronin, 2008; Brukner et al., 2014).

The patterns of muscle activity during Bulgarian squat was similar to the lunge exercise. Aguilera-Castells et al. (2019) conducted a comparative study between different Bulgarian Squat, the researchers found activation values very similar to ours (RF = 32.72;BF = 24.50;VM = 64.58;VL = 72.34 %MVIC).

Youdas, Hollman, Hitchcock, Hoyme, and Johnsen (2007) used Bulgarian squat on a stable surface to compare the EMG% ratio between men and women; they reported that RMS% of RF and BF, were 20% and 25% of their MVIC, respectively on the stable surface. Although the results are like the ones of this research, it should be mentioned that the subjects of the study were amateur athletes, they did not bear any load, and activity was only recorded on the way up, i.e., during knee concentric phase. Begalle et al. (2012) reported an average RMS% for VM and VL of 113% during eccentric-concentric Bulgarian squat, which largely exceeds the RMS% obtained in this investigation However, the authors recorded RMS% for the hamstrings of 22%, which is consistent with the RMS% of this study thereby confirming the greater activity of the quadriceps as compared to the hamstrings during Bulgarian squat.

In summary, subjects working out a submaximal loaded Bulgarian squat, will tend to activate their quadriceps by more than a 50% of its MVIC, whereas hamstring activity will be close to 30% (Figure 2), which yields an H:Q EMG ratio of 0.5 approximately (Figure 2). However, players and coaches must be careful, as a predominance of quadriceps activation over hamstrings may lead to an injury to the knee due to a lack of equilibrium between the posterior and anterior muscles of the thigh (Beynnon et al., 1997). Such an imbalance is discouraged in the early stages of rehabilitation from a knee injury, specifically when open kinetic chain exercises are used (Beynnon et al., 1997).

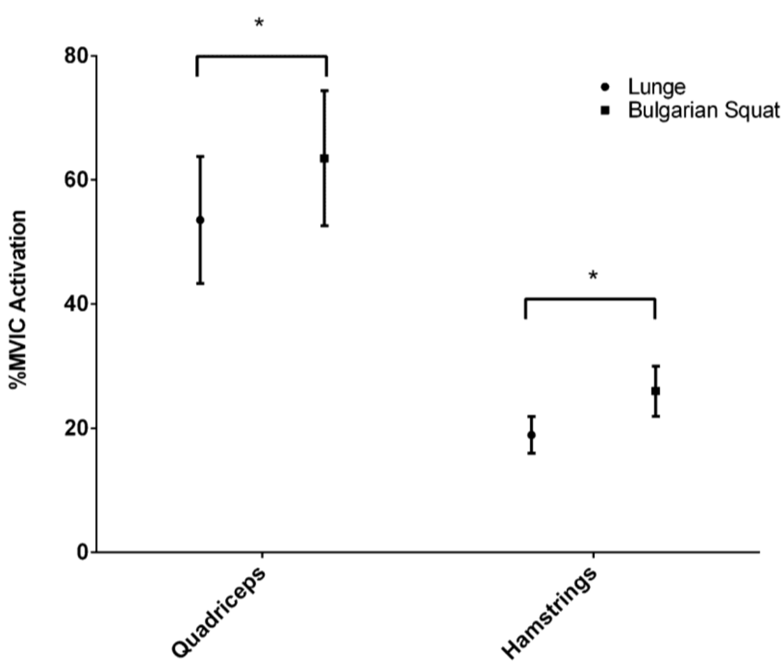

Figure 2. RMS% of muscle activation, normalized to the Maximum Voluntary Isometric Contraction, in the quadriceps and hamstring muscle groups.

H:Q ratios below 1 indicate that the predominant work in both exercises is done by the quadriceps. However, the ratio in the two exercises was higher than that reported by previous researchers (Begalle et al., 2012; Ekstrom, Donatelli, & Carp, 2007). This may be because higher external loads were used in this study and an increase in load could cause a greater increase in hip thrust than knee thrust (Riemann, Lapinski, Smith, & Davies, 2012). The coactivation shown in this study for both exercises is beneficial for ACL and hamstring rehabilitation (More et al., 1993), although based on the results, the Bulgarian Squat exercise would be the best option between the two analysed.

These results are in the same line as those reported by Dedinsky, Baker, Imbus, Bowman, and Murray (2017), showing that single leg exercises can be a good option to produce H:Q ratios. The increase in the H:Q time of the Bulgarian Squat exercise with respect to the Lunge is due to the increased activation of the hamstrings to a greater extent than the increased activation of the quadriceps muscles. Focusing on BF, the increased activation can be explained by the inclination of the trunk when performing the exercise. The increase in quadriceps activity in the Bulgarian Squat exercise compared to Lunge was 18.5%, while the increase in hamstrings was 37.5%.The much smaller quadriceps increase may be due to the fact that the quadriceps muscles are working close to their maximum and that the hip maintenance work could increase (hamstrings) more if the external load were increased. Therapeutic exercises reinforcing hamstring-quadriceps coactivation have been considered in rehabilitation for several musculoskeletal injuries. Unfortunately, authors analysing the EMG activity in relation with HSIs (Orishimo & McHugh, 2015; Tsaklis et al., 2015) in therapeutic exercises neither recorded the activation of quadriceps nor the H:Q coactivation. The activation pattern can be used after an injury as a way to quantify when the player has returned to his initial physical form, so it is very important that EMG tests are carried out at different times of the season (Begalle et al., 2012).

Bilateral muscle strength asymmetry is common in football players due to their tendency to kick the ball with their preferred leg (Navandar et al., 2018) being identified as a risk factor for HSIs (Croisier et al., 2008; Fousekis et al., 2011). Bilateral differences have been documented in rugby, Australian football (Opar et al., 2015), and football (Croisier et al., 2008; Fousekis et al., 2011) using isometric or isokinetic force measurement systems. Croisier et al. (2008) reported that 47% of 467 analysed players had some type of muscle imbalance using a tolerance of 15% of difference. Fousekis et al. (2011) in a similar study showed that 89% showed bilateral imbalance in isokinetic concentric and eccentric strength of the knee.

In line with our results, previous studies obtained similar results (Fousekis, Tsepis, & Vagenas, 2010) and the researchers concluded that the differences between legs decrease the more level the players have. The players in our study belonged to high level teams, many of the players in the team had debuted in Spanish first division, so the highly competitive level makes them have to dominate both legs equally. In addition, physical trainers pay a lot of attention to the work of equal strength between both legs.

CONCLUSION

Exercises commonly used for strength development and rehabilitation have been studied in this study. For both exercises, a pattern of activation of each muscle analysed (RF;VM;VL;BF;ST) is established consisting of both exercises (VM > VL > RF > ST > BF). This pattern could be used in injury recovery processes, so it is important to perform measurements throughout the season.

In terms of total activation for quadriceps and hamstrings, the Bulgarian Squat exercise has been shown to be better for both strength development and H:Q coactivation work, with better %MVIC and H:Q ratio values than the lunge exercise. The non-existence of differences between legs, reaffirms the idea that at a higher level of players, less differences exist between legs, and our sample were professional football players of the Spanish league so both legs work equally. Data found in this work, could be used as a reference for assessing

H:Q coactivation balance in football players, however, in the future, more research is needed using these procedures analysing the relationships between these data and the factor risks of hamstring strain injury.

AUTHOR CONTRIBUTIONS

All authors have contributed in a significant way to this work, however they have had specific responsibilities in the different task as follows: David Chorro and Gonzalo Torres (data collection, data processing and writing of the manuscript), Archit Navandar (determination of the variables, graphs and tables of the manuscript and writing of the manuscript), Javier Rueda (statistical treatment), Santiago Veiga (writing of the manuscript) and Enrique Navarro (project management and writing of the manuscript).

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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