ORIGINAL ARTICLE

Special and preventive exercises for hamstring muscles in the training process of experienced football players

Pavlo O. Sirenko[1,2ABCDE], Andrii H. Istomin[1ABCD], Romana R. Sirenko[3ABCD], Bohdan V. Khorkavyy[4ABCD], Ivan E. Rybchych[4CD]

[1]*Latvian Academy of Sports Education, Latvia*
[2]*Kharkiv National Medical University, Ukraine*
[3]*Ivan Franko Lviv National University, Ukraine*
[4]*Ivan Boberskyi Lviv State University of Physical Culture, Ukraine*

Authors' Contribution: A – Study design; B – Data collection; C – Statistic analysis; D – Manuscript preparation; E – Funds collection

Abstract

Background and Study Aim In-depth analysis of electrical activity of certain muscles in athletes contributes to improvement in the technique of physical actions. Hamstring muscles are an important factor for making physical actions by experienced football players. The purpose of the study consisted in substantiation for factors of optimization of physical capacity to work in experienced football players.

Material and Methods The study involved 20 experienced football players (n=20, aged 18-33, the period of going in for football ≥ 10 years). We used equipment of M-TEST computer electromyography device manufactured by research and development enterprise DX-Systems (Kharkiv, Ukraine). The maximum bioelectrical activity (MBA) of *m. biceps femoris, m. semitendinosus* and *m. semimembranosus*, which are hamstring muscles (HM), depending upon the angle of applied effort. The study was conducted with positions of the lower leg at angles of 180°, 165°, 145° and 125°. We used two-way analysis of variance and regression analysis. The fact that the distribution was normal was checked by Shapiro-Wilk W test.

Results Conditions for manifestation of the maximally effective realization of contractile abilities of HM were determined. Positions of the body and lower extremities for the largest overlaying of myofilaments in sarcomeres of HM were determined. Conditions of using external movement-disorganizing influence for HM were revealed. Models for special activity of experienced football players were systematized.

Conclusions HM will manifest their MBA in case of the coaxial position of the trunk and lower extremities. The angle of the lower leg position, equal to 180°, is the optimum one for the maximum overlaying of sarcomeres in the above muscles. Exercises with a component, which destabilizes the body position, are the most effective ones for realizing contractile abilities of HM.

Keywords: electromyography, hamstring muscles, special exercises, preventive exercises, football.

Introduction

The dynamics of team sports involve contraction of most muscles in the locomotor apparatus [1, 2].

These conditions necessitate development of effective preventive methods of training with integrated optimization of all its components [3, 4, 5]. One of these components is based on a thorough analysis of the essence of contractile abilities of the muscle with respect to the angle of applied effort [3]. Therefore, it is necessary to investigated diarticular hamstring muscles (HM) that flex the knee, extend the thigh and regulate the athlete's body movement forwards.

In jumps, preservation of the body position during a contact with an opponent or performance of technical element the high-priority task consists in maintaining the vertical body position [6, 7, 8]. The above elements mostly engage muscles of the back and hamstring ones, which create powerful extending pulls [3, 7, 9].

The contractile ability of HM is interrelated with a change in the position of adjacent joints [6]. Hence the question arises concerning their relationship with location of the lower extremity segments and trunk. It is necessary to study the ability to maintain an intended body position (posture) in the structure of performance of a certain technical element in optimum conditions for manifestation of force [10]. Maintenance of the constant posture is only an individual case of positional activity of muscles [10, 11]. Usually, in the process of specific activity of football players there is a change of their postures, transition from movement to some or another posture, each time engaging HM [12, 13]. Each such case places its demands on the initial position, conditions of a technical element [14]. It precedes the moment of posture fixation, maintenance (restoration) of the body balance [3, 15].

In team sports, a single technical element

doi:10.15561/26649837.2022.0501

can be regarded as a complete movement [16]. A systemic structural analysis makes it possible to isolate parts of a technique, its elements in time, which are called phases [1, 4]. The preparatory, basic (working) and final phases are separated with a proper redistribution of the emphasis of physical effect on a certain muscular area. The basic phase is aimed at solution of the movement task of the given technique [13, 14, 16]. During its final phase the football player tries to take up a stable initial position of balance. The latter is provided by isotonic muscular contraction required for further actions [3, 17, 18].

At present, detection of the position of the above segments becomes the element, which requires a thorough study. Gordon et al., Zatsiorsky and Verkhoshansky examined the relationship between the force and the muscle length. They noticed that it was the maximum one with a certain average length [10, 11, 19]. They simultaneously registered the sarcomere length, force of pull and overlaying of actin-myosin filaments. The largest overlaying of the above areas was accompanied by the maximum manifestation of force. A certain average length, with which contractile components of the muscle can manifest their maximum effort, is called the "length of rest" [10, 11].

It becomes an urgent problem in the professional sport to conduct studies for revealing localization of an effort on a certain muscle area or for generalized action on their group. Dependence upon the initial position (the initial angle and lever) of a movable segment is a significant component [3, 10]. As far as further researches are concerned, it becomes necessary to choose a set of special exercises for practical realization of results of this study and coordinate with the general structure for training qualified football players as special and preventive means [3, 13]. The above conditions for using special exercises will be essential in the structure of optimization of the level of technical fitness too.

The aim of study. Scientific-methodological substantiation of force factors for optimization of physical capacity to work in experienced football players by data of interference electromyography (IEMG) of HM. Development of sets of exercises, regulation of conditions for their use.

Materials and methods

Participants

The study involved 20 experienced football players (n=20, aged 18-33, the period of going in for football > 10 years). We received informed consent for participation in the experiment.

Research Design.

The study was aimed at detection of the optimum angle in the position of the lower leg for manifestation of MBA of HM in the exercise "knee flexion in prone position". Interference electromyography was used. The study was performed with help of an M-TEST computer electromyography device manufactured by research and development enterprise DX-Systems (Kharkiv, Ukraine) and intended for registration and analysis of electromyograms (EMG). Ag/AgCL Skintact Easitab RT34 electrodes, which have an adhesive base, were used.

Immediately before making our examination we conducted warming up on an ellipsoid stair stepper. It lasted 10 minutes with a gradual increase of loading from 30 to 120 W at a rate of 80 steps per minute. Then there was a rest for 5 minutes with doing exercises for development of flexibility.

We used electrodes with an arbitrary interelectrode distance. The fastening of the active electrode was provided in the muscle innervation area (over the belly of muscle), in the projection of the movement area. The reference electrode was in the proximal area of the tendon part.

The ground electrode was placed in the lower third part of the opposite lower leg and connected to the proper terminal on the electrode panel of the electromyograph.

The advance speed of the "chart" was 200 mm·s^{-1}. Amplification (displayed amplitude) of the signal was 5 mV·cm-1 with the current value of deviation rate equal to 40 ms·cm^{-1}. The current value of an increase of deviations was equal to 0.9 mV·cm^{-1}.

The angle in the position of a movable segment was determined on the basis of its previous measuring on a mechanical training machine and with help of photogoniometry.

In the process of our study we processed electromyograms during 5-second manifestation of the maximum effort followed by a rest for 1-1.5 minutes.

The task was performed with an ability to regulate the angle and the lever of counteraction (by changing the angle of knee flexion) alternately with the right and left legs. It was envisaged to perform the exercise with the position of the extended foot, the toe being in the plane parallel to the sagittal one. The study used angles of 180°, 165°, 145° and 125° (Fig. 1).

The initial position was regulated by design features of the training machine (thigh position at its flexion angle equal to 35°).

The coaxial location of the pelvic girdle segments and trunk with the vertical body position is caused by the content of a special component [3]. This condition can be modelled on the basis of special exercises. Two following blocks are envisaged.

Block 1: *the horizontal body position*. Its basic elements include rear lying, rear lying with forearm support and legs resting on an unstable structure (Fig. 2a). The element of swinging with the other extremity is regarded as an additional component, which disorganizes maintenance of the position. In these positions the basic element of physical effect consists in counteraction of the muscles, which keep the horizontal position of the body [14].

Block 2: *the vertical body position* with performance of a certain technical element in conditions of an external counteraction. It is mostly observed during frontal movement in the sagittal plane, performance of a swinging element or a counteraction from behind. *Standing on an unstable structure* (Fig. 2b) and *with an external counteraction* (Fig. 3a,b) (a rubber rope) provide for a generalized destabilizing effect on the support extremity.

The conditions for use of exercises standing on a hemisphere, in conditions of studied IEMG data on the basis of a set of exercises, developed by us, are as follows (Fig. 2b, Table 1).

Statistical analysis

Descriptive statistics, testing of the hypothesis

a) b)

Figure 1. Positions of the thigh at an angle of 35° and of the lower leg at an angle of 180° (a) and 145° (b).

a) b)

Figure 2. Fragments of a training session with special and preventive exercises for hamstring muscles by IEMG data (on a hemisphere).

a) b)

Figure 3. Fragments of a training session with special and preventive exercises for hamstring muscles by IEMG data (with an external counteraction).

Table 1. Special and preventive exercises in the position "standing on a hemisphere".

No.	Content	Duration	Rest	Organizational-methodological recommendations
1.	A jump onto a hemisphere on the left leg; return of a ball by air with the middle part of the bridge of the foot.	30''	1'	Alternate performance of the exercise with the right and left leg. Before the jump onto the hemisphere 2-3 quick steps in place are made. Landing onto the hemisphere necessitates flexion of the support leg towards the force of gravity with subsequent extension during performance of the technique. The foot of the flexed support leg is located on the surface of the training machine in its upper marginal area. Performance of the technique is followed with movement backwards at a slack pace.
1.1.	A jump onto a hemisphere on the right leg; return of a ball by air with the middle part of the bridge of the foot.	30''		
2.	A lateral jump onto a hemisphere on the left leg; return of a ball by air with the middle part of the bridge of the foot.	30''	1'	Alternate performance of the exercise with the right and left leg. Before the jump onto the hemisphere 2-3 quick steps in place are made. Landing onto the hemisphere necessitates flexion of the support leg towards the force of gravity with subsequent extension during performance of the technique. The foot of the flexed support leg is located on the surface of the training machine in its upper marginal area. Performance of the technique is followed with movement sideways at a slack pace.
2.1.	A lateral jump onto a hemisphere on the right leg; return of a ball by air with the middle part of the bridge of the foot.	30''		
3.	A jump onto a hemisphere on the left leg; return of a ball by air with the inner side of the right foot.	30''	1'	Alternate performance of the exercise with the right and left leg. Before the jump onto the hemisphere 2-3 quick steps in place are made. Landing onto the hemisphere necessitates flexion of the support leg towards the force of gravity with subsequent extension during performance of the technique. The foot of the flexed support leg is located on the surface of the training machine in its upper marginal area. Performance of the technique is followed with movement backwards at a slack pace.
3.1.	A jump onto a hemisphere on the right leg; return of a ball by air with the inner side of the left foot.	30''		
4.	A lateral jump onto a hemisphere on the left leg; return of a ball by air with the inner side of the right foot.	30''	1'	Alternate performance of the exercise with the right and left leg. Before the jump onto the hemisphere 2-3 quick steps in place are made. Landing onto the hemisphere necessitates flexion of the support leg towards the force of gravity with subsequent extension during performance of the technique. The foot of the flexed support leg is located on the surface of the training machine in its upper marginal area. Performance of the technique is followed with movement sideways at a slack pace.
4.1.	A lateral jump onto a hemisphere on the right leg; return of a ball by air with the inner side of the left foot.	30''		
5.	A jump onto a hemisphere on the left leg; return of a ball by air with the right thigh.	30''	1'	Alternate performance of the exercise with the right and left leg. Before the jump onto the hemisphere 2-3 quick steps in place are made. Landing onto the hemisphere necessitates flexion of the support leg towards the force of gravity with subsequent extension during performance of the technique. The foot of the flexed support leg is located on the surface of the training machine in its upper marginal area. Performance of the technique is followed with movement backwards at a slack pace.
5.1.	A jump onto a hemisphere on the right leg; return of a ball by air with the left thigh.	30''		
6.	A jump onto a hemisphere on the left leg; return of a ball by air with the right thigh.	30''	1'	Alternate performance of the exercise with the right and left leg. Before the jump onto the hemisphere 2-3 quick steps in place are made. Landing onto the hemisphere necessitates flexion of the support leg towards the force of gravity with subsequent extension during performance of the technique. The foot of the flexed support leg is located on the surface of the training machine in its upper marginal area. Performance of the technique is followed with movement sideways at a slack pace.
6.1.	A jump onto a hemisphere on the right leg; return of a ball by air with the left thigh.	30''		

about the kind of distribution, two-way analysis of variance and regression analysis aimed at finding of the optimum position for the extremities were used. The fact that the distribution was normal was checked by Shapiro-Wilk W test. This criterion is realized in some software programs, namely OriginPro, which was used at this stage of our study.

Results

Our analysis of IEMG of HM revealed a dependence of manifestations of muscle contraction upon the relationship between the hip and knee joints. When the angle of thigh flexion was 35°, the angle of MBA manifestation in HM was 145° (Fig. 2b). After a change in the angle of the thigh position by 35° the lower leg position also changed by 35 degrees for manifesting MBA. When the trunk and thigh were in the same plane, manifestation of MBA was with the lower leg angle of 180° .

In the exercise "knee flexion in prone position" we observed uniform distribution of bioelectrical activity on HM (Fig. 4).

A visually asymmetrical change in the amplitude of curves can be observed, when a flexed knee rotates outwardly or inwardly.

In compliance with the conclusion of two-way dispersion analysis we constructed a polynomial regression model of the third order. A smaller polynomial order produced a significant scatter of theoretical and experimental data (Fig. 5).

The regression equations gave us the optimum angles, which corresponded to the maximum values of the studied parameters.

The positions, studied by us, are those of the largest overlaying of actin-myosin filaments in a sarcomere with MBA. We assume that it is these positions that are positions of the "length of rest" for HM [10, 11].

We also determined redistribution of bioelectrical activity of HM in outward or inward

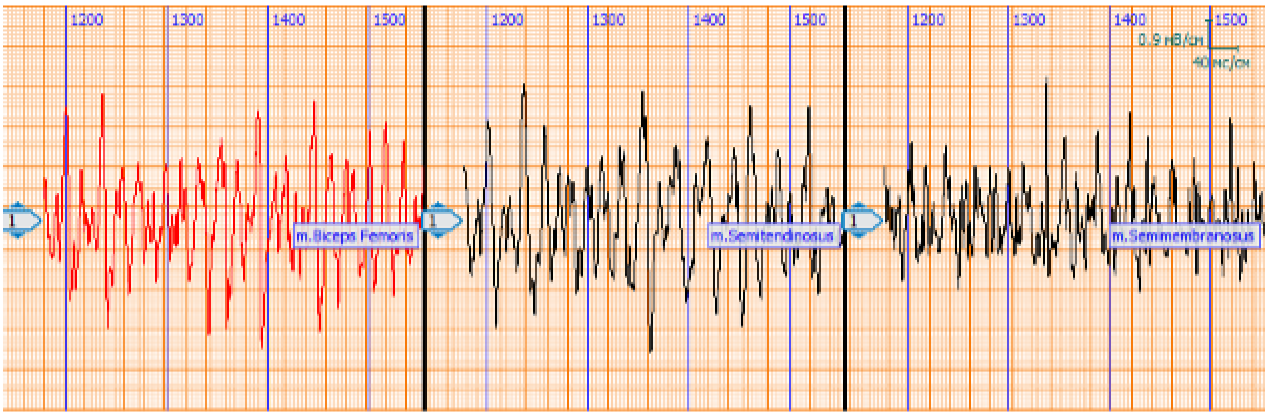

Figure 4. Fragment (IEMG) at knee flexion angle of 145°

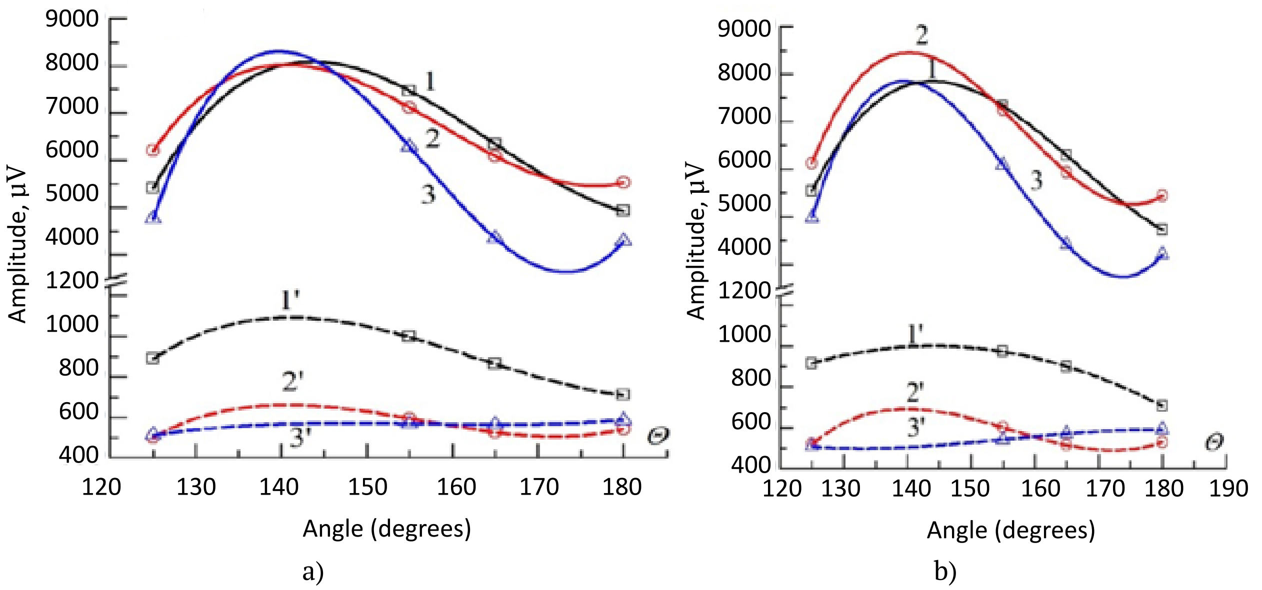

Figure 5. Regression dependence with experimental points of the maximum (continuous lines) and mean (dashed lines) amplitude of myograms for the right (a) and left extremity (b): 1, 1' – m. biceps femoris; 2, 2' – m. semitendinosus; 3, 3' – m. Semimebranosu;.vertical axis X (µV), horizontal axis Y (angle) [15]

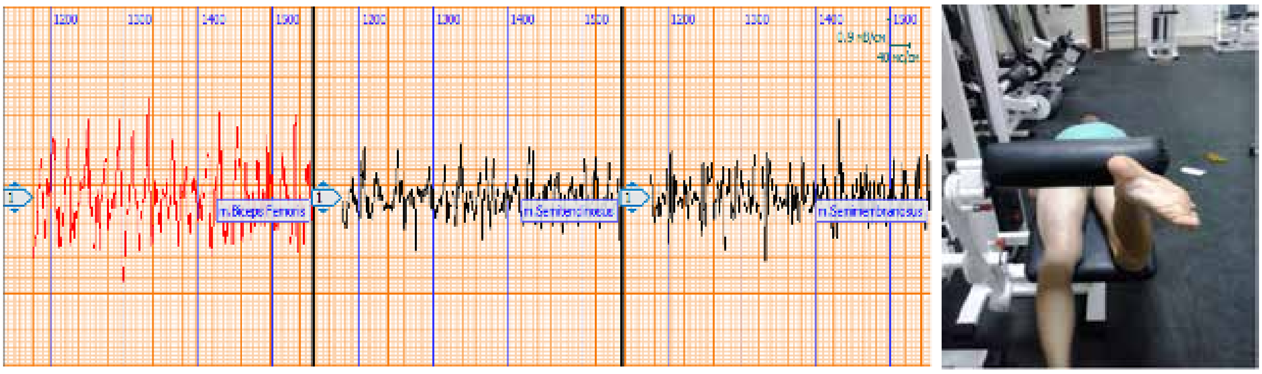

Figure 6. IEMG fragment at the flexion angle of 125° with external rotation of lower leg.

rotation of the knee. Supination increased contractile manifestations of *m. biceps femoris* with their similar decrease in *m. semitendinosus* and *m. semimebranosus* (Fig. 6). Pronation increased contractile manifestations of *m. semitendinosus* and *m. semimebranosus* with their similar decrease in *m. biceps femoris*.

Discussion

Performance of all specific movements is in direct relationship with spatial transfer of extremity segments. A well-defined biomechanical structure is envisaged in the organization of contraction of some or another muscle [8, 9, 20, 21, 22]. All specific movements, whose structure includes flexion-extension of segments of the lower extremities, provide for movement in the sagittal plane, abduction-adduction in the frontal plane or other ones parallel to them [3]. It is possible to isolate several basic movements used by football players during their training and competitive processes [3, 14, 17]. These movements are as follows: *knee flexion* (it engages HM and lower leg muscles during a frontal body movement in the sagittal plane), *thigh extension* (with a straight leg) as a basic element during a frontal movement, etc. [3]. We would like to note the preventive content of the set of exercises, suggested by us. Its structure provides position for the maximum realization of contractile abilities by the muscles in conditions, which resemble competitive activity. The use of unstable structures as an additional factor, which disorganizes the basic movement, will involve into contraction several areas of muscles [3, 8]. These are both basic muscles, which make counteraction, and small ones, which are responsible for "fine" regulation of the basic movement. Harmonious development of all muscle areas, engaged into a specific movement act contains more than only a preventive component [15]. Optimization of technical skills of qualified football players is a significant factor [1, 23, 24, 25].

Performance of technical elements such as a pass, a kick of a ball, a transfer with a sudden change of direction, etc., satisfies the limits determined by us. In case of our study the priority consisted in the choice of exercises, where HM could manifest their "positional activity" [11]. This fact confirms Zatsiorsky's theory about a change of strength abilities of the muscle in retraction and maximum extension of the motor area [11] with a complex combination in exercises with engagement of "deep layer" muscles, which will have preventive content [26].

These exercises are in the same plane of regulation and serve as a contextual continuation of FIFA Medical Assessment and Research Centre (F-MARC) "FIFA 11+" sets of exercises "Strength, coordination, balance" [27]. They were updated by us and today their structure unites several blocks of exercises with an asymmetric direction in different planes. The presence of an additional destabilizing component (a hemisphere, an unstable platform, etc.) is an important component. We suggest using the above sets of exercises during the basic period of training, general preparatory and special preparatory stages of the preparatory period and in the structure of the competitive period as an element of the preparatory part of training.

We would like to emphasize existence of direct relations between competitive activity components and dynamics of movement of lower extremity segments during use of special and preventive exercises [3]. The higher is the level of development of physical qualities, the more abilities for perfect mastering of the technique and its realization exist. The higher is the technique, the better physical and other qualities are realized [8, 9, 28, 29]. Our above revealed positions and movements of kinematic links correspond to the structure of competitive activity of professional football players and everyday human activity.

The movement of a kinematic link in the exercise "knee flexion in prone position" for HM was not systematized before from the position of contractile ability. Only muscle function with respect to the direction of movement was examined [3]. The scientific-methodological component of the aspect of load redistribution on the area, which contracts, was optimized.

Kendall et al. [6] examine the exercise for HM, studied by us, from the position of a diagnostic attempt, where the foot is in the plane parallel to the sagittal one.

The redistribution of bioelectrical activity of HM depending upon rotation of the lower leg, which we revealed, will optimize components for carrying out muscular-fascial testing. This will also make it possible to qualitatively regulate conditions of a local physical effect on the area of contraction in functional imbalance [30, 31].

Conclusions

The research results show the necessaty of the following:

- to use the revealed positions for manifestation of MBA of HM in the training process of experienced football players;
- to aim for symmetrical relationships of adjacent angles "thigh-trunk" and "lower leg-thigh" in special exercises with standing;
- to maintain the coaxial position of the lower extremities and trunk in special exercises "rear lying";
- to regulate load redistribution on HM with the inward or outward rotation of the knee;
- to use redistribution of contractile abilities of HM depending upon rotation of the knee in the block of muscular-fascial testing.

Prospects of further studies consist in conducting force-measuring studies in proper positions.

Redistribution of the contractile influence on HM depending upon rotation of the knee necessitates further studies.

Acknowledgements

The authors are grateful to football clubs Metalist (Kharkiv, Ukraine), Veres (Rivne, Ukraine) and Karpaty (Lviv, Ukraine) for support and cooperation.

Conflict of interests

The authors report about absence of any conflict of interests.

References

1. Kostiukevich VM. *Theoretical and methodological aspects of training qualified athletes.* Vinnitsa: Planer; 2007. (in Ukrainian).
2. Shamardin VM. *Technology of training of football team of the highest qualification.* Dnipropetrovsk: Innovation; 2012. (in Russian).
3. Sirenko PA. *Special and preventive exercises in professional football.* Kharkiv: New word; 2012. (in Russian).
4. Dulibskyy A, Khorkavyy B. The use of strength and coordination of football players. In: *Conference materials - VI Symposium. Contemporary technical thought in medical and biological sciences*. Wrocław; 2015. P. 29-30. (in Polish).
5. Häkkinen K, Newton RU, Walker S, Häkkinen A, Krapi S, Rekola R et al. Effects of Upper Body Eccentric versus Concentric Strength Training and Detraining on Maximal Force, Muscle Activation, Hypertrophy and Serum Hormones in Women. *Journal of Sports Science & Medicine,* 2022; 21(2): 200–213. https://doi.org/10.52082/jssm.2022.200
6. Kendall FP, McCreary EK, Provance PG. *Muscle Testing and Function.* 4th Edition, Lippincott. Philadelphia: Williams and Wilkins; 1993.
7. Sak AE. Anatomical and biomechanical basis vertical position of the body and sport. *Slobozhansky Scientific and Sport Bulletin,* 2013;4:65–67. (in Ukrainian).
8. Sirenko P, Korolinska S, Sirenko Y. Features interference EMG leg extensor muscles of skilled players in the context of the special exercises. *Pedagogics, Psychology, Medical-Biological Problems of Physical Training and Sports,* 2013;17(7):70–6. (in Ukrainian).
9. Sirenko P, Korolinska S, Sirenko Y. Features interference electromyogram rectus femoris for skilled players in the context of special exercises. *Pedagogics, Psychology, Medical-Biological Problems of Physical Training and Sports,* 2013;17(8):92–8. (in Ukrainian).
10. Verkhoshansky YuV. *Basics of the special physical training of sportsmen*. Moscow: Physical Culture and Sports; 1988. (in Russian).
11. Zatsiorsky VM, Arunin AS, Seluyanov VN. *Biomechanics of human musculoskeletal system*. Moscow: Physical Culture and Sports; 1981. (in Russian).
12. Bergstrom HC, Dinyer TK, Succi PJ, Voskuil CC, Housh TJ. Applications of the Critical Power Model to Dynamic Constant External Resistance Exercise: A Brief Review of the Critical Load Test. *Sports*. 2021; 9(2): 15. https://doi.org/10.3390/sports9020015
13. Garrett J, Graham SR, Eston RG, Burgess DJ, Garrett LJ, Jakeman J et al. A Novel Method of Assessment for Monitoring Neuromuscular Fatigue in Australian Rules Football Players. *International Journal of Sports Physiology and Performance*. 2019; 14(5): 598–605. https://doi.org/10.1123/ijspp.2018-0253
14. Khorkavyy B, Oherchuk O, Kolobych O. Peculiarities of the development of physical qualities of young football players with the help of non-specific and specific means. *Sports Science of Ukraine*, 2017;2(78):45-53. (in Ukrainian).
15. Sirenko PO. *Innovative technologies of skilled football players.* [PhD thesis]. Lviv; 2015. (in Ukranian).
16. Brennecke A, Guimarães TM, Leone R, Cadarci M, Mochizuki L, Simão R, et al. Neuromuscular Activity During Bench Press Exercise Performed With and Without the Preexhaustion Method. *Journal of Strength and Conditioning Research,* 2009; 23 (7): 1933–1940. https://doi.org/10.1519/JSC.0b013e3181b73b8f

17. Khorkavyy B, Gargula L. *Modern Football Theory and Practice. Contemporary Concepts of Training Young Footballers*. Opole; 2016. (in Polish).
18. Kamali AM, Saadi ZK, Yahyavi SS, Zarifkar A, Aligholi H, Nami M. *Transcranial direct current stimulation to enhance athletic performance outcome in experienced bodybuilders*. *PLOS ONE,* 2019; 14(8): e0220363. https://doi.org/10.1371/journal.pone.0220363
19. Gordon AM, Huxley AF, Julian FJ. The variation in isometric tension with sarcomere length in vertebrate muscle fibres. *The Journal of Physiology*. 1966;184(1): 170–192. https://doi.org/10.1113/jphysiol.1966.sp007909
20. Luca de C J. The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics,* 1997; 13:135–163. https://doi.org/10.1123/jab.13.2.135
21. Liu Y, Kong J, Wang X, Shan G. Biomechanical analysis of Yang's spear turning-stab technique in Chinese martial arts. *Physical Activity Review,* 2020;8(2):16–22. https://doi.org/10.16926/par.2020.08.17
22. Matúš I, Kandráč R. Kinematic analysis of the kick start from OSB12. *Physical Activity Review,* 2020;8(2): 86–96. https://doi.org/10.16926/par.2020.08.25
23. Çilli M, Yasar M, Çakir O. Electromyographic responses to Nordic curl and prone leg curl exercises in football players. *Physical Education of Students,* 2021;25(5):288–9. https://doi.org/10.15561/20755279.2021.0505
24. Kukrić A, Joksimović M, Petrović B, Latino F, Pavlović R, Kuvalja R. Ratio of maximum hamstring torque to maximum quadriceps torque in professional basketball and soccer players. *Health, Sport, Rehabilitation*, 2021;7(4): 8–18. https://doi.org/10.34142/HSR.2021.07.04.01
25. Aktaş S, Çakmakçı O. Examination of lower-upper limb of power and force parameters of elite athletes. *Physical Education of Students,* 2020;24(6):340–7. https://doi.org/10.15561/20755279.2020.0606
26. Rodríguez-Ridao D, Antequera-Vique JA, Martín-Fuentes I, Muyor JM. Effect of Five Bench Inclinations on the Electromyographic Activity of the Pectoralis Major, Anterior Deltoid and Triceps Brachii during the Bench Press Exercise. *International Journal of Environmental Research and Public Health,* 2020; 17(19): 7339. https://doi.org/10.3390/ijerph17197339
27. Bizzini M, Junge A, Dvorak J. *The "11+" Manual. A complete warm-up programme to prevent injuries.* FIFA Medical Assessment and Research Centre (F-MARC Football for health); 2007.
28. Kalinowski P, Jerszyński D, Nowakowska M. Level of speed abilities of young football players in various training periods. *Health, Sport, Rehabilitation*, 2021;7(2):57–64. https://doi.org/10.34142/HSR.2021.07.02.05
29. Bayrakdar A, Kılınç BH. The effect of functional movement screen and lower extremity training on hamstring/quadriceps ratio in football players. *Physical Education of Students,* 2020;24(2):80–5. https://doi.org/10.15561/20755279.2020.0202
30. Herold JL, Sommer A. A model-based estimation of critical torques reduces the experimental effort compared to conventional testing. *European Journal of Applied Physiology,* 2020; 120(6): 1263–1276. https://doi.org/10.1007/s00421-020-04358-w
31. Krzysztofik M, Trybulski R, Trąbka B, Perenc D, Łuszcz K, Zajac A et al. The impact of resistance exercise range of motion on the magnitude of upper-body post-activation performance enhancement. *BMC Sports Science, Medicine and Rehabilitation,* 2022; 14(1): 123. https://doi.org/10.1186/s13102-022-00519-w

Information about the authors:

Pavlo O. Sirenko; (Corresponding Author); PhD of Physical Training and Sport (Olympic and Professional Sport); http://orcid.org/0000-0002-2787-6497; pavlo.sirenko@gmail.com; Latvian Academy of Sport Education; Riga, Latvia.

Andrii H. Istomin; Doctor of Medical Science, Professor, Head of the Department of Sports, Physical and Rehabilitative Medicine, Physical Therapy, Ergotherapy; http://orcid.org/0000-0002-1510-6516; andrii.istomin@gmail.com; Kharkiv National Medical University; Kharkiv, Ukraine.

Romana R. Sirenko; Doctor of Public Administration Science, Professor, Head of the Department of Physical Education and Sports; http://orcid.org/0000-0001-9100-4709; romanaua@gmail.com; Ivan Franko Lviv National University; Lviv, Ukraine.

Bohdan V. Khorkavyy; Assistant Professor Department of Football; Boberskyj; https://orcid.org/0000-0003-4679-0047; b.khorkavyy@gmail.com; Ivan Boberskyj Lviv State University of Physical Culture; Lviv. Ukraine.

Ivan E. Rybchych; PhD of Public Administration Science, Associate Professor of the Department of Sport Medicine, Human Health; http://orcid.org/0000-0002-4578-4705; ribchich@gmail.com; Ivan Boberskyj Lviv State University of Physical Culture; Lviv, Ukraine.

Cite this article as:

Sirenko PO, Istomin AH, Sirenko RR, Khorkavyy BV, Rybchych IE. Special and preventive exercises for hamstring muscles in the training process of experienced football players. *Pedagogy of Physical Culture and Sports,* 2022;26(5):344–352.
https://doi.org/10.15561/26649837.2022.0509

Received: 20.09.2022
Accepted: 21.10.2022; Published: 30.10.2022