

10-1-2021

Comparing effects of Nordic hamstring exercise in combination with electrical stimulation and in combination with the FIFA 11+ program on footballers with strained hamstring muscles

Amornrat Kaewsri

Onuma Boonyarom

Kanokwan Srisupornkornkool

Follow this and additional works at: <https://digital.car.chula.ac.th/clmjjournal>



Part of the [Medicine and Health Sciences Commons](#)

Recommended Citation

Kaewsri, Amornrat; Boonyarom, Onuma; and Srisupornkornkool, Kanokwan (2021) "Comparing effects of Nordic hamstring exercise in combination with electrical stimulation and in combination with the FIFA 11+ program on footballers with strained hamstring muscles," *Chulalongkorn Medical Journal*: Vol. 65: Iss. 4, Article 5.

DOI: 10.14456/clmj.2021.50

Available at: <https://digital.car.chula.ac.th/clmjjournal/vol65/iss4/5>

This Article is brought to you for free and open access by the Chulalongkorn Journal Online (CUJO) at Chula Digital Collections. It has been accepted for inclusion in Chulalongkorn Medical Journal by an authorized editor of Chula Digital Collections. For more information, please contact ChulaDC@car.chula.ac.th.

Original article

Comparing effects of Nordic hamstring exercise in combination with electrical stimulation and in combination with the FIFA 11+ program on footballers with strained hamstring muscles

Amornrat Kaewsri^a, Onuma Boonyarom^{a,*}, Kanokwan Srisupornkornkool^b

^aDepartment of Rehabilitation and Movement Sciences, Faculty of Sports Science, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand

^bDepartment of Physical Therapy, Faculty of Allied Health Science, Naresuan University Phitsanulok 65000, Thailand

Background: Football is a popular sport with many subjects. Hamstring muscle strain injury is one of the most common injuries. This type of injury occurs at a high rate and has a high re-injury rate, which results in a loss of training and competition time. However, an efficient prevention and rehabilitation program could help to reduce the impact of injuries on football athletes.

Objectives: This study aimed to investigate and compare the effects of Nordic hamstring exercise in combination with electrical stimulation and in combination with the Federation International de Football Association 11+ program on football athletes with hamstring muscle strain.

Methods: Sixteen footballers from Kasetsart University's Kamphaengsaen campus, aged 18 - 25 years old (mean age = 19.9 ± 1.5 years old), participated in the study. Through random sampling, the subjects were assigned to a group involving Nordic hamstring exercise combined with either electrical stimulation or FIFA 11+.

Results: The results showed that, after 6 weeks of training, both groups showed improvements in the strength of strained hamstring muscles (Nordic hamstring exercise with electrical stimulation was 9.8 ± 2.4 kg before training and 17.7 ± 2.0 kg on week 6; Nordic hamstring exercise with FIFA 11+ was 9.8 ± 2.8 kg before training and 15.8 ± 2.3 kg on week 6), but there was no significant difference between the 2 groups.

Conclusion: This study concluded that the training program used for either group could increase the strength of strained hamstring muscles.

Keywords: Electrical stimulation, FIFA 11+, Nordic hamstring exercise, strained hamstring muscles.

Football is the most popular sport of all time; however, the rates of participation and injury are quite high.⁽¹⁾ At the slow step forward before the late swing phase in running, the hamstring performs eccentric contraction. At this point, hamstring muscle strain can occur if the muscle strength is low. The incidence rate is 39.5%^(2,3) with a 48.0% possibility of re-injury that affects training and competition. However, an efficient preventive and rehabilitation program could

help to minimize possible injuries from football by up to 39.0%.⁽⁴⁻⁶⁾

Injury prevention and rehabilitation can be achieved by strengthening hamstrings via exercise or electrical stimulation (ES). Regarding exercise, eccentric contraction is more effective for strengthening hamstrings than isometric contraction or concentric contraction.⁽⁷⁾ An ES (faradic current) is a physical therapy treatment modality used to produce muscle contractions.^(4,8)

A group of scientists from Oslo Sports Trauma Research Centre (OSTRC) identified Nordic (or Russian) hamstring exercise as the eccentric contraction exercise that most efficiently prevents injury from hamstring strain^(9,10) within 10 weeks of training.⁽¹¹⁾ Nordic hamstring exercise not only allows

*Correspondence to: Onuma Boonyarom, Department of Rehabilitation and Movement Sciences, Faculty of Sports Science, Kasetsart University, Nakhon Pathom 73140, Thailand. E-mail: fssomb@ku.ac.th

Received: July 30, 2020

Revised: August 13, 2020

Accepted: September 5, 2020

muscle contraction that is similar to the posture that causes the injury but also increases strength by up to 51.0% and torque for muscle contraction by up to 7.0%. Importantly, it can be applied to healthy athletes or those with hamstring muscle strain problems; however, results might not be obvious to those who have sustained an acute injury.^(4, 8, 12)

In 2003, (FIFA) and the FIFA Medical Assessment and Research Center (F-MARC) added Nordic hamstring exercise into the FIFA '11',⁽¹³⁻¹⁵⁾ an injury-prevention program, which was further developed and later had its name changed to the FIFA '11+' in 2006.⁽¹⁶⁾ The FIFA 11+ is a 10 - 15 minutes exercise program that aims to prevent injury to the lower body, especially hamstring muscle, and help reduce injury rate of football players by up to 95.0%. Moreover, it activates muscular functions, increases muscular contraction force, increases muscular strength^(16, 17) in performing regular contractions, and initiates the functions of main and stabilized muscles, as well as improving the strength of gross motor skills for multi-directional movement.⁽⁷⁾

Neuromuscular Electrical Stimulation (NMES) is a method used to strengthen muscles in patients who have physical therapy coupled with training to reinforce muscles. ES causes more muscle contraction and increases strength 40.0% higher than normal training. It increases muscle contraction by 30.0%, and improves muscular efficiency, and activates muscular functions for contraction under voluntary control, similar to that during exercise.^(18 - 20) Eccentric contraction coupled with ES strengthens muscles more effectively than either ES⁽²¹⁾ or exercise⁽²²⁾ alone.

Previous studies have shown that Nordic walking exercise efficiently prevented injuries. However, muscle contraction during exercise would be inefficient if there was muscle injury. Therefore, the researcher would like to study Nordic exercise in combination with ES, as it produced the injury muscle contraction than the normal muscle contraction in order to strengthen muscles. Moreover, the researcher would like to examine Nordic exercise in combination with FIFA 11+, as Nordic hamstring exercise is the eccentric contraction that improves strength more than other contraction patterns.⁽⁷⁾ However, in the case of an injured muscle, contractions would not be efficient. In contrast, FIFA 11+ is the isometric and concentric contraction, so both techniques could strengthen and activate muscles that could not perform eccentric contraction.⁽⁷⁾ In addition, FIFA 11+

maximizes the increase in muscle contraction force and strengthens muscles in both legs.^(16, 17) For these reasons, the researcher would like to study Nordic hamstring exercise in combination with ES and in combination with FIFA 11+ in footballers with hamstring muscle strain.

Materials and methods

Subjects

The sample group consisted of 16 male footballers aged 18 - 25 years old from Kasetsart University, Kamphaengsaen Campus, who trained 3 - 5 days per week and had sustained hamstring injuries during the past 6 months. The sample size was determined based on a previous study.⁽²⁾ The sample group did not include individuals with hamstring pain (pain scale = 0), which was measured with a numeric rating scale, and individuals were able to do regular exercise and had never been trained in eccentric contraction training or ES. They were divided into 2 groups, namely: group 1 performed the Nordic hamstring exercise in combination with ES (NH+NMES, 8 players) and group 2 performed the Nordic hamstring exercise in combination with FIFA 11+ (NH+FIFA 11+, 8 players).⁽²⁾ All of them were interviewed to confirm the following criteria, and also signed a consent form for their participation.

Inclusion criteria:

1. Having no congenital disease related to heart, vessels and metabolic system.^(23, 24)
2. Having never participated in hamstring eccentric contraction training.⁽²⁵⁾
3. Having experienced hamstring muscle strain pain within the past 6 months.⁽²³⁾
4. Having sustained no anterior cruciate ligament injury within the past 6 months.^(24, 26)
5. Having a normal body mass index (BMI = 18.5 - 24.9 kg/m²).

Exclusion criteria:

1. Having sustained injury at bones and hamstring muscles while participating in the program.
2. Having sustained an injury of the nervous system, muscular system or fascia at the hip or leg within the past 6 months.⁽²⁷⁾
3. Having experience more pain during hamstring isometric contraction test.⁽³⁾
4. Having processes other additional treatments concurrently.

5. Having sustained re-injury of hamstrings muscle strain during training.
6. Having been disqualified from being an athlete during the research period.
7. Having participated in the training program < 9 times.

Data collection

Hamstrings muscle strength evaluation

The isometric muscle strength of hamstrings was measured using a wireless muscle strength tester (Tracker™ version 5, JTECH Medical Industries, Inc., USA). The intratester reliability was tested and found to be of a high level (ICC = 0.99).

Each member of the sample group lied flat on their stomach on a bed with their knees straight and proceeded to bend their knees 90° with resistance to create the highest level of muscle contraction. They held this posture for 5 seconds and stretched, then took a break for 10 seconds before starting the second round. The contraction value (in kg) was recorded using Tracker™ version 5 and the best value was selected in order to divide the sample group into 2 groups, each consisting of 8 players ranking from the highest to lowest value, and lots were drawn for group 1 (NH+NMES) and group 2 (NH+FIFA 11+). A test of normality was then conducted to assess indifference between 2 groups.

Both groups were trained twice a week (on Monday and Thursday) for 6 weeks^(21, 28, 29) (12 times in total). All players signed a consent form before training and had their muscle strength evaluated in week 6.

Potential errors were controlled for. The researcher, who is a licensed therapist, was the trainer

of both Nordic hamstring exercise groups (ES and FIFA 11+).

Training programs

Group 1 (NH+NMES)

Nordic hamstring exercise

The sample group sat on their heels while crossing their arms before lifting the hip to change posture and sit on their knees with their feet flat on the floor. The angle of the knees and hip was 90°. The helper held both ankles to prevent movement. Then, they slowly contracted their muscles and bent over to the front, 60° to the floor, within 3 - 5 seconds, then remained in a flat posture. They took a 20-second break after each repetition and a 2-minute break after each set. They repeated these steps according to the planned numbers and sets per week^(25, 29) (Table 1).

Neuromuscular electrical stimulation

The sample group lay down on their stomachs to identify the locations of the motor point for hamstrings, referring to the position above the lateral condyle of the femur. The maximum intensity tolerance was tested by cleaning the area and applying the stimulating pole with cotton and alcohol. The pole was applied at the motor point position, aligned with the position above the motor point.^(19, 30) ES was started with surge faradic current for 15 minutes^(31 - 33) to contribute to isometric contraction at the ratio surge on : surge off = 10 : 30 seconds at 50 Hz. The maximum intensity tolerance was adjusted to apply a stimulation and the training intensity was recorded.

Table 1. Nordic hamstring exercise training program.

Week	Frequency	Sets	Reps	Total reps
1	2	2	5	10
2	2	2	6	12
3	2	2	6	12
4	2	2	7	21
5	2	2	7	21
6	2	2	8	24
Sum				100

Applied from Presland JD, *et al.*⁽²⁹⁾

Group 2 (NH+FIFA 11+)

Nordic hamstring exercise

The Nordic hamstring exercise procedure and adjustment of the intensity applied were as same as for group 1.

FIFA 11+

There were 4 postures including: 1. cross-country skiing, 15 times; 2. chest passing in single-leg stance, 10 times; 3. forward bend in single-leg stance, 10 times; and 4. figure of eight in single-leg stance, 10 times.

Both groups attended the training 12 times and no one sustained an injury during the program.

Statistical analysis

Physical characteristics included age, weight, height, body mass index, and isometric muscle strength of the hamstring muscle. These values were displayed as mean \pm standard deviation (SD).

For the comparison of the results, the before and after (6 weeks of training) results for each group were compared using a paired *t*-test. As for the comparison between groups after 6 weeks of training, an unpaired *t*-test was used. The statistical significance was set at $P < 0.05$.

Results

Physical characteristics

Average and SD of group 1 (NH+NMES) age, weight, and BMI was 20.0 ± 1.3 years old, 59.9 ± 5.8 kg, and 21.4 ± 1.4 kg/m², respectively. Average and SD of group 2 (NH+FIFA 11+) age, weight, and BMI was 19.8 ± 1.8 years old, 63.9 ± 10.1 kg, and 20.5 ± 2.8 kg/m², respectively (Table 2).

Hamstring muscle strengthening comparison

The results showed that the value for group 1 (NH+NMES) was 9.8 ± 2.4 kg before training and 17.7 ± 2.0 kg on week 6. The value for group 2 (NH+FIFA 11+) was 9.8 ± 2.8 kg before training and 15.8 ± 2.3 kg on week 6 (Table 3). When comparing the difference in hamstring muscle strengthening between both groups before and after training using a paired *t*-test (at a statistical significance of $P < 0.05$), the value of group 1 (NH+NMES) was $P = < 0.001$, while that of group 2 (NH+FIFA 11+) was $P = 0.001$.

The result illustrated that the strengthening of hamstring muscles between both groups after week 6 was no significant difference (Table 4).

Table 2. Physical characteristics of study groups.

	(NH+NMES) (Mean \pm SD)	(NH+FIFA 11+) (Mean \pm SD)	<i>P</i> -value
Age (yr)	20.0 ± 1.3	19.8 ± 1.8	0.764
Weight (kg)	59.9 ± 5.8	63.9 ± 10.1	0.762
BMI (kg/m ²)	21.4 ± 1.4	20.5 ± 2.8	0.421

Table 3. Comparison of hamstrings muscle strength before and after the training in week 6 in the NH+NMES group and in the NH+FIFA 11+ group.

Group	Before (kg) (Mean \pm SD)	After (kg) (Mean \pm SD)	<i>P</i> -value
NH+NMES (n=8)	9.8 ± 2.4	17.7 ± 2.0	<0.001
NH+FIFA 11+ (n=8)	9.8 ± 2.8	15.8 ± 2.3	0.001

Table 4. Comparison of hamstrings muscle strength before and after the training in week 6 between the NH+NMES group and the NH+FIFA 11+ group.

Isometric	Group	Mean	SD	<i>P</i> -value
Equal Variances Assumed	NH + NMES (n=8)	17.7	2.0	0.098
	NH + FIFA 11+ (n=8)	15.8	2.3	

Discussion

The results indicated that the hamstring muscle strength of the group with NH+NMES was significantly higher. It implied that training twice per week for 6 weeks maximized the increase in hamstring muscle strength by up to 7.9 kg (9.8 ± 2.4 before training and 17.7 ± 2.0 on week 6), accounting for an 80.5% increase.

Previously, OSTRC reported that after 10 weeks of training, Nordic exercise could significantly strengthen the muscles by 65.0%.⁽¹¹⁾ Alonso-Fernandez D, *et al.*⁽²⁵⁾ found that it increased muscular strength by 34.0% with a statistical significance after 8 weeks of training.⁽²⁵⁾ Moreover, Bourne MN, *et al.*⁽³⁴⁾ discovered that the 6 weeks of training strengthened muscles by 16.0% with a statistical significance.⁽³⁴⁾ It showed that doing Nordic exercise for 6 weeks prevented hamstring muscle injury. This was found to be in line with a study by Presland JD, *et al.*⁽²⁹⁾ in which the impacts of Nordic exercise on biceps femoris were examined. The findings showed that Nordic exercise would be effective after 6 weeks of training.^(21, 28, 29) From this research, it was found that training Nordic for 6 weeks could strengthen hamstrings muscles by up to 80.5%, which is 64.5% higher than that found in previous research. This is because the researcher added the ES to encourage the injured muscles with faradic current at 50 Hz, which activated muscles via the nerves to maximize tetanic contraction.^(31 - 33) As a result, it contributed toward the highest tonus in muscle, 4 times more than the normal contraction, since the motor unit was activated by an electric current during ES. Normally, while muscles contract, the first activated muscle fibers are those with small motor systems or slow-twitch fibers. Conversely, when the contraction force increased by over 20.0% of the highest contraction rate, large motor systems or fast-twitch fibers initiated the function. This was different from muscle contraction from ES, as ES activated the large motor system or fast-twitch fiber first because the large nerves were easily activated. Furthermore, the large motor unit generated more force than the small motor unit. Thus, it was predicted that ES increases muscle strength more than normal contraction, making it very useful for muscle strengthening. Additionally, surge on : surge off = 10 : 30 was set for ES to minimize the chance of muscle fatigue, while the stimulating pad was placed on the motor point in order to reduce the current intensity.^(19, 30) Each stimulation applied

the maximally tolerated current to activate the highest muscle contraction.^(19, 33, 35) Furthermore, the input during ES also strengthened muscles isometrically, which promoted higher muscle strength.^(19, 36) It was consistent with the mechanism of the stimulation of muscles via nerves. Two theories could be applied to provide an explanation. The first is the overload theory, which was the same principle with voluntary contraction: the greater the muscle contraction, the greater the increase in muscular strength. The second theory was that ES delivered the recruitment to the large motor unit and stimulated the fast-twitch fiber to cause muscle contraction.⁽³³⁾ Furthermore, muscle stimulation promoted more strengthening than exercise alone.⁽³⁷⁾ ES and normal muscle contraction were different types of stimulation that resulted in dissimilar acute physiologic effects. Thus, both techniques should be applied in the continuation of training because it also initiates the qualitative physiological adaptation. The physiological principle can be explained according to 2 areas. Firstly, the increase in strength could be explained by the large muscle fiber adaptation that was mostly required among the athletes and could occur during ES, when the highest torque was the result of nervous system adjustment activating large muscle fibers; consequently, muscle became stronger. Secondly, ES synchronized the motor unit, which did not occur due to normal contraction. ES provided a better interface at the highest range of contraction.⁽³³⁾ This is in line with a study on quadriceps muscle eccentric contraction, in which ES was compared to ES after only 6 weeks of training. Results showed that the group that applied quadriceps muscle eccentric contraction with ES had significantly more muscular strength than the group that applied only ES. All results illustrated that eccentric contraction with ES promotes muscular strength efficiently.⁽²¹⁾ This is in line with the results on the group that applied eccentric contraction with ES and the group that applied only exercise. Results showed that eccentric contraction with ES strengthened muscle more efficiently than exercise alone.⁽²²⁾ Most related previous studies examined athletes with muscle injury. Salephon K, *et al.*⁽³³⁾ investigated the impacts of exercise with ES compared to exercise alone on the muscular strength of healthy athletes after 4 weeks of training. It was found that the overall muscular strength of both groups increased by 5.2 kg. However, when comparing the statistical results, there was no statistical significance.

Meanwhile, a study involving athletes with muscle injuries showed that it maximized muscular strength by up to 7.9 kg. It was implied that ES with exercise was more effective for athletes with muscle injury than it was for healthy athletes.

For the group that applied Nordic exercise with FIFA 11+, the hamstring strength increased significantly, which implies that the 6 weeks of exercise, twice a week, helped to strengthen hamstring muscles by up to 6.0 kg (9.8 ± 2.8 kg before training and 15.8 ± 2.3 kg after week 6), accounting for a 61.1% increase. Some reports regarding Nordic exercise stated that after 6 weeks of training, it significantly strengthened muscles by 16.0%. Moreover, this research found that the 6 weeks of training could strengthen hamstring muscles by up to 61.1%, which was 45.1% higher than the previous study, as the researcher added FIFA 11+ to support the function of injured muscles. Nordic exercise is a type of exercise involving eccentric contraction that increases strength, torque, and efficiency of muscular ability more than concentric contraction or isometric contraction.⁽⁷⁾ In the case of muscle injury, it would not contract efficiently. FIFA 11+ stimulated isometric contraction and concentric contraction, which reinforced and activated efficient muscular function. This finding is consistent with muscle contraction principle during exercise, in which muscle fibers within the small motor system or slow-twitch fibers functioned first. When the contraction was up to 20.0% from the highest rate, the large motor unit or fast-twitch fibers started to function.⁽²³⁾ Regular muscle contraction increased the functional strength of muscles, depending on the speed, joint position, and movement pattern used in the training. Nordic exercise required the movement of the knee joint that was limited within the training. FIFA 11+ improved muscular strength via the exercise with the movement of joints. It stimulated deep muscle and built gross motor skills that supported multiple movement,⁽¹⁸⁾ which would be more effective if both types of training were applied simultaneously.⁽³⁸⁾ Furthermore, both exercises maximized muscle contraction and strengthened leg muscles,^(16, 17) which reduced the level of re-injury from the highest muscular force during utilization.

There was no significant difference in hamstring strength between the NH+ NMES group and NH+FIFA 11+ group because ES supported the contraction of injured muscles and increased the efficiency of stimulated motor units. It maximized the

strength of the stimulated superficial muscle, while deep muscles and other muscles were not stimulated, only stabilized muscle, and could not function multiple movement due to the limitation of degree.⁽¹⁸⁾ FIFA 11+ involved the regular muscle contraction, in which the small motor system started to function first and the large motor system activated when muscle contraction exceeded 20.0%.⁽³⁰⁾ Muscles were stimulated, including superficial, deep, stabilized, and other muscles. Additionally, it strengthened gross motor skills for multiple movement,⁽¹⁸⁾ as the angle was not limited and it involved the movement of joints. For this reason, the training results of both groups were not significantly different.

The pattern of exercise in both groups resulted in similar average hamstring strengths, which explained that both groups exhibited increased muscular strength. To strengthen muscle, either NH+NMES and NH+FIFA 11+ could be applied. However, in cases of injured muscles, the researcher suggested the application of ES coupled with exercise to allow muscle contraction, in order to improve strength, and start Nordic exercise after the acute injury phase. In case of rain or limitations on training space, Nordic exercise with ES provides a feasible alternative, as it only requires a small space and simple body movements. However, for those preferring the movement of many joints, Nordic exercise with FIFA 11+ (NH+FIFA 11+) is an option, as FIFA 11+ involves the movement of muscles and joints throughout the exercise.

Further study on the hamstring strength of injured and non-injured leg are warranted. Electromyography (EMG) should be used to monitor muscles during body strength tests, exercise, and ES processing.

Conclusion

NH+NMES training and NH+FIFA 11+ training may enhance hamstring muscle strengthening in football athletes with hamstring muscle strain.

Acknowledgments

We are grateful to the Department of Rehabilitation and Movement Sciences, Faculty of Sports Science, Kasetsart University, for their support. And also thank the volunteers who participated in this study.

Conflict of interest

The authors, hereby, declare no conflict of interest.

References

1. Whalan M, Lovell R, McCunn R, Sampson JA. The incidence and burden of time loss injury in Australian men's sub-elite football (soccer): A single season prospective cohort study. *J Sci Med Sport* 2019;22:42-7.
2. Sconce E, Jones P, Turner E, Comfort P, Graham-Smith P. The validity of the nordic hamstring lower for a field-based assessment of eccentric hamstring strength. *J Sport Rehabil* 2015;24:13-20.
3. Daly C, Persson UM, Twycross-Lewis R, Woledge RC, Morrissey D. The biomechanics of running in athletes with previous hamstring injury: A case-control study. *Scand J Med Sci Sports* 2016;26:413-20.
4. van den Tillaar R, Solheim JAB, Bencke J. Comparison of hamstring muscle activation during high-speed running and various hamstring strengthening exercises. *Int J Sports Phys Ther* 2017;12:718-27.
5. Wan X, Qu F, Garrett WE, Liu H, Yu B. The effect of hamstring flexibility on peak hamstring muscle strain in sprinting. *J Sport Health Sci* 2017;6:283-9.
6. Jones A, Jones G, Greig N, Bower P, Brown J, Hind K, et al. Epidemiology of injury in English Professional Football players: A cohort study. *Phys Ther Sport* 2019;35:18-22.
7. Voukelatos D, Kirkland M, Pain MTG. Training induced changes in quadriceps activation during maximal eccentric contractions. *J Biomech* 2018;73:66-72.
8. Kalli K, Dimitrios S. Hamstring injuries: Prevention and rehabilitation. *Biol Exerc* 2016;12:15-34.
9. Brockett CL, Morgan DL, Proske U. Human hamstring muscles adapt to eccentric exercise by changing optimum length. *Med Sci Sports Exerc* 2001;33:783-90.
10. Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports* 2003;13:244-50.
11. Mjøltnes R, Arnason A, Østhaugen T, Raastad T, Bahr R. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scand J Med Sci Sports* 2004;14:311-7.
12. Al Attar WS, Soomro N, Pappas E, Sinclair PJ, Sanders RH. How effective are F-MARC injury prevention programs for soccer players? A systematic review and meta-analysis. *Sports Med* 2016;46:205-17.
13. Steffen K, Myklebust G, Olsen OE, Holme I, Bahr R. Preventing injuries in female youth football—a cluster-randomized controlled trial. *Scand J Med Sci Sports* 2008;18:605-14.
14. Gatterer H, Ruedl G, Faulhaber M, Regele M, Burtscher M. Effects of the performance level and the FIFA “11” injury prevention program on the injury rate in Italian male amateur soccer players. *J Sports Med Phys Fitness* 2012;52:80-4.
15. van Beijsterveldt AM, van de Port IG, Krist MR, Schmikli SL, Stubbe JH, Frederiks JE, et al. Effectiveness of an injury prevention programme for adult male amateur soccer players: A cluster-randomised controlled trial. *Br J Sports Med* 2012;46:1114-8.
16. Al Attar WS, Soomro N, Sinclair PJ, Pappas E, Sanders RH. Effect of injury prevention programs that include the nordic hamstring exercise on hamstring injury rates in soccer players: A systematic review and meta-analysis. *Sports Med* 2017; 47: 907-16.
17. Sadigursky D, Braid JA, De Lira DNL, Machado BAB, Carneiro RJE, Colavolpe PO. The FIFA 11+ injury prevention program for soccer players: A systematic review. *BMC Sports Sci Med Rehabil* 2017;9:18.
18. Paillard T. Combined application of neuromuscular electrical stimulation and voluntary muscular contractions. *Sports Med* 2008;38:161-77.
19. Canning A, Grenier S. Does neuromuscular electrical stimulation improve muscular strength gains of the vastus medialis muscle. *Int J Phys Med Rehabil* 2014;2:1-5.
20. Duhig SJ, Williams MD, Minett GM, Opar D, Shield AJ. Drop punt kicking induces eccentric knee flexor weakness associated with reductions in hamstring electromyographic activity. *J Sci Med Sport* 2017;20: 595-9.
21. Tanaka S, Kamiya K, Matsue Y, Yonezawa R, Saito H, Hamazaki N, et al. Effects of acute phase intensive electrical muscle stimulation in frail elderly patients with acute heart failure (ACTIVE-EMS): Rationale and protocol for a multicenter randomized controlled trial. *Clin Cardiol* 2017;40:1189-96.
22. Gomes da Silva CF, Lima ESFX, Vianna KB, Oliveira GDS, Vaz MA, Baroni BM. Eccentric training combined to neuromuscular electrical stimulation is not superior to eccentric training alone for quadriceps strengthening in healthy subjects: A randomized controlled trial. *Braz J Phys Ther* 2018;22:502-11.
23. Elerian AE, El-Sayyad MM, Dorgham HAA. Effect of Pre-training and post-training nordic exercise on hamstring injury prevention, recurrence, and severity in soccer players. *Ann Rehabil Med* 2019;43:465-73.
24. Hegyi A, Lahti J, Giacomo JP, Gerus P, Cronin NJ,

- Morin JB. Impact of hip flexion angle on unilateral and bilateral nordic hamstring exercise torque and high-density electromyography activity. *J Orthop Sports Phys Ther* 2019;49:584-92.
25. Alonso-Fernandez D, Docampo-Blanco P, Martinez-Fernandez J. Changes in muscle architecture of biceps femoris induced by eccentric strength training with Nordic hamstring exercise. *Scand J Med Sci Sports* 2018;28:88-94.
 26. Šarabon N, Marušič J, Marković G, Kozinc Ž. Kinematic and electromyographic analysis of variations in Nordic hamstring exercise. *PLoS One* 2019;14:e0223437.
 27. Taberner M, Cohen DD. Physical preparation of the football player with an intramuscular hamstring tendon tear: Clinical perspective with video demonstrations. *Br J Sports Med* 2018;52:1275-8.
 28. Boonyarom O. Rehabilitation: Atrophy of skeletal muscles. *Naresuan Univ J: Sci Technol (NUJST)* 2009; 17:85-90.
 29. Presland JD, Timmins RG, Bourne MN, Williams MD, Opar DA. The effect of Nordic hamstring exercise training volume on biceps femoris long head architectural adaptation. *Scand J Med Sci Sports* 2018;28:1775-83.
 30. Latronico N, Fagoni N, Gobbo M. Neuromuscular electrical stimulation in critically ill patients. In: Prabhakar H, editor. *Essentials of neuroanesthesia*. United States: Academic Press; 2017. p.771-81.
 31. Boonyarom O. Comparison between electrical stimulation by faradic current and interferential current on strength of quadriceps femoris. *Naresuan Univ J: Sci Technol (NUJST)* 1999;7:62-9.
 32. Somtavil S. The effect of maximal isometric exercise and maximal isometric exercise combined with electrical stimulation on shooting performance in pistol shooters. *Naresuan Univ J: Sci Technol (NUJST)* 2000;8:102-13.
 33. Saleophon K, Boonyarom O, Jorrakate C. Effects of neuromuscular training and electrical stimulation on ankle stability and muscle strength of peroneus longus in rock climbers. *Chula Med J* 2020;64:203-9.
 34. Bourne MN, Duhig SJ, Timmins RG, Williams MD, Opar DA, Al Najjar A, et al. Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: implications for injury prevention. *Br J Sports Med* 2017;51:469-77.
 35. Caggiano E, Emrey T, Shirley S, Craik RL. Effects of electrical stimulation or voluntary contraction for strengthening the quadriceps femoris muscles in an aged male population. *J Orthop Sports Phys Ther* 1994;20:22-8.
 36. Laughman RK, Youdas JW, Garrett TR, Chao EY. Strength changes in the normal quadriceps femoris muscle as a result of electrical stimulation. *Phys Ther* 1983;63:494-9.
 37. Stevens-Lapsley JE, Balter JE, Wolfe P, Eckhoff DG, Schwartz RS, Schenkman M, et al. Relationship between intensity of quadriceps muscle neuromuscular electrical stimulation and strength recovery after total knee arthroplasty. *Phys Ther* 2012; 92:1187-96.
 38. Proske U, Morgan DL, Brockett CL, Percival P. Identifying athletes at risk of hamstring strains and how to protect them. *Clin Exp Pharmacol Physiol*