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Modulation of the Hip Range of Motion for Kick Following Combination Exercise in Iranian Elite Male Taekwondo Players: Quasi-Experimental Study

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Original Article

Abstract

Introduction: Taekwondo is one of the most famous martial arts in the world; according to its rules, kicks have full points. The purpose of this research was to investigate and compare the effect of strength and stretching with the method of proprioceptive neuromuscular facilitation (PNF) and their combined exercises on the range of motion (ROM) of kicks as a factor related to sports injuries in Iranian elite male taekwondo players.

Materials and Methods: The current research was semi-experimental. The statistical sample of the study was 24 Iranian elite male taekwondo players who entered the study voluntarily, were available, and completed the informed consent form. To compare the effect of three methods of strength training, stretching with PNF method, and combined on hip joint active, passive, and kick ROM, the subjects were divided into three groups of 8 people. The subjects underwent an 8-week training program consisting of three 45-minute gym sessions per week. Statistical analysis was performed using Shapiro-Wilk descriptive and inferential methods, correlated t, multivariate analysis of covariance (ANCOVA), and pairwise comparisons. Moreover, the level of significance in the present study was considered 0.05.

Results: All three types of exercises significantly increased the hip joint active and kick ROM. Besides, two other exercises significantly affected the passive ROM except for strength exercises.

Conclusion: It seems that the combination of strength exercises with stretching exercises (PNF) can improve the ROM of the kick in elite taekwondo players more than each of these exercises alone.

Keywords: Strength training; Proprioceptive neuromuscular facilitation stretching; Range of motion; Taekwondo

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Introduction

Flexibility refers to a person's ability to perform movements with a wide range of motion (ROM) in their joints. It is influenced by factors such as the shape of the joints (articular geometry), the elasticity of muscles and ligaments and others. Flexibility plays a crucial role in the rehabilitation, injury prevention, and athlete performance. Improving flexibility can speed up the recovery and rehabilitation of athletes during injury. Proper flexibility and stretching techniques can also prevent delayed onset muscle soreness after intense exercise (1). Therefore, training and improving flexibility is essential, especially for young athletes (2).

Stretching exercises are an effective way to improve flexibility. There are various ways to do stretching exercises, and proprioceptive neuromuscular facilitation (PNF) has become increasingly popular in the last fifteen years, especially among athletes (3). PNF exercises involve an isometric contraction before stretching, resulting in greater benefits than stretching alone (3).

Muscle weakness and reduced ability to produce fast muscle contractions can hinder getting up from a sitting position and starting movements that involve

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the lower body (2). Participating in simultaneous resistance exercises is effective in improving flexibility (4). It also appears that increasing the tensile strength of tendons and ligaments, muscle mass, and contraction power can increase an individual's flexibility (4-6). The positive effect of a combination of strength and balance exercises on flexibility in people with Parkinson's disease has also been reported (7).

Taekwondo is a popular martial art that combines the most correct, scientific, strongest, and fastest techniques (8). Three basic movements in martial arts, especially taekwondo, are kicking with the back of the leg (Dwit Chagi), kicking with the side of the leg (Yop Chagi), and kicking with the chest of the leg (Ap Chagi). The correct implementation of these movements is an indicator of a person's skill level in the martial art of taekwondo (9). Moreover, high flexibility is required to perform Up-Chagi and Dolyo-Chagi kicks, in addition to skill and balance.

In taekwondo fights, kicks are executed quickly and explosively. Combining stretching and strength exercises can give taekwondo players a higher ROM while performing kicks. As a benefit, higher muscle strength is useful for athletes, especially for sports with strength requirements, because it reduces the risk of muscle sports injuries. (10).

Muscle flexibility is vital for taekwondo players to optimize power usage and achieve high leg speeds (8). It is essential for quickly raising the leg to reach the opponent's head and earn points. Its absence can lead to unsuccessful technique execution and injuries (11). In Canada, 166.7 injuries per 1000 athletes exposed to injuries were reported in national competitions, with lower limb injuries being the most common (46.5%) and muscle strain being the most common type of injury (12). Iranian elite male taekwondo players had a rate of 148.4 injuries per 1000 athletes exposed to injuries. The most common site of injury was the lower limb (68.4%), and muscle strain was the most common type of injury (12.78%), followed by joint injuries (8.27%) (13).

Flexibility is crucial for executing movements in fighting or Kiu Rogi (9). It allows for better and more complete movements in performing advanced kicks (12). Flexibility is not only crucial in taekwondo movement skills but also in providing general health and improving physical fitness (5, 14). Stretching exercises play a vital role in preventing osteoporosis in taekwondo players, reducing muscle and hip joint injuries, and increasing the longevity of taekwondo players in the championship period (10, 15).

Improving performance and effectively preventing injuries in taekwondo is a significant goal of its federations and coaches. To achieve this, appropriate stretching exercises such as PNF stretching or strength exercises need to be taught to taekwondo players. While limited studies have investigated the effect of stretching exercises with the PNF method on the flexibility of muscles and joints of professional taekwondo players, none have compared and combined it with strength exercises (16). Therefore, this research aims to determine and compare the effect of strength, PNF stretching exercises, and a combination of these two exercise regimens on the kick ROM and the flexibility of contractile and non-contractile tissues in Iranian elite male taekwondo players.

Materials and Methods

The current study was conducted with a quasi-experimental design using a pre- and post-test approach but without a control group. The statistical population consisted of 25 male taekwondo players who ranked first to third in the country's national team selection in 2019 and were active at the professional level. Of these players, 24 voluntarily participated in the study after completing an informed consent form, which aligns with the sample size suggested by Morgan's table. The participants were selected based on their physical health and winning medals in previous competitions. Before the research protocol was implemented, all participants were evaluated to ensure that they did not have any postural or skeletal-muscular problems or deformities of the lower body, such as genu varum and genu valgum, pes planus and cavus, tibial torsion, chronic ankle sprain, or diseases such as stress fractures, osteoarthritis, shin splints, and leg and foot pains. Those who had such issues were excluded from the study.

The Ethics Committee of Gilan University of Medical Sciences, Rasht, Iran, approved all the steps of this study. The study was conducted in collaboration with participants who met the necessary conditions and provided their agreement to this cooperation. The candidates were thoroughly informed about the study's purpose and the appropriate way of conducting the test. Written informed consent was obtained from those who expressed interest in participating in the study.

The execution of kicks in taekwondo requires not only flexibility but also other factors, such as skill acquisition. To adjust the effect of confounding variables, this study compared the ROM of the hip joint in both passive and active as well as kicks movements. Additionally, the study aimed to compare the effect of strength training, stretching with PNF, and combined methods and randomly divided the subjects into three groups of 8 people. Due to the limited number of professional taekwondo players, the sample size could not be increased. The subjects performed PNF stretching exercises, leg press strength training, or a combination of both for eight weeks, with three sessions per week, each lasting 45 minutes in the gym of Gilan University. The training protocol was as follows:

For the warm-up, 7 minutes of gentle jogging with lower body stretching was done.

The main exercise routine consisted of 11 minutes. The first group of exercises was the PNF exercise group, which involved three stages. In the first stage, there was a maximum isometric contraction in the hamstring muscles (antagonist) while resisting the assistant. In the second stage, the assistant slowly guided the leg towards more stretching in the hamstring muscles. For the third stage, the subjects flexed their thigh, and the assistant carefully helped them. The number of repetitions was four times, and the rest time between each exercise stage was 2 minutes (17). The second group was the group of strength exercises in a pyramid way, which entailed a gradual increase of the load and a decrease of the number of repetitions until reaching the maximum strength in the last period. This group performed five periods, with the first round consisting of 50% of maximum repetition [one-rep max (1RM)] or ten repetitions for warm-up.

The second round was with 85% of 1RM (equivalent to 6 repetitions), the third round was with 90% of 1RM (equivalent to 3-4 repetitions), the fourth round was with 95% of 1RM (equivalent to 2-3 repetitions), and the fifth round was with 100% of 1RM (equivalent to one repetition). The exercises for this group were performed with a 3-minute rest between each set (18). The third group was the group of combined exercises. The duration of contraction, rest, and all stages of PNF stretching exercises were similar to the first group. The strength exercises of this group were completely similar to the exercises of the second group.

For the cool-down, slow movements and relaxation exercises were performed for 5 minutes to return to the initial state.

In both tests (pre-test one day before starting the exercises and post-test one day after the end of the exercises), to estimate the active and passive ROM, the subject's dominant leg was brought up without bending the knee. To measure the active ROM, the subject stood in the calibrated location of the camera, placed hands on the waist, and raised the dominant leg at high speed without bending the knee. The ROM was recorded by a Vicon high-speed camera (England), with a sampling frequency of 200 Hz (Figure 1-A). To measure the passive ROM of hip flexion, the subject stood in the calibrated location of the camera and placed hands on the waist. At the same time, the helper standing next to the subject raised the leg as softly and calmly as possible (as long as the subject's balance was not disturbed) without bending the knee, and its ROM was recorded by a high-speed camera (Figure 1-B). To measure the ROM in kick, the subject stood at the calibrated location of the camera, and while his hands were on his waist, he raised his dominant leg at high speed without bending the knee three times in a row. The ROM was recorded by a high-speed camera (Figure 1-C).

The initial step involved saving the camera data in static mode using the Vicon Nexus software (Figure 2-A), then conducting the pop lining and other data analysis processes. Further, to measure the ROM using the software, the angle of the hip joint was gauged from the static state to the maximum flexion angle (Figure 2-B).

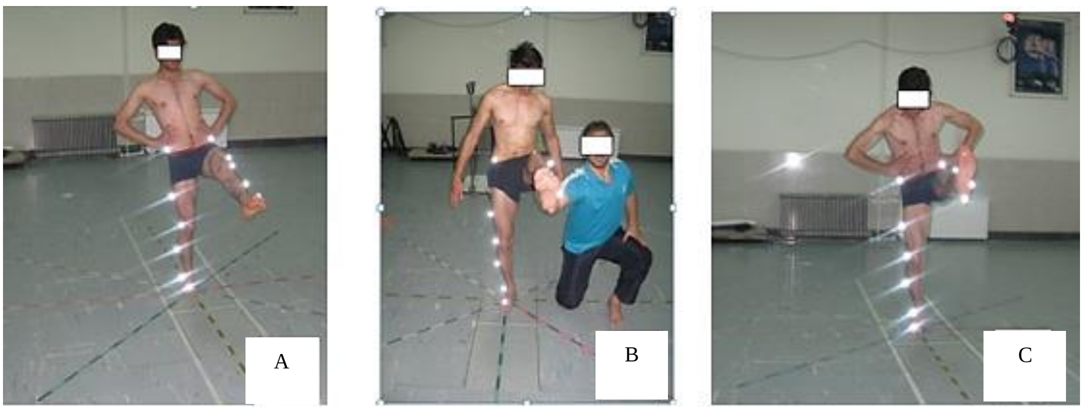
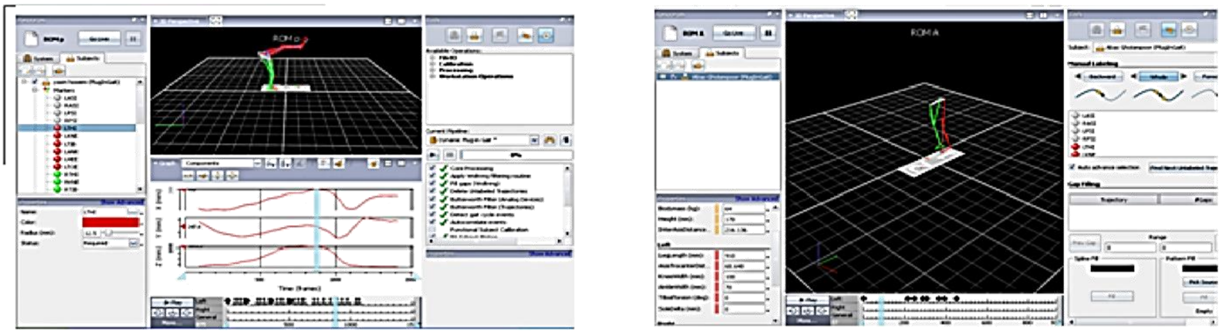


Figure 1. Measure of Range of motion (ROM) A) Active, B) Passive, C) Kicking



A B

Figure 2. Static mode for performing the movement of the active ROM of the hip joint (A), static mode for performing the movement of the active ROM of the hip joint (B)

To record kinematic data, 16 markers were placed on the individual's legs according to the Plug-in Gait protocol. Markers were placed on both legs in the following locations: on the beginning of the second metatarsal bone, outer ankle, medial outer leg, outer epicondyle of the femur, medial outer femur, anterior superior iliac spine (ASIS), and posterior superior iliac spine (PSIS) (16).

The tools used in the study included a researcher-made form for recording personal information, a Frolic wall height gauge (China) for measuring height with an accuracy of 1 mm up to a scale of 200 cm, a caliper (Model 1108-200, China) for measuring the width of the knee and ankle bones, a tape measure for measuring the length of the foot with an accuracy of 1 mm to a scale of 150 cm, a digital scale for measuring weight, double-sided adhesive for sticking the marker to the body skin, and a chronometer made by Q&Q company (Japan) with a measurement accuracy of 0.01 seconds to keep the duration of contraction and rest of the subjects. Additionally, four Vicon cameras (made in England) with a sampling rate of 200 Hz and 16 light-reflecting markers were used to measure the hip joint's active, passive, and kick ROM.

The study's statistical analysis was conducted using SPSS statistical software (version 21, IBM Corporation, Armonk, NY, USA). The descriptive section employed mean and standard deviation (SD) to describe statistical samples. In the inferential part, the Shapiro-Wilk test was used to verify the normal distribution of the data, while the analysis of variance (ANOVA) test was utilized to compare the pre-test values of the groups. The correlated t-test was used to determine intra-group differences. To compare the post-test values between groups, the analysis of covariance (ANCOVA) test was used to control the pre-test's effect. The study considered a significance level of 0.05.

Results

The mean age of taekwondo practitioners (n = 24) was 27.10 ± 77.04 years, height 182.50 ± 11.05 cm, weight 77.00 ± 6.27 kg, body mass index (BMI) 23.10 ± 22.16 kg/m^2, duration of activity in taekwondo 7.10 ± 4.34 years, and duration of official activity at the national level was 2.10 ± 5.14 years.

Based on the Shapiro-Wilk test results, the distribution of analyzed data followed the normal distribution ($P > 0.05$), and therefore parametric tests were used to analyze the data. The hip joint active, passive, and kick ROM in three groups are collected in table 1. ANOVA test results showed that the pre-test values in the hip joint active ($P = 0.057$, $F = 2.64$), passive ($P = 0.062$, $F = 2.31$), and kick ROM ($P = 0.051$, $F = 2.09$) was not significantly different between the three groups. However, in the group of stretching exercises with the PNF method, after the test was compared to the pre-test, there was a significant difference shown in the hip joint active ($P = 0.022$, $t = 1.35$), passive ($P = 0.017$, $t = 3.43$), and kick ROM ($P = 0.005$, $t = 2.14$). In the group of resistance exercises, no significant difference was observed in the hip joint passive ROM ($P = 0.057$, $t = 1.42$). Still, a significant difference was observed in the hip joint active and also in the kick ROM ($P = 0.006$, $t = 1.92$; $P = 0.014$, $t = 1.32$, respectively). Moreover, in the combined group, there was a significant difference in the hip joint active, passive, and kick ROM ($P = 0.023$, $t = 1.19$; $P = 0.021$, $t = 1.17$; $P = 0.030$, $t = 8.30$, respectively).

Levene's test was used to check the post-test values of the investigated indicators in the experimental groups. The results showed that the groups had equal variances, and the significance level for each research group was more than 0.05.

Table 1. Comparison of active, passive, and kick range of motion (ROM) in three groups of strength, stretching with proprioceptive neuromuscular facilitation (PNF) method, and combined exercises during the pre-test and post-test

Group	Hip ROM type	Hip joint ROM (degree)					t-statistics	P value compared to the pre-test
		Pre-test (mean ± SD)	Comparison of hip active ROM pretest values between groups	Comparison of hip passive ROM pretest values between groups	Comparison of hip ROM during kick pretest values between groups	Post-test (mean ± SD)		
Strength exercise	Active	82.4 ± 3.3	P = 0.057, F = 2.64	P = 0.062, F = 2.31	P = 0.051, F = 2.09	94.3 ± 2.2	1.92	0.006*
	Passive	86.6 ± 4.5				92.3 ± 6.1	1.42	0.057
	Kick	91.9 ± 3.2				98.8 ± 1.2	1.32	0.014*
Stretching exercise (PNF)	Active	86.4 ± 4.9				95.5 ± 2.3	1.35	0.022*
	Passive	85.2 ± 2.1				97.5 ± 3.2	3.43	0.017*
	Kick	90.1 ± 5.2				101.6 ± 4.6	1.14	0.005*
Combined (PNF + strength)	Active	86.8 ± 7.2				97.3 ± 6.4	1.19	0.023*
	Passive	89.9 ± 3.2				102.3 ± 1.2	1.17	0.021*
	Kick	91.1 ± 6.8				103.6 ± 7.8	8.30	0.030*

*$P < 0.05$
PNF: Proprioceptive neuromuscular facilitation; ROM: Range of motion; SD: Standard deviation

Therefore, to eliminate the effect of the pre-test values of the groups, the multivariate ANCOVA test was used to compare the post-test values of the groups.

The results of ANCOVA test by removing the effect of the pre-test and comparing the changes in active, passive, and kick ROM among all three groups in the post-test were significant [$P < 0.05$, eta = 9 (active), eta = 12 (passive), and eta = 16 (during foot strike)]. Examining all possible pairwise comparisons between groups of independent variables showed that the ROM changes of the combined training group in active (9 percent), passive (12 percent), and kick ROM (16 percent) could be more likely to perform combined exercises (Figure 3).

Discussion

In this study, we aimed to investigate the effects of strength training, PNF exercises, and their combination on the active, passive, and kick ROM in elite male taekwondo athletes in Iran. Our results showed that all three types of exercises led to a significant increase in the active ROM and the execution of kicks. Besides strength exercises, the other two also significantly affected the passive ROM. To the best of our knowledge, this is the first study that examines the effects of three types of strength training, PNF stretching, and their combination in taekwondo. However, previous research has shown that PNF stretching exercises increase the ROM of the knee joint and improve the vertical jump in taekwondo athletes (19).

One of the unique features of PNF stretching exercises is the presence of an isometric contraction phase, which helps improve the ROM through the facilitation of proprioceptive receptors. Moreover, isometric contraction during the maintenance phase of PNF stretching exercises may increase the force in the ROM. This increase in strength may be due to the faster increase compared to the muscle environment during the early stages of strength training. These exercises can stimulate non-morphological factors, such as nerves, which may contribute to increased strength (20).

The strength component of exercises, even if it is short-term, can lead to special muscle tension, pennate muscle angle of arrangement, connective tissue content, and can affect the torque-length relationship of the muscle (19). These factors, alone or together, can create a clear distinction between the increased maximum muscle strength (21). Passive movement of the leg during exercise can cause the stretching of the thigh extensor muscles and the activation of the stretching reflex due to the transmission of the message in the primary afferents of the muscle spindle. This reflex results in the contraction of the hamstring muscle to prevent the change in the length of this muscle (22). PNF stretching exercises can increase muscle flexibility by modulating muscle spindle activity adhesion-elastic adaptations of collagen and elastin within the muscle unit, tendon, and ligament (23). It is believed that physical activities, such as heavy strength exercises that cause a lot of muscle tension, can increase the muscle's maximal contraction force (23). Physical exercise can stimulate both neural and muscular adaptations, which increase muscle strength (24). Therefore, the increase in maximum contraction force does not happen only due to the increase in muscle cross-section or muscle volume (24).

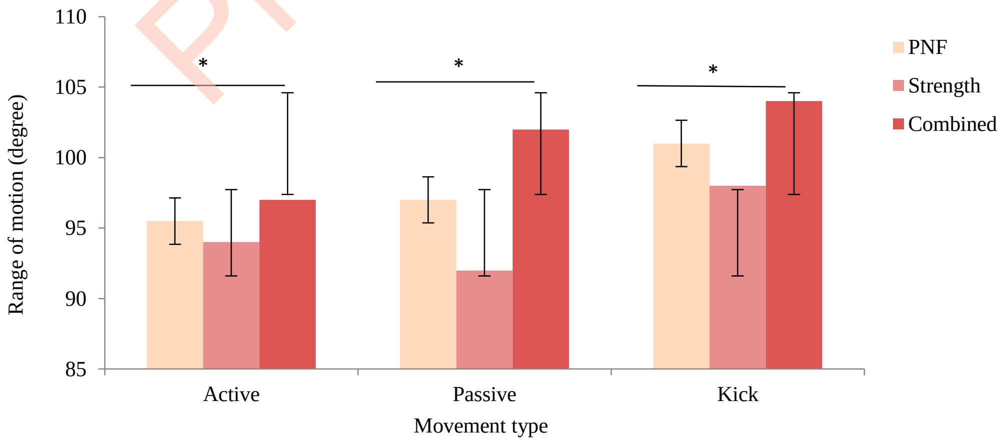


Figure 3. Comparison of the post-test values of active, passive, and kick range of motion (ROM) in strength training, proprioceptive neuromuscular facilitation (PNF), and combined groups

Still, the increase in neuro-muscular connection also contributes to the increase in maximum contraction force resulting from exercise. Maximal strength development occurs through increases in neural drive and can occur without increasing muscle size. Thus, not only the size of the muscle and its appearance but also the innervation or adaptation in the nerve structures are among the most critical factors determining the maximum muscle contraction power. The muscle spindle is one of the deep receptors located in the ventricle of the muscle that sends information about the amount and speed of muscle length change to the nervous system. The sensory receptors of the muscle spindle are stimulated in two ways - the elongation of the whole muscle and the contraction of the end parts of the fibers inside the spindle, both of which cause the middle part of the spindle to stretch and stimulate the receptor (22).

In taekwondo, kicks require explosive force production that involves the sudden pulling up of the sole, leading to the stretching of the hamstring muscle and stimulation of the sensory receptors of the muscle spindle. Taekwondo athletes can improve their muscle efficiency against sudden movements by performing strength exercises in the quadriceps and hamstring muscles. These exercises can cause contraction of the end parts of the fibers inside the muscle spindle, stretching the middle part of the spindle and stimulating the receptor. If the muscle spindle is healthy, alpha and gamma efferent cooperate during contraction to maintain the muscle's force at the desired level (25). However, if the muscle spindle is damaged, the force level decreases due to the non-cooperation of alpha and gamma. Strength training can train leg muscle spindles of taekwondo athletes to maintain leg strength by promoting the cooperation of alpha and gamma motor neurons. In addition to PNF stretching exercises, strength exercises can cause neuromuscular facilitation, resulting in a significant increase in the ROM compared to the other two exercises.

Limitations

In this study, only elite men participated in taekwondo, and considering that the study aimed to evaluate the performance of the champions of this field, the number of subjects was limited.

Recommendations

It is suggested that the effect of the desired exercises on improving the ROM be investigated and measured in other joints, types, and levels of sports, and in different ages and genders.

Conclusion

It appears that when strength exercises are combined with PNF stretching exercises, the ROM of the foot strike in elite taekwondo athletes can be enhanced more effectively than when these exercises are performed individually.

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Authors' Contribution

Project design and ideation: Neda Boroushak, Hosein Rashedi, Mohammadreza Batavani
Providing financial resources for the project: Neda Boroushak, Hassan Ashena, Mohammadreza Batavani
Scientific and executive support of the project: Neda Boroushak, Hosein Rashedi, Mohammadreza Batavani, Hassan Ashena
Providing equipment and statistical sample: Hosein Rashedi, Mohammadreza Batavani
Data collection: Hosein Rashedi, Mohammadreza Batavani
Analysis and interpretation of the results: Neda Boroushak, Hosein Rashedi, Mohammadreza Batavani
Specialized statistics services: Neda Boroushak, Mohammadreza Batavani
Manuscript preparation: Neda Boroushak, Mohammadreza Batavani
Specialized scientific evaluation of the manuscript: Neda Boroushak, Hosein Rashedi, Mohammadreza Batavani, Hassan Ashena
Confirming the final manuscript to be submitted to the journal: Neda Boroushak, Hosein Rashedi, Mohammadreza Batavani, Hassan Ashena
Maintaining the integrity of the study process from the beginning to the publication, and responding to the reviewers' comments: Neda Boroushak, Hosein Rashedi, Mohammadreza Batavani, Hassan Ashena

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Conflict of Interest

There is no declaration in this study.

References

1. Siff MC. Training routines: Flexibility in sport. South African Journal of Sports Medicine 2007; 19(1): 2-6.
2. Cejudo A. Lower Extremity Flexibility Profile in Basketball Players: Gender Differences and Injury Risk Identification. Int J Environ Res Public Health 2021; 18(22).
3. Kok SQ. Effect of PNF and dynamic stretching on kicking techniques among taekwondo beginners. [BSc Thesis]. Kuala Lumpur, Malaysia: Tunku Abdul Rahman University College; 2018
4. Alizadeh S, Daneshjoo A, Zahiri A, Anvar SH, Goudini R, Hicks JP, et al. Resistance training induces improvements in range of motion: A systematic review and meta-analysis. Sports Med 2023; 53(3): 707-22.
5. Morton SK, Whitehead JR, Brinkert RH, Caine DJ. Resistance training vs. static stretching: Effects on flexibility and strength. J Strength Cond Res 2011; 25(12): 3391-8.
6. Elsangedy HM, Oliveira GTA, Machado DGDS, Tavares MPM, Araujo AO, Krinski K, et al. Effects of self-selected resistance training on physical fitness and psychophysiological responses in physically inactive older women: A randomized controlled study. Percept Mot Skills 2021; 128(1): 467-91.
7. Bambaeichi E, Rahnama N, Mahmoudi F. The effect of combined training (balance and resistance) on balance, flexibility and motor function in patients with Parkinson. Studies in Sport Medicine 2014; 5(14): 45-58. [In Persian].
8. Boroushak N, Eslami M, Kazemi M, Daneshmandy H, Johnson JA. The dynamic response of the taekwondo roundhouse kick to head using computer simulation. Ido Movement for Culture 2018; 18: 54-60.
9. Kashefi T, Daneshjoo A, Mousavi Sadati SK. The effect of a course of up-cholugi and yup-chagi exercises on the kinematic indices of the knee and the incidence of bow-leggedness (Genu varum) in professional taekwondo practitioners. J Sport Biomech 2021; 6(4): 214-25. [In Persian].
10. Mailapalli D, Benton J, Woodward TW. Biomechanics of the taekwondo axe kick: A review. J Hum Sport Exerc 2015; 10(1): 141-9.
11. Kazemi M, Shearer H, Su Choung Y. Pre-competition habits and injuries in Taekwondo athletes. BMC Musculoskelet Disord 2005; 6(1): 26.
12. Rahnama N, Nazarian A, Batavani MR, Batavani M. Incidence and mechanism of acute injuries in Iranian professional men taekwondo competitors in 2008 super league. Research on Biosciences and Physical Actiuity 2015; 2(3): 55-62. [In Persian].
13. Sindic M, Macak D, Todorovic N, Purda B, Batez M. Effect of Integrated Neuromuscular Exercise in Physical Education Class on Health-Related Fitness in Female Children. Healthcare (Basel) 2021; 9(3).
14. Iwamoto J. A role of exercise and sports in the prevention of osteoporosis. Clin Calcium 2017; 27(1): 17-23. [In Japanese].
15. Alter MJ. Science of Flexibility. Champaign, IL: Human Kinetics; 1996.
16. Choi GJ. The effcts of static and pnf stretching on range of motion and jump performance in the taekwondo player. The Journal of the Korea institute of electronic communication sciences 2013; 8(11): 1771-6.
17. Burgess T, Vadachalam T, Buchholtz K, Jelsma J. The effect of the contract-relax-agonist-contract (CRAC) stretch of hamstrings on range of motion, sprint and agility performance in moderately active males: A randomised control trial. S Afr J Sports Med 2019; 31(1): v31i1a6091.
18. Sayyah A, Asghari E, Arazi H. The effects of two loading patterns of resistance training (skewed pyramid & reverse step) on some physical and physiological capabilities of non-athlete men. Turkish Journal of Kinesiology 2021; 7(4): 123-31.
19. Gardiner PF. Neuromuscular Aspects of Physical Activity. 1st ed. Trans. Gharakhanlou R, Azad A. Nor-e Giti Publications; 2017; p. 275. [In Persian].
20. Leonard CT. The neuroscience of human movement. 1st ed.Tehran, Iran: Imam Hossein University Publications; 2005. p. 26-7. [In Persian].
21. Marek SM, Cramer JT, Fincher AL, Massey LL, Dangelmaier SM, Purkayastha S, et al. Acute effects of static and proprioceptive neuromuscular facilitation stretching on muscle strength and power output. J Athl Train 2005; 40(2): 94-103.
22. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. J Appl Physiol (1985) 2002; 92(6): 2309-18.
23. Hammett JB, Hey WT. Neuromuscular adaptation to short-term (4 weeks) ballistic training in trained high school athletes. J Strength Cond Res 2003; 17(3): 556-60.
24. Boroushak N, Rashedi H, Anbarian M. Physiology of nerve and muscle. 1st ed. Tehran, Iran: Avay-e Zahoor Publications; 2015. [In Persian].
25. Batavani MR, Dehghani F, Zolaktaf V. The comparison and association of incidence and severity of exercise-induced injuries among various genotypes of ACTN3 in Iranian male elite weightlifters. Med J Mashad Univ Med Sci 2022; 65(4): 1400-13. [In Persian].