International Journal of Nutrition Sciences

Journal Home Page: ijns.sums.ac.ir

ORIGINAL ARTICLE

The Effect of Six-Week Neuromuscular Training and Calcium-Magnesium-Zinc Supplementation on Balance and Electromyographic Activity of the Lower Limb Muscles among Elite Taekwondo Athletes

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ARTICLE INFO

Keywords:
Neuromuscular training
Electromyography
Balance
Calcium-magnesium-zinc supplementation
Lower limb muscles

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Received: July 10, 2024
Revised: September 2, 2024
Accepted: September 13, 2024

ABSTRACT

Background: Neuromuscular coordination and the ability to maintain one-legged balance are two important prerequisites for successful taekwondo performance. This study investigated the effect of six weeks neuromuscular training (NMT) and calcium-magnesium-zinc (Ca-Mg-Zn) supplementation on balance and electromyographic (EMG) activity of lower limb muscles among taekwondo athletes.

Methods: In a randomized control trial from September to December 2023 in the Regional Sports Concussion Center, sixty elite taekwondo athletes were enrolled and assigned to four fifteen-member groups, namely the control, Ca-Mg-Zn, NMT, and Ca-Mg-Zn+NMT groups. NMT was performed three times a week for sixty minutes for six consecutive weeks. Between-group and within-group analyzes were performed to determine differences in demographics, static, control of dynamic balance, and EMG between the 4 groups.

Results: The mean value of displacement of the center of pressure decreased in all groups. There were significant differences between the groups in terms of static and dynamic balance with eyes open. There was no significant difference between the groups in the mean value of dynamic balance with eyes closed. EMG activity of the tibialis anterior, rectus and biceps femoris muscles 100-200 milliseconds after first contact did not change significantly between the groups, while the effect size of the Ca-Mg-Zn+NMT intervention on the increase in EMG activity and balance control after the intervention was higher than other groups.

Conclusion: The combination of NMT and Ca-Mg-Zn supplementation was more effective than NMT and Ca-Mg-Zn supplementation to improve static and dynamic balance and EMG activity in taekwondo athletes.

Please cite this article as: Esmealy B, Esmealy L, Zarneshan A. The Effect of Six-Week Neuromuscular Training and Calcium-Magnesium-Zinc Supplementation on Balance and Electromyographic Activity of the Lower Limb Muscles among Elite Taekwondo Athletes. Int J Nutr Sci. 2025;10(1):50-62. doi: 10.30476/ijns.2025.102992.1329.

Introduction

Taekwondo is an Olympic martial art. According to the International Taekwon-Do Federation, 153 countries from five continents are members of the federation. This sport encompasses a wide range of high-intensity attacks and low-intensity counter-attack techniques. Taekwondo athletes may have to compete in five fights per day to reach the finals (1). Neuromuscular coordination and the ability to maintain one-legged balance are two important prerequisites for successful taekwondo performance (2). Improving balance and space has a significant positive effect on the performance of taekwondo athletes and reduces the risk of lower limb injuries (3). Balance and coordination training are among the most common interventions to prevent deep sense disorders, improve postural and center of pressure (COP) awareness, and increase muscle activity (4). Balanced control relies on the mechanisms that receive sensory information from the visual and vestibular systems and the deep sense, combine and process it in the central nervous system, and provide effective and coordinated neuromuscular responses. Improving lower limb function in taekwondo athletes can improve static and dynamic balance and the ability to control posture (5).

Neuromuscular training (NMT) is a potentially effective intervention for improving balance in taekwondo athletes. It is a form of strength and fitness training that combines specific resistance, balance, central strength, dynamic stability, agility and plyometric exercises to improve motor skills (6). One study showed that NMT significantly improved lower limb function and joint position sense in athletes with chronic ankle instability (7). A systematic review also showed that athletes who incorporate NMT into their training can experience an improvement in their reaction time, coordination, performance, strength and balance (8). NMT also affects the sensitivity and responsiveness of the central nervous system and improves performance, motor coordination, muscle activity and strength, balance, functional stability of joints and the ability to control their body COP (9). In addition, NMT increases mechanoreceptors and neuromuscular coordination, allows the central nervous system to activate the motor nerves of the muscles in a coordinated pattern, improves the perception of joint position, improves the accuracy of information transmitted from the joint receptors to the central nervous system, and thereby improves performance and postural control (10). Some studies suggest that NMT improves dynamic balance, postural control, lower limb stability and deep sensory abilities (11).

Supplementation with minerals, especially calcium (Ca), magnesium (Mg) and zinc (Zn), is a new performance-oriented approach to improve various metabolic and physiological processes and recovery after exercise. Some of the physiological functions of minerals include improving muscle contraction, nerve impulse transmission, oxygen transport, enzyme activation, immune function, bone health and blood acid-base balance (12). It was shown that combined mineral supplements such as Ca-Mg-Zn may have a stronger effect than single mineral supplements (13).

The calcium component of Ca-Mg-Zn helps maintain muscle strength, reduces the risk of injury and shortens recovery time (14). The Ca-Mg-Zn component improves cardiovascular system function, increases energy levels, reduces fatigue and even improves muscle function and recovery after performance (15). Its zinc component also improves cell healing, immune function, hormone production, tissue oxygenation and aerobic endurance, reduces blood viscosity and injury risk, and shortens recovery time (16). Nevertheless, most athletes were found not to consume some supplements such as Ca-Mg-Zn adequately (17), which can negatively impact their performance and put them at risk of injury. For taekwondo players using mineral supplements such as Ca-Mg-Zn can protect athletes' health status by preventing nutrient deficiencies and to aid recovery after training (18). In a study conducted by Sousa *et al.*, most athletes stated that they use nutritional support products to speed up recovery, increase athletic performance and reduce fatigue. According to another study, the most common reason for using these products is to increase athletic performance and manage fatigue, which can improve muscle balance and EMG activity (19).

Although the positive effect of NMT on some body functions, especially balance, has been proven, some studies recommend further research to prove the best and most effective NMT protocols (10, 16). In addition, some studies reported the insignificant effect of NMT on athletes' balance and performance (20). Despite athletes' great interest in nutrition, they do not have sufficient nutritional knowledge to meet performance requirements and despite the lack of nutritional knowledge, athletes do not hesitate to utilize various sources for nutritional recommendations. In general, recommendations from teammates, competitors and influential people to improve performance or prevent disease were identified as the most important factors driving athletes to use nutritional supplements. Lack of knowledge of the athlete's mineral requirements due to incomplete and inadequate information from family, teammates and coaches has a negative impact on the athlete's performance. Furthermore, there is insufficient evidence of the positive effect of supplements on the physical performance of taekwondo athletes (21) and we could not find any studies on the effects of NMT and Ca-Mg-Zn supplementation among athletes. Therefore, the present study was conducted to investigate the effect of six weeks of NMT and Ca-Mg-Zn supplementation on balance and EMG activity of lower limb muscles among taekwondo athletes.

Materials and Methods

From September to December 2023, elite male taekwondo athletes who ranked 1-3 in national or international championships in the last five years or had participated in the premier league for five years were enrolled. Sixty athletes were purposively selected from 75 volunteers to participate in this study. The selection criteria were an age of 16-20 years, regular taekwondo training and regular participation in championships in the last six months before the study, first Dan black belt, no injury in the last three months, no participation in other NMT classes, and no special diet during the study. Exclusion criteria were three or more absences from taekwondo training sessions, any absence from NMT sessions, and muscle injuries during the study.

Participants were assigned to four fifteen-member groups, namely the control, the Ca-Mg-Zn, the NMT, and the Ca-Mg-Zn+NMT groups. A research assistant, who was not involved in the study, performed random allocation using random allocation software (RAS) and block randomization in four and eight blocks. Allocation was masked by identical opaque envelopes numbered 1-60. Accordingly, the interventionist and participants were blind to the order of allocation until the envelopes were opened. In addition, both the participants and their coaches were blind to the primary outcomes. The sample size was calculated using the software G*Power (v. 3.0.10) and with the F-test, the constant effect of the analysis of variance, a power of 0.85, a confidence level of 0.05, an effect size of 0.50 and a df of 3.0. The software issued 54 participants for four groups, which were increased to sixty (fifteen per group) to compensate for probable dropouts (22).

To assess Body Mass Index (BMI), weight was measured with as little clothing as possible and without shoes using a scale with an accuracy of 0.1 kg (Seca, Hamburg, Germany). Also, height was calculated in standing up position, without shoes and using a stadiometer with an accuracy of 0.1 cm (Seca, Hamburg, Germany). Finally, the BMI was determined by dividing the weight (kg) by the height squared (m^2). Balance was assessed using the Star Excursion Balance Test for dynamic balance and the Flamingo Balance Test for static balance. In the Star Excursion Balance Test (23), a star shape with eight lines in eight directions was formed on the floor. Each participant warmed up for five minutes and then stood with one leg in the center of the star and pulled the other leg as far as possible in the eight directions. Then, they repeated the test with the other leg. Each test was measured in centimeters from the center of the star.

Each participant performed the test twice immediately and twice thirty minutes after the NMT. The average of the moves in each direction was then calculated and divided by the leg length to determine the score of dynamic balance in the posterior-interior and anterior-posterior directions. The difference between the scores of the two rounds of testing was considered as the COP shift. The test was aborted and repeated if the participant lost balance or released their hands from their buttocks. The reliability of this test was confirmed elsewhere with correlation coefficients of 0.86-0.98 (24). The test was discontinued and repeated if the participant lost his balance or detached his hands from his buttocks. The reliability of this test was confirmed elsewhere with correlation coefficients of 0.86-0.98 (25).

The Flamingo Balance Test was used to assess static balance. In this test, each participant removed their shoes, placed their hands on their flank and bent one leg at the knee to attach the foot to the other knee. The stopwatch was started as soon as the sole was lifted and was stopped as soon as the hands were released from the flank, and the foot was released from the other knee or balance was lost. This test was performed three times for each participant, both with eyes open and closed, with an interval of three seconds. The difference between the best and worst performance was scored as the COP shifted. If there were more than fifteen falls in the first thirty minutes, the test was terminated and the participant scored zero (26).

In EMG activity, a sixteen-channel wireless electromyogram (V 4.24; Biomed Co., Iran) was used to measure the electrical activity (27) of the tibialis anterior, medial and lateral gastrocnemius, rectus femoris, and biceps femoris; while the participant performed the Dollyo Chagi taekwondo technique. First, we documented the maximum isomeric contraction of each muscle during its voluntary contraction. Each participant was asked to stand on the force plate at a distance of twenty centimeters from a taekwondo glove holder. They were then asked to perform the Dollyo Chagi technique so that their standing leg touched the force plate after a small jump. Electrical activity was measured for each participant for three successful performances of the technique and the average was used for data analysis. We attached the electrodes based on the Surface EMG for Noninvasive Assessment of Muscles (SENIAM) recommended in a previous study (27). Balance and EMG activity were assessed before (T1), three weeks (T2) and six weeks (T3) after the intervention.

All participants came from a taekwondo club, took part in competitions at the same level, completed identical technical exercises in four 120-minute training sessions per week from 18:00 to 20:00 pm, had the same coaches and did not engage in any other sporting activities apart from taekwondo. Participants in the NMT and Ca-Mg-Zn+NMT groups performed NMT four hours before their main taekwondo sessions in three sixty-minute sessions over six consecutive weeks. Each session consisted of five NMT exercises, namely flexibility, stability and proprioceptive training, core muscle strengthening, speed training, and plyometric and dynamic movements (Table 1). The perceived exertion of the NMT was determined to be 15-17 based on the Borg Rating of Perceived Exertion with a possible total score of 6-20. Participants in the control group and the Ca-Mg-Zn group completed their routine taekwondo exercises in four 120-minute sessions per week (28).

The Ca-Mg-Zn tablets (Omid Parsina Damavand Pharma, Tehran, Iran) used in this study contained 1050 mg Cal (RDA%=105), 525 mg Mg (RDA%=131) and 15 mg Zn (RDA%=136). Participants in the Ca-Mg-Zn and Cl-Mg-Zn+NMT groups received one Ca-Mg-Zn tablet daily for six weeks. Adherence to therapy was assessed at each taekwondo training session by counting the number of tablets remaining. In addition, participants were asked to complete a daily questionnaire on side effects and to inform us of any serious side effect that should be treated by a treating physician. We also asked them about their lifestyle habits, medical history and the food they had eaten in the three days prior to the procedure. They were asked not to take any mineral supplements during the study.

This study was ethically approved by the Ethics Committee of Shahid Madani University of Medical Sciences, Tabriz, Iran (code: IR.AZARUNIV.REC.1402.015) and registered in the Iranian Registry of Clinical Trials (code: IRCT20160523028028N3). The participants were informed about the aim, methods, advantages and possible disadvantages of the study in an introductory session, and informed consent was obtained from all of them. IBM SPSS software (version 16.0, Chicago, IL, USA) was used to analyze the data at a significance level of less than 0.05. Normality was tested using the Shapiro-Wilk test.

Table 1: The NMT intervention in our study.

Procedures
A. Warm-up (10 minutes)
General activities: a. Jogging: 3 minutes; b. Backwards running: 3 minutes; c. Lateral shuffling: 1 minute.
Specific activities: a. Carioca (Knee over and back out): 1 minute; b. Potentiation (depth jump and walking lunges): 3-5 repetitions×2-3 sets for each of them).
B. NMT (40-45 minutes, 3 exposures per week up to 6 weeks).
Mobility: a. Lunge to hamstrings dynamic stretch; b. Standing hip out; c. 90–90 hip stretch: 3 minutes.
Stability and proprioceptive exercises: a. Ap-Chagi: It can be performed by the front or rear leg in a given stance keeping balance, closing or furthering the distance, controlling spatial positioning 12 repetitions×2 sets×60 seconds rest per set; b. Catching and throwing a basketball without putting the foot down 12 repetitions×2 sets×60 seconds rest per set; c. One legged stance with the knee flexed on balance board. Throw and catch a ball over head alone while maintaining balance 60 seconds×2 sets×60 seconds rest per set.
Strengthening the core muscles: a. Dumbbell Split Squat (80% one-repetition maximum) 6 repetitions×2 sets×60 seconds rest per set; b. Dumbbell Thruster (80% one-repetition maximum) 6 repetitions×2 sets×60 seconds rest per set; c. Dumbbell Chest Press (80% one-repetition maximum) 6 repetitions×2 sets×60 seconds rest per set; d. Sit-up exercises 15 repetitions×2 sets×60 seconds rest per set.
Speed training: Running sets of 5 repetitions×20 m×30 seconds rest per set.
Plyometric and dynamic movement training: a. Single leg hop/switch for 30 seconds ×3 sets×30 seconds rest per set; b. Jumping over 30-60 cm obstacle for 30 seconds×3 sets×30 seconds rest per set.
C. Recovery and cool down (10 minutes).
Cycling recovery: The progressive recovery will help remove metabolic waste products from athlete muscles. Lightweight stationary bike was used for this purpose (AMH Fitness E110 stationary bike). 5 minutes.
Stretches aim to cool down: Forward fold 30 seconds; Standing Hamstring Stretch 30 seconds for each extremity; Standing Glute Stretch 30 seconds for each extremity; Chest opener 30 seconds; Standing Quad Stretch 30 seconds for each extremity around 5 minutes.

NMT: Neuromuscular training

The measures of descriptive statistics utilized to describe the data were mean, standard deviation, confidence level and frequency. One-way analysis of variance was used to compare the groups in terms of participants' baseline characteristics, baseline muscular EMG activity and baseline static and dynamic balance. In addition, repeated measures analysis of variance was performed for within-subject and between-subject comparisons across the three measurement time points. Sphericity was tested using the Mauchly test and post-hoc analyses were performed using the Bonferroni test. Cohen's standardized effect size was calculated for pairwise comparisons.

Results

Sixty male taekwondo athletes participated in the study in four groups of fifteen each, all of whom completed the study (Figure 1). None of the group comparisons regarding age, weight, height and BMI of the participants were significant ($p>0.05$; Table 2).

Participant balance improved in all four groups. The effect of time on static and dynamic balance (with the exception of the flamingo balance test with eyes closed) was significant in all groups ($p<0.05$). The effect of group on the result of the dynamic balance with eyes closed was not significant ($p=0.45$ at T2 and $p=0.18$ at T3) and the effect of time was only significant in the Ca-Mg-Zn+NMT group ($p<0.001$) (Table 3).

The effect of time and time-group interaction on dynamic balance with closed eyes were not significant ($p>0.05$). However, the effect of time on dynamic balance with eyes closed was significant in the Ca-Mg-Zn+NMT and NMT groups ($p<0.05$) (Table 3).

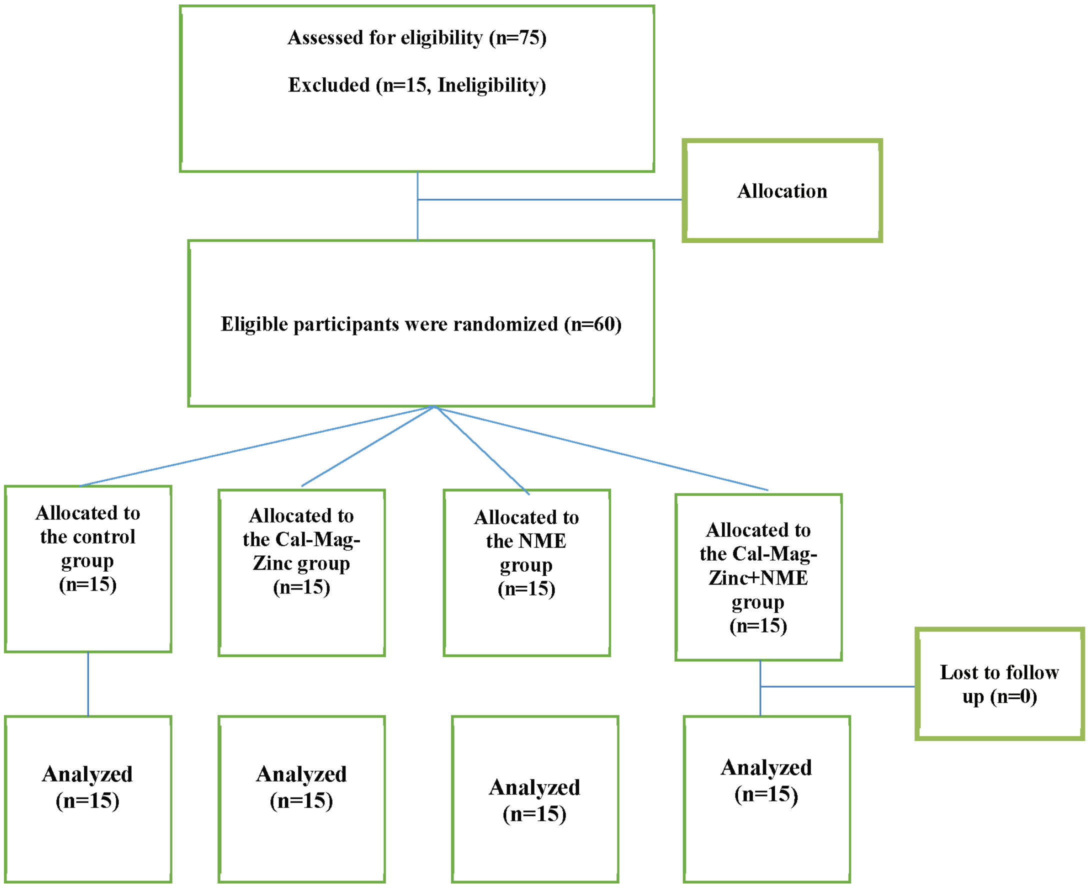

Figure 1: The flow diagram of the study.

Table 2: Participants' baseline characteristics.

Group	No.	Age (Year) Mean±SD	Weight (Kg) Mean±SD	Height (Cm) Mean±SD	BMI (Kg/m²) Mean±SD
Ca-Mg-Zn	15	17.93±1.48	69.13±6.43	177.20±5.30	21.95±2.40
NME	15	17.86±1.45	68.66±5.42	175.3±5.96	22.39±2.25
Ca-Mg-Zn+NMT	15	17.73±1.38	69.33±6.35	177.46±6.55	22.07±2.52
Control	15	18.20±1.26	70.33±7.99	172.93±6.25	23.44±2.85
P value*		0.82	0.91	0.16	0.36

NMT: Neuromuscular training; BMI: Body Mass Index; SD: Standard deviation; *:The results of the One-Way Analysis of Variance.

Table 3: Within- and among-group comparisons regarding the mean scores and the center of pressure variations across the three measurement time points.

Variable	Direction	Group	Mean±SD			*P* value[b]			Effect size
			Pre-intervention	Three weeks after intervention	Six weeks after intervention	Time	Group	Time* group	
COP (cm) displacement (static)	Posterior-interior	Ca-Mg-Zn+NMT	13.94±0.50	11.78±1.05	10.46±0.60	< 0.001 [All]	<0.001	<0.001	0.90
		NMT	13.79±0.56	12.69±0.95	12.26±0.90	0.001 [1-2] < 0.001 [1-3] 0.003 [2-3]			0,72
		Control	14.11±0.51	13.93±0.55	13.91±0.55	0.06 [1-2] 0.04 [1-3] 0.004[2-3]			0,34
		Ca-Mg-Zn	14±0.58	13.64±0.62	13.46±0.70	0.01 [1-2] 0.001 [1-3] 0.20 [2-3]			0.55
	P value[a]		0.44	<0.001	<0.001				
	Anterior- interior	Ca-Mg-Zn+NMT	14±0.47	12.41±0.43	11.37±0.48	<0.001 [All]	<0.001	<0.001	0.91
		NMT	14.38±0.43	14.07±0.47	13.38±0.69	0.01 [1-2] <0.001 [1-3] 0.10 [2-3]			0.74
		Control	14.10±0.70	14.07±0.69	13.93±0..3	0.01 [1-2] 0.07 [1-3] 0.12 [2-3]			0.29
		Ca-Mg-Zn	13.85±0.51	13.77±0.49	135.5±0.47	0.02 [1-2] 0.09 [1-3] 0.08 [2-3]			0,37
	P value[a]		0.06	<0.001	<0.001				
COP(s) displacement (dynamic)	Closed eyes	Ca-Mg-Zn+NMT	7.68±0.48	7.27±0.45	6.82±0.61	0.005 [1-2] <0.001 [1-3] 0.02 [2-3]	0.32	0.41	0.62
		NMT	7.64±0.44	7.43±0.45	7.17±0.40	0.04 [1-2] 0.002 [1-3] 0.03 [2-3]			0.49
		Control	7.58±0.63	7.55±0.54	7.28±0.59	0.20 [1-2] 0.009 [1-3] 0.21 [2-3]			0.39
		Ca-Mg-Zn	7.72±0.31	7.38±0.45	7.13±0.70	0.01 [1-2] 0.01 [1-3] 0.09 [2-3]			0.43
	P value[a]		0.63	0.45	0.18				
	Open eyes	Ca-Mg-Zn+NMT	6.32±0.27	5.89±0.36	4.73±0.55	0.010 [1-2] <0.001 [1-3] <0.001 [2-3]	<0.001	<0.001	0.82
		NMT	6.28±0.28	5.81±0.4	5.45±0.60	0.009 [1-2] <0.001 [1-3] 0.01 [2-3]			0.60
		Control	6.26±0.30	6.21±0.30	6.21±0.30	0.009 [1-2] 0.008 [1-3] 0.49 [2-3]			0.48
		Ca-Mg-Zn	6.31±0.25	6.07±0.37	6±0.43	0.015 [1-2] 0.016 [1-3] 0.45 [2-3]			0.41
	P value[a]		0.93	0.02	<0.001				

a: The results of the one-way analysis of variance for among group comparisons; b: The results of the repeated measures analysis of variance with Bonferroni's post hoc test for between group comparisons; NMT: Neuromuscular training; COP: Center of pressure. SD: Standard deviation; Ca-Mg-Zn; Calcium-Magnesium-Zinc.

Table 4: Within- and among-group comparisons regarding the root mean scores of muscular EMG activity 100 milliseconds before foot initial contact across three measurement time points.

Variable	Direction	Group	Mean+SD Pre-intervention	Mean+SD Three week after intervention	Mean+SD Six week after intervention	*P* value[b] Time	*P* value[b] Group	*P* value[b] Time * Group	Effect size
100 milliseconds before contact	Anterior tibialis	Ca-Mg-Zn+NMT	54.5±0.04	48.3±0.04	37.6±0.03	<0.001 [All]	<0.001	<0.001	0.83
		NMT	42.4± 0.05	38.2 ±0.03	39.4±0.04	0.002 [1-2] <0.001 [1-3] 0.001 [2-3]			0.67
		CG	44±0.03	43.1±0.03	42±0.03	0.05 [1-2] 0.02 [1-3] 0.33 [2-3]			0.36
		Ca-Mg-Zn	42±0.05	40.2±0.04	43.2±0.05	0.006 [1-2] 0. 001 [1-3] 0.56 [2-3]			0.49
	P value[a]		0.69	<0.001	<0.001				
	Medial gastrocnemius	Ca-Mg-Zn+NMT	48.3±0.45	42±0.05	40.8±0.04	<0.001 [All]	0.002	<0.001	0.87
		NMT	48±0.67	52±0.58	50±0.05	0.001 [1-2] <0.001 [1-3] <0.001 [2-3]			0.73
		CG	46±0.05	48±0.04	50±0.06	0.19 [1-2] 0.17 [1-3] 0.25 [2-3]			0.22
		Ca-Mg-Zn	47±0.05	47±0.50	62±0.07	1.00 [1-2] 0.25 [1-3] 0.08 [2-3]			0.20
	P value[a]		0.83	0.04	<0.001				
	Lateral gastrocnemius	Ca-Mg-Zn+NMT	46±0.06	49.1±13.52	52±0.06	<0.001 [1-2] 0. 93 [1-3] 0.96 [2-3]	0.55	0.56	0.87
		NMT	46±0.06	49±0.06	51±0.06	<0.001 [All]			0.84
		CG	46±0.03	47±0.03	39.98±13.55	0.02 [1-2] 0.99 [1-3] 1.00 [2-3]			0.56
		Ca-Mg-Zn	45±0.06	47±0.06	47±0.05	0.01 [1-2] <0.001 [1-3] 0.06 [2-3]			0.54
	P value[a]		0.91	0.06	0.56				
	Rectus femoris	Ca-Mg-Zn+NMT	64±0.05	55±0.03	48±0.03	<0.001 [All]	<0.001	<0.001	0.86
		NMT	56±0.02	54±0.02	49±0.04	0.002 [1-2] 0.001 [1-3] 0.013 [2-3]			0.60
		CG	47±0.06	49±0.05	50±0.06	0.19 [1-2] 0.32 [1-3] 0.71 [2-3]			0.17
		Ca-Mg-Zn	50±0.05	51±0.04	52±0.04	0.013 [1-2] 0.001 [1-3] 0.24 [2-3]			0.51
	P value[a]		0.60	0.01	<0.001				
	Biceps femoris	Ca-Mg-Zn+NMT	61±0.06	59±0.06	55±0.07	<0.001 [All]	0.21	0.48	0.87
		NMT	71±0.02	63±0.03	55±0.06	0.001 [1-2] 0.001 [1-3] 0.051 [2-3]			0.58
		CG	51±0.08	53±0.07	54.2±0.89	0.03 [1-2] 0.90 [1-3] 0.98 [2-3]			0.07
		Ca-Mg-Zn	53±0.05	51±0.06	53±0.05	0.001 [1-2] <0.001 [1-3] 0.14 [2-3]			0.65
	P value[a]		0.21	<0.001	0.46				

[a]: The results of the one-way analysis of for among group comparisons; b: The results of the repeated measures analysis of variance with Bonferroni's post hoc test for between group comparisons; NMT: Neuromuscular training: Ca-Mg-Zn; Calcium-Magnesium-Zinc; SD: Standard deviation.

The effect of time-group interaction in all groups and the effect of time on dynamic balance with eyes open in the Ca-Mg-Zn+NMT and NMT groups were significant ($p<0.05$) (Table 3). The effect of group and time-group interaction on the EMG activity of the anterior tibialis, medial and lateral gastrocnemius, rectus femoris, and biceps femoris muscles were not significant ($p>0.05$). The results of the Bonferroni test also showed significant differences between the groups in terms of RMS of EMG activity of the anterior

Table 5: Within- and among-group comparisons respecting the root mean scores of muscular EMG activity 100-200 milliseconds after foot initial contact across three measurement time points.

Variable	Direction	Group	Mean+SD Pre-intervention	Mean+SD Three week after intervention	Mean+SD Six week after intervention	*P* value[b] Time	*P* value[b] Group	*P* value[b] Time Group	Effect size
100-200 milliseconds after contact	Anterior	Ca-Mg-Zn+NMT	16.5±0.003	16.3±0.005	16±043	0.001 [1-2] 0.002 [1-3] <0.001 [2-3]	0.63	0.001	0.59
		NMT	14.5±0.43	15±0.30	15.1±0.21	0.13 [1-2] 0.06 [1-3] 1.00 [2-3]			0.26
		CG	14.7±0.41	13.9±0.41	13±0.41	<0.001 [1-2] 0.001 [1-3] 0.001 [2-3]			0.009
		Ca-Mg-Zn	15±0.43	15.5±0.39	15.3±0.39	0.091 [1-2] 0.091 [1-3] 0.001 [2-3]			0.19
	P value[a]		0.51	0.10	0.05				
	Medial gastrocnemius	Ca-Mg-Zn+NMT	13±0.002	12.4±0.003	10.9±0.003	<0.001 [All]	<0.001	<0.001	0.87
		NMT	12.4±0.002	12.2±0.002	11.9±0.003	<0.001 [1-2] <0.001 [1-3] 0.001 [2-3]			0.73
		CG	11.8±0.002	11.8±0.002	11.8±0.002	1.00 [1-2] 1.00 [1-3] 1.00 [2-3]			0.22
		Ca-Mg-Zn	12±0.003	12±0.003	12.1±0.003	1.00 [1-2] 0.058 [1-3] 0.058 [2-3]			0.20
	P value[a]		0.18	<0.001	<0.001				
	Lateral gastrocnemius	Ca-Mg-Zn+NMT	13.8±0.003	13.3±0.005	12±0.006	<0.001 [All]	0.005	>0.001	0.80
		NMT	13.3±0.005	13±0.005	12.8±0.005	0.03 [1-2] 0.001 [1-3] 0.002 [2-3]			0.56
		CG	12.5±0.007	12.5±0.007	12.5±0.007	1.00 [1-2] 1.00 [1-3] 1.00 [2-3]			0.06
		Ca-Mg-Zn	12.7±0.005	12.8±0.006	12.8±0.006	0.54 [1-2] 0.33 [1-3] 0.49 [2-3]			0.14
	P value[a]		0.49	0.01	<0.001				
	Rectus femoris	Ca-Mg-Zn+NMT	16.3±0.003	16.1±0.006	15.8±0.43	0.004 [1-2] 0.005 [1-3] <0.001 [2-3]	0.62	0.65	0.59
		NMT	16.5±0.006	16.2±0.006	16±0.430	0.001 [1-2] 0.001 [1-3] 0.002 [2-3]			0.52
		CG	14.3±0.42	14.4±0.005	14.2±0.001	0.026 [1-2] 0.026 [1-3] 1.00 [2-3]			0.40
		Ca-Mg-Zn	14±0.42	14.3±0.004	15.2±0.004	0.001 [1-2] 0.001 [1-3] 0.14 [2-3]			0.50

P value[a]		0.64	0.003	<0.001				
Biceps femoris	Ca-Mg-Zn+NMT	13.2±0.006	13.6±0.005	14.1±0.004	<0.001 [1-2] <0.001 [1-3] 0.001 [2-3]	0.39	0.40	0.74
	NMT	13.7±0.007	13.4±0.006	14±0.005	0.001[1-2] 0.001 [1-3] 0.002 [2-3]			0.64
	CG	13.3±0.007	13.8±0.0	13.9±0.01	1.00 [All]			0.06
	Ca-Mg-Zn	13.6±0.007	13.7±0.007	13.8±0.007	0.24 [1-2] 0.06 [1-3] 0.52 [2-3]			0.25
P value[a]		0.18	0.40	0.007				

[a]: The results of the one-way analysis of variance for among group comparisons; b: The results of the repeated measures analysis of variance with Bonferroni's post hoc test for between group comparisons; NMT: Neuromuscular training: Ca-Mg-Zn; Calcium-Magnesium-Zinc; SD: Standard deviation; EMG: Electromyography.

tibialis, medial gastrocnemius and biceps femoris in 100 milliseconds before foot contact ($p<0.01$). The effect of the time-group interaction on the EMG activity of these muscles was also significant ($p<0.001$) (Table 4). The analysis of EMG activity in the 100-200 milliseconds interval after foot contact with the mitt showed significant differences among the groups at both T2 and T3. However, the effect of group on the EMG activity of the anterior tibialis, rectus femoris, and biceps femoris muscles and the effect of time-group interaction on the EMG activity of the rectus femoris and biceps femoris muscles were not significant ($p>0.05$) (Table 5).

Discussion

The aim of this study was to investigate the effect of six weeks of NMT and Ca-Mg-Zn supplementation on balance and EMG activity of lower limb muscles in Taekwondo athletes. Significant improvements were observed in the mean values of most study outcomes, with effect sizes of dynamic and static balance and muscular EMG activity at T3 being greater in the Ca-Mg-Zn+NMT group than in the other groups. These results suggest that the addition of Ca-Mg-Zn to NMT more significantly improved neuromuscular function and reduced COP shift. NMT may lead to these changes by improving neuronal adaptation of muscle fibers, Golgi apparatus, and deep sensory receptors, enhancing deep senses and increasing lower limb strength. Postural control when standing on one foot is a key factor in improving physical function. In addition, improving neuromuscular control of the trunk has a positive effect on balance by improving the stability of the body's COP. A previous study revealed that training depth perception and trunk stability had significant positive effects on the balance abilities of taekwondo athletes (29).

Balance control is a complex motor function that requires the interaction of several dynamic sensorimotor processes. It involves motor coordination and muscular synergy to stabilize the COP (30). It was shown that NMT significantly improved athletes' postural control, reduced COP displacement and thereby improved static and dynamic balance (10). NMT stimulates the different parts of the nervous system involved in stability and shortens the time required to receive sensory stimuli and execute motor responses. It appears that NMT causes continuous stimulation of articular and periarticular mechanoreceptors, thereby improves the sensitivity of neuromuscular receptors to joint position (31).

The acceleration of reflexive muscle contractions also reduces joint loads during exercise and improves static and dynamic balance (27). The sport-induced improvement of neural mechanisms, the use of more effective muscle mass, the reduction of inhibitory neural responses and the facilitation of sensory signaling can lead to structural changes in the muscles and increase muscle strength. Greater muscle strength, in turn, provides greater muscular support to the joints, particularly the knee and hip, and ultimately improves joint stability and balance (32). It was demonstrated that strength training and NMT increased lower limb muscle strength and improved balance, lower limb stability and postural control (29). Another study found that training on stable and unstable surfaces could improve balance (33).

Balance is controlled by various neuromuscular processes, including sensory afferents, central control processes and muscular responses. Therefore, the improvement of muscular EMG strength is a factor that contributes to the improvement of balance (34). A significant increase in calf muscle activity after NMT is strongly correlated with the ability to control balance. In addition, NMT has a positive effect on central nervous system sensitivity and responsiveness, motor unit coordination, muscle activation, muscle strength and balance in taekwondo athletes. In addition, the integration of balance exercises into NMT protocols appears to increase periarticular muscle activation and active joint stability through increased muscular EMG activity (8).

NMT focuses on exercises that train muscles and neurons, thereby helping the brain to improve the relationship between the body and the subconscious mind. This coordination helps athletes improve their muscular EMG activity and their brain's ability control balance (8). One study illustrated that NMT, such as standing on unstable ground, increased EMG activity in the muscles of the lower limbs (35). Successful taekwondo performance is largely dependent on rapid changes of direction, and increases and decreases in speed and jumps, which describe why maintaining static and dynamic stability of the ankle joint, EMG strength of the muscles and good depth sense function are essential for the prevention of ankle injuries (35).

According to one study, an integrative NMT program successfully improved all assessed aspects of functional performance (movement quality, speed, agility, strength, endurance, flexibility and power). The isolated NMT program, on the other hand, only improved strength and flexibility (36). The principle of specificity of training reveals that training must stress the systems involved in performing a particular activity in order to achieve specific training adaptations. This principle is one explanation for the greater effectiveness of the NMT program in our study. These results suggest that integrated training programs are better suited to improve balance and EMG activity in elite taekwondo athletes. Efforts to improve balance and EMG activity have been successful by integrating various plyometric, resistance, flexibility, balance, and agility exercises into a training program. The results of this study are novel, as there is one study that exhibits a simultaneous improvement in exercise quality and performance measures (37).

Training volume may also be a key factor in the change in balance and EMG activity. In a previous study, the duration of the program was 10-15 minutes and did not result in improvement in movement control in subjects who began the program (37). In this study, the integrative NMT program was performed three times a week and for the same amount of time per day (60 minutes), resulting in a higher total training volume. This result suggests that individuals with good training quality can improve even further by increasing the integrative training volume. Furthermore, due to the exacerbation of muscle damage associated with the inflammatory response following NMT training, research has shown great interest in recovery strategies that reduce the production or promote the degradation of compounds associated with inflammation and oxidative stress. However, it is important to keep in mind that the inflammatory process acts as a stimulus for adaptation to NMT and taekwondo training. At this point, the degree of adaptation may even be impaired as the individual's ability to training decreases. For this damage, the recovery strategies are designed to prevent. Various food components contain nutrients that can accelerate recovery after exercise. In practice, taking Ca-Mg-Zn supplement may improve performance in multi-day or multi-week sporting events or allow for a higher training load with less risk of injury and/or excessive fatigue (38).

In contrast to our findings, an insignificant effect of NMT on balance and EMG activity of lower limb muscles was demonstrated before (33). One explanation for this contradiction may be the difference between the studies in terms of their NMT protocol. In addition, these studies did not use Ca-Mg-Zn supplementation together with NMT. As far as we know, this was the first comparative study on the effect of Ca-Mg-Zn supplementation and NMT. Given the greater efficacy of the Ca-Mg-Zn+NMT intervention in comparison to only Ca-Mg-Zn or NMT intervention to significantly improve balance and EMG activity, Ca-Mg-Zn supplementation can be used together with NMT to synergistically enhance their efficacy. Physical activity increases Ca requirement for stronger muscle contractions, so insufficient Ca intake in athletes may lead to a reduction in muscle strength and balance control, increasing the risk of sports injuries and premature osteoporosis (39).

Ca-Mg-Zn also plays an important role in the transmission of nerve signals and muscle contraction. One study revealed that taking Mg can increase glucose absorption and lactate accumulation in the muscles, thereby improving performance and balance (40) and reducing muscle cramps. Zinc also improves the function of fast-twitch muscle fibers, physical performance during speed training, muscle energy production and protein synthesis. One study showed the significant increase in dynamic isokinetic strength in angular endurance and speed in athletes who received zinc. Consequently, zinc deficiency may have a negative impact on athletic performance (40). There were limitations in our study such as our study sample that consisted only male taekwondo athletes.

Conclusion

The combination of NMT and Ca-Mg-Zn supplementation can be an effective strategy to significantly improve static and dynamic balance and muscular EMG activity in taekwondo athletes. However, NMT may have little effect on muscular EMG activity and dynamic balance with eyes closed. Therefore, NMT together with Ca-Mg-Zn supplementation is recommended to improve postural control and muscle function and prevent sports injuries in taekwondo athletes. Also, further studies with different age and gender groups are needed to better substantiate the effect of NMT and Ca-Mg-Zn supplementation on balance and EMG activity of lower limb muscles among taekwondo athletes.

Acknowledgement

The authors of this study would like to thank the taekwondo athletes who participated in the study and the authorities of the study setting.

Funding

This project was supported by a research grant from Azarbaijan Shahid Madani Unversity (garant number 1402/493/1).

Authors' Contribution

All authors have made a direct and intellectual contribution to the work. The authors designed and conducted intervention, wrote the manuscript, collected date and interpreted it, revised paper for content and edited it grammatically and scientific witting.

Conflict of Interest

None declared.

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