Sport Sciences and Health Research
EISSN:2981-0205
https://sshr.ut.ac.ir/
University of Tehran Press

The influence of neuromuscular training and Ca-Mg-Zn therapy on reaction time and electromechanical delay in taekwondo athletes

Azam Zarneshan[1], Leyla Esmealy[2], Babak Esmealy[3]*

1. Department of Sport Sciences, Faculty of Shohada, University of Azarbaijan Shahid Madani, Tabriz, Iran.
2. Department of Nursing Sciences, Faculty of Nursing and Midwifery, Tabriz University of Medical Sciences, Tabriz, Iran.
3. Department of Exercise and Sport Physiology, Faculty of Physical Education and Sport Sciences, University of Tabriz, Tabriz, Iran. (*Corresponding author: ✉ babakesmaeili97@gmail.com, https://orcid.org/0000-0001-6634-1404)

Article Info

Article type:
Original Article

Article history:
Received: 18 March 2024
Revised: 03 May 2024
Accepted: 16 June 2024
Published online: 01 July 2024

Keywords:
dietary supplementation, electromyography, neuromuscular training, physical exercise, rehabilitation.

Abstract

Background: Neuromuscular training (NMT) and supplementation with essential minerals such as calcium (Ca), magnesium (Mg), and zinc (Zn) may enhance muscular reaction time (RT) and electromechanical delay (EMD). However, research on this topic, particularly among taekwondo athletes, is limited.

Aim: This study aimed to evaluate the effects of NMT and Cal-Mg-Zn supplementation on RT and EMD in taekwondo athletes.

Materials and Methods: Sixty athletes from a single taekwondo club in Tabriz, Iran, were randomly assigned to four groups of fifteen: Control, Ca-Mg-Zn, NMT, and Cal-Mg-Zn + NMT. NMT was conducted in 60 min sessions, four times a week, for six consecutive weeks, prior to main taekwondo training. RT and EMD were measured using electromyography before the intervention (T1), three weeks after (T2), and six weeks after (T3). Data were analyzed using SPSS with a confidence level greater than 0.95, employing repeated measures ANOVA and Bonferroni post hoc tests.

Results: No significant differences in RT and EMD were observed among the groups at baseline ($P > 0.05$). In both post-test assessments, the Cal-Mg-Zn + NMT group exhibited significantly lower RT and EMD compared to the other groups ($P < 0.05$).

Conclusion: The inclusion of NMT with zinc supplementation can effectively improve RT and EMD, thereby enhancing the athletic performance of taekwondo athletes.

Cite this article: Zarneshan A, Esmealy L, Esmealy B. "The influence of neuromuscular training and Ca-Mg-Zn therapy on reaction time and electromechanical delay in taekwondo athletes". *Sport Sciences and Health Research*. 2024; 16(2): 191-204. DOI: https://doi.org/10.22059/sshr.2024.378153.1149.

EISSN: 2981-0205 | Web site: https://sshr.ut.ac.ir/ | Email: sshr@ut.ac.ir
 Publisher: University of Tehran

1. Introduction

Taekwondo is a very popular martial art practiced by 75 to 120 million athletes in 140 countries [1]. A key factor in the success of Taekwondo athletes is the ability of the lower limbs to perform fast kicking, jumping and landing techniques, which are highly dependent on reaction time (RT).

Research has shown that winning in taekwondo is related to a shorter RT rather than the complexity of the techniques [2, 3]. Fast, explosive movements, the simultaneous use of hands and feet and the ability to attack and defend quickly are all influenced by RT. Consequently, an athlete's success in both offensive and defensive maneuvers in martial arts depends largely on their speed of movement, joint flexibility and RT [4].

RT is the time it takes to react to a stimulus, e.g. an opponent's kick. Exercises that improve RT can increase the effectiveness of taekwondo techniques and increase the chances of winning competitions [5]. Conversely, prolonged RT can negatively impact a muscle's ability to quickly stabilize joints against external forces during physical activity, increasing the risk of muscle and ligament injuries [6]. Normally, the sensory organs, nervous system and muscle strength contribute to an inherent delay in muscle response. This delay is referred to as the electromechanical delay (EMD) and is defined as the time interval between neural stimulation at the neuromuscular junction and the onset of force development in the muscle [7, 8].

One study found that prolonged EMD may increase the risk of anterior cruciate ligament (ACL) injuries and ankle sprains by impairing metabolic-muscular interactions and excitation-contraction coupling [9]. Therefore, techniques to reduce RT and EMD are critical to improving performance and minimizing injury risk. Neuromuscular training (NMT) is one strategy that can have a positive impact on RT and EMD. It includes resistance, balance, strength and stability exercises that can improve dynamic resistance mechanisms and joint support velocity [10, 11].

A meta-analysis found that athletes who practiced NMT had shorter RT and EMD, improved performance, greater flexibility, better coordination, higher endurance, and lower risk of injury [12]. In addition, two recent studies have shown that NMT significantly improves lower limb function and joint position sense in athletes with functional ankle instability [13] and decreased RT and EMD of the peroneus longus muscle in athletes with a history of concussion [14].

A study with female rugby players showed that NMT reduces injuries and RT. NMT improves retrieval patterns and muscular RT while generating stabilizing forces in the joints that counteract stability-reducing forces, prevent connective tissue injuries and improve joint control and positional awareness [15, 16]. However, the combination of NMT and regular taekwondo training can lead to increased excretion of essential minerals via sweat and urine [17]. Calcium (Ca), magnesium (Mg) and zinc (Zn) are crucial for athletic performance. Although these minerals occur naturally in the diet, this is often not enough to cover the requirements. Therefore, combined mineral supplements, such as Ca-Mg-Zn, have become very popular.

The intake of this dietary supplement by athletes can help to regulate changes in the skeletal, metabolic and immune systems. Calcium (Ca) is essential for bone health; therefore, Ca supplementation can promote bone formation and inhibit bone resorption. In addition, Ca is crucial for the conversion of vitamin D into its active form [18, 19]. Magnesium (Mg) supplementation has been shown to reduce chronic inflammatory markers such as C-reactive protein and interleukin 6 [20]. In addition, Ca-Mg-Zn supplementation supports the regulation of glucose levels in competitive athletes [21, 22, 23], reduces inflammation [24], alleviates anxiety by stimulating the parasympathetic nervous system [25, 26] and improves sleep quality [27]. As a result, this can lead to shorter RT and improved explosive muscle development (EMD), which ultimately enhances athletic performance [28]. The physiological functions of these minerals are particularly important for Taekwondo athletes as they are involved in muscle contraction, heart rhythm regulation, nerve signaling, oxygen transport, protein synthesis, cellular integrity and bone health. These processes are enhanced during exercise and contribute to improved RT and EMD [28].

Although NMT and mineral supplements can reduce RT and EMD [15, 29, 30], further research is needed to establish optimal protocols for their use [29, 31]. In addition, there is limited research on the combined effects of NMT and mineral supplementation on RT and EMD in taekwondo athletes. This study aims to address these gaps by investigating the effects of NMT and Ca-Mg-Zn therapy on RT and EMD in this population.

2. Materials and Methods

This study, conducted in 2023, used a four-group randomized controlled design. The sample size was determined with G*Power software (v. 3.0.10) using the parameters for the F-test of variance analysis with a constant effect, a type I error rate of 0.05, a type II error rate of 0.15, an effect size of 0.50 and three degrees of freedom for four groups. The calculations revealed a need for 54 participants, and 60 athletes were finally recruited [32, 33]. Participants were randomly divided into four groups of 15 each— control, Ca-Mg-Zn, NMT and Ca-Mg-Zn+NME— using block randomization with block sizes of 4 and 8.

A colleague not involved in the study created the randomization sequence using the Random Allocation Software. To conceal this sequence, it was placed in sixty identical opaque envelopes numbered from 1 to 60 for each participant. This ensured that both the researchers and the participants were unaware of the randomization until the envelopes were opened. In addition, the participants and their taekwondo instructors were kept in the dark about the preliminary results of the study (Figure 1).

2.1. Participation

Sixty elite male taekwondo athletes who had placed first to third in national or international competitions in the past five years participated in the study. Out of 75 athletes from a single club in Tabriz, Iran, 60 were randomly selected to participate. All participants competed at the same level, underwent identical technical exercises, had the same coaches and regularly attended two-hour training sessions four times a week from 18:00 to 20:00.

The sampling criteria included people aged 16 to 20 years who had regularly practiced taekwondo at first dan (black belt) level in the last six months. Participants were not allowed to have suffered any sports injuries in the last six months, not have participated in other NMT programs and not have taken any dietary supplements during the study. Those who missed taekwondo training more than three times, missed NMT training once, or sustained a muscle injury during the study were excluded.

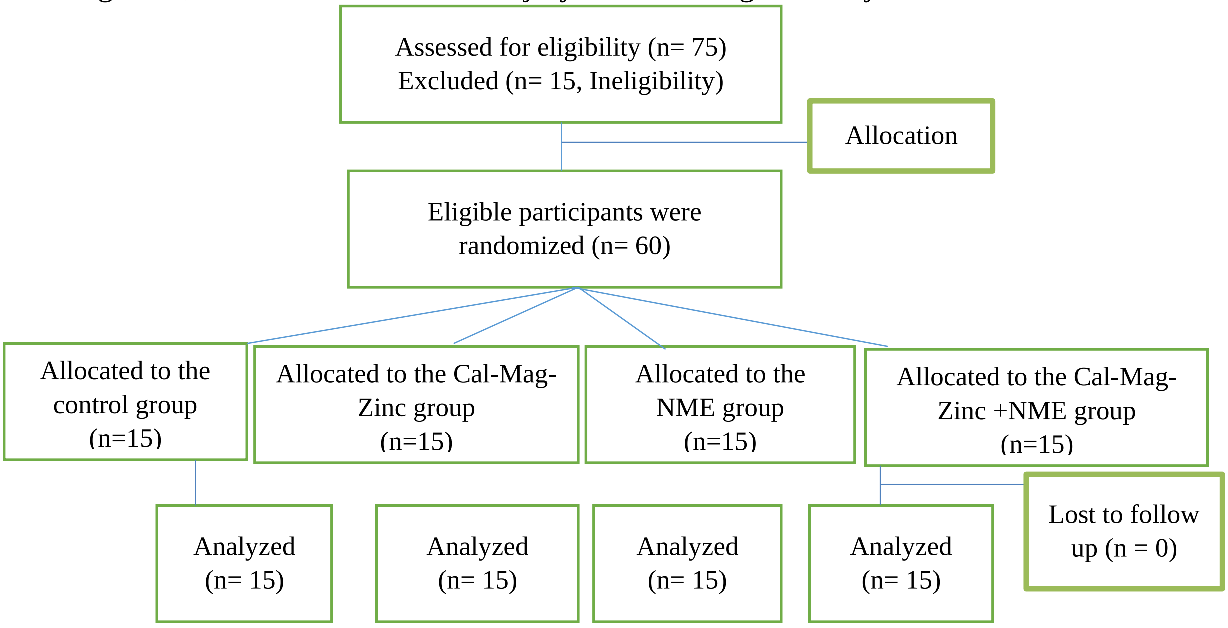

Figure 1. The flow diagram of the study

2.2. Instrument

RT was measured by five repetitions of the bandal tchagui technique, the most common taekwondo kick, with a 3-5 sec pause between sets [34]. Trochanter height, defined as the distance from the trochanter to the ground, was used to determine the target distance. An electronic device emitted a light stimulus to indicate the optimal moment for the kick. RT was recorded as the time from the light stimulus to the athlete's foot movement using either a foot guard with electronic sensor (GEN2, Daedo) or a trunk guard with electronic sensor (HGD10, Daedo). The impact time was measured from the light stimulus to the contact of the foot with the target. The best and worst performance of each participant was excluded, and the mean of the three remaining trials was recorded. Prior to the measurements, participants attended an orientation session to familiarize themselves with the equipment.

EMD was measured using transcutaneous electrical stimulation (EMG) of the common peroneal nerve [35]. The EMG electrode was placed on the nerve at the posterior aspect of the fibular head. The reaction force on the lateral floor indicated the mechanical response to the stimulation. Each participant positioned their test leg at a specific location on the force plate, with the other leg resting outside the plate to support themselves while holding onto a railing to prevent swaying. They were instructed to maintain this position and look forward. The stimulation intensity was gradually increased until a maximal efferent response was recorded via electromyography. At this intensity, the peroneal nerve was stimulated ten times, with an interval of 15 sec between each stimulation. The time of onset of the electromyographic response and the strength of the lateral ground response were identified as the moment at which the signal exceeded the mean resting activity during standing. EMD was defined as the time interval between the onset of electromyographic activity in the longus peroneus muscle and the onset of the lateral floor response strength.

Electromyographic activity was recorded using a sixteen-channel wireless electromyograph (V.4.24, Biomed Co., Iran) with pre-taped Ag-AgCl disposable electrodes for amplification. Data were recorded at a sampling rate of 1000 Hz. The amplifier had an input impedance of 1.0 MΩ, a common mode rejection ratio of 90 dB, and high-pass and low-pass filters of 20 Hz and 400 Hz, each. RT and EMD were measured at three time points: before the intervention, three weeks after, and six weeks after (T1–T3).

2.3. Procedure

The NMT intervention was conducted with participants from both the NMT and Ca-Mg-Zn + NMT groups. It consisted of five core exercises (Table 1) performed in 6 min sessions four times a week, four hours before actual taekwondo training, for six weeks.

Table 1. The NME protocol of the study

1. warm-up (10 min) • General activities: a) Jogging: 3 min b) Running backwards: 3 min c) Lateral shuffle: 1 min • Specific activities: a) Carioca (knee rollover and backflip): 1 min b) Potentiation (depth jumps and walking lunges): 2–3 sets of 3–5 repetitions each
2. NMT (40–45 min, 3 sessions per week for up to 6 weeks) • Agility (3 min total): a) Dynamic lunge to stretch the hamstring b) Standing hip abduction c) 90–90 hip extension • Stability and proprioception exercises: a) Ap-chagi: Perform the exercise with either the front or back leg while maintaining balance. Perform 12 repetitions for 2 sets with 60 sec rest between sets. b) Catch and throw a basketball without putting your foot down: 12 repetitions for 2 sets with 60 sec rest between sets. c) One-legged stand on a balance board: Maintain balance while throwing and catching a ball overhead for 60 sec. 2 sets with 60 sec rest between sets. • Core strengthening: a) Dumbbell split-squat (80% of maximum for one repetition): 6 repetitions for 2 sets with 60 sec rest between sets. b) Dumbbell thruster (80% of maximum in one repetition): 6 repetitions for 2 sets with 60 sec rest between sets. c) Dumbbell chest press (80% of maximum for one repetition): 6 repetitions for 2 sets with 60 sec rest between sets. d) Sit-ups: 15 repetitions for 2 sets with 60 sec rest between sets. • Speed training: a) Running: 5 repetitions of 20 meters with 30 sec- Plyometric and dynamic movement training. b) Single leg jump/switch: 30 sec for 3 sets with 30 sec rest between sets. c) Jump over a 30–60 cm high obstacle: 30 sec for 3 sets with 30 sec rest between sets.
3. Recovery and cooling down (10 min) • Cycling for recovery: Progressive cycling helps the athlete to remove metabolic waste from the muscles. This is done on a light stationary bike (AMH Fitness E110) for 5 min. • Stretching to cool down (5 min): a) Forward bend: 30 sec b) Standing hamstring stretch: 30 sec for each leg c) Standing glute stretch: 30 sec for each leg d) Chest opener: 30 sec e) Standing quad stretch: 30 sec for each leg.

The Borg RPE, which ranges from 6 to 20, was used to ensure that the intensity of NMT was maintained at a level of 15 to 17. Participants in the Ca-Mg-Zn and Ca-Mg-Zn + NMT groups received one Ca tablet each night [34]. Each tablet contained 1,050 mg calcium carbonate, 525 mg magnesium oxide and 15 mg zinc oxide. To assess treatment adherence, the number of tablets not taken was recorded. Participants also completed a side effect booklet and were advised that they should contact us for medical help in the event of severe side effects. In addition, each participant was asked about their medical history and lifestyle habits and kept a food diary to document their food intake over the previous three days (Table 1).

2.4. Statistic

The data analysis was performed with IBM SPSS (v.16.0) with a confidence level of over 0.95. The Shapiro-Wilk test assessed the normality of the study data. A one-way analysis of variance compared the demographic characteristics of the participants as well as the TR and EMD baseline scores of the individual groups. In addition, a repeated-measures analysis of variance was used for within-group and between-group comparisons to assess TR and EMD variation at four measurement time points. Sphericity was tested using the Mauchly test, and post-hoc analyses were performed using the Bonferroni method. Cohen's effect size was calculated for pairwise comparisons.

3. Results

No significant differences were found between the four study groups in terms of age, height, weight and body mass index of the participants ($P > 0.05$; Table 2).

Table 2. Participant's demographics characteristics

Groups	n	Age (years) Mean± SD	Weight (kg) Mean± SD	Height (cm) Mean± SD	BMI (kg/m^2) Mean± SD
Cal-Mag-Zinc	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
Cal-Mag-Zinc+ NME	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
*The results of the one-way analysis of variance, $P<0.05$

While there was no significant difference in RT at baseline ($P= 0.47$), the interaction between group and time in RT was significant ($P< 0.05$). Notable differences in mean RT were found at T2 and T3 ($P< 0.01$), with the Ca-Mg-Zn+ NMT group showing a significantly lower mean RT compared to the other groups ($P< 0.05$).

In addition, the effect of time on RT was significant in the Ca-Mg-Zn + NMT and NMT groups, with significant differences found between T1 and T2, T1 and T3, and T2 and T3 ($P< 0.05$). However, the effect of time on RT was not significant in the control and Ca-Mg-Zn groups ($P> 0.05$). The largest and smallest effect sizes were recorded in the Ca-Mg-Zn + NMT group (0.88) and the control group (0.04), respectively.

There were no significant differences in the mean EMD values of the biceps femoris, semimembranosus and semitendinosus between the groups during knee flexion at velocities of 60, 180 and 300 degrees/second ($P> 0.05$). The range of motion for knee extension ranged from 120 to 0 degrees, with 0 degrees representing full extension.

Table 3. Comparisons of mean values for EMD within and between groups at three measurement time points

Muscles	Group	Time	Ca-Mg-Zn+ NMT	NMT	Control	Ca-Mg-Zn	P value[a]	P value[b]	
								Group	Time×group
Biceps femoris	60 °/s	Baseline	23.51±0.76	23.53±0.97	23.46±0.74	23.42±0.99	0.98	< 0.001	< 0.001
		3 weeks after	21.80±0.94	23.13±0.91	23.76±0.94	23.90±1.16	< 0.001		
		6 weeks after	20.53±0.74	22.60±0.91	23.96±0.85	24.03±1.10	< 0.001		
		Effect size	0.84	0.36	0.25	0.44	-		
	P value[b]	Time	< 0.001 [All]	0.33 [1-2] 0.01 [1-3] 0.01 [2-3]	0.29 [1-2] 0.004 [1-3] 0.56 [2-3]	0.02 [1-2] 0.004 [1-3] 0.49 [2-3]	-		
	180°/s	Baseline	42.06±1.10	42.30±1.49	42.76±1.62	41.63±1.43	0.18	< 0.001	< 0.001
		3 weeks after	39.93±0.96	40.86±1.4	43.24±1.66	42.26±1.43	< 0.001		
		6 weeks after	36.66±1.67	39.46±0.99	43.30±1.72	42.26±1.43	< 0.001		
		Effect size	0.92	0.85	0.23	0.77	-		
	P value[b]	Time	< 0.001 [All]	< 0.001 [All]	0.13 [1-2] 0.002 [1-3] 1.00 [2-3]	< 0.001 [All]	-		
	300°/s	Baseline	49.53±3.02	52.66±1.91	51.26±4.00	51.13±3.39	0.07	< 0.001	< 0.001
		3 weeks after	46.13±2.97	51.26±2.71	51.53±3.90	50.93±3.47	< 0.001		
		6 weeks after	41.73±3.03	49.73±2.76	51.66±3.99	50.80±4.21	< 0.001		
		Effect size	0.92	0.66	0.18	0.019	-		
	P value[b]	Time	< 0.001 [All]	0.005 [1-2] < 0.001 [1-3] 0.002 [2-3]	0.31 [1-2] 0.16 [1-3] 1.00 [2-3]	1.00 [All]	-		
Semimembranosus	60 °/s	Baseline	24.20±0.86	23.83±1.33	24.63±1.49	24.16±1.53	0.44	< 0.001	< 0.001
		3 weeks after	22.20±0.94	22.53±1.12	25.06±1.70	24.20±1.82	< 0.001		
		6 weeks after	20.13±0.35	21.53±0.91	25.13±1.72	24.60±2.32	< 0.001		
		Effect size	0.92	0.77	0.35	0.10	-		
	P value[b]	Time	< 0.001 [All]	< 0.001 [All]	0.05 [1-2] 0.02 [1-3] 1.00 [2-3]	1.00 [1-2] 0.73 [1-3] 0.16 [2-3]	-		
	180°/s	Baseline	45.13±3.41	44.76±2.69	44.46±3.28	44.23±2.36	0.85	0.007	< 0.001
		3 weeks after	41.33±2.41	42.86±2.09	44.86±3.56	44.13±2.64	0.005		
		6 weeks after	37.53±2.97	41.33±0.002	44.93±3.55	44.20±3.66	< 0.001		
		Effect size	0.84	0.77	0.30	0.002	-		

Muscles	Group	Time	Ca-Mg-Zn+ NMT	NMT	Control	Ca-Mg-Zn	P value[a]	P value[b] Group	P value[b] Time×group
	P value[b]	Time	< 0.001 [All]	< 0.001 [All]	0.12 [1-2] 0.04 [1-3] 1.00 [2-3]	1.00 [All]	-		
	300˚/s	Baseline	50.73±2.89	51±3.38	51±3.83	51.93±2.71	0.75	0.001	< 0.001
		3 weeks after	46.66±2.76	48.93±3.63	50.86±4.42	51.66±3.69	0.002		
		6 weeks after	42.73±2.86	46.93±3.21	51.20±4.03	51.26±5.21	< 0.001		
		Effect size	0.87	0.72	0.045	0.033	-		
	P value[b]	Time	< 0.001 [All]	0.001 [1-2] 0.001 [1-3]< < 0.001 [2-3]	1.00 [1-2] 0.24 [1-3] 1.00 [2-3]	1.00 [All]	-		
Semitendinosus	60 ˚/s	Baseline	24.11±1.06	23.66±1.12	23.60±0.87	24.33±1.71	0.31	< 0.001	< 0.001
		3 weeks after	22.33±1.23	22.06±0.96	24±0.92	24.46±2.09	< 0.001		
		6 weeks after	20.33±0.61	21.46±0.99	24.13±0.83	24.66±2.38	< 0.001		
		Effect size	0.89	0.85	0.48	0.07	-		
	P value[b]	Time	< 0.001 [All]	< 0.001 [1-2] < 0.001 [1-3] 0.008 [2-3]	0.01 [1-2] 0.001 [1-3] 0.49 [2-3]	1.00 [1-2] 0.68 [1-3] 1.00 [2-3]	-		
	180˚/s	Baseline	44.36±2.83	45.26±3.14	44.66±3.17	43.73±2.66	0.55	< 0.001	< 0.001
		3 weeks after	40.80±2.45	43.33±2.89	44.86±3.29	44.33±2.63	0.001		
		6 weeks after	37.46±2.44	41.53±2.50	45±3.20	44.33±2.63	< 0.001		
		Effect size	0.84	0.79	0.25	0.43	-		
	P value[b]	Time	< 0.001 [All]	< 0.001 [All]	0.24 [1-2] 0.05 [1-3] 0.49 [2-3]	0.0017 [All]	-		
	300˚/s	Baseline	50±2.42	51.66±2.82	50.53±3.41	50.13±3.75	0.46	< 0.001	< 0.001
		3 weeks after	46±3.13	49.06±3.53	51.26±3.36	50.40±3.81	0.001		
		6 weeks after	41.13±1.95	47.13±3.81	51.06±3.34	50.60±4.18	< 0.001		
		Effect size	0.90	0.78	0.15	0.16	-		
	P value[b]	Time	< 0.001 [All]	< 0.001 [1-2] < 0.001 [1-3] 1.00 [2-3]	0.42 [1-2] 0.26 [1-3] 1.00 [2-3]	0.31 [1-2] 0.20 [1-3] 1.00 [2-3]	-		

[a] The results of the one-way analysis of variance; [b] The results of the repeated measures analysis of variance and Bonferroni's post hoc test; NMT: Neuromuscular training;*P<0.05

Table 4. Comparisons of mean values for RT within and between groups at three measurement time points

Time Groups	Baseline Before intervention Mean±SD	3 weeks after Mean±SD	6 weeks after Mean±SD	Effect size	P value[b] Time	Group	Time× Group
Ca-Mg-Zn+NMT	0.38±0.04	0.33±0.03	0.29±0.02	0.88	< 0.001 [All]		
NMT	0.38±0.03	0.38±0.04	0.36±0.03	0.66	0.007 [1-2] < 0.001 [1-3] 0.009 [2-3]	0.005	< 0.001
Control	0.36±0.04	0.38±0.04	0.36±0.02	0.04	1.00 [All]		
Ca-Mg-Zn	0.35±0.03	0.38±0.03	036±0.02	0.09	1.00 [1-2] 0.57 [1-3] 0.49 [2-3]		
P value[a]	0.47	0.003	< 0.001	------------------			

[a] The results of the one-way analysis of variance; [b] The results of the repeated measures analysis of variance and Bonferroni's post hoc test; NMT: Neuromuscular training; RT: reaction time; *$P<0.05$

All eccentric knee extension movements were performed with maximal voluntary effort over the entire range of motion, with subjects starting without any pre-activation. Subjects were initially monitored during the movements and then given several exercise trials in which they were instructed to apply maximal resistance to the machine-controlled knee extension at constant velocities of 60, 180 and 300 degrees.

However, significant differences in EMD values for these three muscles were observed between groups at all knee flexion angles at T2 and T3 ($P< 0.05$), with the Ca-Mg-Zn + NMT group having significantly lower EMD values than the other groups. In addition, the effect of time was significant in the Ca-Mg-Zn^{+} NMT and NMT groups ($P< 0.05$), while it was not significant in the control and Ca-Mg-Zn groups ($P> 0.05$). The interaction between time and group also had a significant effect on the mean EMD values ($P< 0.05$), with the Ca-Mg-Zn + NMT intervention showing the largest effect size for EMD.

4. Discussion

This study investigated the effects of NMT and Ca-Mg-Zn therapy on RT and EMD in taekwondo athletes. The results showed that both NMT and the combination of Ca-Mg-Zn with NMT significantly reduced RT and EMD while improving neuromuscular control for joint stabilization. This is consistent with several previous studies [35, 36, 37]. Of note, the Ca-Mg-Zn + NMT intervention was more effective than other interventions in reducing EMD in the lower limb muscles. EMD varies with the structure of the musculotendinous unit and the action potential of the muscle membrane. The Ca-Mg-Zn + NMT intervention reduced EMD probably by increasing the stiffness of the muscle-tendon unit, which may improve the speed of force transmission. Increased stiffness may reduce the time required for force transmission during contractions and movements [8].

One study found that increased stiffness of the musculotendinous unit was associated with a shorter EMD [38]. Our results show that angular velocity during knee flexion significantly affects the electromyographic delay (EMD) of lower limb muscles. Increased angular velocity may impair hamstring neuromuscular function, potentially reducing knee joint stability [39]. The study found that the Ca-Mg-Zn + NMT intervention significantly decreased EMD at all measured angles. In contrast, another study reported that NMT did not significantly reduce RT or EMD. This discrepancy may be due to the fact that we used an integrated NMT protocol, whereas the other study focused solely on plyometric and dynamic stability exercises [40].

We also observed that the Ca-Mg-Zn + NMT intervention was more effective in reducing RT compared to other interventions. RT varied depending on factors such as age, type of exercise (static or dynamic) and warm-up training. One study suggests that optimal warm-up training positively influences neuronal conduction and signal transmission [41]. We performed both static and dynamic warm-up exercises before the pretest and posttest to ensure uniform conditions for all participants. Additionally, NMT improves strength, neural response, agility and speed. It utilises the reciprocal coordination of concentric and eccentric muscle contractions and allows the muscles and connective tissue to store elastic potential energy for immediate concentric contractions [42]. These improvements may result from increased neuromuscular activation, shortened contact time and increased stiffness of the muscle-tendon unit [12]. The positive effect of Ca-Mg-Zn therapy on RT and event-related potential (EMD) may be due to its ability to increase attention. This therapy appears to activate motivational and motor response pathways, increasing arousal and focus on specific targets, which could lead to improved RT and EMD [43]. In addition, dietary supplements containing essential minerals such as Ca-Mg-Zn improve the speed of target identification and retention [44].

To our knowledge, this study is the first to show that the combination of NMT with Ca-Mg-Zn therapy significantly reduces RT and EMD. At elevated Ca concentrations, troponin shifts from its actin partner to the calcium-loaded troponin, allowing tropomyosin to return to a position near the grooves of the actin double helix. This repositioning exposes the myosin binding sites, facilitating the interactions between actin and myosin that generate force. An important mechanism in this process is the increased phosphorylation of regulatory myosin light chains, which increases the sensitivity of actin-myosin interactions to Ca ions released from the sarcoplasmic reticulum [14]. Consequently, this effect may improve muscle stiffness and further reduce RT and EMD. In addition, maintaining adequate Zn levels in skeletal muscle through supplementation may help prevent muscle fiber loss [45]. Mg can enhance the effect of NMT by increasing the availability of glucose to the brain and muscles while reducing the accumulation of lactate in the muscles. In one study, a significant positive correlation was found between Mg levels and muscle function, including grip strength, lower leg strength and maximal isometric trunk flexion [46]. In addition, Ca-Mg-Zn therapy before taekwondo main training can improve athletes' performance by lowering the motor neuron stimulation threshold [47].

5. Conclusions

This study shows that six weeks of NMT and Ca-Mg-Zn therapy significantly reduces recovery time (RT) and muscle damage (EMD) in taekwondo athletes. Their combined application brings even more pronounced benefits. Together, NMT and Ca-Mg-Zn therapy can increase the intensity of the fight for these athletes. In addition, Ca-Mg-Zn therapy can improve muscle strength, adaptation and overall athletic performance, especially in multiple daily competitions. Future research with larger, more diverse samples and longer intervention periods is recommended to further clarify the effects of NMT and Ca-Mg-Zn therapy on RT and EMD.

6. Limitation

There were few studies in the area of the study subject that could be used for comparison, and we had no follow-up to assess the durability of the effects of the study interventions. In addition, the study sample consisted only of male taekwondo athletes.

Conflict of interest

The authors declare no conflicts of interest.

Authors' contributions

All authors contributed directly and intellectually to this work. They designed and conducted the intervention, wrote the manuscript, collected and analyzed the data, and revised the content for clarity and scientific rigor.

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc. This study was approved by the Ethics Committee of Azarbaijan Shahid Madani University, Tabriz, Iran (CODE: IR.AZARUNIV.REC.1402.015) and registered with the Iranian Clinical Trials Registry (Code: IRCT20160523028028N3). Participants attended an induction session one week prior to the intervention, where they were informed about the study's aims, methods, benefits, and potential risks. Informed consent was obtained from all participants before the intervention.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

Funding

This project was supported by a research grant from Azarbaijan Shahid Madani University [grant number 1402/493/1].

References

[1] Altarriba-Bartes A, Drobnic F, Til L, Malliaropoulos N, Montoro JB, Irurtia A. "Epidemiology of injuries in elite taekwondo athletes: two Olympic periods cross-sectional retrospective study". *BMJ Open*. 2014; 4(2): e004605. DOI: https://doi.org/10.1136/bmjopen-2013-004605.

[2] Cid-Calfucura I, Herrera-Valenzuela T, Franchini E, Falco C, Alvial-Moscoso J, Pardo-Tamayo C, et al. "Effects of strength training on physical fitness of olympic combat sports athletes: a systematic review". *International Journal of Environmental Research and Public Health*. 2023; 20(4): 3516. DOI: https://doi.org/10.3390/ijerph20043516.

[3] Hakimi Poor M, Rajabi R, Alizadeh MH, Zandi S. "Kinematic changes of the lower limb in individuals with chronic ankle instability during unilateral landing tasks: A systematic review". *PTJ*. 2022; 12(3): 133-146.

[4] Polat SÇ, Akman O, Orhan Ö. "A comparison of the reaction times of elite male taekwondo and kickboxing athletes". T*he Online Journal of Recreation and Sports*. 2018; 7(2): 32-9. DOI: https://doi.org/10.22282/ojrs.2018.32.

[5] Sant'Ana J, Franchini E, da Silva V, Diefenthaeler F. "Effect of fatigue on reaction time, response time, performance time, and kick impact in taekwondo roundhouse kick". *Sports Biomechanics*. 2017; 16(2): 201-9. DOI: https://doi.org/10.1080/14763141.2016.1217347.

[6] Heering T, Lander N, Barnett LM, Duncan MJ. "What is needed to reduce the risk of anterior cruciate ligament injuries in children?–Hearing from experts". *Physical Therapy in Sport*. 2023;

61: 37-44. DOI: https://doi.org/10.1016/j.ptsp.2023.02.007.

[7] Sant'Ana J, Sakugawa RL, Diefenthaeler F. "The effect of a pace training session on internal load and neuromuscular parameters in taekwondo athletes". *Frontiers in Physiology*. 2021; 12: 710627. DOI: https://doi.org/10.3389/fphys.2021.710627.

[8] El-Ashker S. "Differences in electromechanical delay subsequent to neuromuscular fatigue: A potential relationship to physical fitness training". international journal of sports science and arts. 2019; 3(02): 58-71. DOI: 10.21608/eijssa.2019.87512.

[9] Schmid L, Klotz T, Siebert T, Röhrle O. "Characterization of electromechanical delay based on a biophysical multi-scale skeletal muscle model". *Frontiers in Physiology*. 2019; 10: 1270. Doi: https://doi.org/10.3389/fphys.2019.01270.

[10] Gonçalves C, Bezerra P, Clemente FM, Vila-Chã C, Leão C, Brandão A, et al. "Effect of instability and bodyweight neuromuscular training on dynamic balance control in active young adults". *International Journal of Environmental Research and Public Health*. 2020; 17(23): 8879. DOI: https://doi.org/10.3390/ijerph17238879.

[11] Mahdieh L, Zolaktaf V, Karimi MT. "Effects of dynamic neuromuscular stabilization (DNS) training on functional movements". *Human Movement Science*. 2020; 70: 102568. DOI: https://doi.org/10.1016/j.humov.2019.102568.

[12] Akbar S, Soh KG, Jazaily Mohd Nasiruddin N, Bashir M, Cao S, Soh KL. "Effects of neuromuscular training on athletes physical fitness in sports: A systematic review". *Frontiers in Physiology*. 2022; 13:939042. DOI: https://doi.org/10.3389/fphys.2022.939042.

[13] Samadi H, Rajabi R, Karimizadeh Ardakani M. "The effect of six weeks of neuromuscular training on joint position sense and lower extremity function in male athletes with functional ankle instability". *Journal of Exercise Science and Medicine*. 2017; 9(1): 15-33. DOI: 10.22059/jsmed.2017.62869.

[14] Howell DR, Seehusen CN, Carry PM, Walker GA, Reinking SE, Wilson JC. "An 8-week neuromuscular training program after concussion reduces 1-year subsequent injury risk: a randomized clinical trial". *The American Journal of Sports Medicine*. 2022; 50(4): 1120-9. DOI: https://doi.org/10.1177/03635465211069372.

[15] Zhao W, Wang C, Bi Y, Chen L. "Effect of integrative neuromuscular training for injury prevention and sports performance of female badminton players". BioMed Research International. 2021; 2021(1): 5555853. DOI: https://doi.org/10.1155/2021/5555853.

[16] Homaye Razavi SS, Shojaedin SS, Karimi Z, Barzeh S. "Effect of six weeks of neuromuscular and performance balance training on balance and performance lower extremity climber girls". *Physical Treatments-Specific Physical Therapy Journal*. 2020; 10(4): 213-20.

[17] Baek S, Park JB, Choi SH, Lee JD, Nam SS. "Effects of taekwondo training on body composition: A systematic review and meta-analysis". I*nternational Journal of Environmental Research and Public Health*. 2021; 18(21): 11550. DOI: https://doi.org/10.3390/ijerph182111550.

[18] Yamaguchi M. "Role of nutritional zinc in the prevention of osteoporosis". *Molecular and Cellular Biochemistry*. 2010; 338: 241-54. DOI: 10.1007/s11010-009-0358-0.

[19] Uwitonze AM, Razzaque MS. "Role of magnesium in vitamin D activation and function". *Journal of Osteopathic Medicine*. 2018; 118(3): 181-9. DOI: https://doi.org/10.7556/jaoa.2018.037.

[20] Nielsen FH. "Magnesium deficiency and increased inflammation: Current perspectives". *Journal of Inflammation Research*. 2018: 11: 25-34. DOI: https://doi.org/10.2147/JIR.S136742.

[21] Wang X, Wu W, Zheng W, Fang X, Chen L, Rink L, et al. "Zinc supplementation improves glycemic control for diabetes prevention and management: a systematic review and meta-analysis of randomized controlled trials". *The American Journal of Clinical Nutrition*. 2019; 110(1): 76-90. DOI: https://doi.org/10.1093/ajcn/nqz041.

[22] Morais JBS, Severo JS, de Alencar GRR, de Oliveira ARS, Cruz KJC, do Nascimento Marreiro D, et al. "Effect of magnesium supplementation on insulin resistance in humans: A systematic review". *Nutrition*. 2017; 38: 54-60. DOI: https://doi.org/10.1016/j.nut.2017.01.009.

[23] Owens DS, Benton D. "The impact of raising blood glucose on reaction times". *Neuropsychobiology*. 1994; 30(2-3): 106-13. DOI: https://doi.org/10.1159/000119146.

[24] Buonocore D, Negro M, Arcelli E, Marzatico F.

"Anti-inflammatory dietary interventions and supplements to improve performance during athletic training". *Journal of the American College of Nutrition*. 2015; 34(sup1): 62-7. DOI: https://doi.org/10.1080/07315724.2015.1080548

[25] Wienecke E, Nolden C. "Long-term HRV analysis shows stress reduction by magnesium intake". *MMW-Fortschritte der Medizin*. 2016; 158: 12-6. DOI: https://doi.org/10.1007/s15006-016-9054-7.

[26] Ciucurel MM. "The relation between anxiety, reaction time and performance before and after sport competitions". *Procedia-Social and Behavioral Sciences*. 2012; 33: 885-9. DOI: https://doi.org/10.1016/j.sbspro.2012.01.249.

[27] Choudhary AK, Kishanrao SS, Dhanvijay AKD, Alam T. "Sleep restriction may lead to disruption in physiological attention and reaction time". *Sleep Science*. 2016; 9(3): 207-11. DOI: https://doi.org/10.1016/j.slsci.2016.09.001.

[28] Gholipour Baradari A, Alipour A, Mahdavi A, Sharifi H, Nouraei SM, Emami Zeydi A. "The effect of zinc supplementation on sleep quality of ICU nurses: a double blinded randomized controlled trial". *Workplace Health & Safety*. 2018; 66(4): 191-200. DOI: https://doi.org/10.1177/2165079917734880.

[29] Fatahi A, Dehnavi M. "Comparison the effect of neuromuscular exercises with other training modalities on balance and motor function in people with chronic ankle instability: A systematic review and meta-analysis". *Archives of Rehabilitation*. 2022; 23(3): 310-33.

[30] Sharma R. "Effects of integrative neuromuscular training on reaction time of young cricketers". *Indian Journal of Physical Education, Sports Medicine & Exercise Science*. 2018; 18(1): 172-7. DOI: 10.3389/fphys.2022.939042.

[31] Concha-Cisternas Y, Castro-Piñero J, Leiva-Ordóñez AM, Valdés-Badilla P, Celis-Morales C, Guzmán-Muñoz E. "Effects of neuromuscular training on physical performance in older people: A systematic review". *Life*. 2023; 13(4): 869. DOI: https://doi.org/10.3390/life13040869.

[32] Chen PW, Baune NA, Zwir I, Wang J, Swamidass V, Wong AWK. "Measuring Activities of daily living in stroke patients with motion machine learning algorithms: A pilot study". *Int J Environ Res Public Health*. 2021; 18(4): 1643. PMID: 33572116; PMCID: PMC7915561; DOI: 10.3390/ijerph18041634.

[33] Nunes AC, Cattuzzo MT, Faigenbaum AD, Mortatti AL. "Effects of integrative neuromuscular training and detraining on countermovement jump performance in youth volleyball players". *The Journal of Strength & Conditioning Research*. 2021; 35(8): 2242-7. DOI: 10.1519/JSC.0000000000003092.

[34] de Queiroz RS, Saquetto MB, Martinez BP, Cazeta BBR, Hodgson C, Neto MG. "Progressive active mobilization with dose control and training load in critically ill patients (PROMOB): Protocol for a randomized controlled trial". *Plos One*. 2020. DOI: https://doi.org/10.1371/journal.pone.0238352.

[35] Locci S, Cardani R, Brunori P, Lucchiari S, Comi GP, Federico A, de Stefano N, Meola G, Mignarri A. " Co-occurrence of DMPK expansion and CLCN1 mutation in a patient with myotonia". *Neurological Sciences*. 2021; 42(12): 5365-5368. DOI: 10.1007/s10072-021-05538-y.

[36] Linford CW, Hopkins JT, Schulthies SS, Freland B, Draper DO, Hunter I. "Effects of neuromuscular training on the reaction time and electromechanical delay of the peroneus longus muscle". *Archives of Physical Medicine and Rehabilitation*. 2006; 87(3): 395-401. DOI: https://doi.org/10.1016/j.apmr.2005.10.027.

[37] İpekoğlu G, Erdogan CS, Er F, Colakoglu FF, Baltaci G. "Effect of 12 week neuromuscular weighted rope jump training on lower extremity reaction time". *Turkish Journal of Sport and Exercise*. 2018; 20(2): 111-5. DOI: 10.15314/tsed.422945.

[38] Blackburn JT, Norcross MF, Cannon LN, Zinder SM. "Hamstrings stiffness and landing biomechanics linked to anterior cruciate ligament loading". *Journal of Athletic Training*. 2013; 48(6): 764-72. DOI: https://doi.org/10.4085/1062-6050-48.4.01.

[39] Croix MBDS, ElNagar YO, Iga J, James D, Ayala F. "Electromechanical delay of the hamstrings during eccentric muscle actions in males and females: implications for non-contact ACL injuries". *Journal of Electromyography and Kinesiology*. 2015; 25(6): 901-6. DOI: https://doi.org/10.1016/j.jelekin.2015.09.006.

[40] Zouhal H, Abderrahman AB, Dupont G, Truptin P, Le Bris R, Le Postec E, et al. "Effects of neuromuscular training on agility performance in elite soccer players". *Frontiers in Physiology*. 2019; 10: 947. DOI: https://doi.org/10.3389/fphys.2019.00947.

[41] Turna B. "The effect of agility training on

reaction time in fencers". *Journal of Education and Learning*. 2020; 9(1): 127-35. DOI:10.5539/jel.v9n1p127.

[42] Ramírez-delaCruz M, Bravo-Sánchez A, Esteban-García P, Jiménez F, Abián-Vicén J. "Effects of plyometric training on lower body muscle architecture, tendon structure, stiffness and physical performance: a systematic review and meta-analysis". *Sports Medicine-Open*. 2022; 8(1): 40. DOI: 10.1186/s40798-022-00431-0.

[43] Moghaddam MF, Rakhshani T, Khosravi M. "Effectiveness of methylphenidate supplemented by zinc, calcium, and magnesium for treatment of ADHD patients in the city of Zahedan". *Shiraz E-Medical Journal*. 2016; 17(9). DOI: https://doi.org/10.17795/semj40019.

[44] Lee N. "A review of magnesium, iron, and zinc supplementation effects on athletic performance". *Korean Journal of Sport Studies*. 2017; 56(1). DOI: http://dx.doi.org/10.23949/kjpe.2017.01.56.1.59.

[45] Hernández-Camacho JD, Vicente-García C, Parsons DS, Navas-Enamorado I. "Zinc at the crossroads of exercise and proteostasis". *Redox Biology*. 2020; 35: 101529. DOI: https://doi.org/10.1016/j.redox.2020.101529.

[46] James PA, Oparil S, Carter BL, Cushman WC, Dennison-Himmelfarb C, Handler J, et al. "Evidence-based guideline for the management of high blood pressure in adults: Report from the panel members appointed to the Eighth Joint National Committee (JNC 8)". *Jama*. 2014; 311(5): 507-20. MID: 24352797 DOI: 10.1001/jama.2013.284427.

[47] hang Y, Xun P, Wang R, Mao L, He K. "Can magnesium enhance exercise performance?". *Nutrients*. 2017; 9(9): 946. PMCID: PMC5622706 DOI: 10.3390/nu9090946.