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Article

Neuromuscular Strategies in Novice and Advanced Taekwondo Athletes During Consecutive Roundhouse Kicks

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Abstract: Background: This study investigates differences in muscle co-contraction and peak electromyography (EMG) activity between novice and advanced taekwondo athletes during consecutive roundhouse (*bandal chagui*) kicks, examining the influence of body composition and experience level. **Methods:** Sixteen taekwondo athletes (12 males, 4 females; mean age: 20.5±4.3 years) were divided into novice (n=8) and advanced (n=8) groups. Muscle co-contraction indices and peak EMG activity across 15 consecutive kicks were assessed in key lower limb muscles, including the *biceps femoris* (BF), *lateral gastrocnemius* (LG), *rectus femoris* (RF), *soleus* (SO), *semitendinosus* (ST), *tibialis anterior* (TA), *vastus lateralis* (VL), and *vastus medialis* (VM). **Results:** Advanced athletes exhibited significantly higher co-contraction indices in BF–RF, VM–BF, and SO–TA pairs ($p < 0.05$) and increased peak EMG trends in BF and LG ($p < 0.05$). Novice athletes showed significantly reduced peak EMG increases in RF, VM, and VL. Body composition influenced EMG trends, with higher fat mass and lower muscle mass associated with greater variations in muscle activation. **Conclusions:** These findings suggest that advanced athletes refine motor control through increased co-contraction, improving stability and efficiency, while novices exhibit less optimized coordination patterns. This study provides insights into the neuromechanical adaptations associated with expertise development in taekwondo.

Keywords: body composition; co-contraction; combat Sports; electromyography; martial arts

1. Introduction

Taekwondo, originating from Korea, has developed from a traditional martial art into an official Olympic sport and one of the most widely practiced martial arts globally [1]. In competitive settings, kicking actions are fundamental for scoring points and achieving overall sports performance [2]. The effectiveness of these techniques is influenced by multiple factors, including muscle activation, lower limb segment velocity, core stability, and fatigue resistance [3,4]. Additionally, cognitive processes, such as motor inhibition, further contribute to performance outcomes [5–7].

Biomechanical analyses have been conducted to elucidate differences in performance based on the competitive level of taekwondo athletes. This scope explores differences between sub-elite and elite athletes [8,9] and between medallists and non-medallists [10]. Previous studies have demonstrated significant differences in muscle activity ($d > 0.50$; $p < 0.05$) [11], as well as in execution time and impact force between novice and advanced taekwondo athletes [12]. These findings underscore the importance of such analyses for understanding the mechanisms that distinguish successful athletes. However, limited understanding remains of how these differences manifest during the early and advanced stages of technical skill development.

Regarding biomechanical analysis and, more specifically, muscle activity, current literature has documented the use of surface electromyography (sEMG) to examine muscle activation patterns during taekwondo techniques. This approach provides a more profound understanding of muscle function across different phases of movement [6,9,11,13]. In this context, co-contraction represents a crucial mechanism for joint stabilization during high-impact actions [14] and for the precise modulation of movement accuracy [15]. Increased co-contraction reflects greater antagonist resistance to the intended motion during each type of kick performed.

Previous studies on taekwondo athletes have demonstrated that co-contraction indices (a measure of simultaneous muscle activation) during roundhouse (*bandal chagui*) and *Dollyo Chagui* kicks vary significantly depending on the athletes' experience level or competitive category [9,16]. At the hip, significantly greater co-contraction between the gluteus maximus and the tensor fasciae latae has been observed in sub-elite athletes ($d = 1.07$; $p < 0.05$) [16]. These findings may explain their reduced hip internal rotation velocity and, consequently, lower performance during kick execution. In contrast, elite athletes exhibited significantly higher co-contraction indices in the muscles responsible for knee extension ($d = 1.02$; $p < 0.05$) [9]. Increased co-activation of the *rectus femoris* and *biceps femoris* is considered a protective mechanism for knee stability [16,17]. Concerning the ankle, no studies have been identified that specifically examine co-contraction in taekwondo athletes according to their experience level.

From what has been presented in the previous paragraphs, it is evident that very little literature exists on co-contraction in taekwondo athletes as a function of experience level or competitive category [9,16], with no studies existing on the ankle in the antagonist pair of soleus and tibialis anterior. This joint, along with the foot, plays a fundamental role in executing kicks in taekwondo, serving as the primary point of contact with the target and enabling efficient force transfer generated by the leg muscles [14]. Furthermore, additional considerations must be addressed. Firstly, analyzing combat sports requires specific methodological considerations due to their explosive nature. In this regard, careful attention to sEMG challenges, such as movement artifacts, signal processing accuracy, and factors like skin impedance, adipose tissue, and body composition, all of which can impact signal reliability and quality [18,19]. Low-fat mass percentages, adequate muscle mass, and the relationship between body composition and inter-limb asymmetry are significantly associated with performance in male and female taekwondo athletes [20–22]; therefore, these variables should be considered in sEMG analysis.

Another important aspect is that most previous studies focused on reducing motor gesture variability. Aggeloussis et al. [23] suggested that more than 10 repetitions of the kicks should be assessed to obtain reliable data on muscle function. Ervilha et al. [6] analyzed 20 consecutive kicks but reconstructed the sEMG signal by averaging them. Similarly, Valdés-Badilla et al. [11] used 15 kicks and reconstructed the signal by interpolating based on the movement cycle. These studies often

relied on averaged or reconstructed sEMG signals from consecutive kicks without thoroughly examining trends in peak EMG activity [6,11]. Quinzi et al. [17] were the first to study the effect of repeated kicking actions on the performance of the roundhouse kick in karate. No studies on sEMG have been found that seek to identify changes in peak EMG trends during consecutive kicks in taekwondo athletes.

In this context, and given the lack of research on changes in peak EMG activity during consecutive kicks in taekwondo athletes, the present study evaluated differences in muscle co-contraction and peak EMG activity between novice and advanced taekwondo athletes during consecutive roundhouse (*bandal chagui*) kicks. It also aimed to explore the influence of body composition and experience level on these parameters.

2. Materials and Methods

2.1. Study Design

A comparative, cross-sectional design with a quantitative approach and single-blind evaluation (evaluators) was employed. This design compares two groups (novice vs. advanced taekwondo athletes) to measure differences in muscle co-contraction and peak EMG activity during consecutive roundhouse (*bandal chagui*) kicks in taekwondo. Additionally, it examined the impact of variables such as body composition and experience level on these measurements. Assessments were conducted in an 80-minute session, which all participants completed.

2.2. Participants

Sixteen taekwondo athletes (twelve male and four female), aged between 18 and 28 years (mean age: 21.50 ± 3.28 years), participated in the study. The sample was conveniently recruited from the University Taekwondo group. All participants were active competitors and met the following inclusion criteria: (i) a minimum of one year of taekwondo practice; (ii) training at least three times per week; (iii) participation in national tournaments organized by the National Taekwondo Sports Federation (FEDENAT, Chile), a body recognized by the World Taekwondo; (iv) enrollment in a club affiliated with FEDENAT. Athletes were excluded if they had any acute or rehabilitation-phase injury or illness that could affect their physical performance or if there were issues with sEMG signal capture. Based on their years of practice, participants were categorized into novice (six male and two female) and advanced (six male and two female) groups. Novice athletes were defined as those with fewer than three years of taekwondo practice, while advanced athletes had three or more years of experience.

All participants were required to comply with the criteria regarding the use and management of data by signing an informed consent document, thereby providing permission for their information to be used for scientific purposes. The research protocol was approved by the Research Ethics Committee of the Universidad Autónoma de Chile (N°080-16) and was conducted in accordance with the principles outlined in the Declaration of Helsinki for research involving human subjects.

2.3. Surface Electromyography (sEMG) Acquisition

sEMG signals were recorded from the *biceps femoris* (BF), *semitendinosus* (ST), *rectus femoris* (RF), *vastus medialis* (VM), *vastus lateralis* (VL), *lateral gastrocnemius* (LG), *soleus* (SO), and *tibialis anterior* (TA) muscles using a 16-channel Bagnoli surface electromyograph (Delsys Inc., Boston, MA, USA). Before electrode attachment, the skin was prepared by shaving and cleaning with alcohol. Bipolar electrodes (Ag/AgCl) were placed on the dominant leg following the guidelines outlined by SENIAM [24]. BF: 50% of the line between the ischial tuberosity and lateral femoral epicondyle. ST: 50% of the line connecting the medial tibial epicondyle and ischial tuberosity. RF: 50% of the line between the ASIS and superior patella. VM: 4 cm medial and superior to the patella's medial border. VL: 2/3 of the line between the ASIS and lateral patella. LG: 1/3 of the line between the fibular head and Achilles tendon on the lateral belly. SO: midway between the fibular head and Achilles tendon, medial to the

leg. TA: 1/3 of the line between the tibial tuberosity and medial malleolus lateral to the tibia (Figure 1). Signal acquisition was performed using the EMGworks software version 4.0.13 (Delsys Inc., Boston, USA) at a sampling frequency of 4,000 Hz and a gain of 1,000. The sEMG assessment involved performing the maximum voluntary isometric contraction (MVIC), as recommended by SENIAM, with 5 seconds of isometric contraction, three repetitions, and 30 seconds of rest.

2.4. Body Composition Measurement

Body composition was assessed following the guidelines of the International Society for the Advancement of Kinanthropometry (ISAK) by a certified Level II anthropometrist (technical measurement error: 0.8% across all variables) in accordance with ISAK standards [25]. Body weight was measured using an electronic scale (Scale-tronix, USA; accuracy of 0.1 kg), and standing height was recorded with a stadiometer (Seca 220, Germany; accuracy of 0.1 cm). Skinfold thickness was assessed using a skinfold caliper (Harpenden, UK; accuracy of 0.2 mm), body circumferences were measured with a tape measure (Seca 201, Germany; accuracy of 0.1 cm), and bone diameters were determined using anthropometers (Rosscraft, Canada; accuracy of 0.1 mm). Body mass index (BMI) was calculated as body weight divided by height squared (kg/m²). Fat mass and muscle mass were estimated using the indirect pentacompartmental fractionation method [26].

2.5. Procedure

Each taekwondo athlete was individually evaluated at the Movement Analysis Laboratory of the Sports and Health Centre at the [BLINDED FOR REVIEW]. The process began with an individual interview, followed by anthropometric measurements and an sEMG assessment. The warm-up, led by a high-ranking taekwondo instructor and former national coach, included joint mobility, dynamic flexibility exercises with directional movements, technical drills without knee extension, and assisted attack and defense simulations. It concluded with three sets of 12 front kicks and roundhouse (bandal chagui) kicks on an impact shield. After a five-minute active rest (self-directed flexibility exercises), the athletes performed 15 maximum-intensity roundhouse (bandal chagui) kicks, striking an impact shield held by an expert who provided verbal encouragement to ensure optimal performance.

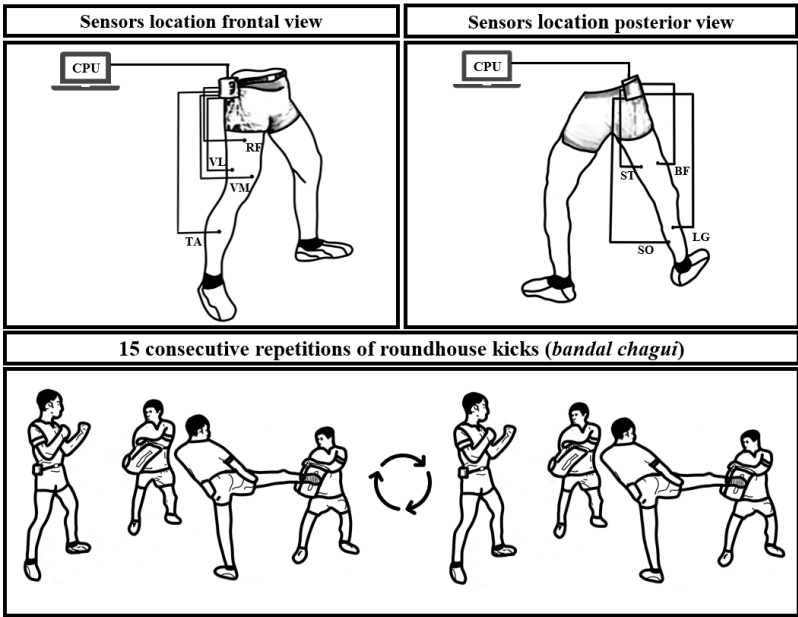


Figure 1. EMG assessment during a series of continuous kicks. BF: biceps femoris; ST: semitendinosus; RF: rectus femoris; VM: vastus medialis; VL: vastus lateralis; LG: lateral gastrocnemius; SO: soleus; TA: tibialis anterior.

The acquired sEMG signal was processed digitally using an algorithm implemented in Matlab R2016a software (MathWorks Inc., MA, USA). Initially, the signal was corrected by offset subtraction using a detrending function. The signal then underwent filtering with fourth-order low-pass and high-pass Butterworth filters, with cut-off frequencies set at 10 Hz and 400 Hz, following methodologies used in previous studies with taekwondo athletes [11,18]. The root mean square (RMS) of the EMG signal was calculated using a sliding window method, with a window width of 20 samples and a one-sample overlap. The amplitude was normalized relative to the MVIC, and each electromyographic burst was segmented to determine the peak amplitude for each muscle analyzed. The co-contraction index was calculated as follows [27]:

$$Co - contraction\ Index = \frac{\sum_{i=1}^N \min (EMG_{agonist}(i), EMG_{antagonist}(i))}{\sum_{i=1}^N (EMG_{agonist}(i) + EMG_{antagonist}(i))}$$

EMG agonist (i) and EMG antagonist (i) represent a specific repetition of the kick, denoted as i. N is the total number of repetitions considered in the analysis. A higher co-contraction index indicates greater simultaneous muscle activation.

2.6. Statistical Analysis

The analysis was performed using RStudio (version 2023.06.2). The Shapiro-Wilk test of normality was applied to assess the normal distribution of the dependent variables. The homogeneity of variances was verified using Levene’s test. Independent samples t-tests were initially performed to compare continuous variables between the groups, including weekly training hours, years of practice, mean peak EMG values, and body composition metrics. To examine the trends in peak EMG activity over a series of 15 continuous roundhouse (*bandal chagui*) kicks, linear regression analyses were conducted for each muscle. This approach allowed for the estimation of the slope and intercept for the EMG data. A mixed-effects model was employed to account for both fixed and random effects. Fixed effects included parameters such as experience level and number of kicks, as well as and principal component analysis (PCA) derived from body composition metrics, combining fat mass and muscle mass. The PCA loading coefficients were used as predictors in subsequent models to determine their effect on EMG activity across different muscles. Random effects were incorporated to control for variability between individual participants and enhance the model’s robustness. The explained variance was calculated for the fixed effects alone and for the complete model, which combined both fixed and random effects. Marginal R²m and conditional R²c were estimated to quantify the proportion of variance explained by the fixed effects and by both fixed and random effects, respectively. Statistical significance was defined as *p* < 0.05.

3. Results

The advanced taekwondo athletes group trained significantly more hours per week (12.3±3.6) compared to the novice group (5.3±0.8, *p* < 0.001; 95% CI: 4.58–15.27). Additionally, significant differences were noted in favor of the advanced group for the variable years of practice, with novice athletes showing 2.2±0.3 years compared to 8.1±2.9 years in advanced athletes (*p* < 0.001; 95% CI: 1.89–10.57). However, no significant differences were found between groups in mean peak EMG or body composition metrics. Table 1 provides descriptive statistics of the mean peak EMG across 15 roundhouse (*bandal chagui*) kicks for each muscle analyzed and body composition metrics for novice and advanced athletes. The results of independent samples t-tests for EMG data and body composition metrics are also presented.

Table 1. Independent samples t-tests between novice and advanced athletes.

Variable	Experience level		95% CI Lower	95% CI Upper	t	p-value
	Novice	Advanced				
	Mean ± SD	Mean ± SD				
BF (%)	71.28 ± 21.59	85.80 ± 28.11	-36.25	7.22	-1.309	0.217

Mean peak EMG from 15 kicks	ST (%)	75.06 ± 21.52	77.74 ± 13.26	-15.87	10.51	-0.399	0.697
	RF (%)	79.61 ± 29.41	63.61 ± 14.55	-7.69	39.68	1.324	0.225
	VM (%)	88.95 ± 17.01	74.29 ± 14.15	-13.74	43.06	1.012	0.341
	VL (%)	80.60 ± 23.26	90.93 ± 28.66	-40.42	19.75	-0.673	0.513
	LG (%)	82.92 ± 23.43	77.60 ± 18.60	-20.47	31.11	0.404	0.692
	SO (%)	101.38 ± 35.24	102.59 ± 30.67	-32.00	29.57	-0.077	0.939
	TA (%)	72.40 ± 25.05	70.58 ± 22.77	-12.43	16.07	0.250	0.806
Body comp.	Weight (kg)	65.76 ± 168.31	68.53 ± 168.84	-13.48	7.96	-0.505	0.623
	Height (m)	23.24 ± 26.58	23.84 ± 29.75	-10.28	9.23	-0.105	0.918
	BMI (kg/m²)	44.82 ± 8.36	42.98 ± 13.02	-3.00	1.80	-0.489	0.633
	Adipose mass (%)	11.15 ± 2.30	8.59 ± 2.60	-9.02	2.68	-1.063	0.307
	Muscle mass (%)	5.12 ± 4.16	6.71 ± 5.71	-3.06	6.73	0.735	0.476

BF: biceps femoris; BMI: body mass index; ST: semitendinosus; RF: rectus femoris; LG: lateral gastrocnemius; SO: soleus; TA: tibialis anterior; VL: vastus lateralis; VM: vastus medialis.

An independent samples t-test revealed significant mean differences in muscle co-contraction for specific muscle pairs between novice and advanced taekwondo athletes (Figure 2). The advanced group demonstrated greater co-contraction across the different muscle pairs studied. The BF–RF pair showed a mean co-contraction index of 0.046 ± 0.011 for the advanced group and 0.037 ± 0.010 for the novice group, with a $t = 3.660$, $p = 0.001$ (95% CI for advanced: 0.042–0.050; for novices: 0.034–0.039), $d = 0.907$ (large effect). The VM–BF pair also showed a significant difference, with mean values of 0.042 ± 0.010 for the advanced group and 0.035 ± 0.009 for the novice group, $t = 2.744$, $p = 0.012$ (95% CI for advanced: 0.026–0.033; for novices: 0.025–0.030), $d = 0.727$ (medium effect). The SO–TA pair exhibited a significant difference as well, with mean values of 0.037 ± 0.012 for the advanced group and 0.028 ± 0.010 for the novice group, $t = 2.407$, $p = 0.025$ (95% CI for advanced: 0.039–0.046; for novices: 0.033–0.038), $d = 0.813$ (large effect). The VL–ST pair demonstrated a p-value of 0.384, while the LG–TA pair showed a p-value of 0.645, indicating no statistically significant differences between the groups.

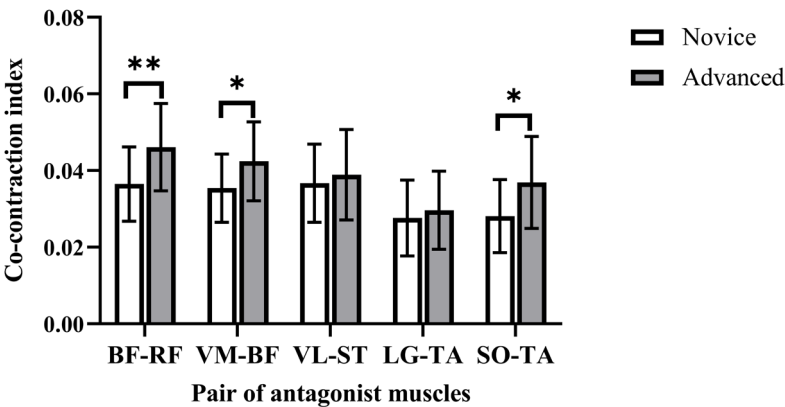


Figure 2. Mean differences in muscle co-contraction for specific muscle pairs between novice and advanced taekwondo athletes. BF–RF: *biceps femoris–rectus femoris*; VM–BF: *vastus medialis–biceps femoris*; VL–ST: *vastus lateralis–semitendinosus*; LG–TA: *lateral gastrocnemius–tibialis anterior*; SO–TA: *soleus–tibialis anterior*; * $p < 0.05$; ** $p < 0.01$.

Figure 3 presents the linear regression analysis of peak EMG during a series of 15 continuous roundhouse (*bandal chagui*) kicks, which demonstrated significant trends in specific muscles: BF (slope = 2.082, intercept = 61.890, $R^2 = 0.661$, $p < 0.001$), LG (slope = 0.866, intercept = 73.331, $R^2 = 0.288$, $p = 0.039$), and TA (slope = -1.192, intercept = 81.024, $R^2 = 0.457$, $p = 0.006$). BF and LG exhibited upward

trends, while TA showed a downward trend. The other muscles did not present significant changes in peak EMG trends ($p > 0.05$).

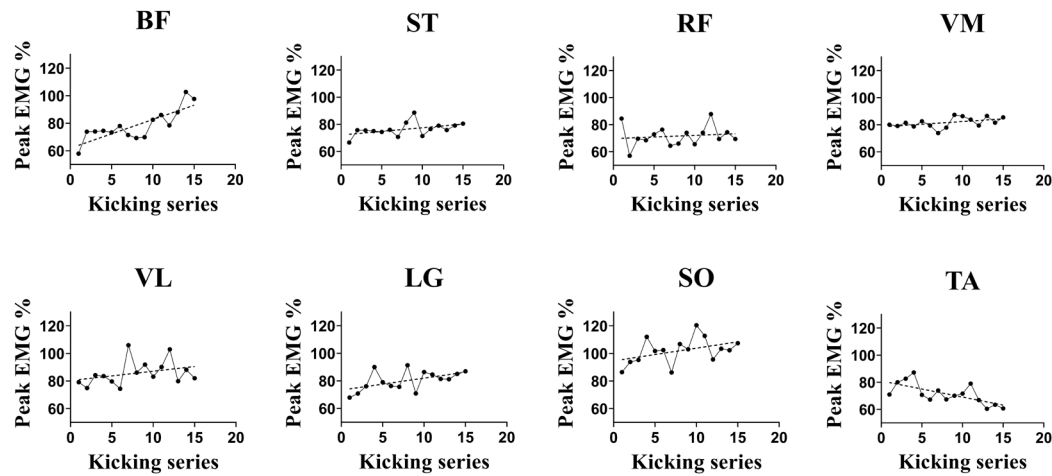


Figure 3. Peak EMG trends during a series of continuous roundhouse (*bandal chagui*) kicks. BF: *biceps femoris*; LG: *lateral gastrocnemius*; RF: *rectus femoris*; SO: *soleus*; ST: *semitendinosus*; TA: *tibialis anterior*; VL: *vastus lateralis*; VM: *vastus medialis*.

Fixed effects explain a range of variance between 0.8% and 11.6%, while the complete models (fixed and random effects) explain 50.4% to 55.8% of the variance. The PCA component of fat mass (loading coefficient = 0.707) and muscle mass (loading coefficient = -0.707) showed a significant and positive effect in the BF, RF, VL, SO, and TA muscles, indicating that higher fat mass and lower muscle mass are significantly associated with an increase in the trend of peak EMG change. The experience level parameter presented a negative and significant impact in the RF, VM, and VL muscles, showing that being a novice is significantly associated with a lower tendency to increase the quadriceps peak EMG. Additionally, the number of kicks was significant in the BF and TA muscles, suggesting that EMG activity increases with successive roundhouse (*bandal chagui*) kicks in the BF, while at the same time, it decreases in the TA. The results of the mixed effects model are presented in Table 2.

Table 2. Mixed effects model.

Muscle	Parameter	Estimate	Std. Error	p-value	95% CI Lower	95% CI Upper	R _m ²	R _c ²
BF	Intercept	57.99	35.52	0.103	-11.63	127.61	0.116	0.558
	PCA Component	10.21	1.68	<0.001***	6.91	13.50		
	Experience level	7.79	4.67	0.095	-1.36	16.94		
	Kick number	2.08	0.52	<0.001***	1.05	3.11		
ST	Intercept	71.00	23.63	0.003*	24.70	117.31	0.008	0.504
	PCA Component	0.78	1.12	0.487	-1.42	2.97		
	Experience level	2.17	3.10	0.484	-3.91	8.26		
	Kick number	0.54	0.35	0.123	-0.15	1.22		
RF	Intercept	80.38	34.47	0.020*	12.83	147.94	0.074	0.537
	PCA Component	8.14	1.63	<0.001***	4.94	11.34		
	Experience level	-21.36	4.53	<0.001***	-30.24	-12.49		
	Kick number	0.24	0.51	0.639	-0.76	1.24		
VM	Intercept	86.35	32.31	0.008**	23.03	149.67	0.030	0.515
	PCA Component	1.75	1.53	0.252	-1.25	4.75		
	Experience level	-15.81	4.25	<0.001***	-24.13	-7.49		
	Kick number	0.40	0.48	0.406	-0.54	1.33		
VL	Intercept	73.29	45.93	0.111	-16.73	163.31	0.022	0.511

	PCA Component	5.63	2.18	0.010*	1.36	9.89		
	Experience level	-14.04	6.04	0.020*	-25.87	2.21		
	Kick number	0.68	0.68	0.315	-0.65	2.01		
LG	Intercept	75.90	35.74	0.034*	5.85	145.95	0.008	0.504
	PCA Component	-0.28	1.69	0.870	-3.60	3.04		
	Experience level	-5.14	4.70	0.274	-14.34	4.07		
	Kick number	0.87	0.53	0.101	-0.17	1.90		
SO	Intercept	96.69	46.18	0.036*	6.19	187.19	0.032	0.516
	PCA Component	8.18	2.19	<0.001***	3.89	12.47		
	Experience level	-4.18	6.07	0.491	-16.07	7.72		
	Kick number	0.92	0.68	0.176	-0.41	2.26		
TA	Intercept	83.04	30.32	0.006**	23.61	142.46	0.026	0.513
	PCA Component	3.35	1.44	0.020*	0.54	6.17		
	Experience level	-4.03	3.98	0.312	-11.84	3.78		
	Kick number	-1.19	0.45	0.008**	-2.07	-0.31		

BF: *biceps femoris*; LG: *lateral gastrocnemius*; PCA: principal component analysis of adipose mass and muscle mass; RF: *rectus femoris*; SO: *soleus*; ST: *semitendinosus*; TA: *tibialis anterior*; VL: *vastus lateralis*; VM: *vastus medialis*.

4. Discussion

The present study evaluated differences in muscle co-contraction and peak EMG activity between novice and advanced taekwondo athletes during consecutive roundhouse (*bandal chagui*) kicks. It also aimed to explore the influence of body composition and experience level on these parameters. The results confirm the first hypothesis proposed, indicating significant differences in co-contraction indices between novice and advanced taekwondo athletes, with effect sizes ranging from moderate to large, particularly in the BF–RF, VM–BF, and SO–TA muscle pairs. These findings suggest that the advanced group exhibited higher co-contraction levels, which may serve as a strategy to enhance joint stabilization and improve precision during consecutive roundhouse (*bandal chagui*) kicks. These findings aligned with Moreira et al. [9,16], where advanced taekwondo athletes demonstrated higher co-contraction indices than novices, specifically in muscles involved in knee extension. In other combat sports, Sbriccoli et al. [15] found that elite karateka exhibited higher levels of co-contraction in the VL and BF compared to amateur practitioners, which is also consistent with our findings. We did not find any previous studies that examined the co-contraction of the SO and TA under kicking conditions. However, Valdés-Badilla et al. [11] found significant differences in SO peak EMG between novice and advanced taekwondo athletes. This finding is noteworthy, as these muscles likely play a pivotal role in dynamic ankle stabilization and effective force transmission.

The linear regression analysis confirms our second hypothesis, revealing significant trends in peak EMG activity for specific muscles. BF and LG activity increased significantly with successive roundhouse (*bandal chagui*) kicks, possibly reflecting progressive motor unit recruitment due to fatigue [28] or the need for enhanced knee stabilization [14]. Sun et al. [13] observed significantly increased activation of the BF and LG when comparing the ‘hit’ and ‘miss’ actions of roundhouse kicks. These muscles play a role in controlling knee flexion and tibial external rotation, counteracting the actions of the VM on the tibia during knee extension [29]. In contrast, the TA reduced peak EMG activity as the number of kicks increased. This decrease could be explained by the reactive forces generated when striking the shield, which are transmitted through the leg [14]. We hypothesized that the neuromuscular system adapts to the impact with each roundhouse (*bandal chagui*) kick by shifting the foot into a more neutral or slightly plantarflexed position, optimizing energy transfer upon contact. This adaptation may progressively reduce the need for intense TA activation to stabilize the joint. Thibordee & Prasartwuth [14] observed that during the impact phase in elite taekwondo athletes, individuals in the high-impact group demonstrated reduced TA muscle activity. This finding suggests that novice athletes may experience lower impact forces, resulting in reduced activation of this muscle. On the other hand, our results differ from those of Ervilha et al. [6], who reported higher TA activity in elite taekwondo athletes compared to novice athletes. This discrepancy may be attributed to our focus on peak EMG, whereas they analyzed the integral of the entire

waveform and phases. While no studies have specifically evaluated this trend under similar conditions, these findings offer new insights into the dynamic role of muscle activation during roundhouse (*bandal chagui*) repetitive kicks.

The mixed-effects model showed that experience level significantly impacted quadriceps muscles (RF, VM, VL), with novice taekwondo athletes displaying a reduced capacity to increase peak EMG during consecutive kicks. This decline could be related to lower technical efficiency or neuromuscular capacity [9,11]. Similarly, the PCA showed that higher fat mass and lower muscle mass were significantly associated with changes in peak EMG trends in the BF, RF, VL, SO, and TA muscles, thereby confirming our third hypothesis. The relationship between higher fat mass and lower muscle mass with increased peak EMG might be explained by greater relative effort and reduced contractile efficiency, whereby muscles would need to recruit more motor units to compensate for the lack of strength [30], thereby increasing EMG activity during consecutive kicks. Although the influence of experience and body composition on peak EMG trends was modest, the results suggest that less experienced athletes have a diminished ability to increase maximum muscle activation in key muscles, such as RF, VM, and VL. Furthermore, it is important to highlight that our study provides additional and well-founded evidence that aligns with previous studies [20–22] on fat control and muscle gain in the performance of taekwondo athletes. It is important to highlight that, although the fixed effects have an influence, there is a high level of individual variability in the muscle activation data.

4.1. Scope and Limitations

The study's primary strength was both novice and advanced taekwondo athletes with similar ages, body weight, standing height, and BMI. Our findings present several practical applications for taekwondo training. Coaches and practitioners should prioritize exercises targeting antagonistic muscle groups to enhance the performance and efficiency of the roundhouse (*bandal chagui*) kick. Novice athletes may benefit from drills designed to strengthen and improve the coordination of the quadriceps and from incorporating controlled co-contraction exercises to enhance joint stability during kicking.

The limitations of this study include the small sample size, which restricts its external validity. Nonetheless, the statistical significance and large effect sizes observed underscore the importance of the differences identified in our research. Participants performed repeated roundhouse (*bandal chagui*) kicks from a static position, which differs from real combat conditions. However, the study aimed to use this setup as an experimental model to simulate task-specific demands and assess performance changes with repetition.

5. Conclusions

Advanced taekwondo athletes exhibited significantly higher co-contraction indices in knee and ankle muscles, suggesting improved joint stabilization during consecutive roundhouse (*bandal chagui*) kicks. In contrast, novice athletes showed a significantly reduced capacity to increase peak EMG in RF, VM, and VL muscles. Although the influence of experience level and body composition on peak EMG trends was modest, the findings suggest that higher fat mass and lower muscle mass may be linked to the observed trend in peak EMG. Additionally, novice taekwondo athletes may face challenges in achieving maximum muscle activation, potentially limiting their performance efficiency.

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