ORIGINAL ARTICLE

Trunk and lower limb muscle activation in linear, circular and spin back kicks

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Abstract

Background & Study Aim: As any martial art, taekwondo can be classified as a specialty that requires high technical skills, such as a fine motor control both in static and dynamic conditions. Practitioners predominantly use kicks with high amplitude in both combat and technique (poomse) modalities. The aim of this study was the knowledge about trunk and lower limb muscle activation according to the type of kick (circular, linear and spin back kick) in the taekwondo technique modality.

Material & Methods: Twelve healthy and elite male taekwondo athletes voluntarily participated in this study. Surface electromyography (EMG) during maximal isometric voluntary contractions (MVC) and execution of the kicks was bilaterally recorded from rectus abdominis (RA), external and internal oblique (EO and IO), erector spinae (ES), rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and gastrocnemius lateralis (GL), in the static phase of the three kicks.

Results: The results of this study (in terms of MVC percentages) showed a main effect of the type of kick ($p < 0.05$); that is, during the static phase of the kick muscle activity changed based on the type of kick. In the kicking leg, trunk and hip flexor and knee extensor muscle activation (mainly RF, IO and RA) was higher in linear kicks than in circular and spin back kicks. GL and RF activation levels were higher in circular kicks than in spin back kicks. In addition, the higher levels of ES activation were found in the spin back kicks. Regarding the supporting leg, no differences between kicks were found for TA and GL, which were possibly activated to ensure ankle stability during the single-leg stance.

Conclusion: These findings may allow researchers and taekwondo coaches to design training programs appropriately.

Key words: electromyography · martial arts · taekwondo · type of kick

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Poomse (*kata* in karate) – it is traditionally understood as the style of conduct which expresses directly or indirectly mental and physical refinements as well as the principles of offense and defense resulting from cultivation of taekwondo spirit and techniques. Nowadays, *poomse* is involved in competition in the taekwondo technique modality.

Roundhouse or circular kick – a type of kick defined as throw-like kicks or progressive movements of hip and knee flexion-extension of the kicking leg that start in the sagittal plane and finish in the transverse plane (i.e., swing motion), with the ankle in plantar flexion to hit in lateral body posture with the instep.

Linear kick – described as a progressive movement in the sagittal plane which consist in hip and knee flexion-extension of the kicking lower limb to hit the target with the plantar forefoot.

Spin back kick – it is a complex rotational body motion which started in the sagittal plane and finished in a posterior-rotated body posture relative to the target (Figure 1c), which consists in pivoting on one leg and hitting with the heel of the other leg, in this posterior-rotated position with the ankle in neutral position (posture).

Electromyography – it is an experimental technique concerned with the development, recording and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fibre membranes.

Surface electromyography – it is a non-invasive technique that allows the evaluation of muscular function in healthy and injured individuals.

Maximal isometric voluntary contractions – it refers to a procedure of electromyography signal normalization by using a reference value.

Co-contraction – defined as a simultaneous activation of muscle pairs, with functionally opposite roles acting about a given joint.

Introduction

As any martial art, taekwondo can be classified as a specialty that requires high technical skills, such as a fine motor control both in static and dynamic conditions [1]. Practitioners predominantly use kicks with high amplitude [2] in both combat and technique (*poomse*) modalities. Combat modality is well known [3], nonetheless, although popularity in the technique modality is increasing (a 35% of increment from 2008 until 2012) [4], there is still a lack of empiric knowledge on this last/second modality. In the technique modality, taekwondo athletes must perform pre-established sequences of techniques, including several types of kicks, which require great concentration, balance and fitness [5] and involve high levels of muscle activation [2].

Taekwondo kicks are classified according to the foot trajectory and lower limb movement in circular (e.g. *bandal chagui*), linear (e.g. *ap chagui*) and spin back kicks (e.g. *dwi chagui*) [6]. Based on several electromyographic studies on lower limb muscle response during circular kicks [7–9], athletes presented a great ability to contract and relax trunk and thigh muscles quickly [8]. Rectus *femoris* and *gastrocnemius* activations are crucial to accelerate the kicking leg and to hit the target with the instep, respectively, especially when the kicks are performed at a high height [7]. In addition, the co-activation of the muscles acting as antagonist for knee and hip joints (e.g. *biceps femoris)* are also essential to brake the foot during the impact phase of this type of kicks [9,10]. Regarding linear kicks, the evaluation of the electromyography (EMG) of five major lower limb muscles during linear kicks suggests that hip flexor and knee extensor muscles reached the highest activation levels [11]. Finally, in spin back kicks McGill et al. [10] noted a stiff activation of the erector spine and some abdominal muscles during fast and powerful executions.

To the best of our knowledge, the few EMG studies that have analyzed muscle activation during martial arts kicks focus on linear and circular kicks [7,10,11]; only a study [8] has analyzed the muscle activation in spin back kicks comparing the trunk and thigh muscle activation, and finding differences between different types of kick.

However, despite its importance [12] there is no full understanding of neuromuscular control of trunk and lower limb in taekwondo kicks. The aim of this study was the knowledge about trunk and lower limb muscle activation according to the type of kick (circular, linear and spin back kick) in the taekwondo technique modality.

Detailed questions: Which muscles are more important to maintain the body balance in each type of kick? How does trunk muscle activation contribute to taekwondo kicks performance?

In spite of a recent study in combat sports field [13], it must be noted that EMG signals captured in static conditions offer higher reliability than those recorded in dynamic actions [14]. Therefore, only the static phase of these techniques (single-leg stance while hitting the target) were analyzed. Based on the body posture differences in the static phase between linear, circular and spin back kicks (frontal, lateral and posterior-rotated position related to the target, respectively), it was hypothesized that muscle activation will change according to the type of taekwondo technique.

Material and Methods

Participants

Twelve healthy and elite male taekwondo athletes voluntarily participated in the study. The mean age, body mass and height were 21.70 ± 5.62 years, 72.50 ± 11.42 kg and 177.7 ± 7.4 cm, respectively. To qualify as an elite athlete, participants should have won at least a bronze medal in a national championship and being involved in international events. They had more than 5 years of experience in competition and had trained for at least 3 h per week in the taekwondo technique modality. Each athlete signed a written informed consent form approved by the Institutional Review Board of the University. Subjects with known medical problems, histories of surgery in the lower extremity or trunk, or episodes of back pain requiring treatment before this study were excluded.

Instrumentation

Surface EMG signals were bilaterally collected from each muscle using the Muscle Tester ME6000â (Mega Electronics, Ltd., Kuopio, Finland). This is a 16-channels portable microcomputer with two 8-channels A/D conversion (14 bit resolution), a CMRR of 110 dB and a band-pass filter of 8-500 Hz. The sample frequency was programmed at 1 kHz. Pregelled bipolar Ag/AgCl surface electrodes (Kendall™/Arbo™ H124SG, Covidien™, Mansfield MA, USA) were placed with an inter-electrode distance of 25 mm in accordance with the recommendations proposed during the European SENIAM project [5].

Experimental Protocol

Before placing the electrodes, the skin was prepared by shaving the area and cleaning with alcohol. On the one hand, for trunk muscles, the bipolar electrodes positioning was performed following the recommendations proposed by Vera-Garcia et al. [15]: 1) *rectus abdominis* (RA), 2) *external oblique* (EO), 3) *internal oblique* (IO), and 4) *erector spinae* (ES). On the other hand, for lower limb muscles, the location of bipolar electrodes was performed following the recommendations proposed by the European SENIAM project [5]: 5) *rectus femoris* (RF), 6) *biceps femoris* (BF), 7) *tibialis anterior* (TA), and 8) *gastrocnemius lateralis* (GL).

Participants were allowed time for an individual warm-up. After several maximal isometric voluntary contractions (MVC) to normalize the EMG, the athletes carried out five trials with six consecutive and alternative kicks (three with the dominant and the other three with the non-dominant side) for each type of kick (linear, circular and spin back kick), in a random and counterbalanced order; a total of 30 kicks were recorded from each athlete. In order to avoid muscular fatigue during the recording session, 1 min of rest interval was provided between kicks and 3 min between trials. The time and cadence to perform the kicks was controlled by a metronome (60 beats per min). The athletes received the standard instruction to kick the target following the cadence. Two experimenters controlled the total process during the measurement protocols. Athletes were encouraged to perform no strength training and to maintain their nutritional habits 48 h prior to data collection

Procedures

Maximal isometric voluntary contractions. Before to perform the kicks, taekwondo athletes performed eight maximal maneuvers against an unbeatable resistance for 5 s, while they were verbally encouraged [15]. For MVC techniques one of the experimenters provided a matching resistance to the participants during the maximal exertions for restraining the athlete's movement. The other experimenter was taking care of the proper execution of MVC techniques; for the trunk muscles the MVC techniques were executed according to the orientations proposed by Vera-Garcia et al. [15]: 1) *trunk flexion*: athlete was in a sit-up posture on a bench with the knees bent and the feet strapped down with a belt. He then attempted to flex the upper trunk in the sagittal plane while his *thorax* was manually braced by the experimenter; 2) *trunk twisting right, and left*: in the same sitting supported posture, the athlete attempted to twist the upper trunk in the horizontal plane while his *thorax* was manually braced by the experimenter; 3) *trunk bending (lateral flexion) right, and left*: in the same sitting supported posture, the athlete attempted to incline the upper trunk in the frontal plane while his *thorax* was manually braced by the experimenter; 4) *trunk extension*: athlete was strapped in a prone position, with the *torso* horizontally cantilevered over the end of the bench (Biering-Sorensen position), and he then attempted to extend the upper trunk in the *sagittal* plane while manual resistance was applied on the shoulders by the experimenter. For lower limb muscles the MVC techniques performed were executed according to the orientations proposed by Barbado et al. [16] and Konrad [17]: 5) *knee extension*: athlete was in a sitting posture with the distal part of the thighs over the end of the bench, the *knees flexed* 90º and the distal part of one leg fixed to the bench by Velcro® straps. Then, he attempted to extend the supported knee in the *sagittal* plane against the straps; 6) *ankle plantar extension*: in the same sitting posture presented in the previous MVC technique, the athlete attempted to raise the forefoot in the *sagittal* plane while manual resistance was applied to his instep by the experimenter; 7) *knee flexion*: athlete was in a lie down prone position on the bench with one *knee flexed* 45º from the horizontal plane and the *pelvis* fixed to the bench by Velcro® straps. In this posture the athlete attempted to flex the knee in the *sagittal* plane while the experimenter generated a manual resistance; 8) *ankle plantar flexion*: in a similar lying posture to that presented in the previous MVC technique, but with the *knee flexed* 90º and the sole of the foot fixed to the bench by Velcro® straps, the athlete attempted to raise the sole of the forefoot in the sagittal plane against the straps while extra manual resistance was applied to the sole of the foot by the experimenter.

Kick data collection. After the measurement of the MVC, athletes were asked to perform the three different types of kicks at the athlete's xiphoid process height (1.21 ± 0.12 m) setting the kicks up at the frontal (linear kick), lateral (circular kick) and posterior-rotated (spin back kick) hitting positions during 5 s (Figure 1). Each kick lasted 7 s: the first second was used to perform the kick (swing phase), the next five seconds were used to maintain the foot as close to the target as possible in a single-leg stance (static phase). Finally, the last second was used to return to the starting position (recovery phase).

Data analysis

EMG signals were transferred via an optical cable to a compatible computer to be monitored and visually

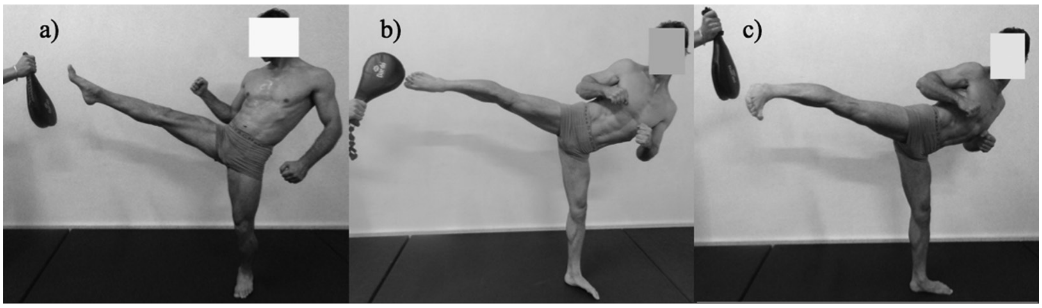

Figure 1. Images of one participant performing the static phase of the linear kick (a), the circular kick (b) and the spin back kick (c).

inspected in order to remove any signal marred with artifacts or other technical problems. The raw EMG signal of each muscle was full-wave rectified and averaged every 0.01 s by using Megawin 3.1 software (Mega Electronics, Ltd., Kuopio, Finland), and then normalized to maximum EMG values obtained during the MVCs [15]. To ensure the stability of the participant's executions, the first and the last trials were discarded and only the second, the third and the forth trial were analyzed. Also, the first and the last second of the static phase of the kick were discarded and only the center 3 seconds window EMG signal of each repetition was selected for further analysis. Data from each repetition was averaged within muscles and type of kicks.

Being kicks performed bilaterally, muscle activities from right and left sides were compared for each type of kick using paired *t*-tests to assess muscle symmetry when they acted as same function (e.g., right and left RA when right and left lower limb were the kicking leg). Since no significant differences were found between muscles activation of right and left sides ($p > 0.05$), EMG amplitudes of both sides were averaged to increase statistical power [24], resulting in a total of eight muscle groups for each person (RA, IO, EO, ES, RF, BF, TA and GL).

Statistical analysis

Statistical analyses were carried out using SPSS 22.0 (SPSS Inc., Chicago, USA). The preliminary analysis (Kolmogorov–Smirnov test) showed a normal distribution of all the considered variables. Taking into account that a previous EMG study on linear kick [18] found poor reliability in waveforms data, we performed a reliability analysis of the three central repetitions (second, third and fourth) of each trial and type of kick. The relative and absolute reliability of the data was analyzed by calculating the intra-class correlation coefficient ($ICC_{2,1}$) and the standard error of measurement (SEM), respectively [19]. ICC scores were classified as follows: poor (0–0.49), moderate (0.50–0.69), high (0.7–0.89) and excellent (0.90–1) [20]. SEM was calculated (in absolute values) as the standard deviation of the difference between two scores and averaged between the three trials. In addition, an analysis of variance (ANOVA) for repeated measures was carried out to compare the mean normalized EMG of each muscle and type of kick between the three central repetitions.

Two consecutive one-way ANOVAs for repeated measures were performed to compare the mean value of the three repetitions between the three types of kick (linear, circular and spin back), first with the kicking side and the second one with the supporting side. Initial exploratory analyses used a significance level of 0.05, but any significant effects were subsequently examined using Bonferroni adjustments for multiple post-hoc comparisons. Partial eta-squared (η_p^2) values below 0.01, 0.01–0.06, 0.06–0.14, and above 0.14 were considered to have trivial, small, medium, and large effect sizes, respectively [21].

Results

Regarding reliability of the three selected repetitions, Table 1 shows moderate to high relative (most values higher than 0.70) and absolute reliability (most values lower than 10% MVC) for most muscles and types of kicks in both the kicking and the supporting sides. In addition, the ANOVA shows no significant differences ($p > 0.05$) between the three repetitions for any muscle, kick and side.

For the kicking side, the ANOVA for repeated measures showed a main effect of the type of kick (linear, circular and spin kicks) in: RA [$F_{(2, 38)} = 13.66$, $p < 0.01$, $\eta_p^2 = 0.37$], EO [$F_{(2, 43)} = 8.10$, $p < 0.01$, $\eta_p^2 = 0.26$], IO [$F_{(2, 43)} = 13.95$, $p < 0.01$, $\eta_p^2 = 0.38$], ES [$F_{(2, 45)} = 56.21$, $p < 0.01$, $\eta_p^2 = 0.71$], RF [$F_{(2, 33)} = 21.96$, $p < 0.01$, $\eta_p^2 = 0.56$], and GL

Table 1. Intra-class correlation coefficient (ICC) and standard error of measurement (SEM) values of the EMG amplitudes according to the type of technique for each side (Kicking and Supporting side) (n = 24).

	Linear Kick				Circular Kick				Spin Kick			
	Kicking side		Supporting side		Kicking side		Supporting side		Kicking side		Supporting side	
	ICC (95% CI, inf limit – sup limit)	SEM	ICC (95% CI, inf limit – sup limit)	SEM	ICC (95% CI, inf limit – sup limit)	SEM	ICC (95% CI, inf limit – sup limit)	SEM	ICC (95% CI, inf limit – sup limit)	SEM	ICC (95% CI, inf limit – sup limit)	SEM
RA	0.76 (0.60-0.88)	3.11	0.89 (0.79-0.95)	1.80	0.86 (0.74-0.93)	6.75	0.85 (0.73-0.93)	2.33	0.95 (0.91-0.98)	1.84	0.75 (0.57-0.87)	2.33
EO	0.96 (0.92-0.98)	4.44	0.82 (0.69-0.91)	2.42	0.98 (0.96-0.99)	3.65	0.85 (0.73-0.93)	5.52	0.70 (0.51-0.84)	6.02	0.56 (0.33-0.76)	5.52
IO	0.80 (0.66-0.90)	3.64	0.64 (0.42-0.81)	2.31	0.89 (0.80-0.95)	2.36	0.90 (0.82-0.95)	2.99	0.70 (0.49-0.85)	3.41	0.78 (0.61-0.89)	2.99
ES	0.84 (0.72-0.92)	2.08	0.84 (0.71-0.92)	4.04	0.71 (0.52-0.85)	6.46	0.73 (0.54-0.86)	6.26	0.71 (0.52-0.85)	7.67	0.69 (0.50-0.84)	6.26
RF	0.84 (0.70-0.92)	8.75	0.77 (0.60-0.88)	4.66	0.73 (0.54-0.86)	23.90	0.72 (0.53-0.86)	5.09	0.69 (0.48-0.84)	5.60	0.63 (0.36-0.81)	5.09
BF	0.85 (0.66-0.94)	0.54	0.65 (0.34-0.86)	5.67	0.57 (0.23-0.83)	1.97	0.51 (0.17-0.80)	4.15	0.85 (0.67-0.95)	7.79	0.67 (0.38-0.87)	4.15
TA	0.85 (0.72-0.92)	4.02	0.63 (0.41-0.80)	9.06	0.65 (0.44-0.81)	4.69	0.73 (0.55-0.86)	12.87	0.69 (0.49-0.84)	6.40	0.54 (0.31-0.74)	12.87
GL	0.95 (0.90-0.98)	5.29	0.70 (0.51-0.84)	13.52	0.78 (0.58-0.89)	10.94	0.82 (0.68-0.91)	11.62	0.50 (0.26-0.72)	9.91	0.62 (0.40-0.79)	11.62

Note: RA: *rectus abdominis*; EO: *external oblique*; IO: *internal oblique*; ES: *erector spinae*; RF: *rectus femoris*; BF: biceps *femoris*; TA: *tibialis anterior*; GL: *gastrocnemius lateralis*

[$F_{(2, 41)} = 12.24$, $p < 0.01$, $\eta_p^2 = 0.36$]. The adjusted Bonferroni statistics for paired comparisons (Figure 2a) showed that RA, IO and RF activation levels were higher in the linear kicks than in the circular and spin back kicks ($p < 0.03$). Also the EO EMG activity in the linear kicks was higher than in the spin back kicks ($p < 0.03$). In the majority of the cases the effect size of these differences was considered as large ($\eta_p^2 = 0.26$). On the contrary, ES EMG activity in spin back kicks was higher than in linear and circular kicks ($p < 0.01$), and in circular kicks higher than in linear kicks ($p < 0.01$); the effect size outcomes of these differences were large ($\eta_p^2 = 0.71$). Although the ANOVA did not show a main effect of the type of kick for BF, the effect size of the differences was considered as medium ($\eta_p^2 = 0.09$), being found the highest activation levels of this muscle in the spin back kicks. Finally, GL EMG activity in circular kicks was higher than in linear and spin back kicks ($p < 0.01$), with a large effect of these differences ($\eta_p^2 = 0.36$).

In the supporting side the ANOVA for repeated measures showed a main effect of the type of kick in: RA [$F_{(1, 31)} = 14.09$, $p < 0.001$, $\eta_p^2 = 0.38$], EO[$F_{(2,41)}$=16.63,P<0.001,η_p^2=0.42],IO[$F_{(1,26)}$=16.10, $p < 0.001$, $\eta_p^2 = 0.41$], ES [$F_{(1, 31)} = 11.89$, $p < 0.001$, $\eta_p^2 = 0.34$], and BF [$F_{(2, 11)} = 5.35$, $p < 0.024$, $\eta_p^2 = 0.49$]. The adjusted Bonferroni statistics for paired comparisons (Figure 2b) showed that RA, EO and IO EMG activity was higher in linear kicks than in circular and spin back kicks ($p < 0.01$). In contrast, ES EMG activity was higher in spin back kicks than in linear and circular kicks ($p < 0.04$). Regarding BF, although the highest activation levels were found in the linear kicks, statistical differences were only found between spin back and circular kicks, being the BF activation higher in the spin back than in the circular kicks ($p < 0.03$). The effect size outcomes of the aforementioned differences were large ($\eta_p^2 = 0.49$).

Discussion

In taekwondo technique modality, there is a lack of information regarding the muscle activation meanwhile performing different techniques so the foundations on which training programs are based are limited. As it was hypothesized, muscle activation changed according to the type of technique, i.e. muscles of the anterior, lateral and posterior part of the body were mainly activated during linear, circular and spin back kicks, respectively.

As Figure 2a shows, anterior body muscles of the kicking side, such as *trunk flexors*, *hip flexors* and *knee extensors* (e.g. RA, IO and RF), were recruited with higher intensity in linear than in circular and spin back kicks. Similar results were reported by Sørensen et al. [11], who found that *hip flexor* and *knee extensor* muscles were activated predominantly in linear kicks. In these techniques, the muscles of the anterior part of the body are activated to set the foot at the xiphoid process height (with *knee extension* and *hip flexion*) while controlling the backward inclination of the trunk against gravity (Figure 1a). In addition, the activation of the abdominal muscles (mainly RA and IO) and RF

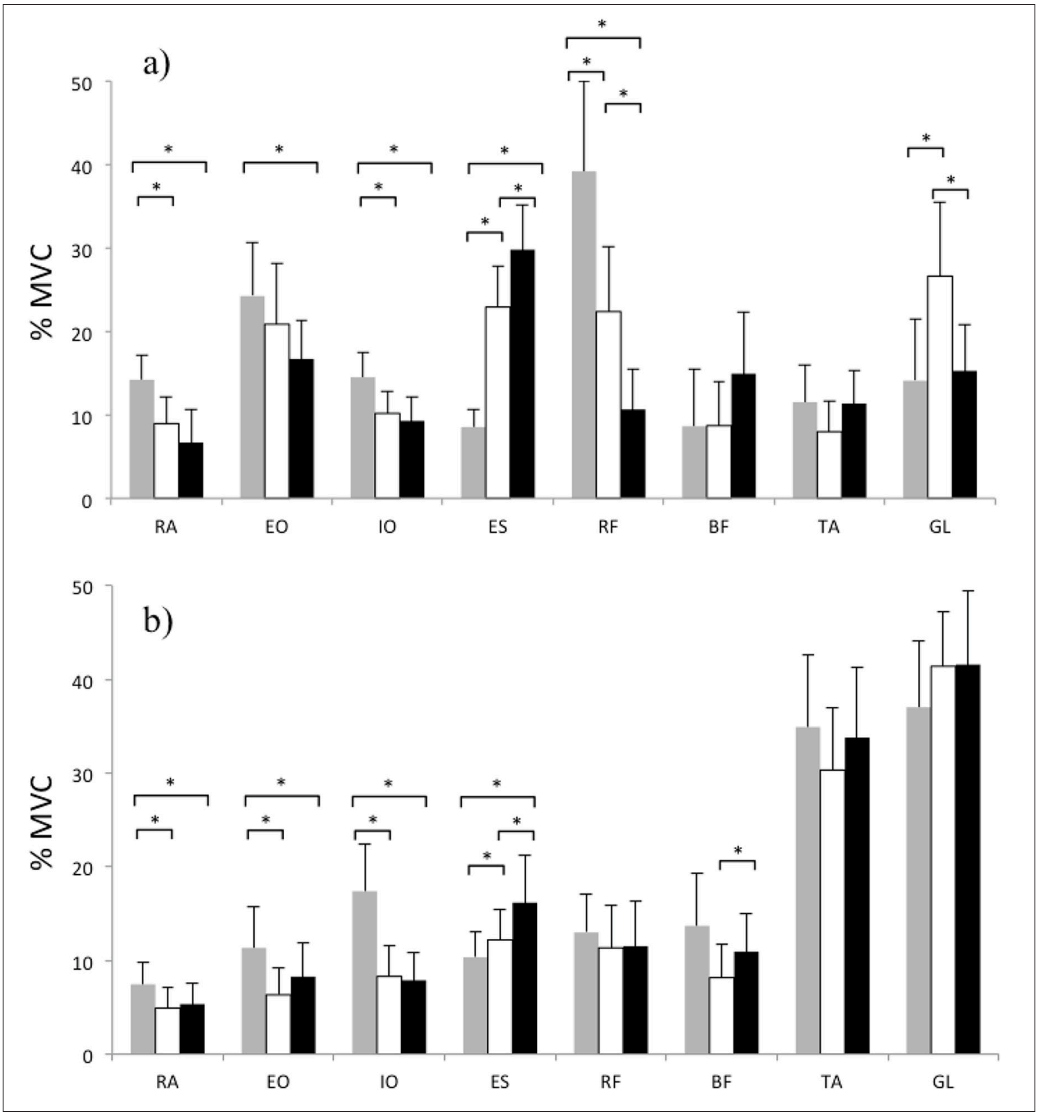

Figure 2. Normalized (%) EMG (mean and SD) of *rectus abdominis* (RA), *external* and *internal oblique* (EO and IO), *erector spinae* (ES), *rectus femoris* (RF), *biceps femoris* (BF), *tibialis anterior* (TA), and *gastrocnemius lateralis* (GL) of the kicking (a) and supporting (b) sides. The grey, white and black columns represent the linear, circular and spin back kicks, respectively. Asterisk and horizontal bracket over the columns mean significant pairwise differences between two types of kicks (P < 0.05).

of the kicking side was higher in circular than in spin back kicks. Probably, while these muscles had an antagonist role during the posterior-rotated position of the spin back kicks, and/or in the lateral position of the body during the circular kicks, the abdominal muscles were activated to generate a trunk lateral flexion moment against gravity [22,23]. Moreover, and in line with previous studies [9,13], RF as a *knee extensor* was recruited to extend the leg to reach the target, highlighting the importance of the activation of this muscle for circular kick performances.

On the contrary to the abdominal muscles and RF results, ES and BF of the kicking side were mainly activated during the spin back kicks. Based on previous EMG studies on the function of these muscles [15,22,23], they were primarily recruited to produce lumbar and hip extensor moments to ensure the maintenance of the posterior-rotated body position in this technique.

Regarding GL of the kicking leg, its activation was higher in circular than in linear and spin back kicks. This could be due to a pronounced plantar flexion needed to hit the target with the instep in this type of kicks [7,9], while in linear and spin back kicks athletes hit the target with the plantar forefoot and the heel, respectively.

In the supporting side (Figure 2b), the comparison between linear, circular and spin back kicks for the trunk muscles showed similar results to those presented in previous paragraphs. This is, while abdominal muscles were mainly activated during the linear kicks, ES activation was higher during the spin back kicks. These results are in agreement with many EMG studies on trunk muscle function [15,23,24], which show the key and agonistic/antagonistic role of the abdominals and ES in producing trunk flexors and extensors moments. Finally, regarding the muscles of the supporting leg, TA and GL activation was similar in the three types of kicks, suggesting a similar function in these techniques. Based on the high TA and GL activation (mean EMG values about 30-40% MVC), and even co-activation has not been analyzed in the current study, they were possibly co-activated to increase ankle stiffness and stability during the single-leg stance [25,26]. Following the method used by Quinzi et al. [13] in circular kicks in karate and the importance of the ankle propioception in taekwondo [12] future studies should analyze co-contraction indexes according to the type of kick so that an insight will be provided in combat sport technique modalities.

Considering the lack of reliability of the EMG data found by Aggeloussis et al. [18] in one of the few studies on taekwondo kicks, a serious concern was the reliability of our EMG data. However, we found moderate to high relative and absolute reliability (Table 1) and no differences in mean normalized EMG between the three selected repetitions for most muscles and types of kicks. This could be due to the high performance level of our athletes and the EMG recorded under static conditions [14]. Nonetheless, as a limitation of the current study, in some muscles (such as BF) the standard deviation of the normalized EMG was considerably high (Figure 2). The data variability and the relatively small size of our sample may explain the lack of pair wise statistical differences between types of kicks in some muscles, even when the effect size was large (i.e. BF with an $\eta_p^2 = 0.49$).

On the basis of the large differences in muscle activity according to the type of kick, the muscle conditioning programs of the technique modality of combat sports (e.g. *poomse* in taekwondo and *kata* in karate) should be focused on the practice of a wide variety of exercises, especially in experienced athletes which normally use a great diversity of techniques when training and competing. However, taking into account that novices often practice sequences of techniques that principally involve linear and circular kicks, muscle conditioning programs in this population should be mainly oriented to strengthen the muscles of the anterior and lateral part of the body. On the other hand, based on the large number of recruited muscles and the great balance demands while maintaining a single-leg stance during linear, circular and spin back kicks, these techniques could be used as part of muscle conditioning and balance programs in physical education, fitness and other sports.

Conclusion

During the static phase of the kicks muscle activation differed according to the type of technique. Specifically, trunk and hip flexor and knee extensor muscles (RA, EO, IO and RF) were mainly activated in the linear kicks. Moreover, GL and RF activation levels were higher in circular than in spin back kicks. Regarding lumbar and hip extensor muscles, ES and BF were predominantly recruited in spin back kicks. In the supporting leg, no differences between kicks were found for TA and GL, which were possibly co-activated to ensure ankle stability during the single-leg stance. These findings may allow researchers and taekwondo coaches to design training programs appropriately.

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Competing interest

The authors declare that they have no competing interests.

References

1. Sbriccoli P, Camomilla V, Di Mario A et al. Neuromuscular control adaptations in elite athletes: the case of top level karateka. Eur J Appl Physiol 2011; 108: 1269–80
2. Machado SM, Osório RAL, Silva NG et al. Biomechanical analysis of the muscular power of martial arts athletes. Med Biol Eng Comput 2010; 48: 573–7
3. Estevan I, Jandacka D, Falco C. Effect of stance position on kick performance in taekwondo. J Sport Sci 2013; 31: 1815–22
4. World Taekwondo Federation. Popularity, latest statistics. http://www.worldtaekwondofederation.net/popularity (accessed 2014 Nov 21).
5. Hermens HJ, Freriks B, Disselhorst-Klug C et al. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000; 10: 361–74
6. Serina ER, Lieu DK. Thoracic injury potential of basic competition taekwondo kicks. J Biomech 1991; 24: 951–60
7. Hong Y, Johns DP, Sanders R, editors. Comparison of electromyography activity between different types of Taekwondo roundhouse kick. Proceedings of the 18th Symposium of International Society of Biomechanics in Sports; 1995 Jun 25–30; Hong Kong; China. Konstanz: International Society of Biomechanics in Sports; 2000
8. McGill SM, Chaimberg JD, Frost DM et al. Evidence of a double peak in muscle activation to enhance strike speed and force: an example with elite mixed martial arts fighters. J Strength Cond Res 2010; 24: 348–57
9. Thibordee S, Prasartwuth O. Effectiveness of roundhouse kick in elite Taekwondo athletes. J Electromyogr Kinesiol 2014; 24: 353–8
10. Quinzi F, Camomilla V, Felici F et al. Differences in neuromuscular control between impact and no impact roundhouse kick in athletes of different skill levels. J Electromyogr Kinesiol 2013; 23:140–50
11. Sørensen H, Zacho M, Simonsen EB et al. Dynamics of the martial arts high front kick. J Sports Sci 1996; 14: 483–95
12. Arsian F, Erkmen N, Taşkin H et al. Ankle joint position sense in male Taekwondo athletes after wobble board training. Arch Budo 2011; 7: 197-201
13. Quinzi F, Camomilla V, Felici F et al. Agonist and antagonist muscle activation in elite athletes: influence of age. Eur J Appl Physiol 2015; 115: 47–56
14. De Luca CJ. The Use of Surface Electromiography in Biomechanics. J Appl Biomech 1997; 13:135–63
15. Vera-Garcia FJ, Moreside JM, McGill SM. MVC techniques to normalize trunk muscle EMG in healthy women. J Electromyogr Kinesiol 2010; 20: 10–6
16. Barbado D, Sabido R, Vera-Garcia FJ et al. Effect of increasing difficulty in standing balance tasks with visual feedback on postural sway and EMG: Complexity and performance. Hum Mov Sci 2012; 31: 1224–37
17. Konrad P. The ABC of EMG. A Practical Introduction to Kinesiological Electromyography. Scottsdale: Noraxon INC; 2005
18. Aggeloussis N, Gourgoulis V, Sertsou M, et al. Repeteability of electromiographic waveforms during the Naeryo Chagi in taekwondo. J Sports Sci Med 2007; 6: 6–9
19. Weir JP. Quantifying test-retest reliability using intraclass correlation coefficient and the SEM. J Strength Cond Res 2005; 19: 231–40
20. Munro BH, Visintainer MA, Page EB. Statistical methods for health care research. Philadelphia: J.B. Lippincott; 1986
21. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum; 1988
22. Ekstrom RA, Donatelli RA, Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. J Ortho. Sports Phys Ther 2007; 37:754–62
23. García-Vaquero MP, Moreside JM, Brontons-Gil E, et al. Trunk muscle activation during stabilization exercises with single and double leg support. J Electromyogr Kinesiol 2012; 22:398–406
24. Vera-Garcia FJ, Moreside JM, McGill SM. Abdominal muscle activation changes if the purpose is to control pelvis motion or thorax motion. J Electromyogr Kinesiol 2011; 21:893–903
25. De Ridder R, Willems T, De Mits S et al. Foot orientation affects muscle activation levels of ankle stabilizers in a single-legged balance board protocol. Hum Mov Sci 2014; 33:419–31
26. Wu G, Liu W, Hitt J et al. Spatial, temporal and muscle action patterns of Tai Chi gait. J Electromyogr Kinesiol 2004; 14:343–54

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