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Surface electromyography in ballistic movement: a comparative methodological analysis from taekwondo athletes

Electromiografía de superficie en movimientos balísticos: un análisis metodológico comparativo en atletas de taekwondo

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Abstract. Surface electromyography (sEMG) signal processing methods used to assess combat sports are heterogeneous. This research aims to compare the electromyography peak (peak EMG) in taekwondo athletes with five processing methods. Secondarily, the coefficient of variation (CV) and the noise percentage regarding the peak EMG (NPRP) were compared. The sEMG record of eight leg muscles of sixteen athletes (12 male and 4 female, ages 20.31+4.1 years) was consulted. The processing methods were: a) Smoothing 1, b) Smoothing 2, c) Root mean square (RMS) 1, d) RMS 2, and e) Empirical mode decomposition (EMD). Results indicate that the peak EMG differs among Smoothing 1 vs. EMD; Smoothing 2 vs. EMD; Smoothing 1 vs. RMS 2; Smoothing 2 vs. RMS 2; Smoothing 1 vs. RMS 1; RMS 1 vs. RMS 2; RMS 1 vs. EMD, and RMS 2 vs. EMD. For all cases $p<.05$ in seven of the eight muscles studied. No differences were found for the CV. The EMD NPRP was lower than the other methods analyzed ($p<.05$). As a conclusion, there are differences among the studied methods and should be considered when interpreting the peak EMG. The EMD seems to be a useful alternative for reducing noise and artifact movement.
Keywords: combat sports; electromyography; muscle activity; data processing.

Resumen. Los métodos de procesamiento de señales de electromiografía de superficie (sEMG) utilizados para evaluar los deportes de combate son heterogéneos. Esta investigación tiene como objetivo comparar el pico de electromiografía (pico EMG) en atletas de taekwondo con cinco métodos de procesamiento. En segundo lugar, se compararon tanto el coeficiente de variación (CV) como el porcentaje de ruido con respecto al pico EMG (NPRP). Se consultó el registro sEMG de ocho músculos de las piernas de dieciséis atletas (12 hombres y 4 mujeres, edades 20,31+4,1). Los métodos de procesamiento fueron: a) Suavizado 1, b) Suavizado 2, c) Raíz cuadrada media (RMS) 1, d) RMS 2 y e) Descomposición en modo empírico (EMD). Los resultados indican que el pico de EMG difiere entre el suavizado vs. EMD; Suavizado 2 vs. EMD; Suavizado 1 vs. RMS 2; Suavizado 2 vs. RMS 2; Suavizado 1 vs. RMS 1; RMS 1 vs. RMS 2; RMS 1 vs. EMD y RMS 2 vs. EMD. Para todos los casos p <.05 en siete de los ocho músculos estudiados. No se encontraron diferencias para el CV. El EMD NPRP fue menor que los otros métodos analizados (p <.05). En conclusión, existen diferencias entre los métodos estudiados y deben tenerse en cuenta al interpretar el pico EMG. El EMD parece ser una alternativa útil para reducir el ruido y el movimiento de artefactos.
Palabras clave: deportes de combate; electromiografía; actividad muscular; procesamiento de datos.

Introduction

Surface electromyography (sEMG) is a biomechanical technique widely used to describe the physiology of muscle contraction by recording its electrical activity (Konrad, 2006; Luca, 1997). This signal is a time-dependent register and can be described in terms of its amplitude, frequency, and phase (Reaz & Hussain, 2006). It allows the quantification of both, moment and magnitude, of the each muscle group contribution when performing a technical sport gesture (De Luca, 1997; Shiavi, 2004).

The SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) (Hermens et al., 2000) proposes a series of recommendations to systematize the acquisition of sEMG, and thus, reduce the noise consequences in the signals. These recommendations include the type of sensor and electrode, the skin preparation, as well as the procedures to place those sensors and electrodes. However, although they are correctly recorded, these signals are contaminated by noise (Chowdhury et al., 2013) which mainly comes from electronic equipment, environmental electromagnetic radiation, signal instability or artifacts motion (Reaz & Hussain, 2006). Therefore, the noisy signals are a problem for the many

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applications sEMG has (Chowdhury et al., 2013; Hakonen et al., 2015). In order to solve this, the processing of the obtained signal is a vital element to filter the signal and then calculate the variables that can help explain the movement (Bo et al., 2013; Chowdhury et al., 2013; Lienhard et al., 2015; Pauk, 2014; Reaz & Hussain, 2006). Moreover, digital smoothing algorithms are also applied to the signal, which summarizes the muscle activity development pattern (Konrad, 2006). Different amplitude variables can be calculated on these filtered and then smoothed signals. For example, the onset and slope of the curve are analyzed in motor patterns. Moreover, the frequency is averaged when analyzing fatigue. Finally, the peak EMG value, which compares the maximum performance of different muscle groups, or the area under the curve are analyzed to measure the degree of contribution of different muscles in a static or dynamic action (Konrad, 2006). In this last context, as there are multiple methods of signal acquisition and processing, the ISEK (International Society of Electrophysiology and Kinesiology) recommends a standard sEMG reporting, including signal acquisition and signal processing methods used (Antworten, 1997). Despite this, we did not find enough studies to analyze how the choice of the type of signal processing can influence the peak EMG value obtained.

Among the main applications of the sEMG, it is worth highlighting the assessment of movement patterns in the sporting context (Bartlett, 2007; Konrad, 2006; Luca, 1997). In this sense, it can be used for measuring the correct use of certain muscle groups, in terms of effort economy and effectiveness of the sports gesture, as well as in preventing injuries (Massó et al., 2010). Combat sports have received a lot of attention in recent years (Simões et al., 2020). For a complete biomechanical analysis in combat sports, the kinematic, kinetic and electromyographic study is performed. One of the most relevant variables is the electromyography peak (peak EMG) as a measure of maximum muscle activity, since these sports require a high level of muscle power and speed from athletes to execute their hits (Herrera-Valenzuela et al., 2020; Kazemi et al., 2013; Pereira et al., 2021; Thibordee & Prasartwuth, 2014; Valdes-Badilla et al., 2018; Vieira et al., 2016). Therefore, assessing sEMG in combat sports should provide exceptional care in areas such as artifacts movement and signal processing. In this sense, the taekwondo *Roundhouse kick* is a blow that is very representative of the speed, strength and power required in combat sports (Castro-Gatrido et al., 2020). In turn, it would be interesting to analyze whether the different processing methods used to calculate the peak EMG generate changes in the result. On the other hand, the approaches to deal with the signals reported in combat sports literature are not completely homogeneous, and some of them are described below.

Sarmet et al. (2016) and Valdés-Badilla et al. (2018) studied the *Roundhouse kick* of taekwondo athletes processing their signals by applying low-pass filter wave smoothing with cut-off frequencies of 10 and 12 [Hz] respectively. Meanwhile, Rinaldi et al. (2018) studied the *Junzuki karate punch* using a cut off frequency of 10 [Hz]. Tsai et al. (2017) analyzed in kendo the *Hiki Waza*, using cut-off frequencies of 6 [Hz], while Zorzi et al. (2015) reported in Tai Chi practitioners during the *First Lu*, the use of cut-off frequencies of 4 [Hz]. Conversely, the signal's root mean square (RMS) is often calculated with different window width parameters in combat sports as a measure of wave softening. Thibordee & Prasartwuth (2014) during the *Roundhouse kick* analysis in elite taekwondo athletes, used the RMS with a 50 ms window. Jemili et al. (2016) analyzed the *guiaku-zuki-punch* and the *kiza-mawashi-guiri-kick* of karate using RMS with a 25 ms window. Quinzi et al. (2016) studied karate kicks using an MSR with a 64 ms window, and also Quinzi et al. (2018) report the use of RMS with a window width of 250 ms during isokinetic contraction of biceps brachial muscle in karate athletes. Therefore, the analysis of different sEMG signal processing methods can help to establish, with greater accuracy, the relevance or selection of the most suitable method for combat sports. In order to generate a recommendation on how to process electromyography signals when analyzing *Roundhouse kicks*.

Traditionally, sEMG processing uses linear tools such as wave reduction and smoothing methods to ease the interpretation (Konrad, 2006). However, the electromyographic signal nature generates non-stationary data that may not represent a linear process. In this context, Huang et al. (1998), proposed the use of the empirical mode decomposition (EMD) for the treatment of this type of data. In addition, other authors have demonstrated its usefulness in EMG data (Andrade et al., 2006; Tsolis & Xenos, 2011). To the extent investigated, research using non-linear methods such as the EMD for this purpose and calculating variables such as the peak EMG in combat sports has not been found. In this sense, this study aims to compare the electromyography peak (peak EMG) in taekwondo athletes with five processing methods. Secondarily, both the coefficient of variation (CV) and the noise percentage regarding the peak EMG (NPRP) were compared. According to previous studies comparing the peak EMG in other contexts (Hibbs et al., 2011; Renshaw et al., 2010), it is hypothesized that statistically significant differences exist in the maximum amplitude value of sEMG, CV and NPRP among the signal processing methods used. These differences may be significant in interpreting peak EMG results when comparing different studies.

Materials and methods

Participants

A previous study database (Valdes-Badilla et al., 2018), which tested sixteen male and female taekwondo athletes (12 male and 4 female, ages: 20.31+4.1 years) was consulted. Inclusion and exclusion criteria for participants, measurement protocol, and measurement procedure were the following: a) taekwondo athletes with more than one year of practice; b) training three or more times per week; c) having participated in national tournaments organized by the National Taekwondo Sports Federation (FEDENAT, Chile; organization recognized by the World Taekwondo); d) enrolled in a club joined to FEDENAT; e) provided an informed consent authorizing the use of the data for scientific purposes; f) provided an informed consent signed by their parent or guardian, in the case of minor participants. Participants presenting some disease or injury that hinder their normal physical performance were excluded. Thus, 16 (12 male and 4 female) taekwondo athletes took part in this study. Years of taekwondo practice were considered to categorize the participants as novice (6 male and 2 female) athletes and advanced (6 male and 2 female). Novices had less than three years of experience in taekwondo, while advanced athletes had three or more years. This research protocol was approved by the Scientific Ethics Committee (N°080-16) of Universidad Autónoma de Chile and developed following the Helsinki Declaration (World Medical Association, 2000).

Equipment set-up

The sEMG signal was obtained during the execution of fifteen *Roundhouse kick* to an impact shield held by a discipline expert and derived from the soleus (SO), tibialis anterior (TA), lateral gastrocnemius (GL), vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF) and semitendinosus (ST) muscles of each participant's dominant leg. It should be noted that the medial gastrocnemius was also measured. However, the analysis of this muscle was excluded because 9 participants had incomplete EMG recording due to problems with electrode fixation. A Delsys surface electromyography Bagnoli model of 16-channel (Delsys Inc., Boston, MA, USA) was used coupled with Ag/AgCl parallel rod electrodes (Single Differential Surface EMG Sensor; inter-electrode distance 1 cm; contact dimensions 10 x 1 mm). Electrodes were placed by a trained physiotherapist following SENIAM guidelines (Hermens et al., 2000), such as shaving, cleaning with alcohol and securing each electrode with adhesive tape towards the muscle fibers, avoiding motor points. The acquisition was made at a default sampling frequency of 4,000 Hz, and a gain of 1,000 with the EMGworks 4.0.13 software (Delsys Inc., Boston, USA).

After completing each experimental session, additional EMG data were recorded during each muscle's maximum voluntary contractions (MVC) to assess the relative magnitude of muscle activation. A trained physiotherapist applied manual resistance according to the standard muscle test protocol (Peterson et al., 2005). The order to perform the MVC was the next: a) soleus: in a seated position with the knee in 90° flexion, the plantiplexion resists from the distal and upper thigh area in the direction of the floor; b) tibialis anterior (TA): in the supine position, dorsiflexion of the ankle and inversion of the foot without extension of the hallux are resisted from the inner edge of the dorsal surface of the foot; c) lateral gastrocnemius (LG): in standing position, the plantiflexion resists from the shoulders towards the ground; d) vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF): in a sedentary position, with the knee in flexion of 70°, the extension against the leg above the ankle resists in the direction of flexion; e) biceps femoris (BF): in a prone position, with the knee flexed at 60° and the thigh in slight external rotation, the flexion against the leg above the ankle resists in the direction of the extension; and f) semitendinosus (ST): in a prone position, with the knee flexed at 60° and the thigh in slight internal rotation, flexion against the leg above the ankle resists in the direction of extension. Three MVCs were performed for each muscle (the average of the three sets was applied to determine the MVC). Finally, participants completed a standardized 15-minute specific warm-up. This warm-up was led by an experienced taekwondo teacher and former national coach. It consisted of joint mobility exercises and dynamic stretching with displacements (forward, backward, diagonal, side shifts and turns), technical movements without knee extension, and simulation exercises consisting of attacks and defences with assistance. The warm-up ended with three sets of 12 front kicks and three sets of 12 *bandalchagui kicks* to the impact shield.

Variables

Five sEMG processing methods were manipulated as the independent variable and named data processing methods, with the following labels: a) Smoothing 1, b) Smoothing 2, c) RMS 1, d) RMS 2, and e) EMD. On the other hand, the muscles studied (SO, TA, GL, VM, VL, RF, BF, ST) were also manipulated as independent variables. The dependent variables were the maximum sEMG wave amplitude (peak EMG), the CV and NPRP of each muscle.

Methods for signal processing

Based on the methodologies presented in published studies on combat sports, we propose the same initial treatment of the data. Next, four of the most reported methods in these studies were selected and finally, the protocol of EMD proposed by Andrade et al (2016) was followed. The MatlabR2016a software (MathWorks Inc., USA) was used to process the sEMG signals. The raw data of each muscle corresponding to each hit (*Roundhouse kick*), was isolated and centered at zero subtracting the wave average. Fourth order Butterworth high-pass and low-pass filters were with cut-off frequencies of 10 and 400 Hz were applied respectively. Five processing methods were then used in the resulting signal (Fig. 1). A) Smoothing 1: A full wave rectification was applied, and the envelope was calculated by applying a fourth-order low-pass Butterworth digital filter with a cut-off frequency of 12 Hz. B) Smoothing 2: Procedure «A» was replicated by changing the filter cut-off frequency to 10 Hz (Both cut-off for A and B were used based on previous literature with electromyographic recording in *Roundhouse kick* in taekwondo athletes; (Sarmet et al., 2016; Valdes-Badilla et al., 2018). C) RMS 1: RMS was calculated. For this purpose, a mobile data window with a 200 sampling width equivalent to 50 milliseconds was established. D) RMS 2: Procedure «C» was replicated by changing the window width to 400 samples, equivalent to 100 milliseconds. E) EMD: The empirical mode decomposition was applied following the proposal by Andrade et al. (2006). The first stage consisted of decomposed the signal through an iterative process into its intrinsic mode functions (IMF). Each IMF had to meet two requirements: 1) Throughout the entire data set, the number of extremes and the number of crosses per zero must be equal or different by no more than one and; 2) At any point, the envelope means value defined by local maximums and the envelope defined by local minimums was zero. The second stage was to establish a threshold value for each IMF. A noise window was selected from the ends of the first signal, and its standard deviation was also calculated. This value was used to soften each IMF according to equation 1 (Andrade et al., 2006), where *t* represents the defined threshold, and *n* represents the IMF number: (1)

$$tIMF_n = Sign(tIMF_n)(|tIMF_n| - t_n)$$

The third stage was the signal reconstruction by adding the softened IMFs.

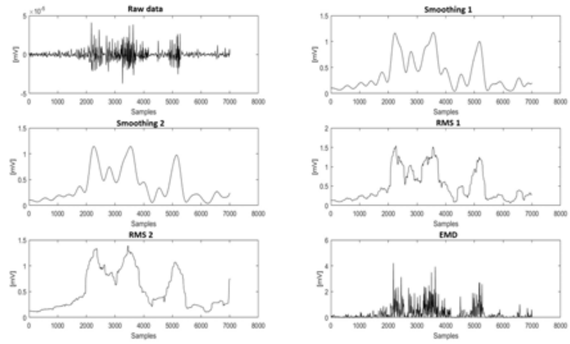

Fig. 1: Surface electromyography processing methods (soleus muscle). Smoothing 1: 12 Hz low-pass filter. Smoothing 2: 10 Hz low-pass filter. RMS 1: Root mean square, moving window, 200 samples window width. RMS 2: Root mean square, moving window, 400 sample window width. EMD: Empirical mode decomposition, threshold and reconstruction.

The following variables were calculated for each of the five processing methods and each of the eight muscles. First, the signal was normalized according to the maximum voluntary contraction, and the maximum amplitude of the sEMG signal (peak EMG) was obtained by identifying the highest value of each wave. Secondly, the CV was established as the standard deviation (SD) normalized according to the wave mean, thus avoiding the influence of the wave magnitude through equation 2 (Hibbs et al., 2011):

(2) CV = (SD/mean) x 100

Third, the calculation of the signal's NPRP was proposed as a measure of the noise magnitude corresponding to each signal. For this, a sampling window corresponding to a moment in the recording, where no muscle activity was representative of noise (noise windows), was established. This interval was identical for each of the five processing methods (see Fig. 2). Besides, the average amplitude of the noise window was also calculated. Finally, each value was normalized as a function of the peak EMG. The procedure is expressed through equation 3, where *n* represents the number of samples in the noise window, and *x* is the wave amplitude at that moment: (3)

$$NPRP = \left(\left(\frac{1}{n}\sum_{i=1}^{n} xi\right) * 100\right) \Big/ peak\ EMG$$

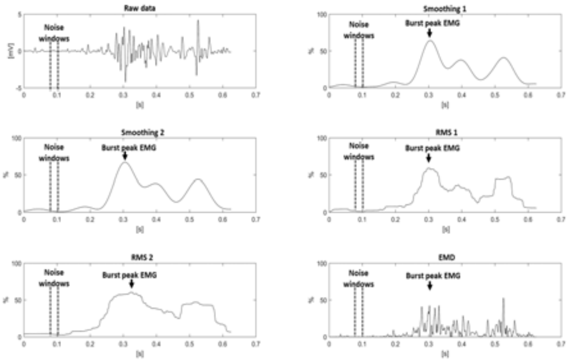

Fig. 2: Selection of a noise window at the same time interval in all processing methods using the signal of all muscles (as an example, one of the lateral gastrocnemius muscle). The peak EMG represents the moment of maximum electromyographic amplitude.

Statistical Analysis

The SPSS (Statistical Package for the Social Sciences) version 23.0 was used. The primary dependent variable (peak EMG) was subjected to a descriptive analysis calculating the mean, standard deviation (SD), CV, and NPRP. The variance analysis was performed independently, for each variable, and for each muscle, through the one-way ANOVA test to evaluate the differences in peak EMG, CV and NPRP among the processing methods studied. Games-Howell's post Hoc multiple comparisons test or the HSD Tukey test were used based on the homoscedasticity results of the Levene test. For all cases, a significance value of $p<.05$ was established.

Results

Table 1 shows the peak EMG, SD, CV, and NPRP values for each muscle and processing method. According to the processing method, the decreasing order of the peak EMG obtained was Smoothing 1, Smoothing 2, RMS 1, RMS 2, and EMD, respectively. The muscles with the highest peak EMG were SO, VL and VM with the Smoothing 1, Smoothing 2, RMS 1, and RMS 2 methods. On the other hand, the highest values with the EMD method were SO, VL and GL. From the eight muscles studied, the highest CV was obtained by the EMD method (51%), followed by Smoothing 1 (46.4%), RMS 1 (44.8%), Smoothing 2 (44.8%), and RMS 2 (40.8%). For NPRP, the results were RMS 2 (3.3%), Smoothing 2 (2.6%), RMS 1 (2.6%), Smoothing 1 (2.5) and EMD (0.1%).

Statistically significant differences in the peak EMG

Table 1
Peak EMG according to signal processing method and muscle studied during the Roundhouse kick in taekwondo athletes.

Processing methods		Peak EMG							
Smoothing 1	Mean	108.01	80.25	84.70	86.69	89.78	79.48	85.68	78.11
	SD	52.06	35.61	37.73	35.64	50.58	40.87	44.53	25.99
	CV	48.20	44.38	44.54	41.11	56.34	51.43	51.97	33.28
	NPRP	6.02	1.70	2.26	1.38	2.87	1.55	2.28	2.07
Smoothing 2	Mean	106.23	78.29	85.17	88.98	90.92	78.79	85.10	78.59
	SD	49.51	34.24	37.87	36.23	47.83	38.89	41.74	24.79
	CV	46.61	43.74	44.46	40.72	52.60	49.36	49.05	31.54
	NPRP	6.29	1.79	2.32	1.48	3.06	1.62	2.32	2.19
RMS 1	Mean	101.98	71.49	80.26	81.62	85.76	71.61	78.54	76.40
	SD	46.86	30.58	35.42	32.71	46.15	36.51	39.27	23.39
	CV	45.96	42.78	44.13	40.08	53.81	50.98	50.00	30.62
	NPRP	6.62	1.69	2.30	1.43	3.20	1.52	2.20	2.08
RMS 2	Mean	91.33	64.51	78.41	80.79	83.04	67.33	75.52	73.54
	SD	37.41	25.35	34.77	31.85	39.38	29.51	33.55	19.75
	CV	40.96	39.30	44.34	39.42	47.42	43.83	44.43	26.85
	NPRP	8.36	2.01	2.68	1.78	4.01	1.90	2.67	2.60
EMD	Mean	91.62	61.00	74.77	73.66	81.66	64.45	62.60	70.51
	SD	53.10	28.18	41.08	33.73	47.18	40.65	30.80	23.52
	CV	57.96	46.19	54.94	45.79	57.77	63.07	49.20	33.36
	NPRP	0.14	0.03	0.04	0.06	0.26	0.39	0.04	0.10
		SO	TA	GL	VM	VL	RF	BF	ST

The maximum amplitude of the sEMG signal (peak EMG) according to the processing method. Smoothing 1: 12 Hz low-pass filter. Smoothing 2: 10 Hz low-pass filter. RMS 1: Root mean square, moving window, 200 samples window width. RMS 2: Root mean square, moving window, 400 sample window width. EMD: Empirical mode decomposition, threshold, and reconstruction. SD=standard deviation; CV=coefficient of variation; NPRP = *noise percentage regarding peak EMG. Soleus (SO), Tibialis Anterior (TA), Lateral Gastrocnemius (GL), Vastus Medialis (VM), Vastus Lateralis (VL), Rectus Femoris (RF), Biceps Femoris (BF) and Semitendinosus (ST).*

value were found among the signal processing methods, specifically when comparing Smoothing 1 and Smoothing 2 vs. EMD in SO, TA, GL, VM, RF, BF, and ST muscles; Smoothing 1 and Smoothing 2 vs. RMS 2 in the muscles SO, TA, RF, and BF; Smoothing 1 vs. RMS 1 in the muscle TA; RMS 1 vs. RMS 2 in the muscle SO; RMS 1 vs. EMD in the muscles TA, BF, and ST; and RMS 2 vs. EMD in the muscle BF. Post-hoc analysis results are presented in Table 2.

Table 2
PeakValue comparison among signal processing methods during the Roundhouse kick in taekwondo athletes.

Muscle	p value									
SO †	0.995	0.671	**0.001***	**0.006***	0.871	**0.002***	**0.017***	**0.048***	0.158	1.000
TA †	0.973	**0.033***	**0.000***	**0.000***	0.148	**0.000***	**0.000***	0.052	**0.001***	0.606
GL	1.000	0.692	0.351	**0.031***	0.604	0.278	**0.020***	0.983	0.493	0.824
VM	0.948	0.479	0.320	**0.000***	0.125	0.065	**0.000***	0.999	0.079	0.148
VL	0.999	0.878	0.503	0.308	0.741	0.339	0.185	0.968	0.869	0.998
RF	1.000	0.146	**0.004***	**0.000***	0.223	**0.008***	**0.000***	0.721	0.225	0.918
BF †	1.000	0.339	**0.040***	**0.000***	0.391	**0.046***	**0.000***	0.894	**0.000***	**0.000***
ST	0.999	0.932	0.210	**0.004***	0.848	0.131	**0.002***	0.673	**0.049***	0.621
	A-B	A-C	A-D	A-E	B-C	B-D	B-E	C-D	C-E	D-E

*Differences in the Maximum amplitude of the sEMG signal (peak EMG) between processing methods. A) Smoothing 1. B) Smoothing 2. C) RMS 1. D) RMS 2. E) EMD. One factor ANOVA test with Games-Howell post hoc multiple comparisons test. † HSD Tukey test. * Statistically significant differences, p < 0.05. Soleus (SO), Tibialis Anterior (TA), Lateral Gastrocnemius (GL), Vastus Medialis (VM), Vastus Lateralis (VL), Rectus Femoris (RF), Biceps Femoris (BF) and Semitendinosus (ST).*

No significant differences were found in CV among processing methods for each of the muscle studied (p=.121). Regarding NPRP, statistically significant differences were found among the methods, the post-hoc analysis showed significant differences between Smoothing 1 vs. EMD (*p*=.034), Smoothing 2 vs. EMD (*p*=.024), RMS 1 vs. EMD (*p*=.024) and RMS 2 vs. EMD (*p*=.003), which are presented in Fig. 3.

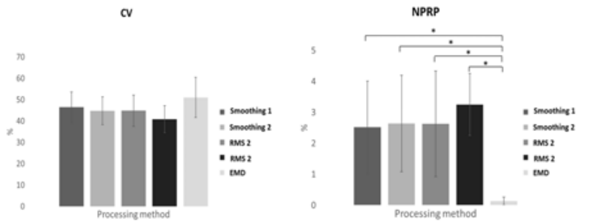

Fig. 3: Differences in the coefficient of variation (CV) among processing methods (left) for all muscles. Differences in the noise percentage regarding the peak EMG (NPRP) among processing methods (right) for all muscles. One factor ANOVA test with Tukey HSD post-Hoc multiple comparisons test. * Statistically significant differences, p < 0.05. EMD: Empirical mode decomposition. RMS: root mean square.

Discussion

This study aimed to compare the peak EMG during the *Roundhouse kick* in taekwondo athletes, using five signal processing methods. Secondarily, both CV and NPRP were compared. We hypothesized that there are statistically significant differences in these variables among the signal processing methods used. The primary outcome of the research indicates that choosing the sEMG signal processing method may directly affect the magnitude of the calculated peak EMG. No differences were found for the CV. The EMD NPRP was lower than the other methods analyzed.

Previous studies used peak EMG as a maximum muscle activation measure in several technical gestures for combat sports (Lee & McGill, 2017; Lenetsky et al., 2015; Quinzi et al., 2016, 2018; Tsai et al., 2017; Valdes-Badilla et al., 2018). However, its susceptibility to the artifacts movement is among the difficulties of using this variable as a measure to estimate signal amplitude; therefore, it would not provide a signal robust enough (Renshaw et al., 2010). The use of signal softening techniques or the use of RMS can limit the outliers and noise effect, thus providing a more reliable measure (Renshaw et al., 2010). According to this, it is interesting to see how these data processing and reduction techniques affect the peak EMG.

Renshaw et al. (2010), compared different methods for calculating the sEMG amplitude. They rectified and softened the signal using the RMS. Besides, they also calculated the peak EMG (RMS peak), RMS mean and EMG integral (area under the curve), finding significantly lower values when using the variable peak EMG (Renshaw et al., 2010). Our results show that higher peak EMG values were obtained with methods based on Smoothing, followed by those based on RMS. The EMD-based method delivered the lowest peak EMG values, which in turn presented a significantly lower NPRP, interpreted as a signal with a lower noise level. In this sense, the EMD usage respects that the sEMG signal is non-stationary and non-linear. Several authors have demonstrated that breaking down the waveform into IMF makes it possible to filter the signals noise background successfully (Andrade et al., 2006, 2012; Savithri & Priya, 2019; Yang et al., 2018).

According to the results obtained in our study, the main differences were found between the EMD method regarding Smoothing and RMS, which differs significantly in up to seven of the muscles studied. A generalized decrease in the wave amplitude could explain this result, which would also be less affected by noise (Andrade et al., 2006; Huang et al., 1998; Ruchika & Dhingra, 1999; Yang et al., 2018). Smoothing 1 and Smoothing 2 methods differ significantly from RMS 2 in four of the muscles studied. These differences may be related to the processing nature, where Smoothing is performed through a low-pass and the established cut-off frequency determines the low-frequency components rescued from the wave and thus the signal smoothing level (Allen & Mills, 2004). Instead, RMS is a measure of central tendency, with the width of the chosen window directly impacting the «smoothness» of the output signal (Merletti & Parker, 2004).

Hibbs et al. (2011) studied eight muscles during core exercises. They compared the peak EMG with the average rectified EMG data, such as amplitude measures, finding statistically significant differences in the CV. Our findings indicate that the processing methods studied for the peak EMG calculation do not significantly modify the CV. This outcome could be given since the data reduction of the methods used keeps the original signal's main characteristics.

On the other hand, the NPRP with the EMD processing was significantly lower than the other processing methods studied. Differences between the noise bandwidth and the peak EMG show that this method decreases the overall wave amplitude. However, this decrease occurs to a greater extent to elements that do not belong to the activation muscle burst. The threshold procedure used could explain this result (Andrade et al., 2006). A threshold was applied to each IMF, where each lower value was brought to zero. Therefore, at the reconstruction stage, the overall sum of the IMFs generates a signal of lower amplitude and less noise contamination. Among the strengths of this research are: a) the use of processing methods reported in the literature regarding combat sports, allowing to identify how their choice could determine changes in the peak EMG magnitude. b) to include the use of EMD for the treatment of sEMG signals, which has not been previously reported in combat sports. Regarding the study's limitations, we could indicate that the time required for signal processing was not considered in each method studied. However, it is worth noting that the use of EMD requires a higher computational cost, as well as the need to perform offline data analysis.

For future studies, a comparison of the different sEMG signal processing methods specifically for combat sports (e.g., Taekwondo, Judo, Karate, Kendo, Tai chi, etc.) is proposed, emphasizing the identification of differences in sports gestures performed with the upper limb (e.g., punch) and lower limb (e.g., kick). As a result, choosing the signal processing method would be precise and following the action to be assessed.

As for practical implications in combat sports, the processing method used to calculate the peak EMG should be considered when comparing the results of different studies. Methods using a low-pass filter such as «softening» deliver higher values. Conversely, the EMD seems to be an useful alternative to reduce noise and artifact movement consequences associated with assessing this kind of sporting gesture.

Conclusions

This study determined that the *Roundhouse kick* analysis in taekwondo athletes through different sEMG signal processing shows significant differences among the methods, which should be considered when interpreting the peak EMG value obtained. Besides, the EMD presents the lowest NPRP with no differences in the CV. Hence, it seems to be a useful alternative to reduce the noise and artifacts movement consequences associated with the analysis of technical gestures for combat sports.

Conflict of interests

The authors state no conflict of interest.

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