

Research article

## Repeatability of electromyographic waveforms during the Naeryo Chagi in taekwondo

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### Abstract

The purpose of the research was to study the repeatability of electromyographic (EMG) waveforms of major lower limb muscles during the naeryo chagi (axe kick) in taekwondo. Six male and female athletes, aged between 20 and 24 years served as volunteers. All participants were black belt holders and performed the naeryo chagi with their right leg. The electromyographic activity of rectus femoris, biceps femoris, gastrocnemius lateralis and tibialis anterior was recorded during the kick through four preamplified surface electrodes. The participants performed 10 successive kicks to a fixed target with 1 min inter-trial interval. The electromyograms were recorded during each kick at a sampling frequency of 1000Hz. After the processing of the raw EMG data, myoelectrical activity was normalized on the time and amplitude domain. The coefficient of variation (CV), intra-class correlation coefficient (ICC) and coefficient of multiple correlation (CMC) were computed to test the repeatability of the electromyographic waveforms in each participant. The electromyographic activity during the naeryo chagi demonstrated poor repeatability. More specifically, all CVs were greater than 80%, all CMCs were lower than 0.75 and the majority of the average measure ICCs as well as all single measure ICCs were lower than 0.55. It seemed that only ensemble averages of EMG waveforms obtained from more than ten kicks may be considered as representatives of the muscle function in naeryo chagi and conclusions that have been drawn from a single trial should be reconsidered.

**Key words:** Electromyography, reliability, axe kick, taekwondo.

### Introduction

Naeryo chagi, also known as axe or downward kick, is a vertical taekwondo kick, which usually strikes the opponent's scull, face or clavicle, in imitation of an axe's movement. From the initial position, the knee is raised in an arc up and forward in front of the body, the leg then extended and pulled down with the heel pointed downward. The arc can be performed in either a clockwise or a counter-clockwise direction.

Surface electromyography is a valid method for the assessment of neuromuscular function (Winter, 1990). However, prior to an electromyographic study of the naeryo chagi, it is important to establish the reliability of the measurement procedure, because the myoelectrical activity that is recorded by surface electrodes depends on a great number of factors. These factors include mainly the length, the size, the number and the contraction velocity of the muscle fibers within the detection area of the electrodes (Basmajian and De Luca, 1985).

In most cases, it is very difficult to control all these factors during several trials of the same athlete, either within the same measurement period for the determination of the athlete's muscle activity pattern or in different periods (pre- and post-measurements) to determine the effects of an intervention (i.e. a training program) in the athlete's muscular activity. For this reason the electromyographic (EMG) activity that is recorded in a naeryo chagi trial cannot recur, in exactly the same way, in any other trial. Consequently, intra-measurement or inter-measurement differences of an athlete's EMG activity during a naeryo chagi depend on the repeatability of the EMG waveforms during the kick. Despite of its importance, the repeatability of EMG waveforms in naeryo chagi kicks has not been studied yet. However, the repeatability of myoelectrical parameters has been studied in other movements.

Finucane et al (1998) studied the repeatability of a single EMG parameter, the rmsEMG, in maximal isometric and sub-maximal concentric and eccentric contractions in an isokinetic dynamometer. Their results showed that the rmsEMG was repeatable in all contractions and that the EMG normalization has not any significant effect on the parameter's repeatability.

Golhofer et al (1990) studied the repeatability of the EMG area of the gastrocnemius, soleus and tibialis anterior muscles during stretch-shortening cycles in various activities: running at a constant speed of 12 km/h, one-leg and two-leg hopping at preferred frequency and drop jumps from 40cm. The results showed different correlation coefficients for different muscles and activities. However, most coefficients had values greater than 0.85.

Goodwin et al (1999) studied the repeatability of the EMG area of several muscles in countermovement vertical jumps. The results showed that the intraclass correlation coefficients (ICC) were 0.88 for rectus femoris, 0.70 for vastus medialis, 0.24 for biceps femoris and only 0.01 for the gastrocnemius. Consequently, it was concluded that the repeatability of EMG parameters is lower than other biomechanical parameters and depends on the recorded muscle.

Karamanidis et al (2004) studied the repeatability of several myoelectrical parameters during different running techniques, combining three different running speeds (2.5, 3.0 and 3.5 m·s<sup>-1</sup>) and three different stride frequencies (preferred and ±10%). EMG signals were recorded in three trials for each running condition. The results showed that the ICC of the EMG parameters of gastrocnemius were greater than 0.69 in 73% of the data, while those for

**Table 1.** Coefficients of variation (CV%) and coefficients of multiple correlation (CMC) for the EMG waveforms of each participant.

Participants	Rectus femoris		Biceps femoris		Gastrocnemius		Tibialis anterior	
	CV%	CMC	CV%	CMC	CV%	CMC	CV%	CMC
1	86.23	0.436	120.61	0.709	94.71	0.541	95.12	0.577
2	87.66	0.252	108.39	0.711	117.6	0.667	89.54	0.583
3	119.71	0.493	109.94	0.446	123.69	0.451	107.41	0.344
4	99.42	0.59	96.23	0.489	98.72	0.273	116.85	0.362
5	140.51	0.592	85.65	0.539	98.4	0.597	95.53	0.326
6	96.15	0.641	92.76	0.619	121.23	0.686	108.97	0.552

vastus lateralis, hamstrings and tibialis anterior were much lower. They also found that the repeatability of EMG parameters depended on the muscle and the parameter studied.

The above researchers studied the repeatability of discrete EMG parameters and not that of EMG waveforms, in activities other than the naeryo chagi. Moreover, their findings were inconsistent and cannot be generalized because EMG repeatability depends on the muscle and the activity studied (Karamanidis et al., 2004). So, the purpose of this research was to determine the repeatability of the EMG waveforms of major muscles of the lower limb in naeryo-chagi (axe or downward kick) in taekwondo.

## Methods

Six taekwondo athletes (3 men and 3 women) with an average age of  $21.66 \pm 1.6$  years (SD), an average height of  $1.68 \pm 0.1$  m and an average mass of  $67 \pm 15.1$  kg, voluntarily participated in the study. All of them were black belt holders and gave their written informed consent.

Four preamplified (bandwidth: 10Hz-1000Hz, CMRR: >100dB, input impedance:  $10^{12}$  Ohms) surface electrodes (Motion Control Inc.) connected to the APAS system (Ariel Dynamics Co.) were used for the recording of EMG waveforms. The detection surface of the electrodes was  $0.9\text{cm}^2$  and the inter-electrode distance was 2cm. An analog micro switch connected to a TTL pulse generator was located under the metatarsals of the kicking leg. The output signal of the micro switch was used for the determination of the instants of the foot take-off and its impact on the target. All signal processing and calculations were performed using MATLAB (MathWorks Inc.).

All participants performed the kicks against a spherical target (30cm diameter) in imitation of an opponent's head. Each participant initially placed the target on his preferred location and this location was maintained steady throughout the trials. The electrodes were positioned over the bellies of rectus femoris (RF), biceps femoris (BF), lateral gastrocnemius (LG) and tibialis anterior (TA) of the participant's right lower limb, according to the guidelines of SENIAM (Surface Electromyography for the Non-Invasive Assessment of the Muscles, BIOMED II) project. Electrode sites were prepared through shaving, skin abrasion and alcohol cleaning. The electrodes were secured to the skin with elastic tapes to reduce motion artefacts.

Each participant performed three kicks for familiarization purposes and then ten kicks at his maximum speed, with an inter-trial interval of 1 min. In each trial

the EMG activity of the four muscles and the output signal of the micro switch were recorded at a sampling rate of 1000Hz.

The EMG signals were full-wave rectified and smoothed with a 4<sup>th</sup> order Butterworth band pass filter with cut-off frequencies of 10Hz and 350Hz. The output signals were normalized on the time domain through interpolation with cubic splines at 1% time intervals of the kick's duration, defined from foot take-off to the impact on the target. EMGs were also normalized on the amplitude domain using the peak dynamic method (Burden et al, 2003; Prilutski et al, 1998). In this method, each data point on a muscle's EMG curve was divided by the muscle's peak EMG value of the intra-individual ensemble average that was calculated from the ten EMG recordings for each participant (Karamanidis et al., 2004; Prilutski et al., 1998).

The repeatability of the EMG waveforms was tested using the coefficient of variation (CV), the single-measure and the average-measure intra-class correlation coefficient (ICC) and the coefficient of multiple correlation (CMC). The level of statistical significance was set at  $p < 0.05$ .

## Results

The coefficients of variation for the duration of the kicks, from foot take-off to the impact on the target, ranged between 2.41% και 5.61%, demonstrating the great temporal stability of the movement in all participants.

On the contrary the coefficients of variation (CV) for the EMG waveforms (Table 1) were much higher than 10% which is the maximal acceptable variability in biomechanical data (Winter, 1991). As it can also be seen in Table 1, the values of the coefficients of multiple correlation were lower than 0.75.

Intraclass correlation coefficients (ICC) are presented in Table 2. Although some average measures ICCs are greater than 0.80, no single measure ICC is greater than 0.55.

## Discussion

The repeatability of EMG waveforms in naeryo chagi was examined in the present study using all the appropriate statistical indices (Duhamel et al, 2004): coefficient of variation (CV), intraclass correlation coefficient (ICC) and coefficient of multiple correlation (CMC).

The results showed that all CVs were greater than 80% and in some cases over 100%, when the maximum

**Table 2.** Intraclass correlation coefficients for average measures (ICC<sub>10</sub>) and for a single measure (ICC<sub>1</sub>), of the EMG waveforms in each participant

Participants	Rectus femoris		Biceps femoris		Gastrocnemius		Tibialis anterior	
	ICC <sub>10</sub>	ICC <sub>1</sub>	ICC <sub>10</sub>	ICC <sub>1</sub>	ICC <sub>10</sub>	ICC <sub>1</sub>	ICC <sub>10</sub>	ICC <sub>1</sub>
1	0.705	0.193	0.911	0.505	0.808	0.297	0.834	0.335
2	0.419	0.067	0.911	0.508	0.891	0.448	0.839	0.342
3	0.766	0.246	0.718	0.202	0.723	0.207	0.578	0.121
4	0.844	0.351	0.761	0.242	0.456	0.077	0.607	0.134
5	0.846	0.355	0.807	0.295	0.849	0.361	0.552	0.111
6	0.875	0.413	0.863	0.387	0.899	0.473	0.816	0.307

acceptable CV for biomechanical data was 10% (Winter, 1991). These large CV values demonstrated very poor repeatability of the EMG waveforms during the naeryo chagi. However, several researchers queried the appropriateness of CV in the examination of repeatability of waveform data (Duhamel et al., 2004) and proposed ICC and CMC as more appropriate statistical tools (Duhamel et al., 2004; Growney et al., 1997).

Regarding ICC, the results showed that the average measures ICC ranged between 0.419 and 0.875 for the rectus femoris, between 0.718 and 0.911 for the biceps femoris, from 0.456 to 0.899 for the lateral gastrocnemius and from 0.552 to 0.839 for the tibialis anterior. The lowest acceptable ICC value to support the hypothesis of data repeatability was 0.80 for discrete parameters (Fleiss, 1986) and over 0.90 for waveforms (Duhamel et al., 2004). Consequently, the average waveforms obtained from the ten successive kicks did not support the EMG repeatability for the naeryo chagi. Single measure ICCs were worst and they did not exceed the value of 0.55 in any case. As a result EMG waveforms obtained from a single trial of naeryo chagi could not be considered representative of the athlete's muscle activity. The low repeatability of the EMG waveforms was also demonstrated by the small CMC values which did not exceed the value of 0.72 in any muscle or participant.

The low intra-measure repeatability of EMG waveforms during the naeryo chagi is probably due to the instability of the factors that determine the amplitude and the pattern of the EMG. The instability seemed mostly to concern the type, the magnitude, the velocity and the synchronization of the muscle contractions during the kick (Winter, 1990; Yang and Winter, 1983) as well as the magnitude, the number and the firing rate of the motor units of the muscles within the detection area of the electrodes (Zuniga et al, 1970). The results of the present study agree with the findings of previous studies for other movements (Goodwin et al., 1999; Karamanidis et al., 2004).

On the contrary, Finucane et al (1998) found adequate repeatability of the rmsEMG in various submaximal muscle contractions. However, their findings concern a discrete EMG parameter and not an EMG waveform, which was studied during a limited single joint movement (isokinetic knee flexion/extension strictly between 15° and 90°). In the present research, a multi joint movement was investigated and the only limitation was that it had to be performed at maximum speed, in imitation with what happened in reality. In such movements, more muscles are involved and the EMG variability is expected greater

than in the single joint movements (Yang and Winter, 1983).

The results of the study of Golhofer et al (1990) also revealed great repeatability of the EMG area in several stretch-shortening type contractions. However, they used an averaging technique during their data reduction that might significantly reduce the non-systematic variations in the different contractions. On the other hand, the EMG patterns (systematic effects) were not significantly affected and this may be the reason for the high coefficients that were observed. In the present study, no averaging technique was used and the coefficients were calculated from the original EMG waveforms, so the effects of the non-systematic variations on the EMG variability were not expected to be reduced.

## Conclusion

In conclusion, the repeatability of EMG waveforms during the naeryo chagi was not very high, even when ten kicks were performed. In any case, only ensemble averages of EMG waveforms obtained from more than ten kicks may be considered as representatives of the muscle function in naeryo chagi and conclusions that have been drawn from a single trial should be reconsidered. Although this might not be the case for other taekwondo kicks, it is suggested that EMG repeatability should be examined prior to any EMG investigation of the kicks.

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### Key points

- The paper is the only known paper focused on the EMG repeatability of a taekwondo kick (naeryo chagi).
- The paper is among the few papers of repeatability dealing with the whole EMG waveforms and not with discrete EMG parameters.
- Repeatability was tested using all the available statistical indices.
- The results suggested that conclusions drawn from a single trial in EMG studies of taekwondo kicks and probably in other sports should be treated carefully.

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