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Recruitment of the Motor Units of Karatekas' Muscles during the Kick Performance

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Abstract The aim of our study was to reveal the relative contribution of the main types of motor units of the low extremities to the front kick performance by karate athletes based on surface electromyogram analysis. Our study involved 11 high-skilled karatekas (I Dan), aged 18–21 years, with training experience of 12–15 years. A surface electromyogram was recorded during the Mae Geri kick from Zenkutsu dachi stance. The electrical activity of the following right (dext.) and left (sin.) muscles was recorded: m. gluteus maximus, m. rectus femoris, m. biceps femoris, m. semitendinosus, m. gastrocnemius (caput lateralis), and m. tibialis anterior. It was found that during 57.6%–83.8% of the kick duration, the electrical activity of the different muscles was below 15% of the maximum. This indicates the activation of slow or low-threshold motor units. The largest percentage of the time of low activity was found for m. gluteus maximus sin., and the shortest one – for m. tibialis anterior. The period of the electrical activity of the muscles at the level of 20–30% from the maximum for different muscles ranged from 10.4% (m. gluteus maximus dext.) to 20.1% (m. tibialis anterior dext.), at the higher level of 35-45% from the maximum, it was shorter – up to 4.2–11.4%. Only for the 1.6% –17.9% of the total time of the kick, the level of electromyogram amplitude exceeded 50% of the maximal level, which indicates a relatively short period of activation of large motor units. The longest period of high electrical activity (50% and more of maximum) was found for m. tibialis anterior sin. (17.9%) and m. gastrocnemius (caput lateralis) dext. (16.9%). In these muscles, the longest period of fast, high-threshold, motor units activity was revealed. The tendency of increasing the periods of high electrical activity of the legs' muscles of karatekas during kicks in the proximal-distal direction has been shown.

Keywords Kyokushin Karate, Mae Geri, Zenkutsu Dachi, Surface Electromyogram

1. Introduction

Today, the literature contains a number of publications devoted to the biomechanical and electromyographic analysis of kicking movements in karate. Kicks that have been analysed include Mae Geri [1, 2], Mawashi Geri [3], Gyaku Zuki [4], Hiza Kiza Mawashi Geri [4], Junzuki [5]. According to the results of electromyographic studies, the features of activation of individual muscles of athletes during the execution of kicks are described. The combination of this description with the analysis of the movement of the athletes' body parts [3-5] makes it possible to find out the optimal exercise technique and identify possible individual deviations from it. It is reasonable to suggest that optimization of movement technique is inextricably linked with improved coordination of muscle contractions and activation of individual motor units. This suggestion is supported by the findings of many authors of a different degree of activation of fast neuromotor muscle units during kicking in experienced athletes compared to beginners [1, 6-8]. Some authors supposed that the improvement of the pattern of movement during kick performance is a result of changes in the strategy of neuromuscular control [1]. Despite the obvious importance of studying the activation patterns of motor units of many muscles, existing studies [4, 6-8] describe only the electrical activity of the kicking limb. In addition, many studies lack quantitative data on the percentage of activation of various motor units [4, 9] of muscles. Therefore, the aim of our study was to reveal the relative contribution of the main types of motor units of the low extremities to the front kick performance by karate athletes.

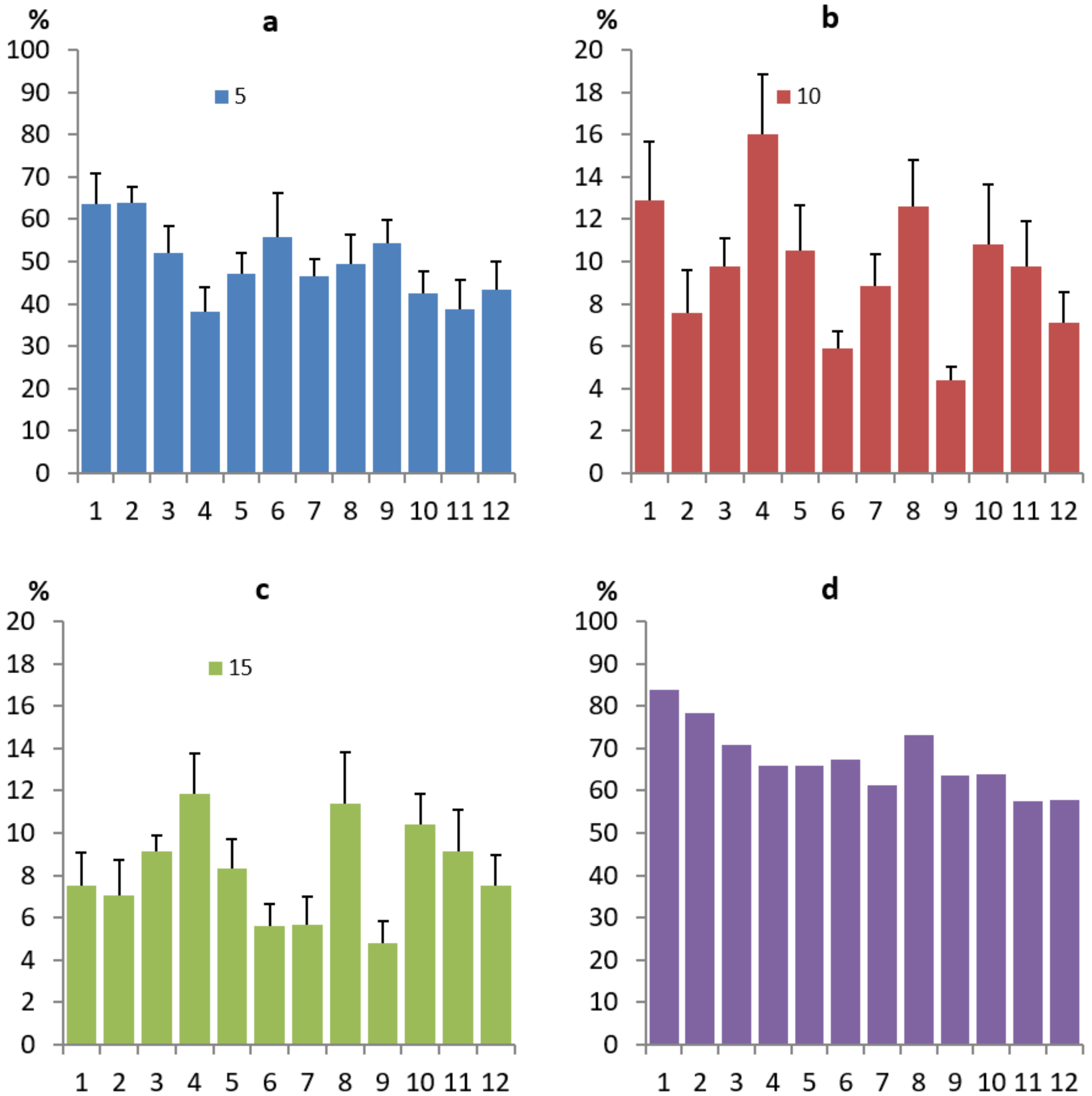
2. Materials and Methods

Our study involved 11 high-skilled karatekas (I Dan), aged 18–21 years, males, with training experience of 12–15 years. All participants provided informed consent to participate in the study. The study met the established standards of the Declaration of Helsinki on the ethical principles of conducting scientific medical studies with human participation. The experiments were carried out in the scientific laboratory of the Department of Anatomy and Physiology of Ivan Bobersky Lviv State University of Physical Culture.

Surface electromyogram (SEMG) was registered during the execution of the Mae Geri kick with the right foot from the Zenkutsu dachi stance. Each of the athletes performed three kicks, the data of which were averaged. Electromyogram recording was performed using a "Neuro-MVP-Micro" electromyograph according to standard requirements [10]. For the recording of the SEMG, we used disposable Argentum-chlorine electrodes, which were placed on the skin of the subject over the localization of the motor point of the corresponding muscles [10]. The distance between the electrodes was 2 cm. The electrical activity of the following right (dext.) and left (sin.) muscles was recorded: m. gluteus maximus (dext./sin. – GMD/GMS), m. rectus femoris (RFD/RFS), m. biceps femoris (BFD/BFS), m. semitendinosus (STD/STS), m. gastrocnemius (caput lateralis) (GCD/GCS), m. tibialis anterior (TAD/TAS). SEMG analysis was performed using the "Neuro-MVP.NETω" software (version 3.01.29.0). We determined the value of the average SEMG amplitude (A, μV) in the consecutive 25 ms segments along the record. To normalize IEMG, the value of A was first recorded at the maximum voluntary muscle contraction of each muscle for each subject. The obtained amplitude of SEMG was taken as 100%. The value of A during the performance of kicks was described as a percentage of those obtained under conditions of maximum voluntary contraction. Standard statistical methods were used to calculate the arithmetic mean and standard error of the mean. The ANOVA analysis was used to detect the significance of systematic factor influence. Statistical significance was set at $p \leq 0.05$ level for all analysis. Statistical analysis was carried out using MS Excel 2010 and OriginPro 9.1.

3. Study Results

Histogram analysis of the distribution of the relative amplitude of SEMG of lower limbs muscles of karatekas during the execution of the kick revealed that the greatest percentage of time of the electrical activity of muscles was at a level below 5% of the maximum (Fig. 1). The highest percentage of the duration of low activity was found in the case of GMS (63.8%), and the smallest – for RFS (38.6%). The total duration of the electrical activity of the muscles was much shorter in the other two intervals – 5–10% and 10–15% of the maximum ($p < 0.01$). The percentage of the total time of electrical activity in these ranges varied from 4.4% to 16%.



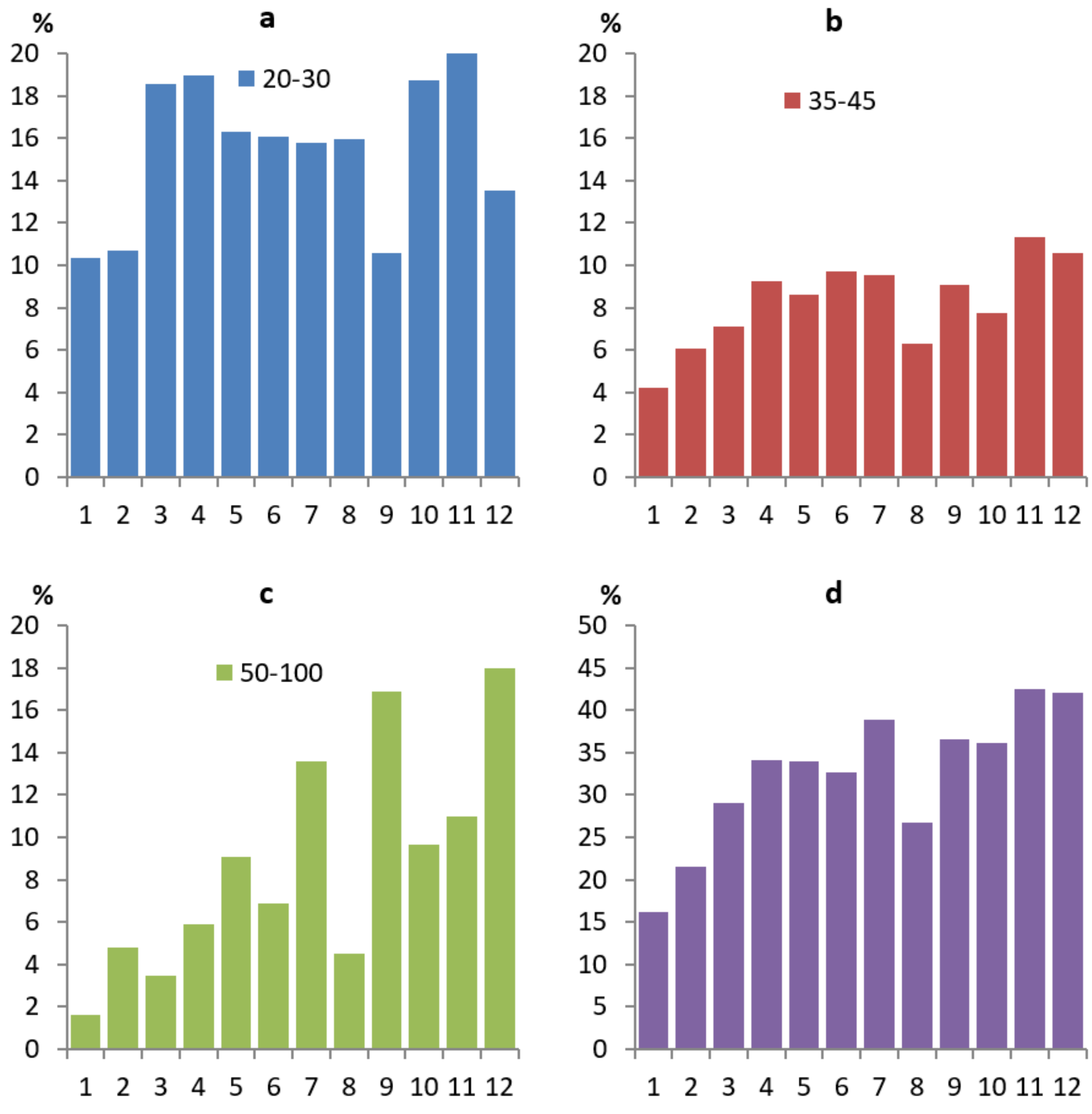
Data are presented for activity at the level of 5% (a), 10% (b), 15% (c), and the total time of activity at the level of up to 15% (d). Muscles: 1 – GMD, 2 – GMS 3 – RFD, 4 – RFS, 5 – BFD, 6 – BFS, 7 – STD, 8 – STS, 9 – GCD, 10 – GCS, 11 – TAD, 12 – TAS. The values of the arithmetic mean and their standard error (M±m) are indicated.

Figure 1. Histograms of the duration of electrical activity of muscles at the level of 5-15% of the maximum.

The smallest values were found for GCD – 4.4 and 4.8% in the ranges of 5–10% and 10–15% of the maximum amplitude, respectively. The longest total duration is typical for RFS – 16.0 and 11.9%. The total duration of the period when the electrical activity of the lower limb muscles was below 15% of the maximum ranged from 57.6% (TAD) to 83.8% (GMD). Therefore, it can be assumed that the karate force of muscle contraction necessary for performing kick movements and maintaining body posture during 58–84% of the kick duration is achieved by activation of slow or low-threshold motor units. For different muscles, the time interval for the predominance of the activity of slow motor units is not the same. Despite some variations, the relative duration of muscle activity at the level below 15% of the maximal (see Fig 1d) decreases in the proximal-distal direction ($p < 0.05$).

We also analyzed the duration of periods of high electrical muscle activity during the execution of the stroke, dividing it into three ranges – 20–30%, 35–45%, and 50–100% of the maximum SEMG amplitude. The results of the analysis (Fig. 2) show that the duration of the electrical activity of the muscles at the level of 20–30% of the maximum for various muscles of the lower limbs ranged from 10.4% (GMD) to 20.1% (TAD). The period of muscle activation at the level of 35-45% from the maximum was shorter ($p < 0.05$) – up to 4.2-11.4%. At the level of 50% or more of the maximum amplitude, the SEMG remained for only 1.6–17.9% of the total duration of the kick. For five muscles, the duration of the period of such a significant increase in electrical activity was higher ($p < 0.01$) compared to the range of 35–45% of the SEMG amplitude. These muscles include the BFD, STD, GCD, GCS, and TAS. The longest was the duration of electrical activity at the level of 50 percent or more of the SEMG amplitude for TAS (17.9%) and GCD (16.9%). It is reasonable to assume that during the kick execution, in these muscles the maximally long activation of fast, high-threshold, motor units occurs. The relative duration of muscle electrical activity at the level above 50% of the maximal (see Fig 2d) increases in the proximal-distal direction ($p < 0.01$).

The total duration of the period of high electrical muscle activity (20% or more) ranged from 16.2% (GMD) to 42.5% (TAD). The highest duration of the high activity period was for right and left TA (over 42%), STD (38.9%), and right and left GC (over 36%). It can be assumed that the longest periods of activation of medium and high-threshold motor units are observed in these muscles.



Data are presented for activity at the level of 20-30% (a), 35-45% (b), 50-100% (c), and the total duration of activity at the level of over 15% (d). Other captions – see Fig. 1.

Figure 2. Histograms of the duration of electrical activity of muscles at the level of 20-100% of the maximum.

4. Discussion

Results of our study clearly suggest that during the execution of striking movements by representatives of Kyokushin-karate, the electrical activity of the muscles of their lower limbs is mostly at a low level. Depending on the muscles, electrical activity up to 5% of maximal is maintained for 38-64 percent of the recording period and up to 15% – for 58-84 percent of the record. Obviously, during this period of time, the necessary level of muscle contraction force is small, supported by motor units, in which fatigue develops slowly, which enables the long-term repetition of impact movements without significant development of muscle fatigue. A long period of low electrical activity was found for large girdle muscles of lower limbs and thigh – GM and RF. Significantly ($p < 0.05$) shorter periods of activation of slow motor units were found for the lower leg muscles – GC and TA. The ANOVA analysis confirms the decrease in the time of slow motor units in proximal-distal direction ($p = 0{,}019$).

The revealed proximal-distal regularity of muscle activation is confirmed by the analysis of the high range (more than 50%) of electrical activity of the muscles. In particular, for GM and RF, the duration of the period of electrical activity at the level of more than 50 percent or more of the maximum is in the range of 2–6% of the total duration of the kick. For GC and TA, this duration ranges from 10–18%. There is a tendency (Fig. 3) to a natural increase in the period of activity of high-threshold motor units of the muscles of the lower limbs in the direction from the proximally located to the more distal ones, confirmed by the results of ANOVA analysis ($p < 0.001$). The only exception is STS, which requires some more research to explain.

The tendency we found for short periods of the significant electrical activity of large, proximally located muscle groups during impact can be explained by the formation of such a pattern of recruitment of motor units during the long training process, which allows athlete/practitioner to perform an impact effort for the shortest possible, economical, periods of activity of rapidly tiring motor units. This hypothesis is supported by the data of other authors [7, 11, 12], who found a lower level of the electrical activity of several muscles of the lower limbs in experienced taekwondo athletes compared to novices during kicking. This also could be explained by the shorter periods of the changes in the velocity of angular motion in the hip joint compared to the motion in the knee and ankle, which is revealed from the data of Pozo et al. [13]. According to their data, movements in hip and knee joints are faster, but in ankle joint they last for the longer part of the kick time.

It is also possible that long-term training leads to a significant increase in strength capabilities/potential of large muscles located proximally. Under these conditions, maintenance of the required force of contraction can be achieved with shorter recruitment of their large motor units. Maintaining the required level of force by smaller and relatively weak muscles located in the region of the distal extremities requires longer recruitment of their large motor units. Short periods of activation of large and medium motor units during the performance of kicking movements by karatekas were also observed in the studies of other authors [4].

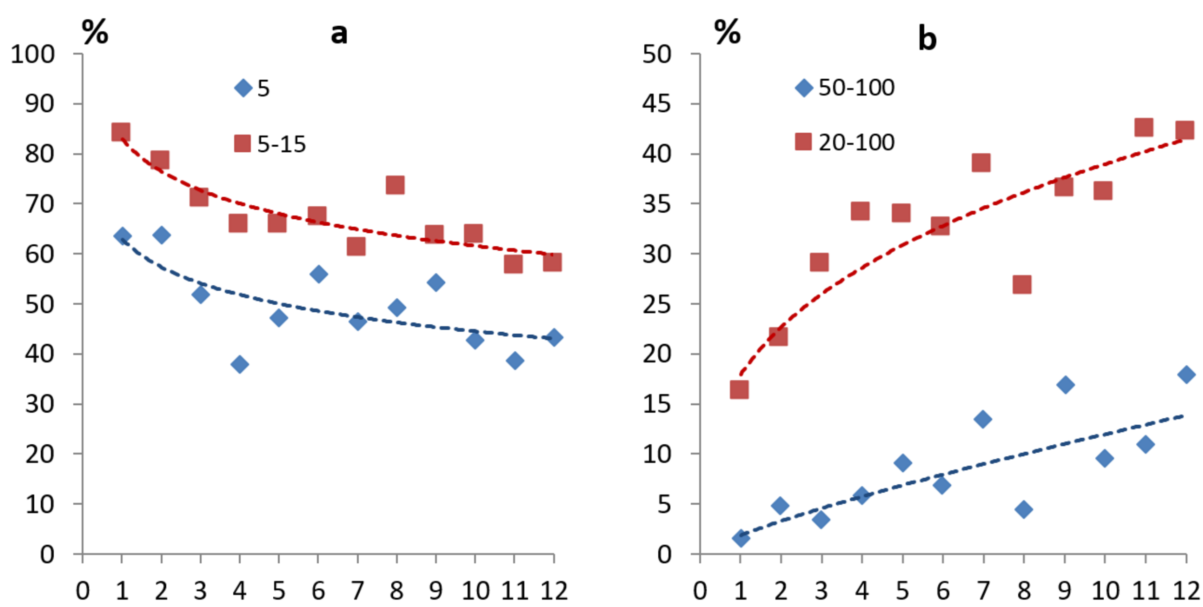


Figure 3. Relative duration of activity of low-threshold (a) and medium- and high-threshold (b) motor units of the muscles of the lower limbs during the execution of a kick. Dotted lines indicate the tendency for changes in the duration of relative activity depending on the location of the muscles in the proximal-distal direction. Other captions – see Fig. 1

A possible reason for the revealed tendency to a different percentage of activation of large motor units in the muscles of different parts of the lower limbs may be differences in their composition. In particular, the low activation of slow motor units in TA may be partly due to the low (39.8%) percentage of type I muscle fibres in this muscle [14]. According to other researchers, the content of type II fibres can reach 30–50% in some areas of TA [15]. A high percentage (up to 59.7) of type IIB fibres in TA was also found in animal models [16, 17]. Analysis by individual authors of the composition of the proximally placed m. vastus lateralis of young women and men revealed the presence of only 20% of type IIB [18] fibres in it. Although the literature search did not reveal a systematic description of the dependence of the composition of the muscles of the lower limbs on their location, the above data suggest the importance of the factor of the content of different types of fibres in determining the nature of the electrical activity of the muscles during kick movements.

5. Conclusions

Based on the analysis of the surface electromyogram of the muscles of the lower limbs of karatekas during the execution of the Mae Geri kick, it was established that during 57.6%–83.8% of the duration of the kick, the electrical activity was below 15% of the maximum, which most probably indicates the activation of slow or low-threshold motor units. For the 1.6%–17.9% of the total time of the kick, the level of electromyogram amplitude exceeded 50% of the maximal amplitude, which indicates a relatively short period of activation of large motor units. We found a tendency to increase the periods of the high electrical activity of the leg muscles of karatekas during kick execution in the proximal-distal direction.

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