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286 *The Open Sports Sciences Journal*, 2017, *10*, (Suppl-2, M10) 286-293

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The Open Sports Sciences Journal

Content list available at: www.benthamopen.com/TOSSJ/

DOI: 10.2174/1875399X01710010286

REVIEW ARTICLE

Physiological and Biomechanical Fatigue Responses in Karate: A Case Study

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Received: May 19, 2016 Revised: July 04, 2017 Accepted: September 14, 2017

Abstract: Knowledge of the fatigue process in karate sport is essential to improve the performance of top athletes. The physiological and biomechanical behavior during the Karate Specific Aerobic Test (KSAT) fatigue protocol in karate was investigated. PCR, lactate, glucose and cortisol were collected before and after the fatigue protocol application in karate, besides that, and heart rate and technical speed were measured. The results indicated increase in C protein reactive (60%), creatine kinase (25%), cortisol (30%), lactate dehydrogenase (90.9%) and decrease in glucose (21.2%). The maximum speed was: in kizami zuki, 5.75 ± 0.31 m/s; in mawashi geri, 9.0 ± 0.24 m/s, in gyako zuki, 7.23 ± 0.54 m/s and in kizami mawashi geri, 6 ± 0.34 m/s. The mean time for each set was 2.99 ± 0.17 s. There was reduction in speed and duration of set for all techniques, especially in the final sets ($p<0.05$), indicating the presence of fatigue. Gyako zuki was the main blow affected by the phenomenon ($p<0.05$). Also, the high values observed in biochemical variables after the protocol application indicate metabolic fatigue with muscle damage. Therefore, the athlete adapted his motor behavior in order to hold his technical speed.

Keywords: Biochemistry of exercise, Cinemetry, Karate, Kicking, Martial arts, Physiological stress, Punching, Speed.

1. INTRODUCTION

Karate is a sport that requires high-speed demands [1]. Indicate that the actions, during simulated combats, are of high-intensity with high-speed blows [1 - 4]. Karate is an intermittent combat sport that requires both aerobic and anaerobic capabilities [4 - 12].

The force-velocity parameters during anaerobic tests indicate that both force and velocity were higher in world-class athletes than non-athletes, suggesting that karate performance depends on the maximal velocity and explosive strength [5]. In combat situation, the duration of high intensity actions per fight is approximately 1-3 seconds each [2]. High demands in production of force-velocity can cause physiological stress, affecting the technical and tactical response from the participants.

Muscle fatigue is classified as a motor deficit, a perception or a decline in mental function; it can describe the gradual decrease in the muscle strength capacity or the endpoint of a sustained activity with reduction in muscle strength [6]. During the fatigue process the speed variable can suffer several changes and compromise the athletes performance [7]. Therefore, it is very important to study the occurrence of biological and motor behavior during karate fatigue process.

It was not found in the literature studies that have analyzed muscle damage markers during a specific incremental load test for karate in association with performance changes in speed of punches and kicks. However, could biochemical changes occur concomitantly with a decrease in technical speed?

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It is unclear how the biomechanical and physiological mechanisms limit human performance and how detailed measurements of an individual's neuromusculoskeletal system can be used to make subject-specific recommendations for training for individual specific sport [8]. The aim of this study was to investigate the physiological and biomechanical behavior during the induced fatigue protocol in karate.

2. MATERIALS AND METHODS

One male karateka volunteer, athlete of karate (21 y.o., black belt, international level, practitioner for 6 years, 78 kg, 1,82 m, 14,4% fat, $VO_{2\ max}$ = 55 $kg.ml^{-1}.min^{-1}$) stated his agreement to participate the research. All procedures received local ethics committee approval (number 38400/2012).

To evaluate pre-participation was applied the Physical Activity Readiness Questionnaire (PAR-Q) [9] as risk identification criteria. Anthropometric data were collected according to the International Society for the Advancement of Kinanthropometry [10]. The body composition was calculated as percentage of fat, bone mass and lean mass [9]. The anaerobic threshold was obtained using the progressive test [10], and calculating the heart rate inflexion method [13] 96 hours before the Karate Specific Aerobic Test (KSAT) protocol (Fig. **1**).

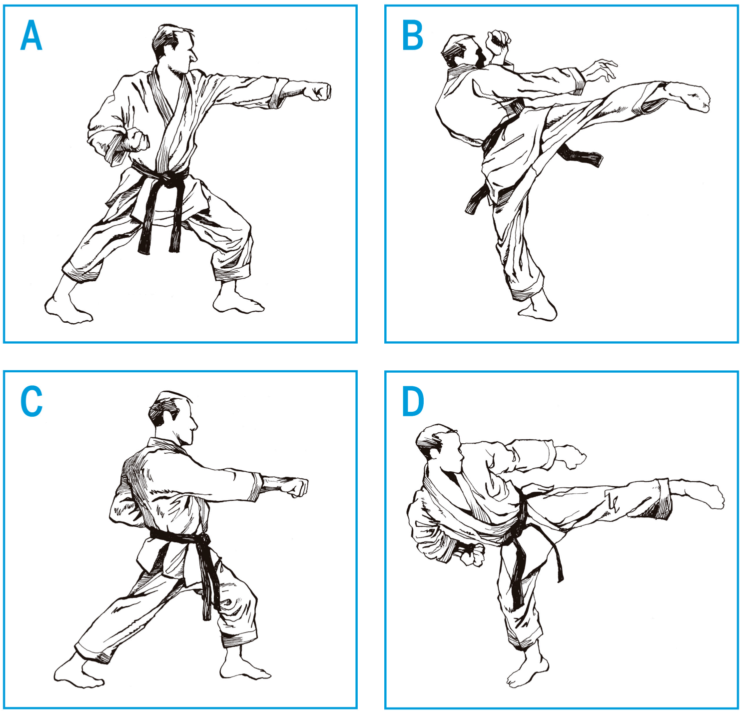

Fig. (1). Description of Karate Specific Aerobic Test (KSAT). In (**A**), front arm punch; in (**B**), roundhouse back leg kick; in (**C**), back arm punch; and in (**D**), roundhouse front leg kick.

The athletes performed the KSAT until exhaustion [14], this test consists in sequential sets (Fig. **1**). Each set is composed of: *kizami zuki* (front arm punch) (**A**), *mawashi geri* (roundhouse back leg kick) (**B**), *gyako zuki* (back arm punch) (**C**) and *kizami mawashi geri* (roundhouse front leg kick) (**D**).

Each set starts with a beep, the time among the beeps decreases along the test. When the subject does not succeed in finishing the complete set before the next beep, the test is ended [15]. The heart rate (V800 Polar heart rate monitor) was measured all the time during the KSAT test. It was collected 5 ml of blood before and after the KSAT test. It was assessed to lactate dehydrogenase (ADVIA automation 1200/1800), creatine kinase, C reactive protein (Imunoturbidimetric method), cortisol (chemiluminescence essay) and glucose (hexokinase method). Ten minutes after the end of KSAT protocol, it was applied the effort perception test (Borg Scale) with a scale from 6 to 20 [16].

The biomechanical model used a six-camera video-based motion analysis system (Vicon System) set to record at 200 Hz. Forty-three reflecting markers were placed on specific anatomical landmarks. The marker protocol was based on the Plug-in-gait marker set of the the full body model Vicon System. The model was reconstructed using the polynomial model, with a Butterworth 4th order filter (6 Hz).

It was developed a Matlab (The MathWorks, Inc.) routine to determining the speed and time landmarks: styloid process of the ulna (both arms) and lateral malleolus (both legs). It was calculated the maximum speed through the landmarks and the time of set in each cycle of the test.

The duration of the set was computed with the interval time between '*kizami zuki – kizami mawashi geri*' peak speed.

The temporal data analysis was obtained in three moment sets: ten first (initial sets), ten middle (middle sets), and ten final (final sets).

Normality was confirmed *via* Shapiro-Wilk test. Linear regression models were computed to predict speed in landmarks. In order to compare the speed in the three moments sets it was applied ANOVA for repeated measurements, with post-hoc Bonferroni ($p<0.05$). Compound symmetry was tested through Mauchy test and Greenhouse-Gleisser correction. Effect size was calculated and linear regression ($p<0.05$) was computed to determine the behavior of speed blows.

3. RESULTS

The athlete completed 30 sets of the KSAT protocol. The heart rate peak was 190 beats per minute (BPM). During KSAT, the athlete was 80% above his anaerobic threshold. The period to exhaustion was 241.95 s. The efforts perception the athlete varied between 'very tired' (for lower limbs) and 'almost tired' (for upper limbs and trunk). There was an increase (Table **1**) in C protein reactive 60% after the protocol application. The cortisol increased 30%, creatine kinase 25% and the lactate dehydrogenase 90.9% after the protocol. The glucose decreased 21.2%.

Table 1. Behavior of biochemical variables.

Biochemical Markers	Pre Test	Post Test
CK (U/L)	190	239
PCR (mg/dL)	0.4	0.9
Lactate (mmol/L)	1.3	12.8
Glucose (mg/dL)	94	74
Cortisol (ug/dL)	15.4	20..1

The average for the maximum speed (Table **2**) was higher in the *mawashi geri* (roundhouse back leg kick) ($F=7,84$; $p=0,002$; $\eta^2 = 0,58$).

Table 2. Maximum speed for technique.

Technique	Average, sd (m/s)	Confidence Interval – CI
Kizami zuki	5.75 ± 0,31	(5.11 – 6,39)
Mawashi geri	9.0 ± 0.24*	(8.5 – 9.5)
Gyako zuki	7.23 ± 0.54	(6.11 – 8.35)
Kizami mawashi geri	6 ± 0.34	(5.35 – 6.75)

* Statistically significant (CI 95% includes the 0.5 value) ($p<0,05$).

The mean time for each set was 2.99 ± 0.17 s (CI=2.64 – 3.35 s). In the Table **3**, there are decreased speed for all techniques, especially in the final sets ($F=12.3$; $p=0.001$; $\eta^2 = 0.32$). The main blow affected by the fatigue was the *gyako zuki* ($F=9.85$; $p=0.001$; $\eta^2 = 0.75$).

Table 3. Behavior of speed and set time in three different moments.

	Initial sets (m/s)	Middle Sets (m/s)	Final Sets (m/s)
Kizami zuki	6,82 ± 0,8	5,36 ± 0,9	5,09 ± 0,75*
Mawashi geri	10,37 ± 0,63	8,9 ± 0,71	7,8 ± 1,2*
Gyako zuki	9,61 ± 0,5	7,35 ± 0,87	4,74 ± 1,6**
Kizami mawashi geri	7,21 ± 0,6	5,93 ± 0,91	5,01 ± 1,1*
Set time (s)	3,46 ± 1,2	2,91 ± 0,9	2,61± 1,4*

* Statistically difference the final sets for initial sets ($p<0,05$); ** Statistically difference the moment final sets for initial and middle sets.

Fig. (**2**) shows the behavior of speed blows. By comparing the maximum speed blows, reduction in the angular coefficient was observed, especially in *gyako zuki* (β = -0,025), followed by *mawashi geri* (β = -0,016), *kizami mawashi geri* (β = -0,015) and *kizami zuki* (β = -0,011). The determination coefficient was higher in *mawashi geri* (R^2 = 0,66) than *gyako zuki* (R^2 = 0,33), *kizami mawashi geri* (R^2 = 0,32) and *kizami zuki* (R^2 = 0,21).

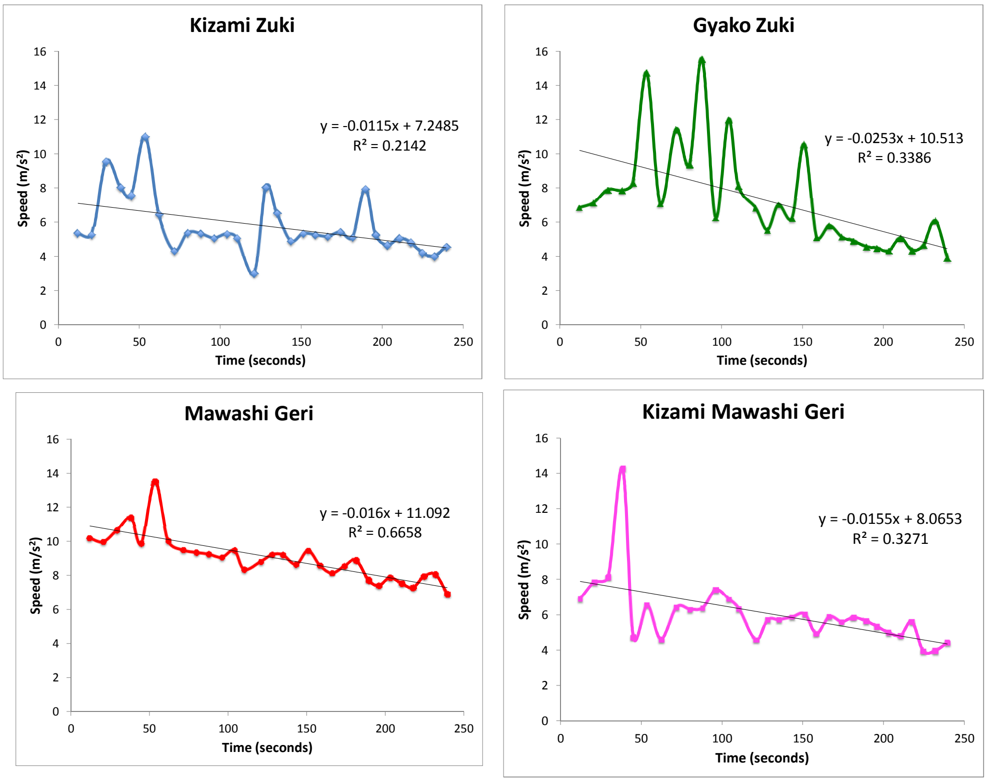

Fig. (2). Speed blows response during the KSAT.

4. DISCUSSION

The present study aimed to evaluate the physiological and biomechanical behavior during the induced fatigue protocol in karate. The physiological response shows that the heart rate peak was greater than the found by Chaabéne *et al*. [4, 5]. Similar values to the anaerobic threshold were found in situation of simulated combat [4, 17, 18]. The period to exhaustion was lower than reported by Chaabéne *et al*. [4] indicating the text leads the athlete to fatigue. The perception efforts were similar to intensities of effort in fight exercises [17].

The protocol applied induced high level of physiological stress with significant changes in lactate dehydrogenase, creatine kinase, protein C, cortisol and glucose, suggesting that the physical effort during KSAT induced muscle damage. Acute high-intensity and prolonged exercise by itself causes production of stress hormones and alterations in the circulating quantity and function of various immune cells, including C-reactive protein (CRP) [19 - 21]. CRP is a biomarker that measures the acute inflammatory response to the exercise [19, 20]. The release of acute phase of CRP helps contain amplification of the inflammatory process in different ways: by activativing the complement system, proteases action, removal of microorganisms and cell metabolites, cellular remodeling and control of gene expression, antithrombotic control, hemostasis, respiratory burst triggered by cells and inflammatory action of proteolytic enzymes, in addition to activation of local inflammation [19]. Despite the increase in protein C, reactive showed a small increase in a present study. Dopsaj *et al*. [18] identified lower values in 18 professionals karatekas.

In present study, the creatine kinase (CK) increased 20% after the KSAT. The sarcolemma rupture allowed the release of enzymes such as CK and lactate dehydrogenase (LDH) to the serum [22]. An increase of these enzyme levels in serum is considered evidence of muscle damage. To evaluated 24 full-contact karate practitioners, Graham *et al*. [23] found that after kicks to the head and body, the practioners showed significant increases in CK serum total

The increase of CK serum, LDH and PCR occurs when muscle fibers are metabolically exhausted due to effort, exhibiting a decrease in the membrane resistance, or even cytoskeletal and sarcolemma disruption, which permits the release of these enzymes to the serum [24].

We had as a limiting factor of our study, the lack of measures of CK, LDH and PCR in some moments after the KSAT. Some studies [22, 24, 25] indicate that there were many clusters of these enzymes in the period of 24-96 hours post exercise. Thus, we believe that higher concentrations of enzymes measured in other moments can indicate higher muscle damage.

The muscle damage occurs because of the damage to the contraction tissue and cytoskeletal protein long with disorganization in myofibrillar structure, disruption, enlargement or extension of the line Z causing subsequent impairment of anchoring filaments and connection of adjacent fiber [25].

The increase of LDH shows the enriched H lactate dehydrogenase (H-LDH) isoenzyme content in slow twitch fibers (LDH). It suggest that the delivery, uptake and subsequent oxidation of lactate are facilitated when these fibers are active during low-intensity exercise, as well as the rate of blood flow which influences lactate efflux from skeletal muscle [26].

The cortisol and lactate increases were also higher than in combat simulation [3, 5, 20], kumite karate training or in competition event [16]. When evaluated 9 elite-level male karatekas in combat situation in Tunisia, Chaabene [27] identified double of cortisol values post combat, when compared to the pre-combat situation. It has been well established that Cortisol, as representative of circulating free cortisol, is an accurate index of training and/or competition stress [28]. Results showed that despite the short duration of karate KSAT (241.95 seconds of test), there is a progressive and very important increase of cortisol.

However, the glucose decreased possibly occurred due to the higher energy demands of the KSAT. Benedini *et al*. [20] found glucose increase after the combat simulation, but not identified the effort intensity. Thus, high-intensity exercise elicits inflammatory responses similar to many clinical physical stressors including surgery, trauma and sepsis, indicating that the high intensity exercise may be a good model for the inflammatory response [19].

The muscle damage can contribute to the decrease the blows speed. After the application of KSAT there was a decrease in the speed of *gyako zuki, mawashi geri, kizami mawashi geri* and *kizami zuki* technicals. During fatigue situation, the speed of the *mawashi geri* (roundhouse back leg kick) was higher than *gyako zuki* (back arm punch). Perhaps due to fatigue process used in this study offer high intensity effort, the *gyako zuki* speed was lower than *gyako zuki* speed reported by Urbinati *et al*. [29].

The protocol requires that the athlete perform the fastest possible the four blows, similar to competition situation. Actions of attack vary between 0.3 until 2.1 s [1 - 3, 16].

Nevertheless, the protocol test induced the fatigue process, which increased the blows time. Other studies did not indicate the time set in KSAT. The decreased speed along the KSAT protocol indicates fatigue.

Changes in the speed of *gyako zuki* will ocassionate decrease in sport performance [1, 4]. In a combat situation, karatekas used more upper-limb than lower-limb techniques [5, 16]. The *gyako zuki* is the most used technique in competitive situation [1, 30, 31]. Punching is a highly complex technique that requires the coordinated action of arm, trunk and leg muscle groups [1].

Despite the blows speed suffer decrease along the protocol, the set time also decreased (Table **3**). Contrary to expectations, the time in the final set and the blows speed were smaller. This fact indicates: (1) that the athlete did not perform the blows in the maximum limbs extension; (2) when the athlete is positioned closer to the target, it decreases the displacement for blows.

Different strategies for motor control and coordination have been developed aiming the maintenance of blows speed [1, 30, 32]. Experienced athletes have longer arm flexion movement and forearm extension in a shorter period of time, which could allow longer segment acceleration [32].

Martinez and Benett [33] compared karate athletes and non-athletes with kinematic analyses, finding that reactive movements had shorter time to reach the speed peak and shorter time to execute the movement.

Experienced athletes are faster than non-athletes because they have better motor control technical. Ferreira and Brito [32] examined the electromyographic (EMG) activity during punch execution of the anterior and posterior portions of deltoid, pectoralis major, latissimus dorsi, triceps brachii, and biceps brachii. The authors found that the athletes had significantly shorter delay in arm flexion of the agonist muscles and significantly higher delay in arm flexion of the antagonist muscles and in agonist forearm extension [32].

Brito *et al*. [34] when evaluating 19 karate athletes, found that the skill performance, the arm, flexion and internal rotation, and the forearm extension and pronation movements were executed with smaller amplitude than in untrained subjects.

In the fulfillment of *gyako zuki* blow, athletes performed multiple moving segments, containing both rigid (bone) and soft structures (muscle, tendon and ligaments) [32]. It is assumed that this ballistic mass flies at the target and strikes it with a measured incoming velocity [35]. The ballistic movements cannot be changed voluntary during the course of the action [32], however experienced athletes can perform faster voluntary decision before the blow [36].

There are other differences between athletes muscles that can influence the adjustments during fatiguing contractions, such as the afferent feedback is activated by the metabolic products of the muscle contraction [6].

Another important aspect is the contribution of the lower body in the maintenance of speed in punches. The lower-body is predictive of punching acceleration [1], suggesting that karate athletes aiming at improving punch acceleration should improve the lower-body propulsive power.

There was short variability in maximum speed, especially in kicks. The roundhouse kicks involved the high muscle groups, but the punches involved the balistic movement. The *gyako zuk*i is directly associated with the mechanical impulse generated in specific movement. It occurs due the sum of the forces the displacement in balistic movements [1]. A higher speed value of technical movements in karate depends on motor learning strategies [35, 36]. Generally is the result in alterations in the internal processes that determine an individual capacity to produce a motor action after practice [34, 36].

Muscle damage markers increased after the KSAT and happened a decrease in technical speed, the *gyako zuki* is the most affected blow at variable speed. Considering speed of blows as potential predictors of karate performance [1], these findings may provide important information for coaches and physical trainers to delineate specific training to improve physical performance. It is recommended that the design of a training regime be directed to ballistic movement in the lower limbs for maintaining optimum levels of neuromuscular performance during punches performance.

Another important aspect is that the speed reduction observed in this study may suggest the possibility of using recovery strategies in competitive situations, which aim to delay the onset of fatigue and improve neuromuscular recovery.

CONCLUSION

Considering that karate is a sport whose variable speed predicts the sporting success, our results show the speed of behavior over an induced fatigue process. The results showed physiological fatigue after the KSAT fatigue protocol. During the protocol application there was a fall in the speed blow due to techniques in execution. There was a fall in the set too, indicating motor adaptations to fatigue process.

The process of fatigue generates motor adaptations to maintain speed blows. Soon, the athlete gets closer to the target, generating competitive disadvantage. Based on our findings, we will further develop studies involving a larger sample and comparing advanced athletes with beginners. We intend to identify at what time the fatigue process occurs more abruptly fall in scams speed.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

The authors are grateful to João Carlin Padilha (coach of the Brazilian national karate) for granting access to the athlete.

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