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Differences in Force-Velocity Characteristics of Upper and Lower Limbs of Male Kickboxers

Author's Conrtibution
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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Abstract

Background: *Despite the increasing popularity of kickboxing, few studies have been conducted with regard to the physiology or the biomechanics of this sport. The aim of the present study is to examine the ratios of mechanical characteristics between upper and lower limbs of male kickboxers.*

Materials and methods: *Fourteen male Caucasians, all members of recreational sport clubs, aged 21.77 (5.19) yr [mean (standard deviation)], body height 1.78 (0.067) m, body mass 75.4 (8.9) kg, body fat 14 (5) % and somatotype 3.5-4.9-2.3, performed the Force-velocity (F-v) test for both upper and lower extremities. The F-v test included five supramaximal pedal sprints, each lasting 7 sec, against incremental braking force (20-60 N for upper limbs and 30-70 N for lower limbs), on modified arm-cranking and on a cycle ergometer (Ergomedics 874, Monark, Sweden).*

Results: *Maximal anaerobic power, P_{max}, of upper limbs was associated with P_{max} of lower limbs (r = 0.81, P < 0.001) and their ratio was 0.464 (0.079). The respective values of correlation coefficients of the theoretical maximal force, F_0, were r = 0.63 (P < 0.05) and 0.57 (0.133), and of velocity, v_0, r = 0.44 (P = 0.12) and 0.829 (0.095).*

Conclusions: *In spite of moderate correlations between upper and lower limbs' F_0 and v_0, a stronger relationship was found with regard to P_{max}. Separate upper and lower extremities' power output measures would be useful in evaluating training programs and in understanding the importance of power output for kickboxing performance.*

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Introduction

Kickboxing is a sport with an increasing popularity, and many sport and fitness centres promote it. It is practiced either for self-defence, general fitness or as a full-contact sport. Performance in kickboxing depends on athletes' physiological [1,2], biomechanical [3] and psychological characteristics [4]. The bioenergetic profile of this sport depends on both the aerobic and anaerobic transfer energy systems. The significant contribution of the aerobic energy transfer system is well-established, since rounds last between 2 and 4 min, a match may have up to 12 rounds, and recovery is facilitated by aerobic metabolism [1]. However, the repetitive delivery of high-power techniques makes kick-boxing an anaerobically demanding sport.

Given that it is a sport that engages both movements of upper and lower limbs, it is necessary to examine their corresponding physiological characteristics. Until now, most of the research on the relationship between upper and lower limbs' characteristics has focused on variables of cardiorespiratory power, such as maximal oxygen uptake, aerobic power output, anaerobic threshold, work efficiency and oxygen kinetics. In 1975, during a study on male subjects, Vokac et al. [5] noted that though the maximal work load in arm cranking exercise was 50–60% of that in cycling, VO_2 in upper extremities work was at maximal effort only 22% lower than in lower extremities' exercise. Subsequent researchers have shown that the anaerobic thresholds for arm cranking and leg cycling occurred at 46.5±8.9% and 63.8±9% of VO_{2max}, respectively [6], and that metabolic efficiency as determined by work efficiency indices was lower during arm crank compared with a cycle exercise at the same relative intensities [7]. Finally, a study of oxygen uptake kinetics demonstrates that the time constant of the fast component response is significantly longer and greater in upper limbs exercise compared to lower limbs exercise [8].

On the other hand, less information with respect to anaerobic characteristics of upper and lower extremities is available. Detailed information on one's anaerobic power can be obtained by valid and reliable laboratory methods, such as Wingate 30 s anaerobic test [9], Bosco 60 s test [10] and Force-velocity (F-v) test [11]. With respect to other tests, F-v test has the advantage that it provides information not only on the maximal power (P_{max}), but also on the constituents of power, i.e. force and velocity. Our previous work, employing the F-v test and conducted on active male students, showed that the upper to lower limbs' ratio with regard to the maximal anaerobic power (P_{max}) was 0.651, in the theoretical maximal force (F_0) 0.625 and in velocity (v_0) 1.09 [12]. Nevertheless, these ratios may be sport-dependent and under the effect of training, and therefore they should be examined separetely for each sport.

Compared with taekwondo, in which athletes predominantly use fast kicks of high amplitude, kickboxing is characterized by full contact between the opponents who kick and punch [3]. Thus, it is important in kickboxing to determine the anaerobic power output for both upper and lower limbs. Separate upper and lower extremities' power output measures would be useful in evaluating training programs and in understanding the importance of power output for kickboxing performance. However, whether there are differences in F-v characteristics between upper and lower extremities of kickboxers is not known. Moreover, it has not yet been determined whether there are associations between upper and lower limbs with respect to these characteristics. Therefore, in the present study, we have examined anaerobic power of both upper and lower limbs of male kickboxers. Our goal was to test two related hypotheses: *1)* there are differences with respect to P_{max}, F_0 and v_0 between upper and lower extremities; and *2)* there is an association between upper and lower limbs with regard to these characteristics.

Material and methods

Participants and procedures. Fourteen male Caucasians, all members of recreational sport clubs, aged 21.77 (5.19) yr [mean (standard deviation)], body height 1.78 (.067) m, body mass 75.4 (8.9) kg, body fat 14 (5) % and somatotype 3.5-4.9-2.3, volunteered for this study. The local Institutional Review Board approved of this study and oral consent was obtained from all participants, or their parents in the case of under-age participants, after a verbal and written explanation of the experimental protocol and its potential risks. Exclusion criteria included history of any chronic medical conditions and use of any medication. All participants visited our laboratory once, where they were tested for anthropometric characteristics and body composition, and they performed the F-v test for both lower and upper limbs after a standardized 15-min warm-up.

Equipment and protocols. Height and body mass were measured using a stadiometer (SECA, Leicester, UK) and an electronic scale (HD-351, Tanita, Illinois, USA), respectively. Percentage of body fat was calculated from the sum of 10 skinfolds using a skinfold calliper (Harpenden, West Sussex, UK), based on the formula proposed by Parizkova [13]. The anthropometric Heath-Carter method of somatotyping was employed for the quantification of the shape and composition of the human body, expressed in a three-number rating representing endomorphy (relative fatness), mesomorphy (relative musculo-skeletal robustness), and ectomorphy (relative linearity or slenderness) [14].

The F-v test was used to assess P_{max}, v_0 and F_0, by employing various applied braking forces that elicited different pedalling velocities in order to derive P_{max} [11]. The warm-up activity which was conducted before the test included stretching exercises, steady-paced cycling, and short submaximal sprints. Minimal warming-up and learning experience was necessary in order to perform a true maximal sprint. Participants were instructed before the tests that they should pedal as fast as possible and remain seated on the saddle throughout the test. The participants performed five supramaximal pedal sprints, each lasting 7 sec, against incremental braking force, separately on an arm-cranking and on a cycle ergometer (Ergomedics 874, Monark, Sweden). The test began with a braking force of 30 N for lower and 20 N for upper extremities. In every subsequent sprint, 10 N was added. During each sprint, the participants were encouraged to reach their maximal velocity as soon as possible. This value of peak velocity was recorded and used to calculate F-v relationship (Fig. 1). The recovery period between each exercise bout was 5 minutes.

Data analysis. For each participant, an individual linear regression (least squares method) was determined between peak pedalling frequency and breaking force for each of the five sprints (five data points for each F-v relationship). F_0 and v_0 corresponded to the intercepts with the force and velocity axes in the F-v graph. At both of these locations, power is equal to zero. Because both velocity and force are nonzero between these endpoints, power varied with a bell-shaped profile depending on the magnitude of the product [15]. P_{max} was determined at an optimal force and optimal velocity of 0.5 F_0 and 0.5 v_0 respectively and it was calculated as $P_{max} = 0.25 \cdot F_0 \cdot v_0$. Relative to body mass values of P_{max} (rP_{max}), expressed in $W \cdot kg^{-1}$, were calculated, too. The dura-

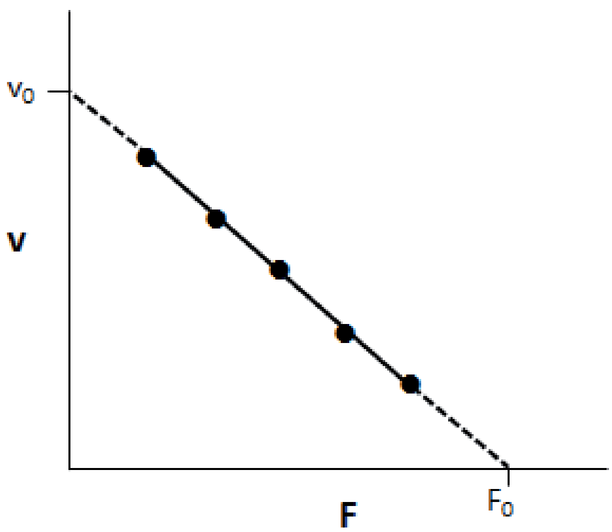

Fig. 1. The inverse linear relationship between braking force (F) and velocity (v), and their corresponding theoretical maximal values (F_0 and v_0)

tion of every flywheel revolution was measured with the help of an electronic sensor, and power output of every revolution was computed by specialized software [16].

Statistical analysis. All data are presented as means ± standard deviations. The Pearson product moment coefficient of correlation (r) was used to examine the association between upper and lower limbs with regard to F-v characteristics. The dependent one-tailed Student t-test was used to determine whether upper and lower limbs mechanical characteristics' means differed from each other. Statistical analyses were performed using SPSS v.17.0 statistical software (SPSS Inc., Chicago, IL, USA). Significance was set at $P<0.05$ for all the tests.

Results

The F-v characteristics of participants' upper and lower limbs are presented in Table 1. Upper and lower limbs differed with regard to P_{max} ($t_{13}=12.2$, $P<.001$), rP_{max} ($t_{13}=15.5$, $P<.001$), F_0 ($t_{13}=12.1$, $P<.001$), v_0 ($t_{13}=37.1$, $P<.001$) and v_0/F_0 ($t_{13}=13.9$, $P<.001$). All participants had lower values in upper than in lower limbs, except for v_0/F_0.

The ratio between upper and lower limbs' P_{max} ranged from 0.35 to 0.59, F_0 0.37-0.77 and v_0 0.71-.098. As shown in Figure 2A, there was a direct relationship between lower limbs' F-v values and the corresponding one of upper limbs. P_{max} of upper limbs was associated with P_{max} of lower limbs ($r=0.81$, $P<0.001$). The respective values of rP_{max} were $r=0.72$ ($P<0.01$, Fig. 2B), v_0 $r=0.44$ ($P=0.12$, Fig. 2C), F_0 $r=0.63$ ($P<0.05$, Fig. 2D) and v_0/F_0 $r=0.41$ ($P=0.14$).

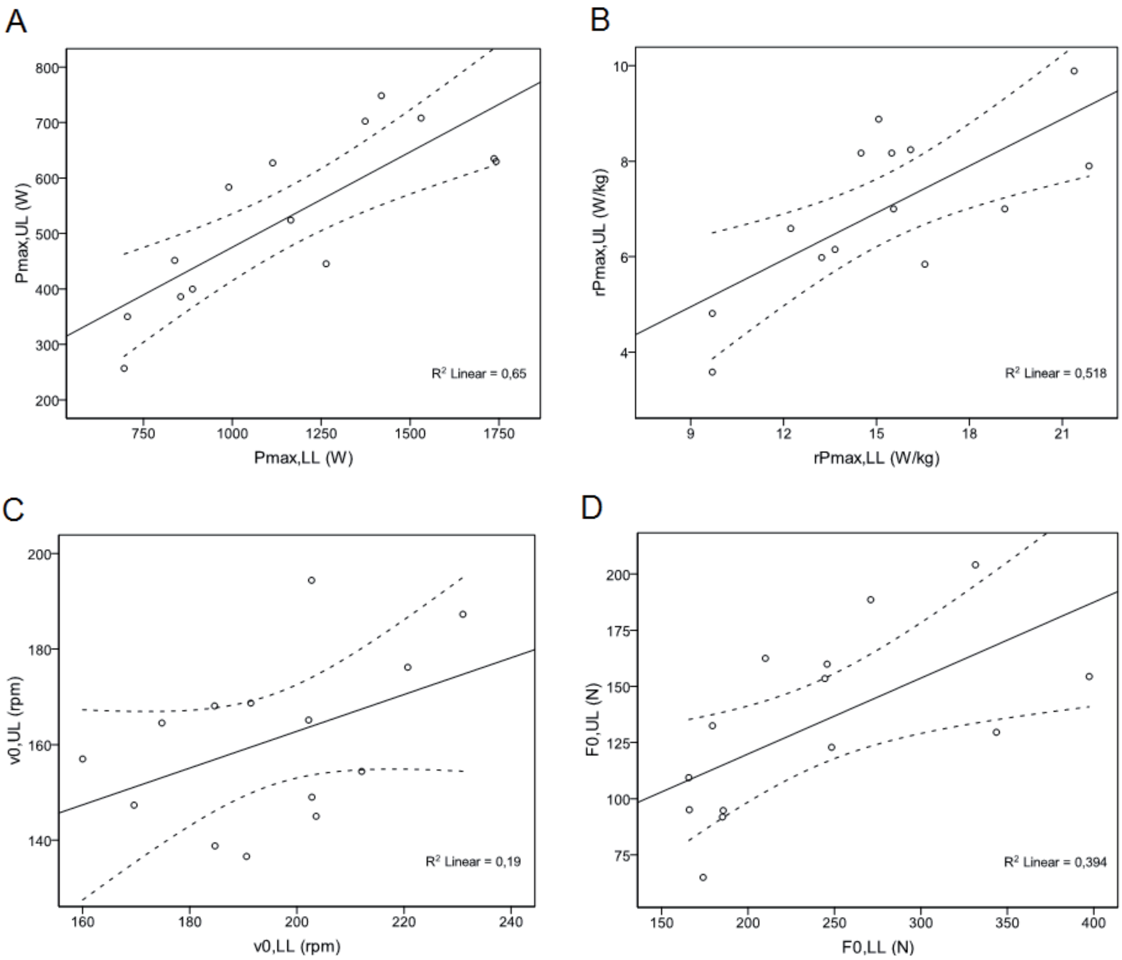

Fig. 2. Relationship between upper and lower limbs' mechanical characteristics. P_{max} and rP_{max} denote maximal anaerobic power in absolute and in relative to body mass values, v_0 theoretical maximal velocity and F_0 force. Dashed lines represent 95% confidence intervals of means

Tab. 1. Force-velocity characteristics of the participants

		Lower limbs	Upper limbs
Mechanical characteristics	P_{max} (W)	1165.31 (356.9)	532.08 (152.1)
	rP_{max} ($W \cdot kg^{-1}$)	15.3 (3.69)	7.01 (1.68)
	v_0 ($rad \cdot s^{-1}$, rpm)	20.43 (2.06), 195.06 (19.65)	16.85 (1.82), 160.89 (17.34)
	F_0 (N)	239.1 (73.8)	133.2 (39.7)
	v_0/F_0 ($rad \cdot s^{-1} \cdot N^{-1}$, $rpm \cdot N^{-1}$)	0.09 (0.03), 0.88 (0.24)	0.14 (.05), 1.33 (0.47)
Upper to lower limbs ratio	P_{max}	0.464 (0.079)	
	F_0	0.57 (0.133)	
	v_0	0.829 (0.095)	

Discussion

To the authors' knowledge, this is the first study to examine the relationship between upper and lower limbs' F-v relationship. Firstly, we demonstrated that P_{max}, rP_{max}, F_0, v_0 and v_0/F_0 differed significantly between upper and lower limbs. P_{max}, rP_{max}, F_0 and v_0 were higher in lower extremities, while v_0/F_0 was higher in upper extremities, i.e. upper limbs had a "faster" profile and lower limbs a "stronger" profile. Secondly, we observed direct relationships between upper and lower extremities' mechanical characteristics, which, except for the case of v_0, were statistically significant. This meant, for instance, that kickboxers with higher P_{max} of lower limbs also had higher P_{max} of upper limbs.

P_{max} of lower extremities accounted for 65% of the variance in P_{max} in upper extremities. Even when power output was adjusted to the effect of body mass, approximately half of the total variance (51.8%) was common in upper and lower limbs. The respective value for F_0 was 39.4% and for v_0 19%. In the case of v_0, and to a lower degree in the case of F_0, a large portion of the variance of these mechanical characteristics in upper extremities could not be accounted for by the corresponding values of lower extremities and vice versa. As shown in the graph of velocity (Fig. 2), for example, there was a case of four participants who had similar values of lower limbs' v_0 (202.2–203.6 rpm), but a very wide corresponding range of upper limbs' v_0 (145–194.4 rpm). These results were scrutinized together with relevant data of other researchers who used similar methods.

F_0, 133.2±39.7 N and 239.1±73.8 N of upper and lower limbs respectively, is similar to the corresponding values of male students (140 N and 223 N [12]) and of active male adults (values only for lower limbs; 112 N [11]; 140 N [17]; 198 N [18]). V_0, 160.89±17.34 rpm and 195.06±19.65 rpm of upper and lower extremities accordingly, is lower than previous findings for upper limbs (228.9 rpm in male students [12]; 254 rpm in young swimmers [17]) as well as for lower limbs (210.6 rpm in male students [12]; 215.9 rpm in young endurance athletes [18]; 228 rpm in recreationally active men [11]). The results of the P_{max} for upper extremities (532.08±152.1 W) are lower than the reference data (790 W [12]; 718 W [17]; 884 W for 44-year-olds; 960 W for physical education students [19]). The corresponding values for lower extremities (1165.31±356.9 W) is similar to other reported data (1211 W [12]; 1180 W in students [20]; 1114 W in 44-year-olds; 1029 W in physical education students [19]; 1090 W in young endurance athletes [17]; 813 W in subjects with recreational activities [11]; 879 W in untrained students [21]). The relative value of P_{max} for upper limbs measured with the F-v test is 7.01±1.68 $W.kg^{-1}$, while other studies reveal higher values (10.7 $W \cdot kg^{-1}$ [12]; 10.1 $W \cdot kg^{-1}$ in young swimmers [17]; 10.7 $W \cdot kg^{-1}$ in 44-year-olds and 12.3 $W \cdot kg^{-1}$ in physical education students [19]; 10.7 $W \cdot kg^{-1}$ in swimmers [22]). The corresponding value for lower limbs (15.3±3.69 $W \cdot kg^{-1}$) is similar to previous reports (16.4 $W \cdot kg^{-1}$ [12]; 13 $W \cdot kg^{-1}$ in untrained students [21]; 13.2 $W \cdot kg^{-1}$ in physical education students, 13.7 $W \cdot kg^{-1}$ in 44-year-olds [19]). The upper to lower extremities ratio with regard to P_{max} (46.4%) is lower than the 65.1% in physical education students [12], 69% in gymnasts [23], 78.1% in 44-year-olds and the

93.2% in physical education students [19]. An explanation for the discrepancy of our results in comparison with previous data might be the specialization according to sport.

Potential differences between upper and lower limbs could be explained primarily due to muscle mass and muscle fibre type distribution. Muscle strength or force generating capacity is found closely related to muscle mass [24,25] and muscle cross-sectional area [26]. Moreover, it is proposed that upper limbs muscle mass is 22.1% [27] to 24.87% of lower limbs [28].

The main drawback of our study was the inherent limitation of laboratory methods to reproduce the real movements of kickboxing. In addition, upper and lower limbs' power output was examined separately, which did not correspond to the complex movements of the sport that involve the coordination of upper and lower limbs. On the other hand, the laboratory methods provided valid and reliable measures of anaerobic power. Moreover, the distinction between upper and lower extremities' power came to terms with the training practice, in which many exercises focus on specific body parts. A remarkable observation from the present study was the variability of the ratios of mechanical characteristics between upper and lower limbs in kickboxers. Based on these findings, it is recommended that these characteristics should be monitored regularly and considered in the training design.

Conclusions

To the best of authors' knowledge, this study was the first one to focus on differences between upper and lower limbs in kickboxers. In summary, we attempted to quantify the proportionality of mechanical characteristics (power, force and velocity) between kickboxers' upper and lower limbs. The results confirmed previous observations in general population that upper extremities had lower values of power and force with respect to lower extremities, and smaller differences concerning velocity. However, the novelty lies in the quantification of the correlations between upper and lower limbs, which indicated that while there was high association with regard to power there were only moderate correlations with respect to force and velocity. This finding emphasizes the need for separate evaluation of upper and lower limbs' force-velocity characteristics and the consideration of these measures in the training design.

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