*Original Research*

# Differences in Force-velocity Characteristics of Upper and Lower Limbs of Non-competitive Male Boxers

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ABSTRACT

*Int J Exerc Sci 5(2) : 106-113, 2012.* Despite the increasing popularity of boxing, only a few studies have been conducted on the physiology or the biomechanics of this sport. The aim of the present study is to examine the ratios of mechanical characteristics (maximal anaerobic power, $P_{max}$, theoretical maximal force, $F_0$, and velocity, $v_0$) between upper and lower limbs of male boxers. Twelve male caucasians, all members of a local fitness club, aged 29.5 (3.2) yr [mean (standard deviation)], stature 1.74 (.05) m, body mass 77.9 (8.1) kg, body fat 22.4 (3.9) % and somatotype 5.5-5.5-1.1, performed a force-velocity (F-v) test for both legs and arms. The F-v test included five supramaximal pedal sprints, each lasting 7 sec, against incremental braking force of 20-60 N for arms and 30-70 N for legs, on modified arm-cranking and on cycle ergometer (Ergomedics 874, Monark, Sweden). The legs had higher $P_{max}$ (910 W vs. 445 W, $t_{11}$=22.9, $p$<.001), $P_{max}$ expressed in relative to body mass values ($rP_{max}$, 11.8 $W \cdot kg^{-1}$ vs. 5.8 $W \cdot kg^{-1}$, $t_{11}$=20.6,$p$<.001), $F_0$ (168 N vs. 102 N, $t_{11}$=21.7, $p$<.001), $v_0$ (217 rpm vs. 177 rpm, $t_{11}$=46.6, $p$<.001) and lower $v_0/F_0$ (1.33 $rpm \cdot N^{-1}$ vs. 1.82 $rpm \cdot N^{-1}$, $t_{11}$=15.3, $p$<.001) than the arms. $P_{max}$ of upper limbs was associated with $P_{max}$ of lower limbs ($r$=.70, $p$<.05) and their ratio was .49 (.06). The respective values of $rP_{max}$ was $r$=.76 ($p$<.01), $F_0$, $r$=.35 ($p$=.26) and .61 (.13), and of velocity, $v_0$,$r$=.17 ($p$=.59) and .812 (.10). In spite of moderate associations between upper and lower limbs' $F_0$ and $v_0$, a stronger relationship was found with regard to $P_{max}$. These findings emphasize the need for separate evaluation of arms' and legs' F-v characteristics on a regular basis and the consideration of these measures in training design.

KEY WORDS: Anaerobic power, force-velocity relationship, martial arts

## INTRODUCTION

Boxing is a sport with an increasing popularity and is promoted in many sport and fitness centres. It is practiced for either self-defence, general fitness or as a full-contact sport. Performance in boxing depends on physiological characteristics of athletes. Oxygen uptake at individual anaerobic threshold and hand-grip strength have been found to be highly related to boxing competition ranking ($rho$=.91, $p$<.01, and $rho$=.87, $p$<.01 respectively) (13). This suggests that cardiorespiratory power and muscular strength are two important determinants of boxing performance. In a comparative study of athletes participating in 26 Olympic events, it was found that athletes participating in sports where a weight class was required, such as boxing, had lower % fat values (28), indicating the significance of body composition in boxing. Compared with athletes engaged in other sport disciplines, boxers had similar explosive power as wrestlers and basketball players (12).

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 about the relationship between arms' and legs' characteristics has focused on parameters of cardiorespiratory power, such as maximal oxygen uptake, aerobic power output, anaerobic threshold, work efficiency and oxygen kinetics (9, 17, 18, 32). In 1975, Vokac and co-workers (32) during a study on male subjects noted that though the maximal workload in arm exercise was 50–60% of that in cycling, $VO_2$ in arm work was at maximal effort only 22% lower than in leg exercise. Subsequent investigators 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 (9) and that metabolic efficiency as determined by work efficiency indices was lower during arm crank compared with cycle exercise at the same relative intensities (17). Finally, a study in oxygen uptake kinetics now demonstrates that the time constant of the fast component response is significantly longer and greater in arm exercise compared to leg exercise (18).

On the other hand, less information with respect to anaerobic characteristics of upper and lower limbs is available. Detailed information about one's anaerobic power can be obtained by valid and reliable laboratory methods, such as Wingate 30 s anaerobic test (3), Bosco 60 s test (5) and Force-velocity (F-v) test (30), which, with the exception of Bosco test, can be performed either with arms or legs. With respect to the other aforementioned tests, F-v test has an advantage, because it provides information not only about maximal power ($P_{max}$), but also about 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 arm to leg ratio with regard to maximal anaerobic power ($P_{max}$) was .651, in theoretical maximal force ($F_0$) .625 and in velocity ($v_0$) 1.09 (25). Nevertheless, these ratios may be sport-dependent and under the effect of training, and therefore they should be examined separetely for each sport.

Separate arms' and legs' power output measures would be useful in evaluating training programs and in understanding the importance of power output for boxing performance. However, whether there are differences in F-v characteristics between upper and lower limbs of boxers is not known. Moreover, it has not yet been determined whether there are associations between arms and legs with respect to these characteristics. Therefore, in the present study, we have examined anaerobic power of both upper and lower limbs of male boxers. Our goal was to test two related hypotheses: *1)* there are differences with respect to $P_{max}$, $F_0$ and $v_0$ between arms and legs, and *2)* there is association between upper and lower limbs with regard to these characteristics.

## METHODS

*Participants*

Twelve male Caucasians (see table 1), all members of a local fitness club, volunteered for this study. The local Institutional Review Board approved this study and all participants provided written consent, after a verbal and written explanation of the experimental protocol and its potential risks. Exclusion criteria included history of any chronic medical conditions and current use of any medication. There were neither age- nor sex-related exclusion criteria. No current injury was reported. All participants visited once our laboratory, in which they were tested for anthropometric characteristics and body composition. They performed the F-v test for both legs and arms after a standardized 15-min warm-up.

Table 1. Demographics of participants.

| | Mean (standard deviation) |
|---|---|
| Age (yr) | 29.5 (3.2) |
| Body mass (kg) | 77.9 (8.1) |
| Stature (m) | 1.74 (.05) |
| Body fat (%) | 22.4 (3.9) |
| Somatotype | 5.5-5.5-1.1 |
| Training experience (yr) | 3 (3.1) |
| Training (days·wk$^{-1}$) | 3.1 (1) |
| Training session duration (min) | 85.5 (17.4) |

*Procedures*

Height and body mass were measured using a stadiometer (SECA, Leicester, UK) and an electronic scale (HD-351, Tanita, Illinois, USA). 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 (27). The anthropometric Heath-Carter method of somatotyping was employed for the quantification of 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).

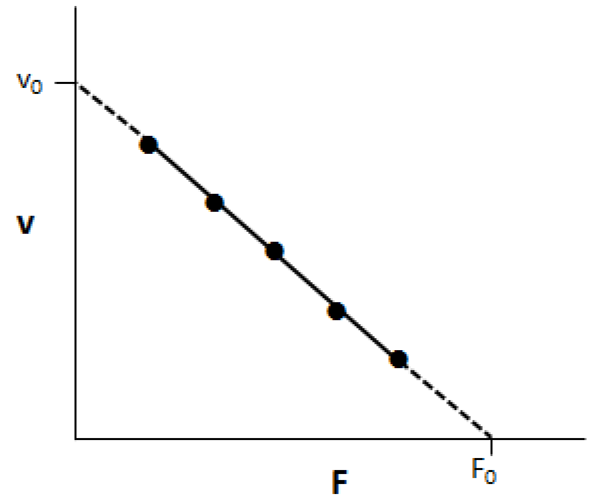


Figure 1. The inverse linear relationship between braking force (F) and velocity (v), and their corresponding theoretical maximal values ($F_0$ and $v_0$).

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 $P_{max}$ (30). 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 to remain seated on the saddle throughout the test. The participants performed five supramaximal pedal sprints, each lasting 7 sec, against incremental braking force, on an arm-cranking and cycle ergometer (Ergomedics

874, Monark, Sweden). The test began with a braking force of 30 N for legs and 20 N for arms. In every subsequent sprint, 10 N was added. During each sprint, 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 (see figure 1). The recovery period between each exercise bout was 5 minutes. Sprints were performed for legs and arms alternately. The reliability of F-v test has been well documented (test-retest coefficient of variation 3% (10)).

*Statistical 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). The theoretical maximal force ($F_0$) and velocity ($v_0$) 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 (11). Maximal power ($P_{max}$) was determined at an optimal force and optimal velocity of 0.5 $F_0$ and 0.5 $v_0$ respectively and was calculated as $P_{max} = 0.25 \cdot F_0 \cdot v_0$. The duration of every flywheel revolution was measured with the help of electronic sensor and its corresponding velocity was computed by specialized software (26).

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 $p<.05$ for all the tests.

**RESULTS**

The F-v characteristics of upper and lower limbs of participants are presented in table 2. Upper and lower limbs differed with regard to $P_{max}$ ($t_{11}=22.9$, $p<.001$), $rP_{max}$ ($t_{11}=20.6$, $p<.001$), $F_0$ ($t_{11}=21.7$, $p<.001$), $v_0$ ($t_{11}=46.6$, $p<.001$) and $v_0/F_0$ ($t_{11}=15.3$, $p<.001$). All participants had lower values in arms than in legs, except of $v_0/F_0$.

The ratio between upper and lower limbs' $P_{max}$ ranged from .38 to .62, $F_0$ .44-.89 and $v_0$ .70-1.02. As shown in figure 2, there was a direct relationship between F-v values of the legs and the corresponding values for

Table 2. Force-velocity characteristics of participants.

| | | Lower limbs | Upper limbs |
|---|---|---|---|
| Mechanical characteristics | $P_{max}$ (W) | 910 (138) | 445 (80) |
| | $rP_{max}$ ($W \cdot kg^{-1}$) | 11.8 (2.0) | 5.8 (1.1) |
| | $v_0$ (rpm) | 217 (16) | 177 (19) |
| | $F_0$ (N) | 168 (27) | 102 (24) |
| | $v_0/F_0$ ($rpm \cdot N^{-1}$) | 1.33 (.30) | 1.82 (.42) |
| Upper to lower limbs ratio | $P_{max}$ | .49 (.06) | |
| | $F_0$ | .61 (.13) | |
| | $v_0$ | .82 (.10) | |

Pmax is maximal anaerobic power, rPmax Pmax in relative to body mass values, $v_0$ theoretical maximal velocity and $F_0$ force.

the arms. $P_{max}$ of upper limbs was associated with $P_{max}$ of lower limbs ($r$=.70, $p$<.05). The respective values of $rP_{max}$ was $r$=.76 ($p$<.01), $F_0$ $r$=.35 ($p$=.26), $v_0$ $r$=.17 ($p$=.59) and $v_0/F_0$ $r$=.17 ($p$=.61).

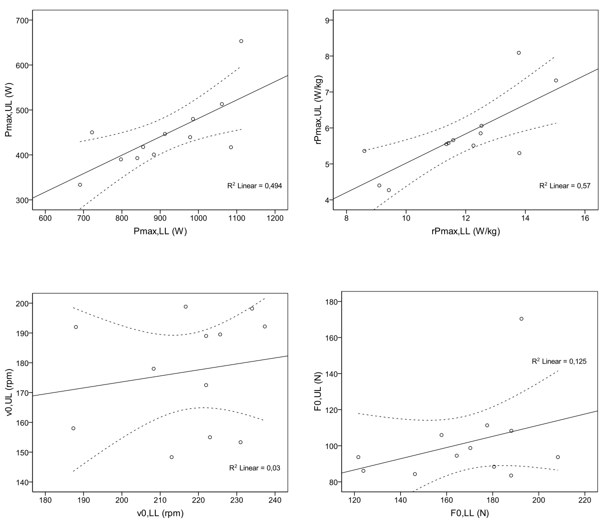


Figure 2. Relationship between upper (UL) and lower limbs' (LL) mechanical characteristics. $P_{max}$ is maximal anaerobic power, $rP_{max}$ $P_{max}$ in relative to body mass values, $v_0$ theoretical maximal velocity, $F_0$ force and $R^2$ coefficient of determination.

## DISCUSSION

Although it is clearly recognized that anaerobic power is linked with performance in boxing, little is known about the F-v characteristics of those who practise this sport. This is the first study to examine the relationship between arms' and legs' F-v relationship in male boxers. First, 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 $v_0$ are higher in legs, while $v_0/F_0$ is higher in arms, i.e. arms had a "fast" profile and legs a "strong" profile. Second, we observed direct relationships between upper and lower limbs' mechanical characteristics, which, except of the case of $v_0$, were statistically significant. This meant, for example, that boxers with higher $P_{max}$ of legs had also higher $P_{max}$ of arms.

$P_{max}$ of legs accounted for by 49.4% of the variance in $P_{max}$ in arms. Even when power output was adjusted to the effect of body mass, approximately more than half of the total variance (57.0%) was common in upper and lower limbs. The respective value for $F_0$ was 12.5% and for $v_0$ 3.0%, highlighting the weak association between upper and lower limbs with regard to these parameters.. As shown in the graph of velocity (figure 2), there was a case of three participants, who had similar values of legs' $v_0$ (222-223 rpm), but corresponding range of arms' $v_0$ very wide (155-189 rpm). These results were scrutinized together with relevant data of other researchers, who used similar methods.

$F_0$ of upper and lower limbs (133 N and 239 N respectively), is similar to corresponding values of male students (140 N and 223 N) (25) and in active male adults (values only for lower extremities; 112 N (25); 140 N (31); 198 N) (31). $V_0$ of upper and lower extremities (161 rpm and 195 rpm respectively), is lower than previous findings for upper limbs (229 rpm in male students (25); 254 rpm in young swimmers) (31) as well as for lower limbs (211 rpm in male students (25); 216 rpm in young endurance athletes (7); 228 rpm in recreationally active men) (30).

$P_{max}$ in absolute values for upper limbs (532 W) is lower than the reference data (790 W (25); 718 W (31); 884 W for 44 year-olds; 960 W for physical education, PE, students) (2). The corresponding values for lower limbs (1165 W) is similar with other reported data

(1211 W (25); 1180 W in students (16); 1114 W in 44 year-olds; 1029 W in PE students (2); 1090 W in young endurance athletes (31); 813 W in subjects with recreational activities (30); 879 W in untrained students) (20).

$P_{max}$, expressed to relative to body mass values, of upper limbs is 7.0 $W \cdot kg^{-1}$, while other studies reveal higher values (10.7 $W \cdot kg^{-1}$ (25); 10.1 $W \cdot kg^{-1}$ in young swimmers (31); 10.7 $W \cdot kg^{-1}$ in 44 year-olds and 12.3 $W \cdot kg^{-1}$ in PE students (2); 10.7 $W \cdot kg^{-1}$ in swimmers) (22). The corresponding value for lower limbs (15.3 $W \cdot kg^{-1}$) is similar with previous reports (16.4 $W \cdot kg^{-1}$ in PE students (25); 13.0 $W \cdot kg^{-1}$ in untrained students (20); 13.2 $W \cdot kg^{-1}$ in PE students, 13.7 $W \cdot kg^{-1}$ in 44 year-olds) (2).

The ratio upper to lower limbs with regard to $P_{max}$ (46.4%) is lower than the 65.1% (25), 69.0% in gymnasts (15), 78.1% in 44 year-olds and the 93.2% in PE students (2). An explanation for the discrepancy of our results in comparison with previous data might be the specialization according to sport.

The differences between upper and lower limbs could be explained primarily due to muscle mass and distribution of muscle fibres. Muscle strength or force generating capacity is found closely related to muscle mass (19, 23) and muscle cross-sectional area (21). Consequently, an exercise intervention (e.g. strength training) can alter F-v relationship through an increase in muscle mass. Moreover, it has been proposed that upper limbs muscle mass is 22.1% (1) to 24.9% of lower limbs (33), which explained the difference between limbs in force. While the differences in force might be attributed to variation of muscle mass, the differences in velocity could be due to variation in fast twitch fibre distribution. It has been shown that isokinetic performance was associated with jumping performance ($.60<r<.74$, $p<.01$) (6), which in turn was significantly correlated with fast twitch fibre distribution ($r=.86$, $p<.01$) (4). In addition, force-velocity characteristics of knee extensor muscles were associated with the percentage of fast twitch fibres (29).

A main drawback of our study was the inherent limitation of laboratory methods to reproduce the real movements of boxing. In addition, arms and legs' 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, and there were indications that F-v test was associated with sport performance (8). Moreover, the distinction between arms and legs' power output came to terms with the training practice, in which many exercises focus on specific body parts. With regard to the estimation of power output, in order for our data to be comparable with previous research, the values obtained from the F-v test did not take into account the effect of flywheel inertia. Corrected values for the effect of inertia can be obtained with a simple post-hoc method with an error of 1.3% (24).

To the authors' knowledge, this study was the first one to focus on differences between upper and lower limbs in boxers. In summary, we attempted to quantify the proportionality of mechanical characteristics (power, force and velocity) between boxers' upper and lower limbs. Regarding our first research hypothesis, differences were revealed between F-v characteristics of arms and legs, confirming previous observations in general population, where arms had lower values of power and force with respect to legs, and smaller differences concerning the velocity. However, what is novel, is the quantification of the correlations between upper and lower limbs (second research hypothesis), which indicated that, while there was a high association with regard to power, there were only low-to-moderate correlations with respect to force and velocity. This finding emphasizes the need for separate evaluation of arms' and legs' force-velocity characteristics and the consideration of these measures in training design.

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