



POWER-VELOCITY CHARACTERISTICS AND JUMPING ABILITIES IN MALE COMBAT ATHLETES

doi: 10.1515/humo-2016-0019

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ABSTRACT

Purpose. The aim of the study was to examine differences in power-velocity characteristics, and the maximal power and height of rise of the body's centre of mass, measured in the counter-movement jump (CMJ) and the spike jump (SPJ), between judoists, boxers and taekwondo athletes. **Methods.** The study involved 7 judoists, 6 boxers, and 6 taekwondo athletes. The maximal power and height of jump were measured at CMJ and SPJ jumps. Force-velocity and power-velocity relations were determined on the basis of 5 maximal cycle ergometer exercise bouts at increasing external loads of 2.5, 5.0, 7.5, 10.0, and 12.5% of body weight (BW). **Results.** The absolute and relative power and velocity recorded for an external force-velocity relationship were similar in the groups. A significant difference was only observed between taekwondo athletes and judoists for absolute power at the external load of 2.5% BW ($p < 0.05$). The judoists had significantly smaller relative maximal power in SPJ ($p < 0.05$) and height of rise of the body mass centre in CMJ ($p < 0.05$) than taekwondo athletes. The relative maximal power in CMJ and height of rise of the body mass centre in SPJ was similar in the groups. **Conclusions.** In martial arts, training and competition should affect physical characteristics, including jumping and power. The power and velocity recorded for an external force-velocity relationship were similar in the groups. Judoists and boxers did not differ in terms of power or height of the jumps. Taekwondo athletes developed the biggest power and height of the jumps. This is consistent with the discipline characteristics.

Key words: force-velocity relationship, power, height of jump, spike jump, counter-movement jump, combat athletes

Introduction

In combat sports, tournament results are determined by a number of interrelated factors: motoric characteristics, technique, tactics, psychological features of the athlete, and the refereeing method [1–4]. Determining athletes' motor abilities requires adequate testing and/or measurements. The measurements of force-velocity characteristics, power and height of jump are routine methods used in laboratory testing in judo, boxing, and taekwondo [5–8]. The amount of professional literature comparing the results in combat athletes is limited. A few comprehensive studies have examined the biomechanical characteristics of taekwondo athletes [9, 10]. There are no extensive studies, however, on biomechanical and physiological characteristics of boxers [11].

The aim of the study was to examine differences in power-velocity characteristic, and the maximal power and height of rise of the body's centre of mass, measured in the counter-movement jump (CMJ) and the spike jump (SPJ), between judoists, boxers, and taekwondo athletes.

Material and methods

The study was granted approval of the Senate Ethics Committee of the Józef Piłsudski University of Physical Education in Warsaw, Poland. The subjects were informed about the scope and protocol of the study, as well as the possibility to withdraw from the study at any moment. The research was conducted in adherence to the

Declaration of Helsinki. It involved 7 judoists, 6 boxers, and 6 taekwondo athletes. Their mean (\pm SD) age, body height, body mass, and training experience were 15.7 ± 0.7 years, 178.3 ± 8.0 cm, 75.8 ± 11.9 kg, 7.5 ± 2.1 years in judoists, 16.8 ± 1.0 years, 185.7 ± 6.0 cm, 75.8 ± 7.1 kg, 2.1 ± 1.2 years in boxers, and 17.7 ± 0.7 years, 179.5 ± 4.1 cm, 62.3 ± 6.0 kg, 6.7 ± 1.5 years in taekwondo athletes, respectively. No significant differences were found between the groups with reference to body height but there were significant differences between the judoists and taekwondo athletes as for age and body mass, as well as among boxers, judoists, and taekwondo athletes as for training experience.

The power of lower extremities and the height of rise of the body mass centre during vertical jumps were measured on a force plate with a Kistler amplifier type 9281A (Switzerland) for CMJs and SPJs. The amplifier was connected to a personal computer (PC) via an A/D converter. The MVJ v. 3.4. software package (JBA, Z. Staniak, Poland) was used for the measurement. In the physical model applied, the subject's body mass bouncing on the platform was reduced to a particle affected by the vertical components of external forces: the gravity force of the body and the reactive force of the platform. The maximal power (P_{\max} [W]), relative maximal power ($P_{\max} \cdot \text{mass}^{-1}$ [$\text{W} \cdot \text{kg}^{-1}$]), and maximal height (h [m]) of rise of the body mass centre (COM, centre of mass) were calculated from the registered reactive force of the plate [12]. Each subject performed 6 vertical jumps with maximal force on the force plate: 3 CMJs and 3 SPJs. The CMJ was defined as a vertical jump from a standing

erect position, preceded by a counter-movement of upper limbs and with lowering of the body mass centre before the take-off. The SPJ was a vertical jump performed with a 3–4-step run-up before the take-off. There were 5-second breaks between the CMJs, and 1-minute breaks between the SPJs. The jump with the highest elevation of the body's COM was chosen for statistical analysis.

The force-velocity ($F-v$) and power-velocity ($P-v$) relationships were determined on the basis of the results of exercises performed on a Monark 874 E cycle ergometer (Sweden) connected to a PC, with the usage of the MCE 4.0 software package (JBA, Z. Staniak, Poland). After adjusting the ergometer saddle and handlebars, each subject performed the tests in a stationary position, without lifting off the saddle, with their feet strapped onto the pedals. Each participant performed 5 maximal cycle ergometer tests, each lasting 10 seconds, with increasing external loads amounting to 2.5, 5.0, 7.5, 10.0, and 12.5% of BW, respectively. There were 2-minute breaks between the tests. The standard procedures of the exercise performance were followed, and the subjects were verbally encouraged to achieve and maintain the maximal pedalling velocity as quickly as possible. With the use of MCE v. 4.0, the maximal power at a given load (P_i ; i – load value) and velocity (v_i) necessary to achieve P_i were determined [7]. On the basis of the obtained results, the $F-v$ and $P-v$ relationships, as well as individual maximal power (P_{max}) and optimal pedalling velocity (v_o) were calculated for each subject. The maximal power and optimal pedalling velocity were computed from individual equations of the second degree polynomial describing the $P-v$ relationship.

Before vertical jump testing, the subjects performed a 5-minute warm-up, consisting of light exercise (i.e. running, circles of the arms, hips and trunk, squats followed by stretching exercises). Before determining the $F-v$ relationship, the participants performed a 2-minute sub-maximal warm-up on a cycle ergometer (Monark 874 E, Sweden). They were instructed to cycle at 50–60 rpm and to maintain the power output of approximately 150 W.

ANOVA procedures with a *post-hoc* Scheffé test were employed to compare the mean values between the

groups. The effect size (ES) in ANOVA was assessed by eta square and interpreted as follows: $0.01 \leq \eta^2 < 0.06$ – small, $0.06 \leq \eta^2 < 0.14$ – medium, and $\eta^2 \geq 0.14$ – large. The level of statistical significance was set at $p < 0.05$. Statistica™ v. 12.0 software (StatSoft, USA) was used in the data analysis.

Results

Mean ($\pm SD$) values of the height of rise of the body mass centre, maximal power, and relative maximal power during the CMJs and SPJs on a force platform are presented in Table 1. The judoists had a significantly smaller relative maximal power in SPJ ($F = 4.02$, $p = 0.039$, $\eta^2 = 0.334$) and height of rise of the body mass centre in CMJ ($F = 5.29$, $p = 0.017$, $\eta^2 = 0.398$) than taekwondo athletes. The relative maximal power in CMJ and height of rise of the body mass centre in SPJ was similar in the groups.

The absolute and relative power and velocity recorded for an external $F-v$ relationship were similar in the groups (Table 2). A significant difference was only observed between taekwondo athletes and judoists for absolute power at the external load of 2.5% BW ($F = 4.500$, $p = 0.030$, $\eta^2 = 0.375$).

Discussion

Success in combat sports requires a high level of physical and performance preparation [3, 7, 13, 14]. The planning of training should focus on the athletes' physical abilities, including jumping and power. The $F-v$ relationship can be described according to Hill's equation (hyperbola) or a straight line. In the presented study, the $F-v$ curves were linear. This is consistent with the results obtained for lower extremities by other authors [15, 16]. There is only one study in the literature that describes the determination of $F-v$ profiles in boxers [16], and no such study for taekwondo athletes. The peak power developed during the determination of $F-v$ profiles was 910 ± 138 W (11.68 ± 1.77 W · kg⁻¹) in boxers [16]. The maximal power recorded for judoists and boxers in the study was similar; in taekwondo athletes it turned out higher than in karate athletes (11.67 ± 0.87 W · kg⁻¹)

Table 1. Mean values ($\pm SD$) of the height of rise of the body mass centre (h), maximal power (P), and relative maximal power ($P \cdot \text{mass}^{-1}$) during counter-movement jumps (CMJ) and spike jumps (SPJ)

Variables	Judoists ($n = 7$)	Boxers ($n = 6$)	Taekwondo athletes ($n = 6$)
PCMJ (W)	2370.1 \pm 572.4	2264.8 \pm 472.6	2413.7 \pm 671.7
PCMJ · mass ⁻¹ (W · kg ⁻¹)	29.83 \pm 7.5	29.83 \pm 7.13	33.68 \pm 6.12
hCMJ (m)	0.420 \pm 0.051	0.430 \pm 0.050	0.496 \pm 0.039*
PSPJ (W)	3403.6 \pm 542.6	3507.2 \pm 582.1	3522.0 \pm 741.7
PSPJ · mass ⁻¹ (W · kg ⁻¹)	43.22 \pm 8.49	45.91 \pm 6.37	54.55 \pm 10.70*
hSPJ (m)	0.516 \pm 0.07	0.511 \pm 0.068	0.551 \pm 0.032

* statistically significant difference from judo athletes, $p < 0.05$

Table 2. Absolute (P) and relative ($P \cdot BW^{-1}$) power recorded for an external force-velocity relationship (mean values \pm SD)

Variables	Load (% BW)	Judoists ($n = 7$)	Boxers ($n = 6$)	Taekwondo athletes ($n = 6$)
P (W)	2.5	369.1 \pm 58.5	353.1 \pm 46.1	294.3 \pm 25.1*
	5.0	652.9 \pm 108.1	637.7 \pm 76.3	532.6 \pm 52.4
	7.5	835.5 \pm 131.0	804.1 \pm 92.5	704.0 \pm 66.7
	10.0	891.8 \pm 159.0	850.6 \pm 106.0	733.4 \pm 71.0
	12.5	837.9 \pm 174.2	727.2 \pm 227.2	708.6 \pm 76.8
P_{\max} (W)		900.8 \pm 152.9	860.7 \pm 95.8	758.2 \pm 61.1
$P \cdot BW^{-1}$ (W \cdot kg $^{-1}$)	2.5	4.73 \pm 0.30	4.73 \pm 0.20	4.73 \pm 0.25
	5.0	8.37 \pm 0.76	8.52 \pm 0.42	8.56 \pm 0.51
	7.5	10.71 \pm 0.76	10.79 \pm 0.74	11.32 \pm 0.73
	10.0	11.44 \pm 1.32	11.41 \pm 0.91	11.83 \pm 1.34
	12.5	10.71 \pm 1.21	9.83 \pm 3.14	11.51 \pm 2.09
$P_{\max} \cdot BW^{-1}$ (W \cdot kg $^{-1}$)		11.56 \pm 1.21	11.56 \pm 0.92	12.25 \pm 1.51
v (rpm)	2.5	193.9 \pm 12.1	193.0 \pm 10.5	190.0 \pm 11.0
	5.0	170.1 \pm 14.3	173.5 \pm 8.4	174.4 \pm 10.0
	7.5	145.3 \pm 10.1	147.1 \pm 9.5	153.0 \pm 9.8
	10.0	116.6 \pm 13.5	116.5 \pm 8.9	120.6 \pm 14.1
	12.5	87.3 \pm 9.8	80.2 \pm 25.4	93.8 \pm 17.4
v_o (rpm)		119.3 \pm 16.0	113.1 \pm 12.5	111.7 \pm 11.5

* statistically significant difference from judo athletes, $p < 0.05$

BW – body weight

[15]. The power at the external load of 7.5% BW obtained in the study for cadet judoists (10.71 ± 0.76 W \cdot kg $^{-1}$) was lower than that reported for cadet (15.5 \pm 0.5 years old) and junior (17.5 \pm 0.7 years old) Polish judoists (11.2 ± 0.5 W \cdot kg $^{-1}$ and 11.32 ± 0.7 W \cdot kg $^{-1}$, respectively) by Sterkowicz et al. [17]. In a study by Heller et al. [18], taekwondo athletes (of the same age and training experience as in the presented study) developed the peak power of 14.7 W \cdot kg $^{-1}$ in a 30-second Wingate test. Furthermore, in a study by Cetin et al. [19], taekwondo athletes developed the peak power of 9.09 W \cdot kg $^{-1}$ in the 30-second Wingate test. The results for combat athletes in the presented study were lower than the values observed by Sterkowicz et al. [17] and Heller et al. [18], and higher than those documented by Cetin et al. [19]. No significant differences were observed between the three groups for the values of velocity and relative power.

In a paper by Detanico et al. [6], the absolute and relative maximal power and height in CMJ of judo athletes (aged 20.6 ± 1.8 years) were 2109.48 ± 307.7 W, 27.62 ± 11.86 W \cdot kg $^{-1}$, and 0.448 ± 0.045 m, respectively. In a study by Loturco et al. [20], Brazilian boxers performed CMJs to the height of 0.374 ± 0.048 m. Roy et al. [21] documented boxers who jumped to the height of 0.373 ± 0.043 m. In the present study, boxers jumped higher. In a study by Cetin et al. [19], taekwondo athletes (of the same age and training experience as in the presented study) performed akimbo CMJs to the

height of 0.472 m. In the research described here, taekwondo athletes jumped higher than taekwondo athletes observed by Cetin et al. [19], and similarly to taekwondo athletes (0.527 \pm 0.111 m) reported by Noorul et al. [8].

A comparison with the findings published by other authors requires considering the measurement methods. In the present study, the height of the rise of the centre of mass was calculated from the ground reaction forces, while in the studies of the above cited authors, the value was obtained on the basis of the flight time. In the present study, the relative maximal power in CMJ and height of rise of the body mass centre in SPJ were similar in the three groups of combat athletes. The judoists had only a significantly smaller relative maximal power in SPJ and height of rise of the body mass centre than taekwondo athletes. On the other hand, during CMJs, the jump height and power are assessed with the body centre of mass lowered before the jump and the leg muscles working in the stretch-shortening cycle. During SPJs, also the lowered body centre of mass is used, as well as the horizontal velocity of the body centre of mass during the take-off phase. Perhaps the development of the taekwondo athletes insignificantly higher power in SPJs is the result of generating more power on cycle ergometer at the external load equal 2.5% BW. This is particularly important during the take-off phase and may result from differences between training experience and training methods.

Conclusions

In martial arts, the conduct of training and competition should affect the physical characteristics, including jumping and power. Basing on the characteristics of the $F-v$ curve, one can observe the direction that the training effects follow (the athletes improve their strength or power in the part of the curve for high force and low velocity or high velocity and low force). It is not always training of maximal external load that improves the maximal power because an increase of force may have a large impact in the neurological context [22, 23]. The power and velocity recorded for the external $F-v$ relationship were similar in the groups. Judoists and boxers did not differ in terms of the power or height of the jumps. Taekwondo athletes developed the most power and height of the jumps. This is consistent with the characteristics of the discipline. The usage of all these methods provides more information for planning optimal training control.

Acknowledgements

The study was supported by the Ministry of Science and Higher Education (grants No.: AWF: DS.134).

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Paper received by the Editor: May 18, 2016

Paper accepted for publication: July 27, 2016

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