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Original paper

Relative power of the lower limbs in drop jump

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The purpose of this paper was to determine the power produced by the lower limbs in the take-off phase in drop jumps (DJ) and the correlation between the power and load measured by dropping height after take-off.

The research group ($N = 17$) contained students practicing football, volleyball, basketball, athletics, high jump, swimming and fencing.

The individual characteristics 'power–load' of the players and the observation of the changes during the training process enable the coaches to choose precise loads and at the same time to improve the training. The criterion of choosing loads in the plyometric training may be relative power output of lower limbs referred to the DJ height. While the condition allowing player to perform this type of training may depend on obtaining greater power in drop jump than in counter movement jump.

Key words: *power, plyometric training, drop jump*

1. Introduction

The power described in many papers as a dynamic force is a desirable variable in many sport disciplines. Thus, training methods improving this variable along with the methods evaluating the effect of this training are being searched. One of such methods is plyometric training based on the exercises during which use is made of elastic energy, produced when the muscle in the stretch–shorten cycle changes its action from the eccentric to concentric [1]. A positive influence of the preliminary stretch on the actions in the concentric phase while running, jumping and walking was observed by many authors [2]. That is why research examining correlations between the range of muscle stretch, the time of change from the eccentric to concentric phase and the power produced by the muscle has been conducted. Typical plyometric exercises of lower limbs are jumps. The usage of the elestic energy is evaluated by the comparison of CMJ (counter movement jump) parameters with DJ (drop jump) parameters [3]. The range of the muscle stretch depends on the height of box from which the squat jump is performed. The time from landing after jump to the take-off phase describes a duration of the stretch–shorten cycle.

Plyometric training is of interest to researchers because of two reasons. It is an effective method of increasing strength and power of a player [4]. It is also related to the sports disciplines where significant loadings of human movement system in the take-off or landing phase are observed. Relative value of the ground reaction force (BW) (force value divided by the body weight of the player) during take-off or landing significantly exceeds the player's body weight in many disciplines. In diving, depending on the type of the jump, while taking-off from the platform the vertical ground reaction forces are from 3 to 9 times higher than the body weight [5]. In ski jumpers, depending on the length of a jump, the value of the normal force while taking-off ranges from 15 to 23 BW [6]. Dynamic force training is also important in sports disciplines based on the multiple performance of take-off. They are characterized by a high value of ground reaction forces while taking-off and short contact with

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a ground while landing, after which there is another take-off (jumps on the path, aerial tumbling, triple jump) [7]. In the strength and power training, landing strategy (normal, more rigid than normal, softer than normal, asymmetrical) specific to certain take-off and landing technique should be considered [8].

Plyometric training may also cause muscle damage [9], especially when the load in the eccentric phase is incorrect [10]–[12]. According to an available literature this type of training is recommended mainly for the adult players, whose motor system is adapted to high loads [4], but training parameters (drop height) should be selected individually for each player [13], [14]. KOTZAMANIDIS [15] states that the low intensity plyometric exercises can be used in children training, yet such training needs to be preceded by coordination exercises, stretching and endurance strength training.

The research conducted is basic and examines the effectiveness of the muscle change from the eccentric to the concentric activity due to coupling time [16]. It searches for the correlations of force with speed in the experiments, in which the external load is changing and electromyographic activity of the lower limbs muscles is analyzed [17]. For the purpose of training, the methods selecting training conditions are searched (drop height), hence in the exercises the maximal power could be reached. The value of the relative power in drop from the height of 0.32–0.59 is 30–40 W per 1 kg of a player's body weight, while for a drop from 1.28 m height is reaches 150 W/kg [18], [8] which reflects the relative value of power of 25 W/kg for ankle, knee and hip joint.

In the plyometric training research, the analysis of the ground reaction forces is based on the analysis and interpretation of the results regarding the duration of the contact with the ground phase after drop from the required height and the duration of a swing phase important to asses the vertical jump height [19], [13], [14], [20], [21], [16].

The application of the dynamometric method recording ground reaction force jump DJ does not enable us to determine the borderline between the amortization phase–eccentric phase and take-off phase–concentric phase. However, a video camera placed in the research post synchronized with a dynamometric plate enables us to determine this borderline as well as the relative power of lower limbs produced in the take-off phase.

The purpose of this work was to determine the power produced by the lower limbs in the take-off phase in DJs and find the correlation between power and load measured by dropping height after take-off. The expected results should help in a precise selection of individual loads in plyometric training of lower limbs.

2. Material and methods

The research group (N = 17) consisted of third-year students at the University School of Physical Education, practicing football, volleyball, basketball, athletics, high jump, swimming and fencing. The average time of practice ranged from 4 to 15 years.

Basic somatic data, age and score of the vertical CMJ were presented in table 1.

Table 1. Characteristics of the group examined

	n	Age (years) $\bar{x} \pm SD$	Body height (cm) $\bar{x} \pm SD$	Body mass (kg) $\bar{x} \pm SD$	CMJ (m) $\bar{x} \pm SD$
Research group	17	23.5±1.12	181.76±7.7	77.82±9.79	0.377±0.027

The dynamometric plate, amplifier, converter A/D, PC computer with BioWare software by Kistler and digital camera with SIMI software were used in the research. Measuring software provided synchronic measurements of the ground reaction force and film recording of students' movement. The research program included: counter movement jump (CMJ) and vertical jumps (DJ) after drop from a certain height. The subjects performed a drop from such selected plate's heights as: 0.15 m, 0.3 m, 0.45 m and 0.6 m. In order to avoid the influence of tiredness on the means obtained in trials, each jump was performed twice, while the sequence of the platform's height selection was random.

Each jump was recorded with the frequency of 50 shots per second. Markers placed on the subjects' bodies enabled us to determine temporary changes of the knee joint angles, which along with the registration of the vertical ground reaction force (500 Hz sampling) makes it possible to determine the times of the contact t_k, amortization t_a and take-off t_o (figure 1).

On the basis of these measurements the height of each separate jump from the impulse of a force was determined (the impulse of a force was determined by the method of integral **course** $F_r - mg(t)$). The final take-off velocity was determined for the take-off phase based on the theory of the impulse of a force

$$v_o = \frac{\Delta p}{m},$$

where:

Δp – the momentum increment,

m – the body weight of the subject.

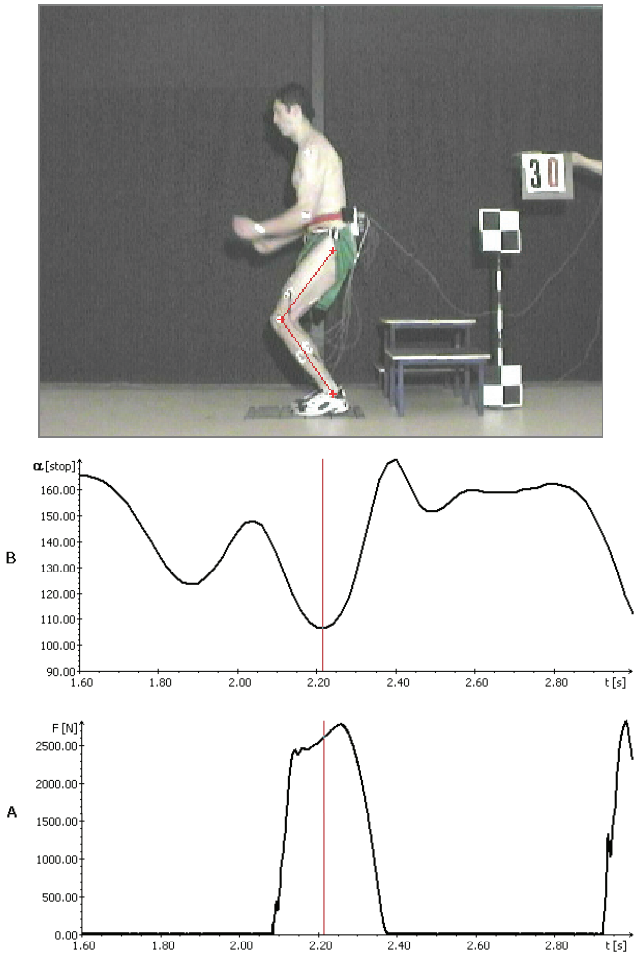

Fig. 1. Ground reaction force (A) and knee joint angle (B) during contact time t = 2.20 s for DJ

Having assessed velocity, we were able to determine the jump height h_s, regarding this type of movement as a vertical throw:

$$h_s = \frac{v_o^2}{2g},$$

where:

v_o – the initial velocity of swing phase,

g – the gravitational acceleration.

Having determined the height of a jump, we assessed the effective work W_u equal to the product of the jumper's body weight, jump height and gravitational acceleration.

The relative power P_u was determined as a quotient of effective work by the take-off time t_o. Dividing the assessed power by the body weight of a subject we determined the relative power P_{ju} expressed as follows:

$$P_{ju} = \frac{gh_s}{t_o}.$$

The research was conducted in the certified Laboratory of Biomechanical Analysis, Department of Biomechanics (ISO 9001:2001), the University School of Physical Education in Wrocław.

Presenting the characteristic of the ground reaction force for DJ, the simultaneously registered positions of knee joint and the assumption that the amortization phase ends when the knee joint angle is minimal, the division of contact phase into the amortization and the time of take-off is obtained.

3. Results

Mean values of the parameters indicated (figure 2) prove that the heights of the jumps and relative power increase in the range of the first three heights of a drop jump. The power obtained in CMJs is significantly lower than the power obtained in subsequent DJs. It should be remembered that such a characteristic may be used for a general evaluation of the group examined and for comparison of the results with similar data published in the literature.

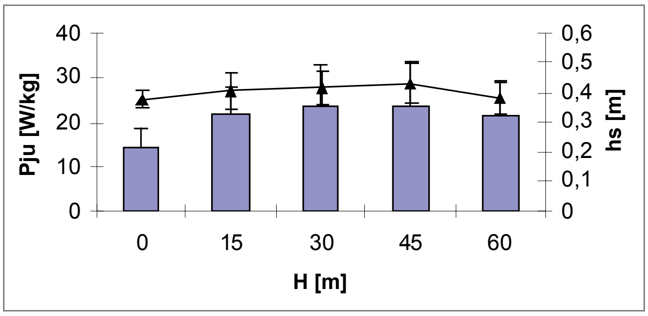

Fig. 2. Mean values (for n = 17) of relative power P_{ju} and jump height h_s versus the required drop heights H: CMJ, DJ_{15}, DJ_{30}, DJ_{45}, DJ_{60}

Hence, in order to evaluate the level of the players' power, an individual characteristic for this parameter should be applied, on the basis of which an individual power training for the player should be adopted.

Individual characteristics $P_{ju}(H)$ indicate that in the whole range of the drops applied the maximal relative power is released by the subjects (table 2). In

Table 2. Ranking of relative power P_{ju} and RSI index

No.	Discipline	P_{ju} (W/kg)	Dropping height (m)
1	volleyball	40.8	0.30
2	height jump	40.0	0.45
3	basketball	39.8	0.30
4	basketball	36.9	0.45
5	fencing	28.7	0.30
6	volleyball	28.4	0.15
7	fencing	28.2	0.45
8	basketball	25.9	0.30
9	athletics	25.6	0.15
10	football	25.4	0.45
11	athletics	23.7	0.45
12	football	23.5	0.30
13	basketball	21.5	0.15
14	swimming	21.4	0.15
15	volleyball	20.9	0.60
16	football	13.9	0.15
17	volleyball	12.4	0.30

Table 3. Mean values for the group examined ($N = 17$): vertical jump height h_s and relative power P_{ju} from the take-off time t_o, contact time t_k – the parameters obtained after drop from the required heights H

H (m)	h_s (m) $\bar{x} \pm SD$	t_o (s) $\bar{x} \pm SD$	t_k (s) $\bar{x} \pm SD$	P_{ju} of t_o (W/kg) $\bar{x} \pm SD$
0	0.38±0.03			14.43±4.13
0.15	0.40±0.06	0.185±0.030	0.325±0.033	21.53±6.42
0.3	0.42±0.06	0.182±0.034	0.329±0.072	23.60 ±9.13
0.45	0.43±0.06	0.188±0.042	0.341±0.081	23.80±9.59
0.6	0.38±0.05	0.189±0.042	0.326±0.085	21.18 ±8.28

the research group of 17 subjects, the maximal power for DJ_{15} was obtained by five players. In the jump from the second height (DJ_{30}), six subjects obtained their highest score, while in the 45-cm drop (DJ_{45}), five subjects obtained maximal relative power. In the jump from the highest box (DJ_{60}), only one person obtained maximal power output (table 3).

Figures from 3 to 6 present individual characteristics $P_{ju}(H)$.

Figure 3 shows a relative power obtained by the basketball player in the entire range of the jumps performed. The subject examined obtained the maximal value of 21.4 W/kg in DJ_{15}.

Figure 4 presents the values of the power obtained by the volleyball player in the subsequent trials. The maximal P_{ju} of 40.8 W/kg was reached by this player in the DJ_{30}. In the group examined, this player obtained the highest power per one kg of the body weight.

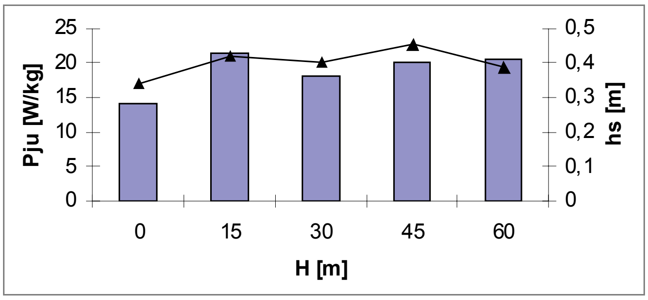

Fig. 3. Relative power P_{ju} of a basketball player and jump height h_s versus the required jump heights H: CMJ, DJ_{15}, DJ_{30}, DJ_{45}, DJ_{60}

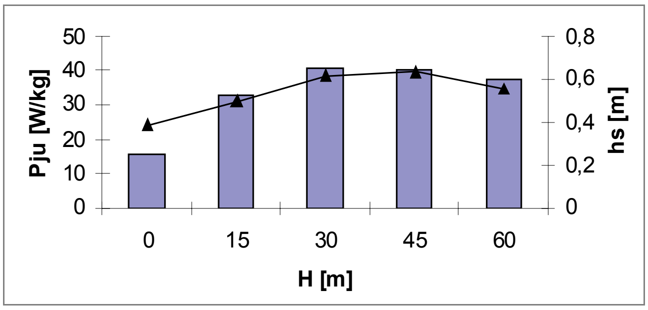

Fig. 4. Relative power P_{ju} of a volleyball player and jump height h_s versus the required drop heights H: CMJ, DJ_{15}, DJ_{30}, DJ_{45}, DJ_{60}

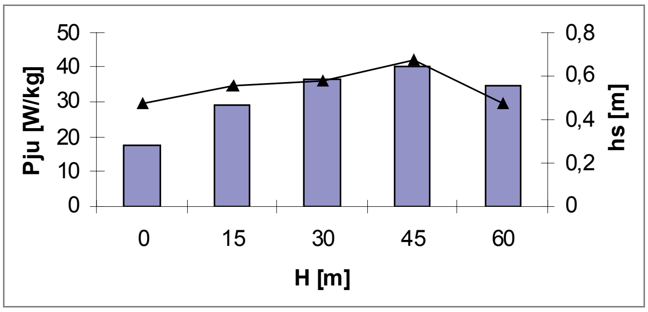

Fig. 5. Relative power P_{ju} of a high jumper and the jump height h_s versus the required jump heights H: CMJ, DJ_{15}, DJ_{30}, DJ_{45}, DJ_{60}

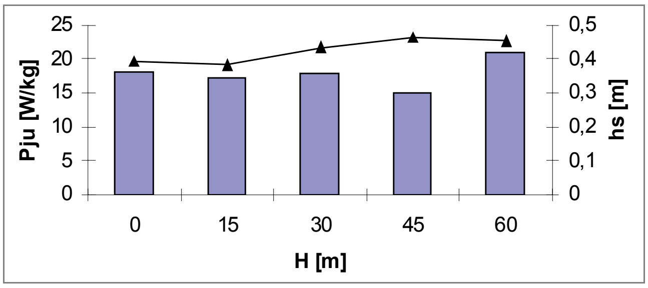

Fig. 6. Relative power P_{ju} of the second volleyball player and the jump height h_s versus the required drop jump heights H: CMJ, DJ_{15}, DJ_{30}, DJ_{45}, DJ_{60}

On the basis of the values of relative power obtained by the next subject it can be stated that the maximal P_{ju} of 40 W/kg was produced in DJ_{45}.

The next volleyball player obtained the maximal P_{ju} of 20.9 W/kg in DJ_{60}.

The above characteristics indicate that producing the maximal power output in DJs depends on the drop height, and such a relationship is specific to each subjects.

4. Discussion

Power measurements are considered to be most important for the evaluation of the training process in the most of the sports disciplines, since power plays a key-role in the sport successes [16], [20]–[23].

The relative power values in drops from 0.32 m to 0.59 m presented in the literature range from 30 W to 40 W per kg of the player's body mass, and for the drop height from 1.28 m a relative power reaches 150 W/kg [2], [8], [18]. This reflects the relative power of 25 W/kg for the ankle, knee and hip joint. However, not every player is able to generate such a high power, thus for the purpose of training, individual conditions enabling him to obtain maximal power output are being searched (e.g., drop height).

Comparing our results, showing a relative power for lower limbs, with the results published in the literature it can be inferred that the mean of the maximal relative power in DJs is comparable with the power obtained for CMJs. The subjects performing CMJs were examined by different authors and obtained relative power ranging from 23 W/kg to 30 W/kg [23]–[25]. However, HASSA et al. [26] report that young, physically active women obtained a relative power of 40 W/kg performing the stride jump with landing on one foot. Comparing the relative power released in the take-off phase the DJs with that released in CMJs and stride jumps, it can be observed that the risk of injury connected with the load of the lower limbs' motor system in DJs and CMJs unlike in the stride jumps, is very small. That is why the players in plyometric training do not face a great risk to their health.

The mean value of the relative power produced during jumps increases along with jumps heights, reaching its maximum for DJ_{45}. While individual relative power values are obtained in the entire spectrum of drop heights the applied (from 0.15 m to 0.60 m). This confirms the necessity of estimating individual heights of drop jumps in the training process and during the observation of the development of the lower limbs' power.

The awareness of the individual $P_{ju}(H)$ 'power–load' characteristics of the players and the observation of the changes during the training process enable the coaches to make a precise choice of loads and at the same time to improve the training. It also should minimize the risk of the injury in the lower limbs' area.

The criterion of choosing the loads in the plyometric training may be relative power output of lower limbs referred to the height of DJs. While the condition allowing the player to perform this type of training may depend on obtaining a greater power in DJ than in CMJ.

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