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Original paper

Effect of increased load on vertical jump mechanical characteristics in acrobats

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In this study, we attempt to answer the following question: To what degree the higher muscular activity determined by increased load in the extension phase (eccentric muscle action) of vertical jump affects its efficiency? Ten high performance acrobats participated in this investigation. The acrobats performed tests that consisted of five single "maximal" standing vertical jumps (counter movement jump – CMJ) and five single vertical jumps, in which the task was to touch a bar placed over the jumping acrobats (special counter movement jump – SCMJ). Subsequently, they performed five single drop jumps from an elevation of 0.40 m (DJ). Ground reaction forces were registered using the KISTLER 9182C force platform. MVJ software was used for signal processing [1] and enabling calculations of kinematic and kinetic parameters of the subject's jumping movements (on-line system). The results obtained show that the height of jump (h), the mean power (P_{mean}) and the maximum power ($P_{\max}$) are statistically significant, and higher in DJ. The results prove fine adaptation of the nervous system in acrobats to muscle extension and workload, due to the 40 cm high drop jump. Presumably, this height is closest to that which acrobats experience during landing, after performing flic-flacs or round-off.

Key words: *acrobats, dynamography, counter movement jump, drop jump*

1. Introduction

The mechanical characteristics of working muscles significantly influence the generated force and also may affect the speed of contraction. The optimal, individual values are an effect of neuromuscular coordination strategy played by the central nervous system (CNS) during fast movements. Such a strategy is also applied in movements of submaximal intensity [2]. The vast majority of everyday activities as well as sport techniques utilize the **stretch–shortening cycle (SSC)**. It begins with a counter movement (swing) which is braked by the eccentric work of muscle (stretching). In the subsequent phase, due to the concentric contraction (shortening) the movement is performed in the desired direction. To recover part of the energy generated during the eccentric phase of movement the time span between the eccentric and concentric phases must be short (≤ 200 ms) [2], [3]–[5].

The benefits of a well coordinated SSC movement in comparison with a strictly concentric muscle work are estimated at 10–20%, depending on the type of activity. The biomechanical or other causes of such a phenomenon have not been yet fully explained [2]. Many experiments have been conducted to explain the nature of the SSC, yet only some of them confirm its existence [6]. It has been established that the mechanical benefits of the SSC are to a large degree dependent on the resistance encountered during the movement [7]. There are 4 possible sources of potential energy generated through the SSC: contractile potentiation, reflex potentiation, storage and reutilization, and the time available for force development [2], [8], [9].

Irrespective of the sources of greater muscle force during the concentric phase of the SSC, sport practi-

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tioners are mainly interested in how to better exploit this phenomenon in sports performance. In sport practice, the exercises based on muscle stretch–shortening cycle are named plyometric exercises or, simply, plyometrics. The practical definition of plyometrics is *A quick powerful movement involving a prestretching of the muscle, thereby activating the stretch–shortening cycle* [10]. These exercises stimulate changes in the neuromuscular system, increasing muscle group abilities to produce a faster and stronger response to small and rapid changes in muscle length [11]. Plyometric training most likely improves the tolerance of greater eccentric muscular forces and increases the potential for concentric work [8], [12]. One purpose of plyometric training is to increase the excitability of the neurological receptors for improved reactivity of the neuromuscular system [10].

Plyometric exercises are most effective for speed-strength athletes. One of the classical examples of such exercises is the vertical depth (drop) jump. A considerable amount of biomechanical research has been done concerning lower-body drop jumping plyometrics [13]–[15]. The main objective of the work was to determine an extent to which the additional stimulation during the eccentric phase of movement influences the jumping ability. During the drop jump (in the landing phase), a high energy load is exerted on the knee joint straightening and ankle joint flexing muscles. Athletes who stereotypically utilize jump movements show increased muscle activity (excitation), which results from adaptation (mainly at the spinal cord level) of the central nervous system (CNS) to sport-specific activities [16]. As confirmed by KOMI [16] in his study on volleyball players, the CNS adaptation during sport-specific exercise extended to a full range of loads (various heights of drop jump). Komi's research, however, showed that, in comparison to the control group (untrained), the group of volleyball players achieved better drop jump results at the height of 0.60 m only. TRZASKOMA and TRZASKOMA [12] are of the opinion that this height approximates the height of an average elevation of the center of gravity during the vertical jump, which was registered in high performance volleyball players. Similarly, results of female gymnasts, in comparison to the control group, were significantly better in the full range of extending loads. The greatest differences were observed in the biggest drop jump heights [17].

In this research, we made an attempt at answering the following question: To what degree the higher muscular activity determined by increased load in the extension phase (eccentric muscle action) of vertical jump affects its efficiency?

2. Material and methods

Ten elite acrobats (males and females) participated in this investigation (table 1). All the subjects gave their written consent to participate in the study. The research project was approved by the Ethics Committee for Scientific Research at the University School of Physical Education in Katowice.

Table 1. Characteristics of the acrobats

Subjects/Athletes (initials; sex)	Age (years)	Body height (cm)	Body mass (kg)	Sports class	Best result	Training experience (years)
A.B., male	16.0	161	55.8	NC	3p. WJC	6
N.M., female	16.2	154	49.2	First	6p. PJC	6
A.D., female	14.6	149	43.5	First	3p. PJC	5
P.W., female	17.5	162	51.2	NC	1p. PJC	9
J.W., male	22.6	170	71.4	IC	2p. EC	14
A.J., female	20.5	166	54.3	NC	1p. PSC	13
A.P., female	21.4	170	66.1	NC	2p. PSC	13
S.S., male	25.1	170	68.2	IC	2p. EC	14
J.R., male	23.5	168	70.1	First	3p. PAC	12
E.M., female	21.9	160	49.6	NC	1p. PSC	13

IC – International Championships Class, NC – National Championships Class, EC – European Championships, PAC – Polish Academic Championships, PJC – Polish Junior Championships, PSC – Polish Senior Championships, WJC – Word Junior Championships.

After a general and specific warm up, the acrobats performed tests that consisted of five single "maximal" standing vertical jumps[1] (counter move-

[1] There was adopted a modified version of the test in which the upper extremities were held behind the back [13].

ment jump – CMJ) and five single vertical jumps, where the task was to touch a bar placed over the jumping acrobats[2] (special counter movement jump – SCMJ). Subsequently, the subjects performed five single drop jumps from an elevation of 0.40 m (DJ). Intervals between consecutive jumps were set in accordance with the literature data [19] and on the basis of prior experience. The rest between the single jumps and series jumps was from 45 to 60 sec. Ground reaction forces were registered using the KISTLER 9182C force platform. MVJ software was used for signal processing [1] and enabling calculations of kinematic (the height of jump *h*) and kinetic variables (the mean power P_{mean} and the maximum power P_{max} during the take-off phase) of the subject's jumping movements (on-line system).

Table 2. The height of jump (*h*), the mean power (P_{mean}) and the maximum power (P_{max}) in three kinds of vertical jump: counter movement jump (CMJ), special vertical jump (touching a bar with the head) (SCMJ) and drop jump (DJ) of acrobats (males and females)

Objects/Competitors (initials; sex)	Kind of vertical jump	*N*	*h* (m)		P_{mean} (W)		P_{max} (W)	
			Mean	SD	Mean	SD	Mean	SD
	CMJ	5	0.428	0.0055	1024	27.4	1946	35.2
A.B., male	SCMJ	5	0.431	0.0035	1034	28.0	2035	86.4
	DJ	5	0.412	0.0071	1129	130.1	2011	90.1
	CMJ	5	0.276	0.0017	497	7.8	990	18.7
N.M., female	SCMJ	5	0.290	0.0035	504	16.2	962	28.8
	DJ	5	0.289	0.0025	493	26.3	1004	25.6
	CMJ	5	0.280	0.0020	373	21.1	791	28.4
A.D., female	SCMJ	5	0.284	0.0047	442	9.5	826	16.5
	DJ	5	0.280	0.0032	715	31.6	1073	80.7
	CMJ	5	0.361	0.0017	639	17.2	1276	17.0
P.W., female	SCMJ	5	0.381	0.0031	640	8.0	1295	27.5
	DJ	5	0.379	0.0070	732	42.8	1361	28.9
	CMJ	5	0.403	0.0029	1464	44.8	2273	55.7
J.W., male	SCMJ	5	0.425	0.0136	1679	25.7	2611	79.8
	DJ	5	0.444	0.0040	1857	152.2	2763	153.9
	CMJ	5	0.300	0.0060	835	32.7	1255	31.8
A.J., female	SCMJ	5	0.325	0.0026	957	12.9	1423	31.1
	DJ	5	0.335	0.0060	1103	5.5	1581	38.4
	CMJ	5	0.223	0.0015	502	12.1	802	15.9
A.P., female	SCMJ	5	0.233	0.0023	525	19.3	832	7.6
	DJ	5	0.241	0.0072	719	22.6	1029	19.5
	CMJ	5	0.422	0.0076	1069	38.4	2128	82.0
S.S., male	SCMJ	5	0.443	0.0181	1106	98.6	2154	40.2
	DJ	5	0.448	0.0093	1384	115.9	2368	99.7
	CMJ	5	0.424	0.0025	1095	27.2	1854	40.5
J.R., male	SCMJ	5	0.425	0.0106	1161	12.9	1926	62.7
	DJ	5	0.427	0.0030	1124	74.0	1747	57.8
	CMJ	5	0.308	0.0117	612	12.0	957	45.0
E.M., female	SCMJ	5	0.300	0.0031	614	29.0	1036	33.3
	DJ	5	0.344	0.0047	934	68.0	1256	77.5

3. Results

The height of CMJ describes the motor potential, and more precisely, according to TRZASKOMA and TRZASKOMA [12], the jumping potential. Based on Trzaskomas' criteria [12], the results of selected competitors, presented in table 2, are relatively poor. However, it needs to be stressed that subjects performed the modified jump version, with their arms behind their back. It is acknowledged that due to the lack of arms swing, jumps can be lower by about 5 cm on average. Compared to ski jump competitors (report for AZS-AWF Katowice club; unpublished data), these results are significantly smaller, as we expected. On the other

[2] According to earlier studies [18], it is known that the full engagement of subjects is achieved only when a specific task is presented to them.

hand, in comparison to the first league soccer players [20] and university students – men, regularly active in sports [21], the results of acrobats are higher.

Interestingly, in most of the cases examined, slightly higher values of jump heights were achieved when subjects performed the drop jump (DJ; table 2). This is even more visible when analyzing mean power (P_{mean}) and maximum power (P_{max}). In order to verify these differences in CMJ, SCMJ and DJ, Wilcoxon's Matched Pairs Test was conducted. The results are presented in table 3.

Table 3. The results of Wilcoxon's Matched Pairs Test for the height of the jump (h), the mean power (P_{mean}) and the maximum power (P_{max}), in three kinds of the vertical jump: counter movement jump (CMJ), special vertical jump (touching a bar with the head; SCMJ) and drop jump (DJ) of acrobats

Parameter	Pair of variables	Number of cases	T	p
h	CMJ; DJ	10	5	**0.0218**
h	SCMJ; DJ	10	16	0.2411
P_{mean}	CMJ; DJ	10	1	**0.0069**
P_{mean}	SCMJ; DJ	10	3	**0.0125**
P_{max}	CMJ; DJ	10	4	**0.0166**
P_{max}	SCMJ; DJ	10	7	**0.0367**

T – value of Wilcoxon's test for group of $N < 25$, **bold** font refers to a statistically significant result ($p < 0.05$).

The results show that the height of the jump (h), the mean power (P_{mean}) and the maximum power (P_{max}) are statistically significant, and higher in DJ. There is only one exception in the paired variable, where SCMJ and DJ were statistically insignificant.

4. Discussion

The results given in table 3 prove fine adaptation of the nervous system of acrobats to muscle extension and workload, as a result of the drop jump from the height of 40 cm. Presumably, this height is closest to that which acrobats experience in landing, after performing flic-flacs or roundoff. TRZASKOMA and TRZASKOMA [12] provided a similar example with volleyball players, however, their optimal height is, as mentioned earlier, 0.60 m or according to KOMI and BOSCO [13], 0.66 m. The figure presented by TRZASKOMA and TRZASKOMA ([12], p. 127) shows jump values of acrobats in drop jumps from different heights. Here, one can observe the highest values of a 0.40 m high drop jump.

Our results do not confirm results presented by BOBER et al. [22], which concern less skilled basketball players. They were jumping from heights ranging from 0.15 m to 0.76 m, and achieved worse results in average DJ than in CMJ. However, the group examined in this study presented a high level of sports performance and many years of training experience (table 1), where the DJ seems to be a very specific trial.

5. Conclusion

- The average jump heights of elite acrobats, obtained in our research, according to TRZASKOMAS' studies [12], should be considered mediocre. This is probably not the most important factor of success in this sport discipline. One must remember that the acrobats performed the jumps without the arm swing, which influenced the height of the jump.
- Higher values of jump heights, and the mean and maximum power seen in drop jumps, in comparison to the counter movement jump, prove good adaptation of the nervous system of acrobats to muscle extension and workload, which is reflected by drop jumps from an elevation of 0.40 m. On the basis of this research it can be concluded that the SSC is an effective mean of developing strength and speed abilities.

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