Baltic Journal of Health and Physical Activity 2021; 13 (3): 1-8
Journal of Gdansk University of Physical Education and Sport
e-ISSN 2080-9999

ORIGINAL

doi: 10.29359/BJHPA.13.3.01

Relationship between vertical jump performance during different training periods and results of 200m-sprint

Authors' Contribution:
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: The purpose of the current study was to investigate: (1) differences between three types of countermovement jumps (CMJ), (2) development of lower-body strength during training periods, and (3) relationship between 200m personal best results and jumping ability in sprinters.

Material and methods: A total of 14 male sprinters from a local university academic sport club participated in the study. Athletes performed three variants of CMJ: with arm swing (AS), without AS, and from a maximal squat position. We took measurements twice: during the active rest period and the final phase of the preparatory period. The Optojump photoelectric cell system was used for measurements. Statistical significance was set at $p \leq 0.05$.

Results: The effect of the training period and the jump variant was shown on all jump parameters (height, total energy, and specific energy; $p<0.001$). Personal best 200m time was significantly correlated only with total energy in both training periods in all jump variants.

Conclusions: According to the results obtained in this study, we conclude that: (1) jumping parameters depend on CMJ variants, (2) jumping abilities improved during sprinter training, (3) 200m-sprint PB are related with total energy, but not with specific energy and jump height.

Key words: biomechanics; physical performance; countermovement jump; sprint; jumping ability.

article details

Article statistics: **Word count:** 2,366; **Tables:** 3; **Figures:** 1; **References:** 31

Received: January 2021; **Accepted:** June 2021; **Published:** September 2021

Full-text PDF: http://www.balticsportscience.com

Indexation: Celdes, Clarivate Analytics Emerging Sources Citation Index (ESCI), CNKI Scholar (China National Knowledge Infrastructure), CNPIEC, DOAJ, EBSCO - Central & Eastern European Academic Source, EBSCO - SPORTDiscus, EBSCO Discovery Service, Google Scholar, Index Copernicus, J-Gate, Naviga (Softweco, Primo Central (ExLibris), ProQuest - Family Health, ProQuest - Health & Medical Complete, ProQuest - Illustrata: Health Sciences, ProQuest - Nursing & Allied Health Source, Summon (Serials Solutions/ProQuest, TDOne (TDNet), Ulrich's Periodicals Directory/ulrichsweb, WorldCat (OCLC)

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interests: Authors have declared that no competing interest exists.

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INTRODUCTION

Jump performance has been suggested as a useful tool for power assessment in athletes [1, 2]. Squat jump (SJ) and countermovement jump (CMJ) are commonly used tests to measure jumping ability [3–5]. SJ is used as a measure of lower-body concentric strength/power, while CMJ as a measure of lower-body reactive strength/power [6]. Both types of vertical jumps are valid and relevant measurement tools of lower-body force and power ability [7]. Moreover, CMJ performance is influenced by the combined effects of eccentric and concentric muscle contractions in the ankle, knee and hip, called the stretch-shortening cycle, as well as by whether or not the arms are swung in the takeoff phase [2]. Pérez-Castilla et al. revealed that the countermovement depth may also affect several CMJ performance variables [8].

Several previous studies have revealed that vertical jumping ability and other motor skills can be related. A relationship between zigzag agility and the ball and jumping performance has been found in soccer players [9]. Running performance in the 800-m race was investigated in the context of a relationship between strength and jumping abilities [10]. CMJ and SJ power generating capabilities have been shown to be strongly related to sprint performance over 10 m from a block start. Previous studies of Loturco et al. showed that correlations of SJ and CMJ with actual 100-m sprinting times amounted to -0.82 and -0.85, respectively. Because of practicality, safety, and a correlation of these tests with the actual times obtained by top-level athletes in 100-m dash events, authors gave their recommendation for regularly incorporating SJ and CMJ into elite sprint-testing routines [11, 12]. Thus, an ability to generate power both elastically during a CMJ and concentrically during a SJ should be considered as good indicators of predicting sprint performance [13]. Increases in lower-body strength positively translate into sprint performance [14]. The results of a study by Comfort et al. illustrate the importance of developing lower-body strength to enhance sprint and jump performance [15]. However, there is limited knowledge and very little research into the relationship between 200m sprint results and jumping ability during different training periods. A training plan is divided into training periods, which fulfil a key function in the traditional theory of training periodization: generalized and preliminary work (general and specific preparatory periods), event-specific work and competitions (competition period). In addition, a third period (transition period) is set aside for active recovery and rehabilitation [16, 17]. Moreover, CMJ can be performed in many ways, e.g. with or without arm swing (AS), with a different depth of the countermovement squatting position. The importance of these CMJ variants as predictors of sport performance has not been well established so far.

Thus, the purpose of current study was to investigate: (1) differences between three types of jumps, (2) development of lower-body strength during training periods (active rest and specific preparation period) (3) relationship between 200m personal best (PB) results and jumping ability in sprinters. It was hypothesized that sprint and jump performance will be related. It was further hypothesized that parameters of jumps variants will be different and results of jumping performance will improve during the training season.

MATERIAL AND METHODS

Participants

A total of 14 male sprinters from a local university academic sport club participated in the study. At the time of testing, the subjects reported no injury that would prevent their participation in physical activity for more than 2 weeks during the previous 6 months. Informed consent was obtained from each subject. Table 1 demonstrates anthropometric characteristic of the participants before the first measurement. The study was approved by the Ethical Committee at the Medical University of Lublin and conducted according to the Declaration of Helsinki.

Table 1. The participants' characteristics

	$\overline{x}$	SD	Min.	Max.
Age [years]	20.43	3.46	17.00	29.00
Training experience [years]	5.21	2.83	1.00	11.00
Body mass [kg]	70.43	8.81	55.00	83.00
Body length [cm]	179.93	5.89	172.00	189.00
BMI [kg/m^2]	21.69	1.86	18.59	25.06
Personal best result 200m [s]	22.95	1.25	21.46	24.79

Design and Procedures

The participants performed their warm-up which consisted, according to Whelan et al. recommendation, of a 3 min jog followed by sprint-specific dynamic exercises of the lower limbs [18,19]. The total warm-up time was 15 minutes. After the warm-up and prior to testing, three variation of the CMJ were demonstrated to the participants. The participants were instructed to jump naturally and as high as they could, performing all jumps with maximal effort. Prior to testing, participants were required to practice CMJ with preferred depth (with and without AS). After that, they were instructed to perform a maximal countermovement (greater than self-preferred depth and greater than "parallel squat"). The knee flexion was not defined in any trial, but it was greater in CMJ from maximal squat than in CMJs from self-preferred depth.

The CMJ without arm swing (AS) was performed with both hands on the waist, while performing a downward movement until preferred knee flexion followed by a vertical jump of maximum effort. The CMJ with AS was performed similarly to the previous jump but with arm movement. The CMJ from the maximal squat position was performed with both hands on the waist during downward movement until the maximal knee flexion (greater than "parallel squat") and followed by a vertical jump.

The participants were required to perform 3 trials of each jump in random order separated by 10 s rest between trials and 2 min rest between sets [19]. The best trial of each jump variant was recorded and further statistically analyzed.

Measurements were taken twice. The first measurement was taken in November 2018 during an active rest period, and the second measurements was taken in May 2019 during the final phase of a specific preparatory period. The period of active rest lasted from the 2018 outdoor competition season to the next preparatory period. It consisted of rest, recovery and recreational activity which did not include resistance training. The specific preparatory period consisted of high-intensity training, speed, plyometric and resistance exercises. Workouts were individually planned based on the results from the last season of each athlete.

For jump measurements, an Optojump photoelectric cells system (Microgate, Bolzano, Italy) was used. The device consists of two parallel bars connected to a computer. One bar acts as a transmitter unit containing light emitting diodes positioned 0.003 m above the ground and the second bar acts as a receiver unit. The Optojump was demonstrated in previous studies as a valid and reliable tool for monitoring jumping performance [20].

Three parameters of jump performance were analyzed in this study: jump height, total energy and specific energy. Total energy means the total energy expressed by the athlete during the test (Specific Energy x Athlete Weight). Specific energy [J/kg] is energy produced during the test calculated with the following formula:

$$\sum h \;\; jumps \times g \;\; (1)$$

Where h is a jump height and g is gravitational acceleration.

Sprinters' personal best (PB) 200m times until 2020 were obtained from a database of the National Athletics Association and included only results with allowed wind conditions (≤2m/s).

Statistical Analysis

The normal distribution of the data was verified with the Shapiro-Wilk test. Jumping parameters were analyzed using repeated measures analysis of variance (ANOVA) in model 3 (jumps variants) x 2 (training period). The significant results were analyzed further using post hoc Tukey HSD test. The partial Eta square (ηp^2) was used for effect size assessment. Pearson's coefficient (r) was used to calculate the correlations between the jump parameters and 200m personal best results. The magnitude of correlation was assessed with the following thresholds: <0.1, trivial; <0.1–0.3, small; <0.3–0.5, moderate; <0.5–0.7, large; <0.7–0.9, very large; and <0.9–1.0, almost perfect [21]. Statistical significance was set at p≤0.05. Data analysis was conducted using the Statistica software (ver. 13.1). The data are presented as means with standard deviations (SD).

RESULTS

A repeated measures ANOVA revealed statistically significant main effect of the training period and the jump variant on all jump parameters (height, total energy and specific energy). Mean jump height was greater in the preparatory period than in the active rest period ($F(1,13)=41.30$; $p<0.001$; $\eta p^2=0.76$) and it was the greatest in CMJ with AS ($F(1,13)=58.26$; $p<0.001$; $\eta p^2=0.82$) comparing with two other jumps variants. Table 2. shows means and SD of the jumps parameters.

Table 2. Means and standard deviations (SD) of the measured parameters

	CMJ with AS		CMJ without AS		CMJ max squat	
	Mean	SD	Mean	SD	Mean	SD
Active rest period						
Jump height [cm]	54.98	5.77	45.39	4.95	52.34	4.96
Total energy [J]	380.64	67.68	313.59	56.13	363.00	65.54
Specific energy [J/kg]	5.39	0.57	4.45	0.49	5.13	0.49
The end of the preparatory period						
Jump height [cm]	58.21	6.25	47.79	4.72	54.42	6.15
Total energy [J]	398.85	69.72	327.31	54.00	373.20	68.49
Specific energy [J/kg]	5.71	0.61	4.69	0.46	5.34	0.60

Mean total energy was greater in the preparatory period than in the active rest period ($F(1,13)=42.13$; $p<.001$; $\eta p^2=0.76$) and, it was the greatest in CMJ with AS ($F(1,13)=56.70$; $p<.001$; $\eta p^2=0.81$) comparing with the two other jumps.

Mean specific energy was greater in the preparatory period than in the active rest period ($F(1,13)=41.68$; $p<.001$; $\eta p^2=0.76$), and it was the greatest in CMJ with AS ($F(1,13)=58.59$; $p<.001$; $\eta p^2=0.82$) comparing with the two other jumps variants. The interactions of the period and jump variant were not statistically significant. Table 3 shows the results of ANOVA.

Table 3. ANOVA results for main effects (training period; jump variant) and interaction (period x jump). Values in bold stand for statistical significance (p<0.05)

	F	p	Eta² partial	Post hoc
Jump height				
Training period	41.30	<0.001	0.76	All comparisons significant p<0.01
Jump variant	58.26	<0.001	0.82	
period x jump	1.20	0.32	0.08	
Total energy				
Training period	42.13	<0.001	0.76	All comparisons significant p<0.01
Jump variant	56.70	<0.001	0.81	
period x jump	1.02	0.36	0.07	
Specific energy				
Training period	41.68	<0.001	0.76	All comparisons significant p<0.01
Jump variant	58.59	<0.001	0.82	
period x jump	1.21	0.31	0.09	

Personal best 200m time was significantly correlated only with total energy in both training periods in all jump variants. In the active rest period, the strongest negative correlation (r=-0.67; p=0.008) with 200m time was observed in total energy of CMJ from the maximal squat position. In the preparatory period, correlation analysis showed a very strong negative relationship (r=-0.71; p=0.005) between total energy of CMJ without AS and 200 PB results. Table 4 and Figure 1 show Pearson correlation results.

Table 4. Pearson correlation of jump parameters and 200m PB results. Values in bold stand for statistical significance (p<0.05)

		r(X.Y)	r²	t	p
Active rest period					
CMJ with AS	Jump height	-0.24	0.06	-0.86	0.41
	Total energy	-0.61	0.37	-2.66	0.02
	Specific energy	-0.24	0.06	-0.87	0.40
CMJ without AS	Jump height	-0.31	0.10	-1.13	0.28
	Total energy	-0.64	0.41	-2.88	0.01
	Specific energy	-0.31	0.10	-1.12	0.28
CMJ max squat	Jump height	-0.40	0.16	-1.52	0.15
	Total energy	-0.67	0.45	-3.16	0.008
		-0.40	0.16	-1.52	0.15
Preparatory period					
CMJ with AS	Jump height	-0.24	0.06	-0.84	0.41
	Total energy	-0.59	0.35	-2.51	0.03
	Specific energy	-0.24	0.06	-0.86	0.41
CMJ without AS	Jump height	-0.39	0.15	-1.45	0.17
	Total energy	-0.71	0.50	-3.45	0.005
	Specific energy	-0.39	0.15	-1.47	0.17
CMJ max squat	Jump height	-0.35	0.12	-1.30	0.23
	Total energy	-0.64	0.41	-2.90	0.01
	Specific energy	-0.35	0.12	-1.30	0.22

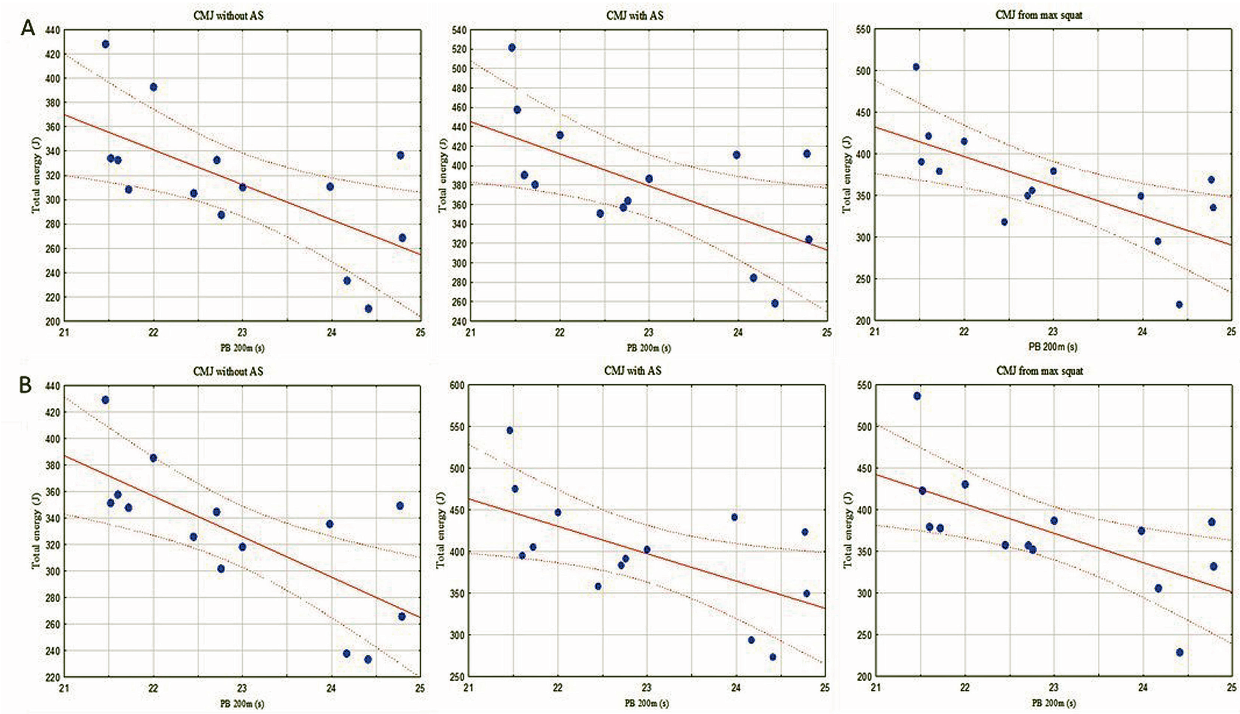

Fig. 1. Scatter plots with trend lines and 95%CIs (confidence intervals) show correlation between total energy and PB 200m during the active rest period (A) and the preparatory period (B)

DISCUSSION

In line with our hypothesis, this study found a relationship between 200m sprint and jump performance, but only in total energy, not in jump height and specific energy. Height, total and specific energies during CMJ with AS were greater than during the two other CMJ variants. Jump performance improved during the preparatory period in comparison to active rest, as it was expected.

Both specific and total energy are calculated based on jump height. However, 200m PB was correlated only with total energy, which is calculated by multiplying specific energy and athletes' weight. We believe that athletes' greater body mass is related with greater musculature and, in result, with a greater strength. Thus, greater strength associated with body mass can explain why greater total energy is related with sprint performance. Previously, Maćkała et al. reported that 200m performance was related to body mass (r=–0.80) but weakly related to horizontal jumping ability [22]. Maximal strength has been shown to determine sprint performance in high level soccer players [23]. For example, Comfort et al. demonstrated that relative and absolute strength are related with 20m sprint, but absolute strength shows the strongest relationship with 5-m sprint and jumping abilities [15]. This author's finding was unexpected due to the fact that body mass has to be accelerated during activities and, therefore, measuring relative strength seemed to better predict performance during sprinting and jumping. Contrary to a previous study by Bachero-Mena et al. [10], who found relationship between jump height and middle distance running, we did not find a relationship between 200m performance and jumps height. Wisløff et al. reported a correlation between vertical jumping performance and sprint times (30 m) as both were derivatives of maximal strength [23]. Results of our study are not consistent with previous observation, probably due to the different distance used in our investigation. Summarizing, as our study demonstrated, grater body mass related with increased muscle mass and strength can be considered as a better predictor of 200m-sprint performance than jump height.

In the active rest period, the strongest negative correlation (r=-0.67; p=0.008) with 200m time was observed in total energy of CMJ from the maximal squat position. In the preparatory period, a very strong negative relationship (r=-0.71; p=0.005) was found between total energy of CMJ without AS and 200 PB results. CMJ without AS isolates lower extremity force production and eliminates potential arm-swing variation [24]. Our study results revealed the strongest relationship between 200m PB results and total energy of CMJ without AS (from a self-selected or larger depth). It may suggest that arm swing can increase jump height, but as a 200m-sprint predictor CMJ without AS is probably more adequate.

CMJ with AS in our study contributed to greater height and energy than CMJ without AS and CMJ from maximal squat. Previously, SJ and CMJ had been compared to investigate differences between concentric power and elastic power generated during stretch shortening cycle [25]. CMJ with and without AS were compared as well demonstrating that AS improved the CMJ by increasing the jump height relative to jumping without an AS. The AS significantly shortened the braking phase and prolonged the accelerating phase [2, 26].

To the best of the authors' knowledge, this is the first study to compare three CMJ variants – with and without AS and with different squat depth during countermovement. Results of the current study indicate that jump height is the greatest with AS and when participants squat to a preferred depth. Comparing CMJs without AS, increased squatting depth gives some advantage in jumping height, probably due to higher velocities of the center of mass than during the self-selected jumps [27]. These results corroborate with results of previous investigations that demonstrated a direct relationship between squat depth and CMJ performance [28]. However, other previous studies indicate that larger countermovement depths were not associated with greater jump height comparing to self-preferred CMJ depth [8]. Findings of the current study can be explained primarily in terms of changes in muscle length resulting from modulations of joint angles achieved in this study. Kinematic parameters and knee flexion, in particular, can by strong determinants of jumping performance [29,30]. For recommendations, these results can be concluded as follows: AS improves CMJ height comparing with CMJs without AS; a deeper squat position during CMJ without AS improves jump height comparing with a self-selected squatting position.

Jumping performance has significantly improved during training. The greatest average improvement in jump height was observed during CMJ with AS (3.23 cm) in comparison with CMJ without AS (2.40 cm) and CMJ from maximal squat (2.08 cm). Our findings are consistent with previous studies [31].

Our study has some limitations. The main limitation is the large dispersion of participants' age (17–29 years old), and as a result, substantial differences in training experience (1–11 years). Thus, further investigations should verified our findings in a more homogeneous group.

CONCLUSION

According to the results obtained in this study, we conclude that: (1) jumping parameter depends on CMJ variants (2) jumping abilities improve during sprinter training, (3) 200m-sprint PB are related with total energy, but not with specific energy and jump height.

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Cite this article as:

Siembida P, Zawadka M, Gawda P.
Relationship between vertical jump performance during different training periods and results of 200m-sprint
Balt J Health Phys Act. 2021;13(3):1-9
doi: 10.29359/BJHPA.13.3.01