IMPROVING THE POSSIBILITIES FOR EVALUATION OF VERTICAL DETECTION EQUIVALENCE

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INTRODUCTION

Vertical jump is a key element in many sports disciplines such as athletics, basketball, volleyball, handball, etc. (Cavanagh, Lafortune, 1980; Clarce, Frederick, Cooper, 1983; Hamill, Bates, Knutzen, 1984; Mc Nitt-Gray, 1991; Zareva I., 2015). A basic method to investigate it is through the ground reaction forces that arise from the interaction between the body of the athlete, and the solid support on which the jump is being performed. The ground reaction is a force and as such it has a vector characteristics. In practice it can be conveniently studied with a device called dynamometric platform. Such a device has been previously used for assessment of the forces during walking, running and jumping (Hamill, Knutzen, 1995). For studying vertical jumps the platform is placed horizontally on a hard, non-deformable surface, and the athlete walks or jumps on it. The forces that the athlete applies on the platform are measured by an array of tensometric sensors placed below the platform's stage. In some simplified versions of the platform the tensometric sensors are replaced with contact switches which do not measure forces but only detect vertical displacement of the stage above a certain detection limit. Such platforms are used only for measuring time intervals between dynamic events (steps, jumps, etc.) (Yordanov et al, 2010).

The second approach to investigate vertical jump is through the so-called kinematic analysis. This type of analysis traces the trajectories of a set of pre-defined points on the surface of the athlete's body in time. It is carried out by filming the motion and later analyzing it with a specific software (APAS, 2019, ScillSpector, 2014).

Our study aims to combine the two approaches for studying vertical jump, dynamometric and kinematic. The study by Gioshev, et al. (2016) established a quantitative relationship between the potential and the kinetic energy of the vertical rebound:

It's $E_{kin.} = m.V_{max}^2 / 2$; $E_{pot.} = P. H_{max}$;

where $E_{kin.}$ - kinetic energy, $E_{pot.}$ - the potential energy, V_{max} - the maximum velocity, H_{max} - the maximum bounce height reached, P - the weight of the athlete and $g = 9{,}8\ m / S^2$

The final result of the mathematical processing according to the above formula justifies that $H_{max} = V_{max}^2 / 2. g$

In the present study we use this relationship to describe the height of the jump as a function of the force of repulsion from the ground (ground reaction) and the duration of its action.

We believe the effective interaction of the athlete with the support (ground) can be optimized so that it would generate maximum velocity of separation from the dynamometric platform to achieve a maximum rebound height.

METHODS

Four athletes performed a total of 48 vertical jumps (12 jumps per athlete) on a dynamometric platform in an attempt to achieve maximal height. The jumps performed were either with or without engaging the hands and the arms in the movement. The movement of the upper limbs additionally complicated the analysis so we considered only jumps with the hands and arms tucked to the body for our analysis.

The study was conducted at the ergometric sector of the indoor athletics track NSA "V. Levski ".

Once the purpose and procedure of the study were explained in detail, informed consent was received from all participants in the experiment (IRB submission procedures - 2020).

The dynamometric platform used for the study was built into the support surface, according to the requirements of the International Society of Biomechanics (ISB), the standardization of the forces acting on the dynamometric platform was carried out in all three dimenshions of space and characterized by the vectors. We studied 12 dynamic and kinematic indicators which are listed in Table 1.

Depreciation and repulsion time are two parts of the ground contact time with the platform.

Repulsion time is a takeoff of the athlete's mass center (Adashevskiy, Iermakov, Marchenko, 2014). Depreciation time is defined as the first part of the ground contact time.

Table 1. *Investigated kinematics and dynamic indicators in vertical rebound*

	Kinematic-dynamic indicators	**Signature**
	Depreciation time	t_1 [s]
	Repulsion time	t_2 [s]
3	Flight time	t_3 [s]
	Interval speeds max Vccg Vstep	t [s]
	Maximum reached height	H_{max} [m]
	Maximal vertical force	F_{max} [N]
	Depreciation gradient	$Grad_1$ [N/s]
	Repulsion gradient	$Grad_2$ [N/s]
	Maximal velocity of COG	V_{CCG} [m/s]
0	Maximal velocity of step	V_{step} [m/s]
1	Maximal acceleration of step	A_{step} [m/s^2]
2	$t_3 / (t_1 + t_2)$	-

The pelvis and the upper part of the foot of the athlete were chosen as main points to trace the body movement and contrast markers were placed on these areas.

Video capture of the vertical jumps was done with the use of a 120-fps video frame of the CASIO ZR 400. To achieve the required contrast, additional lighting was provided.

The dynamometric platform records with frequency (200 measur. per sec.).

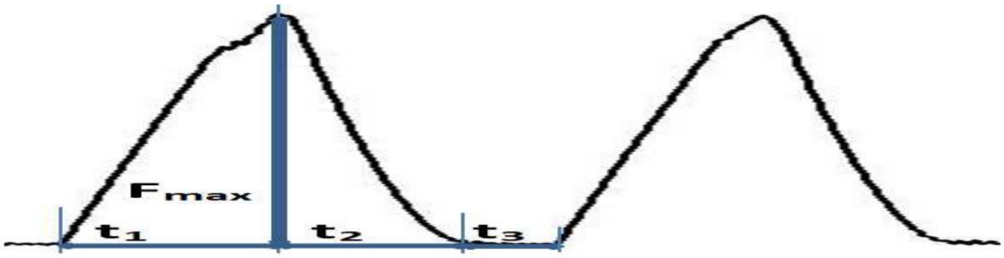


Figure 1. *Dynamogram of a sample jump*

Figure 1 shows an exemplary dynamogram of applied effort on the platform during a vertical jump. The function shows monotonous rise and decrease, t_1 is depreciation time, t_2 is time of repulsion, t_3 is time of flight, and F_m is maximum applied force.

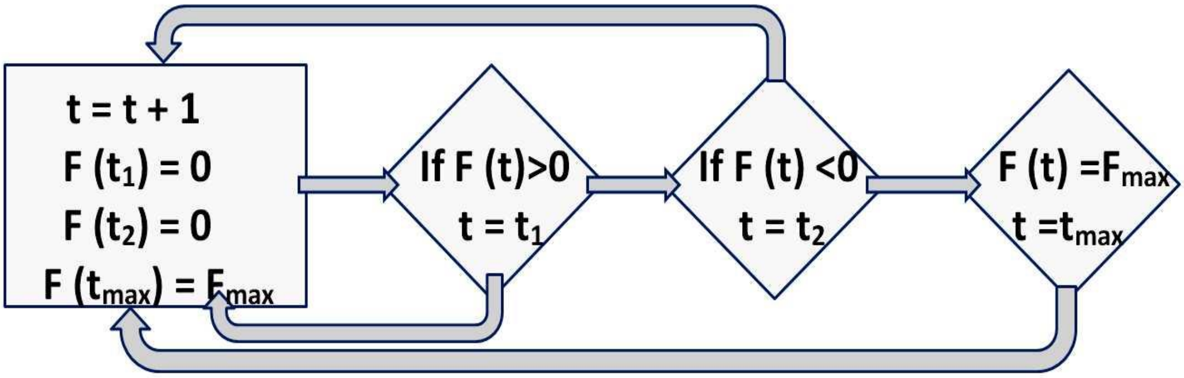


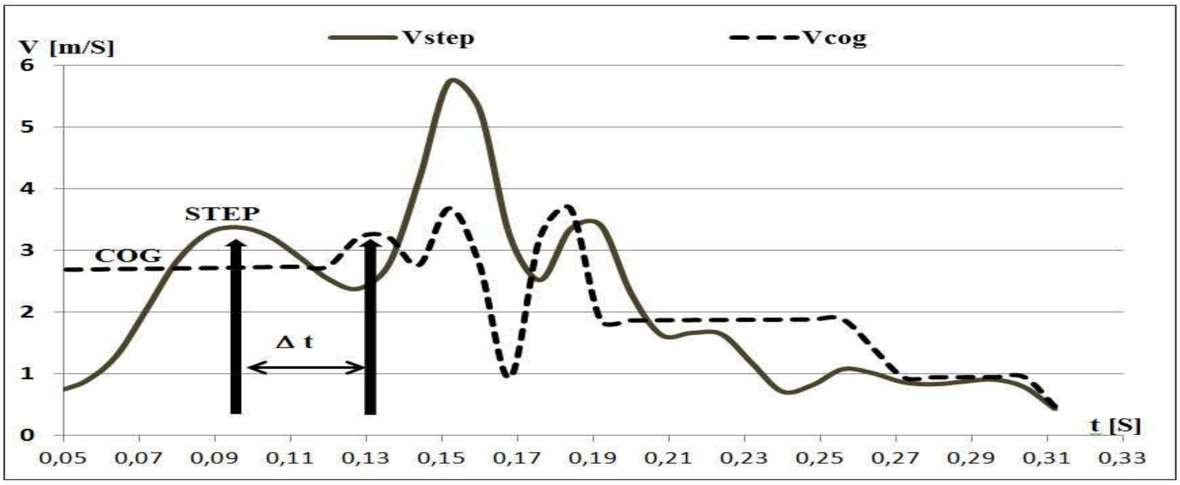
Figure 2. *Block diagram of the computer algorithm for detetmination of Fmax, t1, t2, t3*

Specifically for this study we developed a software which estimates parameters 1 to 3 and 5 to 8 (Table 1) through the algorithm presented in Figure 2. The process stops when the recorded test data is exhausted.

Kinematic analysis of the point coordinates was performed with the use of ScillSpector software (2014).

The data obtained from the survey were subjected to mathematical and statistical processing with variation, correlation and regression analysis methods with SPSS 19 software (Damyanova, Gigova, 2007).

RESULTS & DISCUSION



***Vstep -** *Velocity of the step in the vertical rebound of the lower limb*

***Vcog -** *Velocity of the Center of Gravity (COG)*

Figure 3. *Dynamics of Vcog and Vstep-mod.1*

Figure 3 shows different graphs of the velocity of the Center of Gravity (COG) and the step in the vertical rebound. The broken line indicates the speed of the COG, and the unbroken one indicates the point on the foot. The time intervals were recorded on the horizontal axis, with the delay being within 0.02 seconds, which is a short time interval according to the duration of the engine structure of execution.

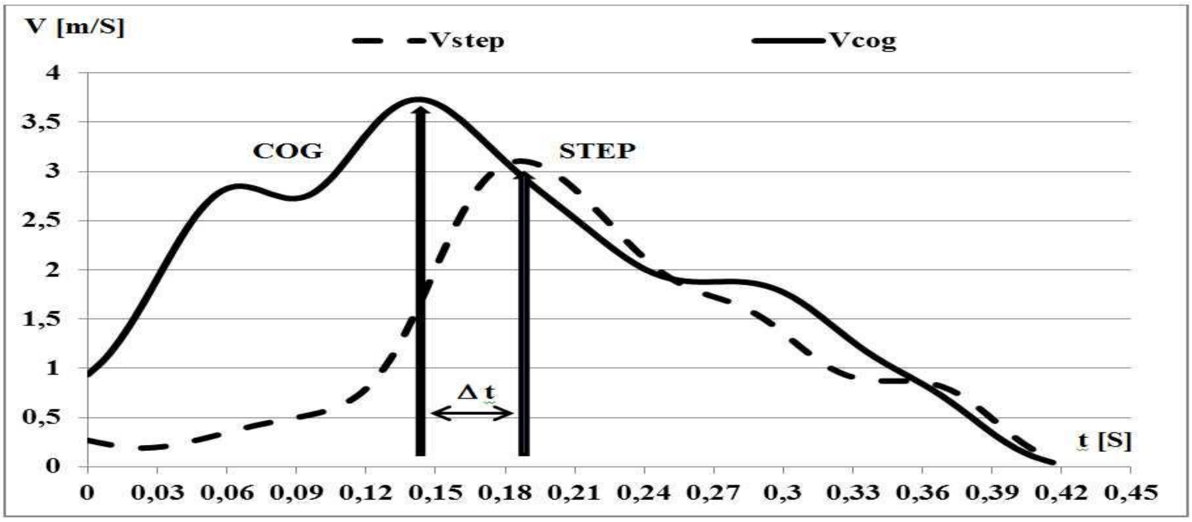


Figure 4. *Dynamics of Vcog and Vstep-mod.2*

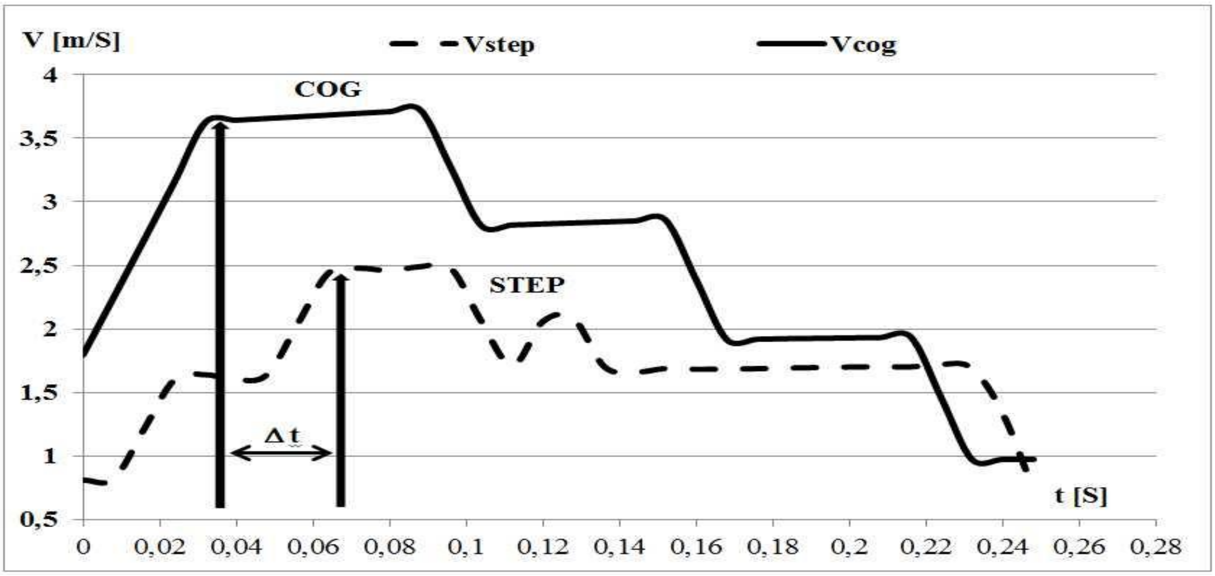
***Vstep -** *Velocity of the step in the vertical rebound of the lower limb*

***Vcog -** *Velocity of the Center of Gravity (COG)*

Figure 4, Figure 5, Figure 6 show different graphs of the velocity of the Center of Gravity (COG) and the step in the vertical rebound. The unvroken lines indicate the speed of the COG, and the broken ones indicate the point on the foot.

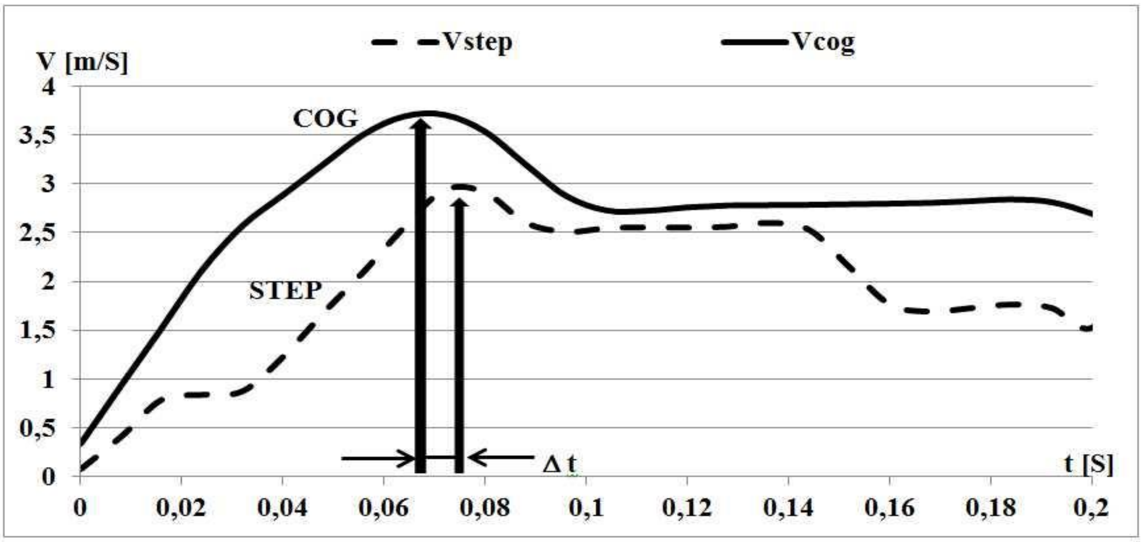
According to the biomechanical fitness criteria adopted in the theory of sports biomechanics, the force of the athlete's pushing should cause the speed to rise initially in the general center of gravity and then in the foot velocity, i.e. the spread of the force should be from a proximal to distal direction - from the thigh muscles, the muscles of the legs, and finally through the muscles of the foot. This is evident in Figure

4 (mod.2), Figure 5 (mod.3) and Figure 6 (mod.4). The increase in the rate of the V_{COG} is reached upon the moment of the step release, whereas in Figure 3 (mod.1) there is a delayed character of reaching the maximum speed of the COG - after separation from the support, which is unjustified in terms of efficiency.



Vstep - *Velocity of the step in the vertical rebound of the lower limb*
Vcog - *Velocity of the Center of Gravity (COG)*

Figure 5. *Dynamics of Vcog and Vstep-mod.3*



Vstep - *Velocity of the step in the vertical rebound of the lower limb*
Vcog - *Velocity of the Center of Gravity (COG)*

Figure 6. *Dynamics of Vcog and Vstep-mod.4*

However, in all the cases examined, there was a difference in the fact that the V_{cog} rate was higher than that of the foot (V_{step}) at the time of its removal from the support surface.

Our opinion is that vertical jumps will be the most effective when the maximum speed in the foot is reached almost simultaneously with the maximum speed in the *COG*. In this aspect, as a benchmark for bounce performance, the time interval between reaching the two maximums can be assumed.

Table 3 presents the average values of the biomechanical indicators calculated with the variation analysis of the investigated jumps.

Table 2. *Biomechanical characteristics of jumps*

Indicators	Average	Aver. Err	S	V%	Max	Min	R
t_1 [s]	0,42	0,046	0,30	72%	1,30	0,09	1,21
t_2 [s]	0,25	0,013	0,08	34%	0,38	0,10	0,28
t_3 [s]	0,54	0,067	0,44	82%	1,93	0,09	1,85
Δt [s]	0,024	0,003	0,022	89%	0,056	0	0,056
H_{max} [m]	0,62	0,011	0,07	11%	0,76	0,49	0,27
F_{max} [N]	1537	82,3	546	36%	2487	605	1882
$Grad_1$[N/s]	4803	265,4	1760	37%	7060	900	6160
$Grad_2$[N/s]	6171	90,9	603	10%	6800	4100	2699
V_{COG} [m/s]	3,36	0,060	0,40	12%	4,00	2,30	1,70
V_{step} [m/s]	2,81	0,061	0,41	14%	3,80	2,00	1,80
A_{step} [m/s²]	81,49	5,994	39,76	49%	300,00	40,00	260
$t_3/(t_1+t_2)$	0,81	0,105	0,69	78%	2,55	0,23	2,32

According to the calculated values, it is possible to consider the following scale of deviations from the normal spacing of the time intervals to reach the maximum speed of the COG and the footstep.

Table 3. *Normative basis for estimating the interval between the* $\boldsymbol{V_{COG}}$ *and* $\boldsymbol{V_{step}}$ *speeds*

Δt [s]	Range
Unacceptable difference over (Average + S)	**Δt > 0,066**
Permissible difference (Average + S)	**Δt < 0,066**
Optimal difference (Average +/- 0,5.S)	**0,002 Δt < 0,024**
Difference beyond normal in asynchronous (Average - 0,5.Sx)	**Δt < 0,002**

Table 4. *Correlation matrix at a critical value of r = 0.288 and significance level [α = 0.05]*

	t_1					
t_2	54**	t_2				
t_3	42**	07	t_3			
H_{max}	23	11	,03	H_{max}		
F_{max}	57**	96**	,11	,17	F_{max}	
Gra	.	.	-	-	-	G

d_1	,89**	,42**	,59**	,05	,42**	rad_1					
Gra d_2	: 08	. ,14	, 10	, 20	, 09	- ,03	G rad_2				
V_{cog}	. ,18	. ,18	- ,21	- ,08	- ,17	, 27	, 07	V_{cog}			
V_{ste} p	: 12	: 20	- ,15	, 22	, 27	- ,04	, 38**	. ,25	V_{step}		
A_{ste} p	. ,02	: 07	- ,23	- ,01	, 10	, 09	, 09	. ,09	, 51**	A_{Step}	
t_3 / (t_1 + t_2)	. ,16	. ,40**	, 73**	- ,02	- ,36*	- ,01	, 12	: 02	- ,27	. ,25	t_3 / (t_1 + t_2)

The labeled darkened rectangles (Table 5) represent significant dependencies from the correlation analysis. In Table 5, two sets of inter-correlation dependencies can be easily distinguished - one group contains the kinematic characteristics and the other is related to the dynamometric features. Thus, according to Table 5, the vertical load F_m is in a positive correlation with the depreciation time t_1 (0,569) against the repulsion time t_2 (0,538) and the depreciation gradient $Grad_1$ (- 0,892).

DISCUSSION

The negative value denotes inverse proportional dependence, which indicates that when the vertical load F_m increases, gradient $Grad_1$ decreases and this is fully understandable according to the mathematical formula of the force gradient.

A very important statistical feature is the inter-group correlation between the maximum velocity of the V_{step} in the displacement and the gradient $Grad_2$ (0,383). This dependence is interpreted by the explanation that the efficient execution of a bounce from the dynamometric platform determines the high value of the foot velocity at the time of separation from the support.

The time t_2 is inversely correlated to the ratio $t_3 / (t_1 + t_2)$ (time of flight divided by support time) - $(t_3 / (t_1 + t_2))$, the correlation coefficient value being (-0,402). This circumstance is explained by the fact that the reduction of the elapsing time t_2 increases the time of the athlete's flight and the height reached. Between the kinematic footstep V_{step} and its acceleration there is a correlation coefficient of 0.514 logically corresponding to the intragroup correlation relationship between them. The flight time is in a proportional relation to the $Divided = t_3 / (t_1 + t_2)$ ratio, which is fully explained by the high positive correlation coefficient of 0.729. When increasing the flight time t_3, the ratio $t_3 / (t_1 + t_2)$ is also increasing, which corresponds to the formula, since t_3 is placed in the numerator.

With a linear step regression, a mathematical formula is defined, linking the V_{step}, $Grad_2$, $Astep$ parameters included in the equation. The coefficients in the equation are determined.

$$V_{step} = 0{,}991 + 0\,{,}0023\,.\,Grad_2 + 0{,}00496\,.\,A_{step}\,;$$

In this case, the maximum foot velocity at the moment of rebound is 2.81 m /S, corresponding to the value in Table 2, with the corresponding gradient and step acceleration values:

$$V_{step} = 0{,}991 + 0\,{,}00023*6172 + 0{,}00496*81 = 2{,}81\ m/S$$

The simultaneous (synchronic) mapping of the COG and foot speeds at the time of separation from the support confirms the effective use of the athlete's attitude.

The vigorous bounce performance using short-term active depreciation and subsequent instantaneous ejection is an effective way to improve the sporting outcome. This effect can be further developed by athletes using a recommended technique to improve vertical bounces by using extra weight placed in the pelvis area. Extra weight has a positive effect on the development of the muscles of the lower limbs (Rodriguez D. at all. – 2017).

The amount of the extra weight should not change the rhythmic structure i.e. increase the ejection time of the support. In cases where there is an increase in elapsed time, the weight should be reduced. The aim is to place the additional weight in the vicinity of the athlete's *COG* to activate the hip, lower leg and foot hump muscles by introducing the additional inertial force directly affecting the growth of the support response.

CONCLUSION

The approach used in the study for determining the biomechanical picture in the implementation of vertical bounces is distinguished by its innovations in the choice of a combination of apparatuses, indicators and a software algorithm for their determination.

The change in the speed of the selected points from the body of the athlete in the implementation of the vertical jumps is an informational basis for revealing the biomechanical suitability of the motor structure of the exercise.

As an optimization criterion for the effective use in vertical jumps, it is advisable to use the difference in the interval to reach the maximum speed of the *COG* and the footstep from the time of separation from the support.

The proposed normative table of criteria allows for an objective assessment of the efficiency of the motor structure of the movement in the implementation of vertical recurrences investigated through the innovative approach.

The dynamometer results obtained from the athlete's interaction with the support provide reliable information about the quantitative interaction between the bodies.

The vigorous bounce performance using short-term active depreciation and subsequent instantaneous ejection is an effective way to improve the sporting result by effectively using the inertial power of the athlete.

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