THE VELOCITY OF COUNTERMOVEMENT JUMP IMPROVE THE PERFORMANCE JUMP IN HEALTHY ATHLETES

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Abstract

Jump performance is of interest in many sports disciplines and after injuries, but many mechanical features could be extracted from a force platform being confusing to understand which mechanical variable could be more related to the high achieved. This knowledge may permit optimization jump skills during training periods. Therefore, we determine the associations between mechanical variables of the center of mass and the height jump during unweight and propulsion phases in countermovement jump in amateur healthy young Athletes. Thirty-six subjects (aged 20.6 ± 2.9 years-old and body mass index of 21.9 ± 2.2 Kg/m2) were included. A jump assessment using a Bertec® force platform was performed obtaining the mean, minimum, maximal and range of vertical ground reaction force, position, velocity, acceleration, impulse, power, and rate of force development for unweighting and propulsion phase during the countermovement jump. A correlation analysis with a type I error of 5% was performed. The main finding was that healthy young athletes showed a moderate association between the height of the jump and minimal velocity during unweight phase of countermovement jump, but also during the propulsive phase existed a very high association between the height of the jump and the maximal velocity during propulsion phase ($p<0.001$). In healthy young athletes, the maximization of velocity execution of triple-flexion during the unweighting phase and the development of a triple-extension with maximal velocity during the propulsion phase are the most important mechanical features to improve the countermovement jump.

Keywords: countermovement jump, performance jump, correlation.

INTRODUCTION

The two-leg countermovement jump involves a fast generation of unweighting and propulsive phases before the flight phase (Bosco et al., 1982). From the vertical ground reaction signal force, unweight and propulsive phase is characterized by values under and over the weight of the jumper respectively (Bosco et al., 1982). The maximal height of the body center of mass (CoM) is sought only by pushing against the ground (Bobbert and van Soest., 2001). This means that to achieve the maximal jump height, a maximization of effective energy related to the initial velocity at take-off needs to be developed during the push-off accordingly with simulations experiments of Bobbert and van Soest in 2001. Hence, muscles must perform mechanical work on the body segments to increase the segmental energies, but only a part of the mechanical work is transmitted at take-off (Bobbert and van Soest., 2001). This segmental energy of lower limbs could be improved storing elastic energy from tendons, muscle-tendinous unit, and muscle tissue before starting the propulsive phase to transform the potential stored energy into kinetic energy, but also could be enhanced by the muscle activation between knee extensors and ankle plantar-flexors (Enoka, 2008).

Currently, the use of force platforms gives a lot of information from the vertical ground reaction signal force as position, velocity, acceleration, impulse, power, leg stiffnes, or rate of ground reaction force of the jumper' CoM (McBride et al., 1999; Linthorne, 2001; Dorrell et al., 2020; Marques et al., 2019) but habitually only the time of contact or non-contact is used by the difficulties related with mathematical calculation and programming. In opposition, a lot of mechanical information might confuse researchers. Therefore, to known the association between jump height and all these mechanical characteristics still be of interest to optimize jump tasks in different populations (Loturco et al., 2017; Abidin et al., 2013; Caruso et al., 2012; Earp et al., 2010; Lee et al., 2000).

The relevance of find features of mechanical variables associated with the height of the countermovement jump i.e. maximal velocity, it would allow improvements of the motor adaptation during training i.e. by plyometric training (Ramirez-Campillo et al., 2014; Slimani et al., 2016; Dorrell et al., 2020; Marques et al., 2019). Based in the systematic review performed by Slimani et al. in 2016, it appears that plyometric training may be an appropriate method to improve the height of countermovement jump (Slimani et al., 2016) due to the capacity to develop the ability to store potential energy and immediately transform it in kinetic energy during a coordinate muscle contraction during jumps (Macaluso et al., 2012). Due to the above, we have hypothesized that during the unweighting and propulsion phases a statistical association between velocity and height of the countermovement jump in healthy young exist. In accordance, this study aims to determine the associations between mechanical variables of CoM (vertical ground reaction force, position, velocity, acceleration, impulse, mechanical work, and rate of vertical ground reaction force) and the height of countermovement jump during the unweighting and propulsion phases in healthy young athletes.

METHODOLOGY

Study Design

A cross-sectional study was conducted to determine if the features of mechanical variables extracted from vertical ground reaction force during the unweighting and propulsion phase of the countermovement jump are associated with the jump height. Forty voluntary healthy young athletes participated in an initial collection of basics data and jumping assessment during the health fair "*Elige vivir sano*" ethics (PUC2013) and authorized by the wellness department. Enough information about the purposes of the study was given to the participants and they were asked to sign the written informed consent approved by the ethics committee assessed by the IRB. The informed consent was generated according to the Helsinki principles.

Participants

Thirty-six amateur young athletes (Table 1) met the inclusion and exclusion criteria of the study. The inclusion criteria were; 1) participant aged between 18 and 25 years-old, ii) perform physical activity at least three times per day during 30 minutes the last 6 months, iii) body mass index between 18.5 and 24.5 m*Kg^{-2}, and iv) amateur athletes of lower limb sports, defined as recreational athletes. The exclusion criteria were; i) no history or presence of orthopedic and/or neurologic pathology, ii) have slept at least 8 hours the last two days, iii) not be under medical treatment, and iv) not be under medication or alcohol effects. The exclusion criteria were determined by the same physician.

Table 1. Characteristics of participants.

Age, mean (sd), years-old	20.6 (2.9)
Height, mean (sd), m	1.72 (0.05)
Weight, mean (sd), Kg	65.0 (9.9)
BMI, mean (sd), Kg/m^2	21.9 (2.2)
Calf circumference of dominant limb,	0.354 (0.029)
mean (sd), m	0.361 (0.030)
Calf circumference of non-dominant	0.43 (0.07)
limb, mean (sd), m	0.236 (0.074)
Flight time, mean (sd), s.	
Jump height, mean (sd), m.	

Data are expressed as mean (standard deviation).
Standard deviation (sd)
Body mass index (BMI).

Procedures and instruments

Basics data as age, weight, height, body mass index were collected. Before performing the jump test, all participants performed a warm-up for 15 minutes in cycle ergometer (Ergoline Gmbh, Bitz, Germany). Then, three jumps were performed to achieve a correct countermovement jump technique, all participant had performed before the jump test, but a correct execution of a countermovement jump was defined as starting with an initial bipedal position, if upper extremity limbs over iliac crests and if after the jump the generated vertical ground reaction force was similar to the morphology described by Bosco et al. (1982), i.e. a countermovement jump was registered only if existed an unweight, propulsive, flight and landing phase such as Bosco et al. (1982) described (Figure 1).

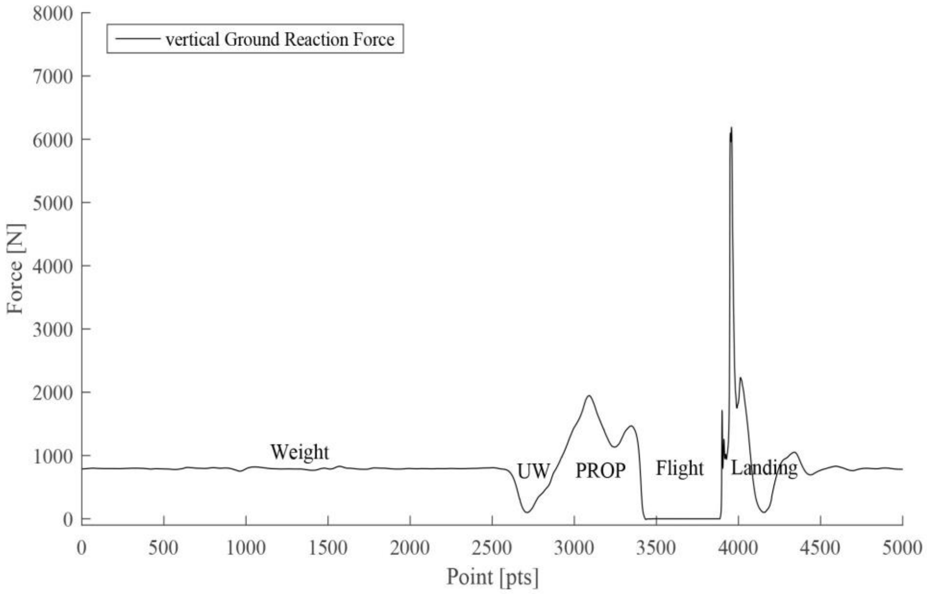

Figure 1. Vertical Ground Reaction Force. Weight represent the initial posture on force platform, UW indicate the unweight phase and triple-flexion movement, PROP indicate the propulsive phase and the triple-extension movement, Flight indicate the flight phase, and landing indicates when the jumper touch the ground.

Each participant performed a two-leg countermovement jump over a 40 x 60 cm force platform (Bertec corporation, OH, USA) embedded at ground level acquiring the force signal at 1000 Hz by Bertec digital acquire 4 software (Bertec corporation, OH, USA).

Data and Statistical analysis

The vertical ground reaction signal force of each participant was used to estimate the variables position, velocity, acceleration impulse, power, and rate of force during unweight and propulsion phases of the countermovement jump by Linthorne in 2001 (Figure 1). For both phases mean, range, minimum and maximal values were obtained generating a data matrix of 36 x (7 x 4 x 2) equal to 2016 jump signals i.e. thirty-six participants, seven signals, four statistical and two jump phases. Additionally, the flight time and height were calculated using the flight method (Linthorne, 2001) to describe the sample of the study (Table 1). All estimation was obtained by a custom algorithm based on Linthorne (2001) equations wrote by the author CD in MATLAB 14.b software (The Mathworks, Inc., Natick, MA, USA).

Descriptive data were reported as mean (standard deviation). The assumption of normal distribution and homoscedasticity was corroborated using the Shapiro-Wilk and Levene's tests, respectively. Inferential analysis of the data was performed using a Pearson correlation analysis with a type I error of 5%. The height jump was correlated with vertical ground reaction force, position, velocity, acceleration, work, impulse, power, and rate of vertical ground reaction force. The features minimum, mean, maximal, and range values for the unweighting and propulsion phases were used to identify the statistical significance correlation ($p<0.05$). The higher coefficients of correlation during the unweighting and propulsion phase were used to identify the highest association between the mechanical feature and height of the countermovement jump. The Person coefficient (r), 95% of confidence interval (95%CI) and the determination coefficient ($R2$) were described. The correlation coefficients were interpreted according to Munro (2005) where a coefficient between 0.0 and 0.25 means little correlation, 0.26 and 0.49 means low correlation, 0.50 and 0.69 means moderate correlation, 0.70 and 0.89 means high correlation, and 0.90 and 1.0 means very high correlation. All statistical analyses were performed using the GraphPad software (GraphPad Software, inc., La Jolla, CA, USA).

RESULTS

Moderate correlation was found between jump height and velocity during the unweight phase and high correlation was found between jump height and velocity during the propulsive phase, see Figure 2 & 3 and Table 2 & 3.

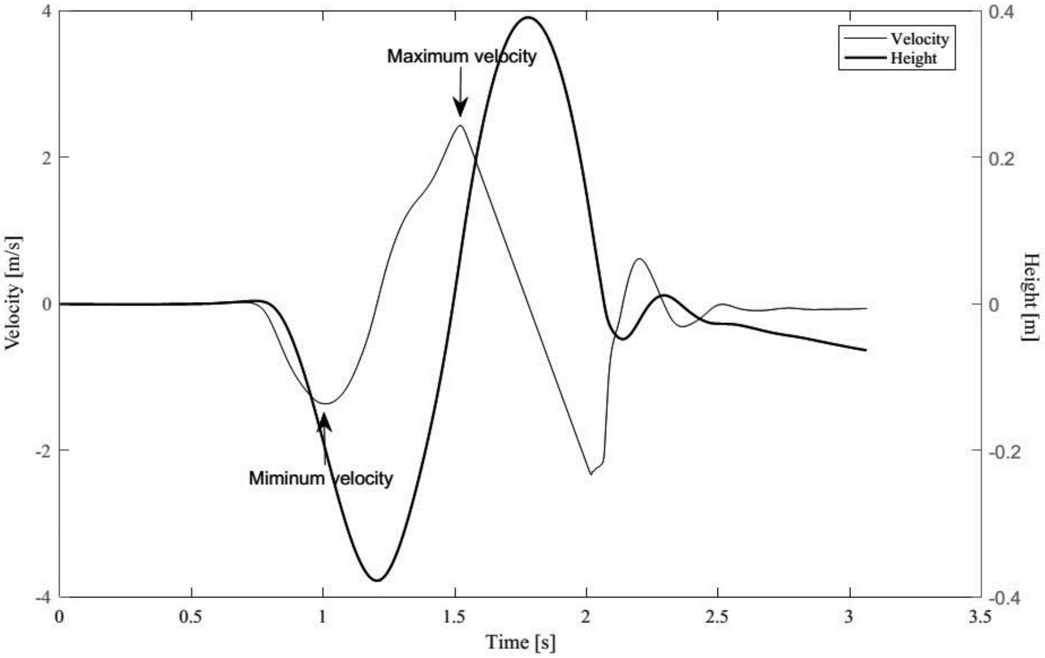

Figure 2. Maximal and minimum velocity respects the height of center of mass.

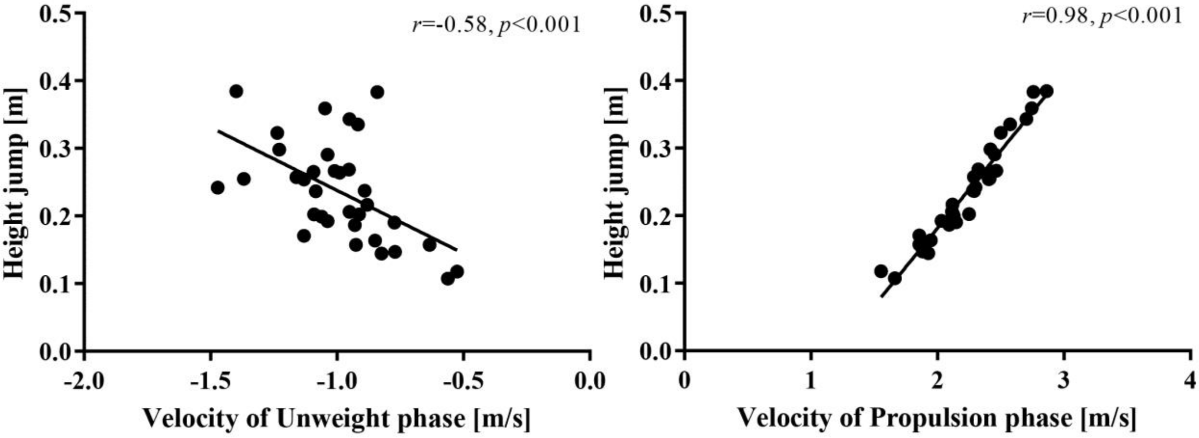

Figure 3. Velocity association with height jump. A Minimal velocity value associated with height jump. B Maximal velocity value associated with height jump.

Table 2. Association results for height jump during unweight phase.

	r	95%CI	*P*-value	R^2
Minimum vGRF	-0.24	-0.53 to 0.11	0.1761	0.06
Minimum position	-0.54	-0.74 to -0.25	0.0010*	0.29
Minimum velocity	-0.58ʒ	-0.77 to -0.30	0.0003**	0.34
Minimum acceleration	-0.33	-0.60 to 0.01	0.0560	0.11
Minimum impulse	-0.51	-0.72 to -0.21	0.0020*	0.26
Minimum power	-0.51	-0.72 to -0.21	0.0020*	0.26
Minimum rate of vGRF	-0.27	-0.55 to 0.08	0.1289	0.07
Mean vGRF	0.34	0.01 to 0.62	0.0467	0.12
Mean position	0.57	0.29 to 0.75	0.0003**	0.33
Mean velocity	0.52	0.22 to 0.73	0.0016*	0.27
Mean acceleration	0.32	-0.02 to 0.60	0.0618	0.11
Mean impulse	0.50	0.19 to 0.72	0.0027*	0.25
Mean power	0.50	0.19 to 0.72	0.0028*	0.25
Mean rate of vGRF	0.29	-0.05 to 0.57	0.0944	0.09
Maximal vGRF	0.16	-0.19 to 0.47	0.3764	0.03
Maximal position	-0.24	-0.53 to 0.11	0.1724	0.06
Maximal velocity	-0.04	-0.37 to 0.30	0.8166	0.00
Maximal acceleration	-0.28	-0.56 to 0.07	0.1113	0.08
Maximal impulse	-0.06	-0.39 to 0.29	0.7476	0.00
Maximal power	-0.06	-0.39 to 0.29	0.7483	0.00
Maximal rate of vGRF	0.27	-0.07 to 0.56	0.1192	0.07
Range vGRF	-0.10	-0.42 to 0.25	0.5788	0.01
Range position	-0.48	-0.71 to -0.17	0.0038*	0.23
Range velocity	-0.52	-0.73 to -0.22	0.0098*	0.19
Range acceleration	-0.32	-0.59 to 0.02	0.0659	0.11
Range impulse	-0.44	-0.68 to -0.12	0.0098*	0.19
Range power	-0.51	-0.72 to -0.20	0.0022*	0.26
Range rate of vGRF	0.00	-0.34 to 0.34	0.9816	0.00

*Statistical significance (P<0.05), *Statistical significance (P<0.001), ʒ Highest association, Person coefficient (r), 95% of confidence interval (95%CI), Coefficient of determination (R^2).*

Table 3. Association results for height jump during propulsion phase.

	r	95%CI	*p*-value	R^2
Minimum vGRF	0.17	-0.18 to 0.48	0.3499	0.03
Minimum position	-0.67	-0.82 to -0.43	<0.0001**	0.45
Minimum velocity	-0.54	-0.74 to -0.25	0.0009**	0.29
Minimum acceleration	-0.23	-0.54 to 0.12	0.1984	0.05
Minimum impulse	-0.51	-0.73 to -0.21	0.0020*	0.26
Minimum power	-0.48	-0.71 to -0.17	0.0039*	0.23
Minimum rate of vGRF	-0.59	-0.77 to -0.31	0.0002**	0.35
Mean vGRF	0.49	0.19 to 0.71	0.0028*	0.25
Mean position	0.75	0.55 to 0.87	<0.0001**	0.56
Mean velocity	0.90	0.79 to 0.94	<0.0001**	0.79
Mean acceleration	0.44	0.12 to 0.68	0.0089*	0.20
Mean impulse	0.66	0.41 to 0.82	<0.0001**	0.44
Mean power	0.73	0.52 to 0.86	<0.0001**	0.54
Mean rate of vGRF	0.60	0.32 to 0.78	0.0002**	0.36
Maximal vGRF	0.37	0.04 to 0.63	0.0299*	0.14
Maximal position	0.24	-0.11 to 0.53	0.1735	0.06
Maximal velocity	0.98ʒ	0.95 to 0.99	<0.0001**	0.95
Maximal acceleration	0.44	0.12 to 0.68	0.0090*	0.20
Maximal impulse	0.69	0.47 to 0.84	<0.0001**	0.48
Maximal power	0.75	0.56 to 0.87	<0.0001**	0.57
Maximal rate of vGRF	0.43	0.11 to 0.67	0.0112*	0.19
Range vGRF	0.39	0.06 to 0.65	0.0219*	0.15
Range position	0.64	-0.80 to -0.39	<0.0001**	0.41
Range velocity	0.54	0.25 to 0.74	0.0010*	0.29
Range acceleration	0.45	0.13 to 0.68	0.0083*	0.20
Range impulse	0.57	0.29 to 0.76	0.0004**	0.32
Range power	0.71	0.49 to 0.84	<0.0001**	0.50
Range rate of vGRF	-0.01	-0.35 to 0.33	0.9443	0.00

Statistical significance ($P<0.05$), *Statistical significance ($P<0.001$), ʒ Highest association, Person coefficient (r), 95% of confidence interval (95%CI), Coefficient of determination (R^2).

DISCUSION

The main findings of the study were a moderate association between jump height and minimal velocity in the unweighting phase, and the very high association between jump height and maximal velocity in the propulsive phase. These findings suggest that the peak velocities developed previously to the takeoff of the jump are the most important mechanical feature to improve the performance, see figure 2. This result are very practical, because means that the inter-limb coordination during the execution of the task of countermovement jump might be the target to develop during training, which correlates with the explosion strength developed by some athletes to be different in their sports, especially in team sport. Our results agree with the higher velocities obtained by countermovement squat where existed a positive influence on jump performance (Sanches-Sixto et al., 2018).

The existence of the minimal velocity during the unweighting phase means that while higher peak velocity of the CoM in direction of the force of gravity is developed by the jumper, a high jump height during the flight phase will be obtained due the negative relationship found between velocity and height jump during the unweight phase. Furthermore, the negative association was found with the minimal position, impulse, power, and range of the position, velocity, impulse, and power. Thus, the velocity of how the triple-flexion of the lower limb during the unweighting phase is generated suggests that this is an essential first neuromechanical target that must need be optimized for jumps tasks based in the challenge of to increase the velocity at take-off, assumption discussed in the past by Bosco et al.

(1982), Bobbert et and van Soest (2001) and Bobbert et al. (1996). A fast mobilization of the CoM during the unweighting phase mechanically permits to develop more mechanical energy to release by the muscle-skeletal system during the propulsion phase in accordance with the velocity-based training programs which have been shown better performance in athletes (Dorrell et al., 2019; Marques et al., 2019). Part of this energy could be stored as elastic energy into the muscle-skeletal system during the eccentric work (Bosco et al., 1982), principally into the tendon units to improve the next stage of a countermovement jump, that is, the propulsion. But the deformation of the tissue of tendons, ligaments, muscles, and skin could also be a source of sensory information to generate appropriate muscle synergies for the next jump stage (Enoka, 2008).

Regarding in the maximal velocity during the propulsive phase, it means that while higher peak velocity of the CoM in the direction opposed to the force of gravity is developed by the jumper, the highest jump height during the flight phase will be obtained due to positive relationship found between velocity and height jump during the propulsive phase. Furthermore, the positive high to the very high association with mean velocity, maximal, range and mean power suggest that during the propulsion phase a fast mechanical work on CoM in the direction opposed to the earth is achieved by the higher velocity of muscle contractions developed previously to the take-off. This is in accordance with Morin et al. (2019) which argued that the power of jump is the most important variable in sports. Hence, the rate of triple-extension of the lower limb during the propulsive phase suggests being the second essential neuromechanical target that must be optimized in jumps tasks. This fast work generated on the CoM during the propulsive phase mechanically permits to elevate the CoM during the flight phase. The stored elastic energy is delivered (Bosco et al., 1982; Bobbert and van Soest., 2001) and appropriate synergies act developing the final part of plyometric muscle contraction. In healthy young athletes and special population who have elevated chances to generate greater performance improvements (Ramirez-Campillo et al., 2014; Slimani et al., 2016), plyometric programs has been indicated as the potential best choice to increase with control joint velocities (Slimani et al., 2016). Findings of our work about the velocity as the most mechanical variable correlated with the height jump support training based in the performance of velocity execution i.e. plyometric training. This is in accordance also with the peak velocities found in trained population in comparison with untrained individuals as well by athletes involved in high-velocity training versus training involving lower movement velocities (McBride et al., 1999; Dorrell et al., 2020; Marques et al., 2019).

CONCLUSION AND PRACTICAL ASPECTS

In conclusion, at healthy young athletes, the maximization of velocity execution of triple-flexion during the unweighting phase and the development of a triple-extension with maximal velocity during the propulsion phase are the most important mechanical features to improve the countermovement jump.

To develop quick body movements it is required the ability to mobilize mass in opposition to inertial forces and create eccentric control to decelerate the body. This is an important motor topic of control. This last issue constitutes a neurophysiological and cognitive challenge in the untrained population during the training. This ability to develop quick body movements appears to be the millstone of the plyometric improvement programs. The present results are relevant for futures exercise design based on velocity abilities.

REFERENCES

1. Abidin NZ, Adam MB. (2013). Prediction of vertical jump height from anthropometric factors in male and female martial arts athletes. Malays J Med Sci, 20(1), 39-45.
2. Bobbert MF, Gerritsen KG, Litjens MC, Van Soest AJ. (1996). Why is countermovement jump height greater than squat jump height? Med Sci Sports Exerc. 28(11), 1402-1412.
3. Bobbert MF, van Soest AJ. (2001). Why do people jump the way they do? Exerc Sport Sci Rev, 29(3), 95-102.
4. Bosco C, Tihanyi J, Komi PV, Fekete G, Apor P. (1982). Store and recoil of elastic energy in slow and fast types of human skeletal muscles. Acta Physiol Scand, 116(4), 343-349.
5. Caruso JF, Daily JS, Mason ML, Shepherd CM, McLagan JR, Marshall MR, et al. (2012). Anthropometry as a predictor of vertical jump heights derived from an instrumented platform. J Strength Cond Res., 26(1), 284-292.

6. Dorrell HF, Smith MF, Gee TI. (2020). Comparison of Velocity-Based and Traditional Percentage-Based Loading Methods on Maximal Strength and Power Adaptations. J Strength Cond Res. 34(1), 46-53.
7. Earp JE, Joseph M, Kraemer WJ, Newton RU, Comstock BA, Fragala MS, et al. (2010). Lower-body muscle structure and its role in jump performance during squat, countermovement, and depth drop jumps. J Strength Cond Res., 24(3), 722-729.
8. Ebben WP, Fauth ML, Garceau LR, Petushek EJ. (2011). Kinetic quantification of plyometric exercise intensity. J Strength Cond Res., 25(12), 3288-3298.
9. Enoka R. (2008). Neuromechanics of human movement: chapter 4: page 157. Third ed. Unites States: Human kinetics.
10. García-Ramos A, Pérez-Castilla A, Jaric S. (2018). Optimisation of applied loads when using the two-point method for assessing the force-velocity relationship during vertical jumps. Sports Biomech, 12, 1-16.
11. Lee RC, Wang Z, Heo M, Ross R, Janssen I, Heymsfield SB.(2000). Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. Am J Clin Nutr., 72(3), 796-803.
12. Linthorne NP. (2001). Analysis of standing vertical jumps using a force platform. Am. J. Phys., 69(11), 1198-1204.
13. Loturco I, Pereira LA, Kobal R, Kitamura K, Cal Abad CC, Nakamura FY, et al. (2017). Peak versus mean propulsive power outputs: which variable is more related to jump squat performance? J Sports Med Phys Fitness., 57(11), 1432-1444.
14. Macaluso F, Isaacs AW, Myburgh KH. (2012). Preferential type II muscle fiber damage from plyometric exercise. J Athl Train., 47(4), 414-420.
15. Marques DL, Travassos B, Sousa AC, Gil MH, Ribeiro JN, Marques MC. (2019). Effects of Low-Moderate Load High-Velocity Resistance Training on Physical Performance of Under-20 Futsal Players. Sports (Basel), 18,7(3).
16. McBride JM, Triplett-Mcbride T, Davie A, Newton RU. (1999). A Comparison of Strength and Power Characteristics Between Power Lifters, Olympic Lifters, and Sprinters. J Strength Cond Res., 13(1), 58-66.
17. Morin JB, Jiménez-Reyes P, Brughelli M, Samozino P. (2019). When Jump Height is not a Good Indicator of Lower Limb Maximal Power Output: Theoretical Demonstration, Experimental Evidence and Practical Solutions. Sports Med. 49(7), 999-1006
18. Munro BH. (2005). Statistical Methods for Health Care Research, Volume 1: Statistical Methods for Health Care Research: Chapter 10: page 239. Illustrated ed. United States: Lippincott Williams & Wilkins.
19. Ramírez-Campillo R, Meylan C, Alvarez C, Henríquez-Olguín C, Martínez C, Cańas-Jamett R, et al. (2014). Effects of in-season low-volume high-intensity plyometric training on explosive actions and endurance of young soccer players. J Strength Cond Res., 28(5), 1335-1342.
20. Sánchez-Sixto A, Harrison AJ, Floría P. (2018). Larger Countermovement Increases the Jump Height of Countermovement Jump. Sports (Basel). 6(4).
21. Slimani M, Chamari K, Miarka B, Del Vecchio FB, Chéour F. (2016). Effects of Plyometric Training on Physical Fitness in Team Sport Athletes: A Systematic Review. J Hum Kinet. 53, 231-247.

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