FACTA UNIVERSITATIS
Series: **Physical Education and Sport**, Vol. 16, No 3, 2018, pp. 577 - 585
https://doi.org/10.22190/FUPES171118052M

Research article

MAXIMAL MUSCULAR STRENGTH AS A PREDICTOR OF OPTIMUM DROP HEIGHT

UDC 796.015.52
796.012.414

Milan Matić, Igor Ranisavljev

Faculty of Sport and Physical Education, University of Belgrade, Belgrade, Serbia

Abstract. *The first goal of the study was to examine the relationship between maximum muscle strength and optimal drop height (DH_{opt}), while the second goal was to examine the relationship between regression models for the prediction of DH_{opt} and DH_{opt} determined by variable H. A total of 30 respondents, students of the Faculty of Sport and Physical Education participated in the experiment. During the experiment, eight altitudes were randomized in the range of 0.12 to 0.82 m. The instruction was to achieve a higher jump, with a shorter duration of rebound. A positive statistically significant correlation between DH_{opt} determined by the prediction method with 1 RM / $BM^{0.67}$ and MDS ($p<0.05$) was calculated. When computing the DH_{opt} connection determined by the dialing method with the maximum muscle strength of the participants, no statistically significant correlation was obtained, but there is a positive trend. Determined by the prediction method DH_{opt} is (0.47±0.17 m) and using the regression model with 1 RM/$BM^{0.67}$ it is (0.47±0.07 m) and with MDS (0.48±0.06 m). In order to explain the high relationship between the models, it should be noted that the muscles of the knee joint have a more important role in motor tasks performed at higher intensity like during the drop jump. With this in mind, DH_{opt} in the jump can be determined depending on the neuromuscular capacity to generate the maximum muscle strength of the knee in order to use the optimal intensity within plyometric training.*

Key words*: dialing method, prediction method, optimal training intensity*

Received November 18, 2017 / Accepted December 25, 2018
Corresponding author: Milan Matić
University of Belgrade, Faculty of Sport and Physical Education, Blagoja Parovića 156, 11000 Belgrade, Serbia
Phone: +381 11 3531000 • E-mail: milan.matic@fsfv.bg.ac.rs

INTRODUCTION

The maximal vertical jump is an important indicator of high performance among athletes in numerous sports. Vertical jump exercises as a part of plyometrics training are mainly divided into slow plyometrics (the Countermovement jump - CMJ and Squat jump), while the drop jump or depth jump are examples of quick plyometrics.

Plyometric training with optimal level of intensity is superior to the classical strength training without precisely defined intensity (Baker & Nance, 1999; Baker, Nance, & Moore, 2001; McBride, Triplett-McBride, Davie, & Newton, 2002). Optimization of load intensity in the drop jump based on the optimal drop jump height is the foundation for precise programming of training load. Stronger subjects need a larger external load to achieve the optimal speed for maximum muscle power in comparison to weaker subjects (Komi, 1992). When the drop height is higher than optimal, load during landing will pass the threshold of the Golgi tendon organ and a consequence is the decrease in muscle electromyographic activity, reduction in the muscle force, power (P) and the height of the jump (H) (Schmidtbleicher, Gollhofer, & Frick, 1988).

We found no previous studies on the relationship between maximum muscular strength (1RM squat, 1RM half-squat etc.) and optimum drop height (DH_{opt}). In a review paper, Kawamori and Haff (2004) suggested testing the relationship between maximum muscle strength and optimal load that will enable generating maximum muscle power output. Maximal power output is the best predictor of jump height according to Lafayette and Choukou (2010). In this regard, the study of Bobbert and Van Soest (1994) reported that the value of the H variable in SJ highly correlated with muscle strength. Ugrinowitsch, Tricoli, Rodacki, Batista, & Ricard (2007) reported a moderate to high correlation between result in the 1 RM leg press and H in CMJ on different subjects (in athletes with r=0.93, bodybuilders r=0.89, physically active subjects r=0.52, p<0.05). Indirectly, it can be hypothesized that there is a correlation between muscle strength and drop jump landing height. Also, studies have shown that adult male subjects achieve maximum jump height after drop jump landing from a greater height in comparison to children (Lazaridis et al., 2013) and female subjects (Komi & Bosco, 1978), which supports the hypothesis of the importance of maximal muscular strength.

Therefore, the first goal of this research was to determine the correlation between maximal muscle strength and DH_{opt}. Hypothesis 1 assumes that a statistically significant correlation will be found between maximal muscle strength and DH_{opt}. The second objective is to test the correlation between regression models for predicting the DH_{opt} and DH_{opt} determined variable H. Hypothesis 2 assumes that a statistically significant correlation will be found when DH_{opt} is determined by variable H and in specific regression models.

METHODS

Participants

The sample included the total of 30 participants, students of the Faculty of Sport and Physical Education, University of Belgrade with an average age of 20.73±1.26 years, body mass 77.4±9.5 kg and height 1.84±0.07 m, which, over the last two years have not been training and competing for a professional club except only at the level of university sport. The Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade has approved the implementation of the research.

Procedures

All experimental measurements were carried out at the Faculty of Sport and Physical Education, University of Belgrade. The participants were tested in a Methodical Research Laboratory (MIL) from 10AM until 2PM.

Anthropometric measures were taken according to the procedures recommended by the International Society for the Advancement of Kinanthropometry (Norton et al. 2000). Body height and body mass were measured to the nearest 0.5 cm and 0.1 kg, respectively. Body composition (percentage of body fat content) was assessed using a bioelectric impedance method (In Body 720, Biospace, Seoul, Korea).

Three days before the experimental measurements, the participants performed familiarization with the drop jump (from every landing height the participants performed 3 to 4 rebounds, making a total of 24-32 rebounds). During the experiment, randomized eight drop jumps heights in the range of 0.12 to 0.82 m were used (0.12, 0.22, 0.32, 0.42, 0.50, 0.62, 0.72, and 0.82 m). From each height, the participants performed 5 maximal drop jumps on a tension-metric platform; the last 3 samples were taken for further analysis. The instruction was to achieve the highest possible vertical jump, with the shortest duration of ground contact (Makaruk & Sacewicz, 2011) and minimal knee flexion during landing (Taube, Leukel, Lauber, & Gollhofer, 2012). During jumps the hands were placed on the hips, in order to eliminate the impact of the arm swing (Viitasalo, Salo, & Lahtinen, 1998; Potache & Chu, 2000; Taube et al., 2012).

A break between the attempts was about 15s (Read & Cisar, 2001) and 3 min between different landing heights (Taube et al. 2012). The criterion for appropriate jump technique was the duration of contact with the ground (not longer than 300 ms) in order to utilize the stretch-shortening cycle-SSC (Schmidtbleicher, 1992; Kibele, 1999).

The sample of variables

The sample of variables included one independent variable - maximum muscular strength; and one dependent - H, that was used for the determination of the optimal drop height - DH_{opt}.

Analysis and processing of data in half-squat test

The data obtained in the test half-squat with weights (determined 1 RM) are shown in two ways, with two variables. The first method involves calculating the maximal dynamic strength (MDS), while the second way involves normalizing the absolute value of the data obtained in relation to body mass.

Maximal dynamic strength

For the purpose of calculating MDS, a standard formula was used:

MDS=1RM+(body mass - mass of the lower leg). The mass of the lower leg is represented as 12% of body mass (Cormie, McCaulley, & McBride, 2007). In order to increase the validity of the results obtained, all the data recorded in the half-squat test were normalized in order to eliminate the influence of body size on the achieved results. Normalization of the data was carried out in relation to the mass of the body according to Jarić (2002). Normalization of the results from the 1 RM half-squat test was calculated by the formula: $R=1\ RM\ /\ BM^{0.67}$

Methods for determining the optimum drop height

We used two methods:
1) Method of selecting (picking), and
2) Method of projection (fitting - regression) for determining DH_{opt}.

In the first method, the drop height where the participants achieved top H was the variable DH_{opt}. The second method was used for the prediction of individual DH_{opt}. Specifically, a second order polynomial (i.e., parabolic) regression was fitted through the individual sets of top H data obtained from eight drop heights (named the *fitting* method). Presuming the regression equation:

$$H = aDH^2 + bDH + c$$

DH is the applied drop height and a, b and c are parameters, and the first derivative allowed for the calculation of the DH_{opt} corresponding to the maximum of the fitted individual curve:

$$DH_{opt} = -b/2a$$

Measuring jump height

A tensiometric platform was used for the measurement of the variable H (AMTI, Inc., Newton MA, USA), installed and calibrated according to the manufacturer's instructions at 1000 Hz dimensions 0.60 × 0.40 m. Jump height is calculated according to the formula (Voigt, Simonsen, Dyhre-Poulsen, & Klausen, 1994): $H = 1/8 \times g \times t^2$

Statistical analysis

Descriptive statistics included the central and dispersion parameters: the arithmetic mean (A) and standard deviation (SD). Before using the Pearson product-moment correlation coefficient (r) a preliminary analysis was carried out to test normality, linearity, homogeneity of variance and determine if there were any outliers. Outliers were determined by a Boxplot. The r values in the ranges from 0.10 to 0.29 are considered to be low, from 0.30 to 0.49 moderate, and over 0.50 high (Cohen, 1988). For the prediction of DH_{opt} a linear regression method was used. Assessment of the validity of the model is determined by: r, standard error of the estimate (SEE), CI95%, the t-test was used to check whether there are systematic differences between DH_{opt} calculated based on the variable H value and the prediction regression model. Evaluation of the obtained regression model was performed by the method of auto-validation (Harrell, 2001). The level of statistical significance was $p < 0.05$ for all measurements. Statistical analysis was performed by SPSS 20.0 (SPSS Inc, Chicago, IL, USA) and Excel 2003 (Microsoft Corporation, Redmond, WA, USA).

RESULTS

The relationship between maximal muscle strength and optimal drop height

Table 1 Descriptive statistics of variables maximum strength (A ± SD)

Variable	A		SD
1 RM / $BM^{0.67}$ (kg)	7.01	±	1.31
MDS (kg)	196.43	±	23.62

Legend: *1 RM / $BM^{0.67}$* − normalized value in 1RM half squat in relation to body mass (*BM*), *MDS* – maximum dynamic strength, *A* − the arithmetic mean, SD − standard deviation.

The relationship between maximum strength variables and DH_{opt} is tested with r. According to the Shapiro-Wilks test, all data (regular and normalized to BM) has normal distribution.

There is a significant positive correlation between a DH_{opt} based on the variable H, when the *regression* method of prediction with 1 RM / $BM^{0.67}$ ($p<0.05$) and MDS ($p<0.05$) is used (Table 2). When a picking method is used, there was no statistically significant correlation, but there is a positive trend.

Table 2 The Pearson correlation coefficient (r) of maximum muscle strength and DH_{opt} based on the H variable by different prediction methods

Variable	Picking (H)	Regression (H)
1 RM / $BM^{0.67}$	0.27	0.42*
MDS	0.19	0.36*

Regression models for the prediction of optimum drop height

The validation and sensitivity of regression models for the prediction of DH_{opt} based on variable H, is checked by auto-validation. Characteristics of regression models to predict the DH_{opt} and their correlation with a given DH_{opt} by a regression method are shown in Table 3. All models used for prediction showed a statistically significant association with DH_{opt}. The t-test for dependent samples showed no significant difference ($p> 0.05$). The results of the t-test for dependent samples of the DH_{opt} variable by the regression method and:

1) a model (1 RM / BM0.67), t (29)= -0.01 and CI95% is from -0.06 to 0.06;
2) a model (MDS), t (29)= -0.38 and CI95% is from -0.07 to 0.05.

Table 3 Characteristics of the regressions model of DH_{opt} and their correlation with DH_{opt} determined by the H variable

Model for DH_{opt}	Predictive equation	R^2	r	SEE
1 RM / $BM^{0.67}$	$Y = 9.68 + 5.34x_1$	0.18	0.42*	0.15
MDS	$Y = -2.92 + 0.26x_2$	0.13	0.36*	0.15

Legends: *R^2*-coeficient of determination, *r*-coefficient of linear Pearson correlation, *SEE*-Standard Error of the Estimate, 1RM-1 repetition maximum, BM-body mass, *MDS*-maximal dynamic strength, *Y*-prediction value of the DH_{opt}, x_1-value of the *1RM / $BM^{0.67}$*, x_2-value of the *MDS*, *Statistically significant at the level $p<0.05$.

Fig. 1 (bar 1) shows *A*, *SD* and DH_{opt} determined by the H variable using regression-fitting method. Bars 2 and 3 show the same variables when the regression model of *1 RM / BM*$^{0.67}$ (0.47±0.07 *m*) and *MDS* (0.48±0.06 *m*) are used, respectively.

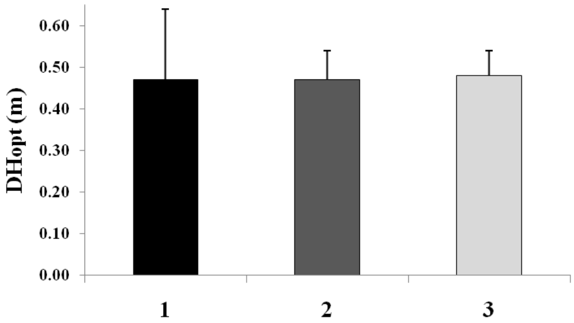

Fig. 1

DISCUSSION

The relationship between the maximum strength of the participants and optimal drop height

The first objective of this research was to examine the relationship between the variables that describe maximum muscle strength and DH_{opt} determined by the variable H. The first hypothesis was confirmed partially. When the regression-fitting method is used for the determination of DH_{opt}, there was a significant correlation between maximum muscle strength and $DH_{opt.}$

In basic testing, we used 1RM half-squat where the knee extensor muscles make a major contribution. For a further explanation of this relationship, we must note that knee extensor muscles have high importance in physical tasks with higher intensities such as the drop jump. The importance of the knee extensor muscles in the high intensity drop jump efforts was shown in previous reports (Hobara et al., 2009; Horita, Komi, Nicol, & Kyröläinen, 2002). Kinematic characteristics of the knee joint during a maximal vertical jump do not differ significantly between different athletes, whereas significant variations are reported in angular velocity of the hip and ankle (Đokić, Radenković, & Stanković, 2018). High angular velocity and full muscle activation during an eccentric contraction, lead to an increase in overall work rate during CMJ (Stojanović, Čoh, & Bratić, 2016). Considering the high speed of muscle lengthening during the eccentric phase of drop jump, the importance of the optimal drop height for the drop jump is even bigger. Based on these results, DH_{opt} in the drop jump should be determined based on neuromuscular properties of maximal muscle strength during measured in multi joint movements.

Regression models for the prediction of the optimal drop height

The second hypothesis that it is possible to predict DH_{opt} is confirmed by a significant correlation of DH_{opt} determined by variable H and specific regression models. We found no studies that checked the possibility of predicting DH_{opt} by regression models. We cannot compare these results with previous papers so the results will be discussed in accordance to different theoretical and practical foundations. A medium level of correlation was found when DH_{opt} was determined by the variable H and by different regression models (Cohen, 1988). A higher level of correlation was found when the variable $1RM / BM^{0.67}$ was in the model, in comparison with variable *MDS*. Therefore, the model with $1RM / BM^{0.67}$ showed higher validity for the determination of relative muscle strength and confirmed the importance of muscle strength for the level of $DH_{opt.}$

Precise determination of optimal intensity is very important for improvement of efficiency of training and the rehabilitation process (Cormie, McGuigan, & Newton, 2011a, 2011b; Cronin & Sleivert 2005). Results of this study show that we should switch between different drop heights based on individual $1RM / BM^{0.67}$ in order to have optimized intensity in plyometric training. Optimization of training intensity showed benefits in maximization of maximal power output during different training means such as SJ with load etc. (Baker & Nance 1999; Baker et al., 2001; McBride et al., 2002).

The presented regression models should be tested in other groups of participants (elite athletes, females etc.). Further experimental studies should allow deeper implementation of these models in training and competitive practice.

CONCLUSION

It may be concluded that the DH_{opt} in the drop jump can be determined based on the neuromuscular capacity to generate maximum muscular strength. The resulting correlation of the DH_{opt} based on variable H and DH_{opt} determined by regression models was moderate. A higher correlation and more precise prediction of DH_{opt} is obtained when the regression model accounted for the variable $1RM / BM^{0.67}$. Practical use of the presented results in sport will allow precise determination of DH_{opt} in training and testing.

Based on the above mentioned, it can be concluded that there is a significant influence of the independent variable maximum muscle strength, and that the impact of this variable should be taken into account when conducting scientific experiments, sports rehabilitation and training programs that include the drop jump as a training and testing procedure.

REFERENCES

Baker, D., & Nance, S. (1999). The relationship between strength and power in professional rugby league players. *Journal of Strength and Conditioning Research*, 13, 224-229.

Baker, D., Nance, S., & Moore, M. (2001). The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *Journal of Strength and Conditioning Research*, 15(1), 92-97.

Bobbert, M.J. & Van Soest, A.J. (1994). Effects of muscle strengthening on vertical jump height: A simulation study. *Medicine and Science in Sports and Exercise*, 26, 1012-1020.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (*2nd Ed*.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cormie, P., McCaulley, G.O., & McBride, J.M. (2007). Power versus strength-power jump squat training: influence on the load-power relationship. *Medicine and Science in Sports and Exercise*, 39, 996-1003.

Cormie, P., McGuigan, M.R., & Newton, R.U. (2011a). Developing maximal neuromuscular power: Part 1 - biological basis of maximal power production. *Sports Medicine*, 41, 17-38.

Cormie, P., McGuigan, M.R., & Newton, R.U. (2011b). Developing maximal neuromuscular power: Part 2 - training considerations for improving maximal power production. *Sports Medicine*, 41(2), 125-46.

Cronin, J., & Sleivert, G. (2005). Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine*, 35, 213-234.

Đokić, M., Radenković, M., & Stanković, R. (2018). Differences in mechanical characteristics of vertical jump between athletes in sports games. *Facta Universitatis, Series Physical Education and Sport*, *16*(1), 85-94.

Harrell, F.E. (2001). *Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis*. New York: Springer-Verlag.

Hobara, H., Muraoka, T., Omuro, K., Gomi, K., Sakamoto, M., Inoue, K., et al. (2009). Knee stiffness is a major determinant of leg stiffness during maximal hopping. *Journal of Biomechanics*, 42, 1768-1771.

Jarić, S. (2002). Muscle strength testing: use of normalisation for body size. *Sports Medicine*, 32(10), 615-631.

Horita, T., Komi, P.V., Nicol, C., & Kyröläinen, H. (2002). Interaction between pre-landing activities and stiffness regulation of the knee joint musculoskeletal system in the drop jump: implications to performance. *European Journal of Applied Physiology*, 88, 76-84.

Kawamori, N., & Haff, G.G. (2004). The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research*, 18(3), 675-684.

Kibele, A. (1999). Technical note.Possible errors in the comparative evaluation of drop jumps from different heights. *Ergonomics*, 42, 1011-1014.

Komi, P.V. (1992). *Strength and power in sport*. London: Blackwell.

Komi, P.V., & Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. *Medicine and Science in Sports*, 10, 261-265.

Laffaye, G., & Choukou, M.A. (2010). Gender bias in the effect of dropping height on jumping performance in volleyball players. *Journal of Strength and Conditioning Research*, 24, 2143-2148.

Lazaridis, S.N., Bassa, E.I., Patikas, D., Hatzikotoulas, K., Lazaridis, F.K., & Kotzamanidis, C.M. (2013). Biomechanical comparison in different jumping tasks between untrained boys and men. *Pediatric Exercise Science*, 25, 101-113.

Makaruk, H., & Sacewicz, T. (2011). The effect of drop height and body mass on drop jump intensity. *Biology and Sport*, 28, 63-67.

McBride, J.M., Triplett-McBride, T., Davie, A., & Newton, R.U. (2002). The effect of heavy-vs. light-load jump squats on the development of strength, power, and speed. *Journal of Strength and Conditioning Research*, 16, 75-82.

Norton, K., Marfell-Jones, M., Whittingham, N., Kerr, D., Carter, L., Saddington, K., et al. (2000). Anthropometric assessment protocols. In C.J. Gore (Ed.). *Physiological tests for elite athletes*, (pp 66-85). Champaign, IL: Human Kinetics.

Potach, D.H., & Chu, D.A. (2000). Plyometric training. In T.R. Baechle, & R.W. Earle (Eds.). *Essentials of strength training and conditioning (2nd Ed.*). (pp. 427-470). Human Kinetics.

Read, M.M., & Cisar, C. (2001). The influence of varied rest interval lengths on depth jump performance. *Journal of Strength and Conditioning Research,* 15(3), 279-283.

Schmidtbleicher, D., Gollhofer, A., & Frick, U. (1988). Effects of a stretch-shortening typed training on the performance capability and innervation characteristics of leg extensor muscles. In de Groot et al., (Eds.), *Biomechanics XI-A* (pp. 185-189), Vol 7-A G. Free University Press: Amsterdam, Netherlands.

Schmidtbleicher, D. (1992). Training for power event. In P.V. Komi (Ed.). *Strength and power in sport* (pp. 381-395). London: Blackwell Scientific.

Stojanović, N., Čoh, M., & Bratić, M. (2016). The role of countermovement in the manifestation of explosive leg strength in vertical jumps. *Facta Universitatis, Series Physical Education and Sport*, 14(1), 13-22.

Taube, W., Leukel, C., Lauber, B., & Gollhofer, A. (2012). The drop height determines neuromuscular adaptations and changes in jump performance in stretch-shortening cycle training. *Scandinavian Journal* of *Medicine* & *Science* in *Sports,* 22, 671-683.

Ugrinowitsch, C., Tricoli, V., Rodacki, A., Batista, M., & Ricard, M. (2007). Influence of training background on jumping height. *Journal of Strength and Conditioning Research*, 21(3), 848-852.

Viitasalo, J.T., Salo, A., & Lahtinen, J. (1998). Neuromuscular functioning of athletes and non-athletes in the drop jump. *European Journal of Applied Physiology and Occupational Physiology*, 78, 432-440.

Voigt, M., Simonsen, E.B., Dyhre-Poulsen, P., & Klausen, K. (1994). Mechanical and muscular factors influencing the performance in maximal vertical jumping after different prestretch loads. *Journal of Biomechanics*, 28, 293-307.

MAKSIMALNA SNAGA MIŠIĆA KAO PREDIKTOR OPTIMALNE VISINE SASKOKA

Prvi cilj istraživanja je bio ispitati povezanost maksimalne jačine mišića i optimalne visine saskoka (DH_{opt}), a drugi cilj ispitati povezanost regresionih modela za predikciju DH_{opt} i DH_{opt} determinisane varijablom H. U eksperimentu je učestvovalo ukupno 30 ispitanika, studenata Fakulteta sporta i fizičkog vaspitanja. Tokom eksperimenta randomizovano je osam visina saskoka u opsegu od 0.12 do 0.82 m. Instrukcija je bila da se postigne što viši skok, sa što kraćim trajanjem odskoka. Izračunata je pozitivna statistički značajna korelacija između DH_{opt} određene metodom predviđanja sa 1 RM/$BM^{0.67}$ i MDS ($p<0.05$). Kada se računala povezanost DH_{opt} određene metodom biranja sa maksimalnom mišićnom jačinom ispitanika nije dobijena statistički značajna korelacija ali postoji pozitivan trend. Određena metodom predviđanja DH_{opt} je (0.47±0.17 m) a pomoću regresionog modela sa 1 RM / $BM^{0.67}$ (0.47±0.07 m) i sa MDS (0.48±0.06 m). Za objašnjenje dobijene visoke povezanosti treba navesti da mišići koji svoju funkciju realizuju u zglobu kolena imaju bitniju ulogu kod motoričkih zadataka koji se izvode pri većim intenzitetima opterećenja npr. kod skoka iz saskoka. Sa tim u vezi DH_{opt} kod skoka iz saskoka se može određivati u zavisnosti od neuromišićnih kapaciteta za generisanjem maksimalne mišićne jačine opružača kolena kako bi se koristio optimalan intenzitet u okviru pliometrijskog treninga.

Ključne reči: metod biranja, metod predviđanja, optimalni intenzitet treninga