INFLUENCE OF INDIVIDUALIZED TRAINING BASED ON MECHANICAL FORCE-VELOCITY PROFILE ON THE BILATERAL VERTICAL JUMP PERFORMANCE

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Abstract:

A detailed review of literature revealed that there is no study of the influence of different types of loads on the performance of a bilateral vertical jump examined on subjects of the same type of F-v profile. Therefore, the aim of this study was to evaluate the influence of two different load types on the squat-jump performance in force-deficient subjects. During the seven-week training program, the 15 participants of force group performed a half back squat with a load of 80-85% 1RM, while the 15 participants of velocity group performed squat jumps with an unloading of 25% of body weight during the same period of time. The force group significantly improved height of the squat jump (+12.43 ± 6.98%; p<.001), with a large effect (ES = 1.92 ± .72), while in the velocity group non-significant changes were recorded (+2.02 ± 5.92%; p=.26), with a small effect (ES = 0.30 ± 0.60). These results in the force group were accompanied by a significant optimization of the F-v profile (+31.53 ± 34.91%; p=.003), with the attribute of large effect (ES = 1.10 ± 0.65), whereas the velocity group again recorded a non-significant change (-2.20 ± 34.34%; p=.70), with a trivial effect (ES = -0.13 ± 0.60). The results of the force group support the hypothesis of the effectiveness of a training program aimed at developing a deficient component of the F-v profile.

Keywords: *jump testing, targeted training, F-v deficit, squat jump*

Introduction

The vertical jump is classified as a ballistic movement pattern, which implies the firing of an accelerated object into free space. In the background of quality performance is the ability to achieve the maximum velocity of the body center of mass (CM) in the shortest possible time (Cormie, McGuigan, & Newton, 2010; Samozino, Rejc, Di Prampero, Belli, & Morin, 2012). According to Newton's second law of mechanics, the CM velocity achieved at the end of the ascending phase is directly influenced by the mechanical impulse (Samozino, et al., 2012; Winter, 2005). Since the mechanical impulse cannot be considered as an intrinsic mechanical property of the neuromuscular system, it is necessary to determine the parameter that can be. Many studies point out that the development of large impulses, and thus the consequent acceleration of CM, depends on the power capacities of the neuromuscular system (Samozino, et al., 2012). Power is a physical quantity that denotes the amount of work done in a unit of time, i.e., it is a product of inversely proportional quantities of force (F) and velocity (v) (Frost, Cronin, & Newton, 2010). Accordingly, it is possible to generate identical maximum power (Pmax) of the vertical jump, but with different combinations of force and velocity values, i.e., with different mechanical F-v profile of the lower extremities.

Given that the level of performance of ballistic movements, such as jump, sprint and change of direction, determines success in many sports activities, it is not surprising that the height of vertical jump is often set as a parameter determining the effectiveness of training modalities in elite athletes (Eagles, Sayers, Bousson, & Lovell, 2015; Ham, Knez, & Young, 2007; Jimenez-Reyes, Samozino, & Morin, 2019). The effects of different training modalities, such as plyometric training, traditional resistance training and weightlifting training, on the development of maximum power has been extensively researched so far, but inconsistent results are noticeable when it comes to vertical jump performance. The cause can be found in the absence of the initial analysis of mechanical F-v profiles, which ultimately generates the implementation of generalized, i.e., undirected training programs. Such training processes can simultaneously amplify power capacities, but also increase the F-v profile imbalance ($F\text{-}_{vIMB}$), which all together may result in invariant or even decreased vertical jump performance (Jimenez-Reyes, Samozino, Brughelli, & Morin, 2017). In contrast, studies examining the impact of training programs targeting the development of deficient component of the mechanical F-v profile of the vertical jump performance show the constancy of positive effects (Escobar-Alvarez, Fuentes-Garcia, Da Conceicao, & Jimenez-Reyes, 2020; Jimenez-Reyes, et al., 2017, 2019; Simpson, Waldron, Cushion, & Tallent, 2021).

However, in this relatively unexplored area, no study has been conducted that examines the influence of different types of loads on the performance of a vertical jump in subjects of the same type of mechanical F-v profile. Given that performing a vertical jump requires maximizing the velocity of the center of mass of the body, which is determined by the ability of skeletal muscles to produce high levels of power, the development of maximum power is crucial. The optimal development of the maximum power requires the use of optimal loads, which many researchers claim are the ones at which maximum power is achieved, despite certain velocity or strength deficits of athletes (Cormie, Deane, & McBride, 2007; Cronin & Sleivert, 2005; Harris, Cronin, & Hopkins, 2007). Although, according to the hypothesis of maximum dynamic output, the leg muscles are designed so that P_{max} is achieved by overcoming the load of body weight and body inertia (Jarić & Marković, 2009), a literature review found a wide range of loads that cause Pmax generation (Pažin, Berjan, Nedeljković, Marković, & Jarić, 2013; Soriano, Jimenez-Reyes, Rhea, & Marin, 2015). It is assumed that individuals with a certain F-v profile imbalance generate P_{max} at loads lesser or greater than their own body weight. Based on this, individuals with force deficit F-v profile will generate P_{max} with loads lesser than their own weight and body inertia, while in individuals with velocity deficient F-v profile the reverse will be the case (Samozino, et al., 2014). Given the previous assumptions, we are of the opinion that examining the impact of two different types of loads on the performance of a vertical jump is of scientific relevance. One type of load would be the one adequate for the development of the deficient component of F-v profile, and the other would target the development of P_{max} in the subjects of the same type of F-v profile. Such an experiment would further test the assumption that the undirected power training, taking F-v profile as a criterion, can increase maximum power output but it, at the same time, would increase $F\text{-}v_{IMB}$, all of which would lead to unchanged vertical jump performance or even the decreased one (Jimenez-Reyes, et al., 2017). Conversely, individualized training, based on the F-v profile, may cause P_{max} invariance but by reducing the F-v profile imbalance, it will cause an amplification of the vertical jump performance.

Methods

Participants

Thirty male students from the Faculty of Kinesiology, University of Zagreb (age 21.97 ± 2.25 years; body height 180.33 ± 6.53 cm; body mass 78.67 ± 9.11 kg) participated in this study. The required sample was defined using the GPower 3.1.9.2 software, which was set with a statistical power of 0.8 and a Type I error probability of 5%. Given the aim of the study, the inclusion criterion was that the participants' mechanical F-v profile of the vertical jump performance was force-deficient, with a lower limit value $S_{Fv\%}$ of 10% and an upper limit of 90%. An additional criterion was the absence of lower extremity injury in the last 12 months. All participants were acquainted in detail with the objectives and protocol of the research, after which they signed a statement of consent to participate in the research. Also, participants were told that they could give up in any part of the experiment. The research was aligned with the Helsinki declaration, and the experimental protocol was approved by the Scientific and Ethical Committee of the Faculty of Kinesiology, University of Zagreb

Sample of variables and experimental procedure

Prior to the formation of groups and the implementation of the training program itself, participants were subjected to initial testing during which the value of the peak height in the squat jump (h_{peak} SJ) was recorded using a force plate (Quattro Jump, Kistler, Winterthur, Switzerland, 9290AD). Then, the level of mechanical F-v profile in the squat jump was defined, following the prescriptions from previous studies (Jimenez-Reyes, et al., 2017, 2019), and one-repetition maximum in the half back squat (1RM HBS) was determined. The criterion for a valid descent depth in determining 1RM HBS was an angle of up to 90° between the upper and lower leg, and a digital goniometer (Medigauge, 900105) was used to determine the desired angle.

When testing the mechanical F-v profile, participants performed SJ in five different conditions: SJ without additional load with their hands on the hips, SJ with additional load of 15% of body mass, SJ with additional load of 30% of body mass, SJ with additional load of 45% of their own body mass, and SJ with additional load of 60% of their own body mass. SJ with loads was performed using free weights. Each participant was instructed to apply force as fast as possible and jump for a maximum height. A countermovement was strictly forbidden. Participants performed three jumps in each load condition with one minute recovery between trials, and two minutes recovery between the conditions.

The collected data were inserted into a free spreadsheet available online (https://www.researchgate.net/publication/320146284_JUMP_FVP_profile_spreadsheet) in which the ratio of actual and optimal profile and P_{max} was calculated (Morin, Jimenez-Reyes, Brughelli, & Samozino, 2019).

Two groups of fifteen subjects were formed by the method of random selection. The force group consisted of the participants who performed a half back squat with a high load (positive load) during the seven weeks of training, while the velocity group performed SJ with unloading (negative load). In total, each participant did fourteen workouts, or two workouts per week. The rest between workouts had to be a minimum of 48h. The force group performed a half back squat with a slight progression during the seven-week cycle. Namely, in the first week, the participants performed four sets of five repetitions with a load of 80% 1RM during one training session, in the second and third week they performed five sets of five repetitions with a load of 80% 1RM, while during the remaining four weeks the participants were exposed to a training volume of five sets of five repetitions with 85% 1RM. All components of the training process are based on findings from the studies conducted so far (ACSM, 2009; Peterson, Rhea, & Alvar, 2004; Ralston, Kilgore, Wyatt, & Baker, 2017; Rhea, Alvar, Burkett, & Ball, 2003; Wirth, Keiner, Hartmann, & Sander, 2016). In total, each participant performed 340 half back squats with a high load in a given training period. The rest between sets was three minutes.

The group whose training targeted velocity development performed SJ with unloading of 25% of their body weight (i.e., with 75% body weight). For the purposes of this research, a specially designed unloading system was used, for the operation of which it was necessary to provide a mountaineering belt, two elastic bands (gold Thera – band®) 2.2 m long, 4.5 m long rope, plate weights, pulley, and digital scale. Before the start of the experimental training, the distance to which the elastic bands-rope complex must be pulled up to ensure a defined negative loading was determined for each participant, and during seven weeks each training session was carefully monitored to meet this criterion. The participants of this group also completed a total of 14 training sessions. In one week, two training sessions were performed with a minimum interval of 48 hours between them. As in the case of the force group, there was a slight progression during these seven weeks of training. In week one, the participants performed seven sets of six jumps per training session, in weeks two and three, eight sets of six jumps each, while in the last four weeks they performed nine sets of six jumps per training session. The rest between the sets lasted 2 minutes and 30 seconds. In total, each participant performed 708 jumps in a given training period. All components of the experimental training were set based on the findings from previous studies (Marković, Vuk, & Jarić, 2011; Marković, Mirkov, Knežević, & Jarić, 2013; Sheppard, et al., 2011).

Participants in both groups had an almost identical warm-up protocol for each workout consisting of one-minute low-intensity running, dynamic stretching for lower body, core muscle activation, ten reps of the half back squat without additional load, five reps of SJ, and eight reps of the half back squat with an additional load of 50% 1RM, with indication that the last exercise was performed only by the group that was developing force.

Data analysis

Data were processed and analyzed using the IBM SPSS Statistics for Windows statistical package (version 24.0, Armonk, NY: IBM Corp.). The normality of the distribution of data was checked by Shapiro-Wilk's test. Examination of differences between the two protocols in chronic effects was done using a 2 x 2 mixed model ANOVA, while the differences within the protocols themselves were examined by the paired *t*-test. The evaluation of individual responses was performed using the parameter of the smallest worthwhile change (SWC), whose criterion level was obtained by multiplying the standard deviation of the initial measurement by 0.2. Participants were considered as harmful (individual change < −1 SWC), trivial (from −1 SWC to +1 SWC) or beneficial (+1 SWC) responders. Differences between the groups in the initial measurement were analyzed by t-test for independent samples. The level of statistical significance was set to $p<.05$ for all analyzes. The within-group difference and between-group differences in pre- and post-training values were also analyzed using effect size parameter (ES). Magnitude changes, expressed by the Cohen's d value, were treated as trivial with values less than 0.2, small in the range 0.2 – <0.6, medium or moderate in the range 0.6 – <1.2, large in the range 1.2 – < 2, and extremely large with values equal to or greater than 2 (Hopkins, Marshall, Batterham, & Hanin, 2009). The effect size for the 2 x 2 mixed ANOVA model was presented by the partial eta square (η^2). The values of η^2 from 0.01 to <0.09 were considered small, from 0.09 to <0.25 medium, and ≥ 0.25 large (Levine & Hullet, 2002).

Results

Table 1 shows the descriptive data of the analyzed variables in the initial and final measurement for both groups of participants. The normal distribution of data in all parameters was observed, so the parametric methods were applied undisturbedly.

It is important to emphasize that the application of *t*-test for independent samples did not record any significant difference in any variable comparing the groups in the initial measurement [(t = -0.28, p=.78, ES = 0.10 for h_{peak} SJ), (t = -0.97, p=.34, ES = 0.35 for $S_{Fv\%}$), (t = 0.50, p=.62, ES = 0.18 for P_{max} in W/kg)]. Consequently, it can be argued that the study was approached by two groups of matching characteristics, which greatly facilitated further interpretation.

While analyzing the transformation effects by the paired *t*-test, different responses were recorded in two groups of participants. The force group manifested a significant increase in h_{peak} SJ (+12.43 ± 6.98%; p<.001; ES = 1.92 ± 0.72); all the fifteen subjects responded positively to the implemented program. The results were accompanied by a significant increase in the value of $S_{Fv\%}$ (+31.53 ± 34.91%; p=.003; ES = 1.10 ± 0.65), which in this case would mean that the average value of the actual F-v profile of the force group shifted to the optimal ratio between two components. No significant changes in P_{max} were observed in that group (+16.07 ± 18.52; p=.49; ES = 0.18 ± 0.60). The opposite trend is present in the velocity group, so non-significant changes were noted in the variables h_{peak} SJ (+2.02 ± 5.92%; p=.26; ES = 0.30 ± 0.60) and $S_{Fv\%}$ (- 2.20 ± 34.34%, p=.70, ES = -0.13 ± 0.60), while a significant increase was noted in the P_{max} (+16.07 ± 18.52%, p=.005; 1.58 ± 0.69) (Table 2).

Using a 2 x 2 mixed ANOVA model, the significance of the interaction of the two factors, in this case the measurement time and the training program, was examined. A significant value of the Wilks lambda, i.e., a significant interaction in all the three variables, was found. A large effect was observed in the parameter h_{peak} SJ ($\eta^2 = 0.44$), while

Table 1. Descriptive data for both groups of participants

Group	Parameter	x̅	SD	*Min*	*Max*	W	p
Force	h_{peak} SJ in (cm)	41.73	5.31	33.20	53.50	0.92	0.18
	h_{peak} SJ fin (cm)	46.73	4.86	39.00	56.30	0.97	0.82
	$S_{Fv\%}$ in	52.07	16.37	19.00	81.00	0.96	0.64
	$S_{Fv\%}$ fin	66.47	21.00	26.00	106.00	0.99	0.99
	P_{max} in (W/kg)	25.96	4.41	20.30	37.30	0.91	0.14
	P_{max} fin (W/kg)	26.46	4.05	19.60	35.70	0.97	0.86
Velocity	h_{peak} SJ in (cm)	42.31	6.03	33.40	55.30	0.92	0.18
	h_{peak} SJ fin (cm)	43.04	5.67	35.00	53.80	0.93	0.27
	$S_{Fv\%}$ in	58.07	17.47	31.00	87.00	0.96	0.62
	$S_{Fv\%}$ fin	56.33	23.60	22.00	99.00	0.95	0.47
	P_{max} in (W/kg)	25.09	5.12	18.60	33.90	0.92	0.19
	P_{max} fin (W/kg)	29.37	8.63	19.20	47.00	0.92	0.20

Note. h_{peak} SJ - peak height of squat jump, $S^{Fv\%}$ - ratio of actual and optimal F-v profile expressed in percentage, P_{max} - maximum power based on F-v ratio, F_0 - theoretical maximum force, v_0 - theoretical maximum velocity, in - initial measurement, fin - final measurement, x̅ - mean, SD - standard deviation, min - minimum result, max - maximum result, W - value of Shapiro - Wilk test, p - level of significance for Shapiro - Wilk test.

Table 2. Difference between the initial and final measurement in both groups

		Initial vs. Final				Individual response		
Group	**Parameter**	**MD ± SD**	**p**	**%Δ ± SD**	**ES ± 90% CI**	**+**	**0**	**-**
Force	h_{peak} SJ (cm)	5.00 ± 2.56	< 0.001*	12.43 ± 6.98	1.92 ± 0.72	15	0	0
	$S_{Fv\%}$	14.40 ± 15.51	0.003*	31.53 ± 34.91	1.10 ± 0.65	11	3	1
	P_{max} (W/kg)	0.50 ± 2.75	0.49	2.67 ± 11.46	0.18 ± 0.60	7	4	4
Velocity	h_{peak} SJ (cm)	0.73 ± 2.40	0.26	2.02 ± 5.92	0.30 ± 0.60	8	2	5
	$S_{Fv\%}$	-1.73 ± 16.94	0.70	2.20 ±34.34	-0.13 ± 0.60	5	5	5
	P_{max} (W/kg)	4.29 ± 4.98	0.005*	16.07 ± 18.52	1.58 ± 0.69	11	2	2

Note. MD - mean difference, SD - standard deviation, p - level of significance in t-test for dependent samples, * - significant difference, %Δ - change expressed in percentages, ES - effect size expressed by Cohen d index, CI - confidence interval, + - change directed towards improvement, 0 - trivial change, - - change directed towards deterioration, h_{peak} SJ - peak height of squat jump, $S_{Fv\%}$ - ratio of actual and optimal F-v profile expressed in percentage, P_{max} - maximum power based on F-v ratio.

Table 3. Testing the interaction of time measurement and training program

Parameter	Multivariate analysis Wilks' Lambda	F	p	η^2	Box's M	p
h_{peak} SJ	0.56	22.15	< 0.001*	0.44	0.40	0.95
$S_{Fv\%}$	0.79	7.40	0.01*	0.21	0.22	0.98
P_{max}	0.81	6.64	0.02*	0.19	10.51	0.02

Note. F - value of F - test, p - level of significance, * - significant interaction, η^2 - partial eta square, Box's M - value of Box's test, h_{peak} SJ - peak height of squat jump, $S_{Fv\%}$ - ratio of actual and optimal F-v profile expressed as a percentage, P_{max} - maximum power based on F-v ratio.

medium effects were observed in the parameters $S_{Fv\%}$ ($\eta^2 = 0.21$) and Pmax ($\eta^2 = 0.19$) (Table 3).

Discussion and conclusion

The main finding of this study is that in the individuals whose F-v profiles are force deficient, the peak height SJ develops significantly more effectively by the short-term force-oriented training program than by the velocity-oriented training. Also, a significant improvement in SJ height was accompanied by a significant reduction in F-v profile imbalance in the force group. In the velocity group, trivial changes in the height of these types of jumps took place parallel with trivial changes in the ratio of current and optimal F-v profile. Such data are consistent with previous research and support the hypothesis of the effectiveness of training targeting the deficient component of the F-v profile (Escobar-Alvarez, et al., 2020; Jimenez-Reyes, et al., 2017, 2019; Simpson, et al., 2021).

The novelty of this research is the evaluation of the impact of a short-term training program targeting the predominant component of the F-v profile, which potentially further disturbs the balance of the mentioned profile, on the performance of vertical jumps. Given the data of previous experimental studies in this area, this type of evaluation may initially be considered irrelevant, but the arguments for it do exist and have already been presented in the introduction. Namely, according to the hypothesis of maximum dynamic output, the leg muscles are designed so that the maximum power output (P_{max}) is achieved by overcoming the load of our own mass and inertia of the body (Jarić & Marković, 2009). In the background of the hypothesis is the notion of how the muscular system adapts its mechanical properties to the loads it constantly overcomes. Since the muscles of the lower extremities of active people during most daily activities are loaded only with their own body mass, the system is adjusted in such a way as to produce maximum power output by overcoming just such loads. However, if individuals frequently and predominantly perform horizontal directional actions (e.g., running) with no additional load, in which the mechanical constraints are lesser than in the performance of vertical jumps by their own body mass, the system adapts to generate P_{max} with lower loads lesser than the body weight. Consequently, there is an imbalance in the F-v profile of the vertical jump with the deficiency of the force component (Samozino, et al., 2014). For the optimal development of P_{max}, a key component of ballistic tasks performance, it is recommended to apply training programs with loads that generate maximum power output (Cormie, et al., 2007; Cormie, McGuigan, & Newton, 2010; Cronin & Sleivert, 2005; Harris, et al., 2007). Although the unloading levels at which P_{max} was produced had not been individually detected, the participants of the velocity group went in that direction by performing SJ with the unloading of 25% of their body mass, and ultimately, with this a more general approach, significantly improved their maximum power output (P_{max}) calculated via the extrapolation of F-v profile parameters. However, analyzing h_{peak} SJ, a non-significant change was found in this group of participants, which was accompanied by a negligible change in the ratio of the actual and optimal F-v profile – $S_{Fv\%}$. This supports the hypothesis that a training program not aiming at correcting the F-v profile imbalance may cause the absence of significant positive changes or may even cause certain performance deterioration (Jimenez-Reyes, et al., 2017). In other words, performing 708 SJ with unloading, over a period of seven weeks, did not positively or negatively affect SJ performance in subjects whose F-v profiles were deficient in force. If we connect the results of the velocity group with the results of the non-optimized group from the study by Jimenez-Reyes et al. (2017), then we obtain almost complementary data, with the exception of P_{max} values. In general, the results of this research indicate a marked inefficiency, as far as the improvement of SJ height/performance is regarded, of the implementation of the training program aiming at the further development of the predominant component of the F-v profile.

Different results were recorded in the group of participants, also F-v profile deficient in force, who performed a half back squat with high loads during the seven-week training process. A significant improvement in h_{peak} SJ with large effect is noticeable. The established level of improvement is fully in line with the research conducted so far (Escobar-Alvarez, et al., 2020; Jimenez-Reyes, et al., 2017, 2019). It is extremely important to point out that in ours and the research by Jimenez-Reyes et al. (2017) all subjects of the group that participated in training intervention targeting force development had a beneficial effect on the change in SJ height. Changes in the participants of our study were accompanied by a significant increase in $S_{Fv\%}$, i.e., with a significant decrease in the imbalance of the F-v profile. It is necessary to emphasize the trivial changes of P_{max}, which strengthen the theoretical assumption that it is possible to improve vertical jump performance with a significant reduction of F-v profile imbalance (Samozino, et al., 2012) and not only with the amplification of maximum power output, obtained by extrapolations of maximum theoretical force – F_0 and maximum theoretical velocity – v_0.

When it comes to SJ height improvements in the force group, similar results were presented in the study in which participants performed a training program until the optimal level of F-v profile was reached (Jimenez-Reyes, et al., 2019). However, having in mind that the participants needed 12.6 ± 4.6 weeks to achieve the said, and that training period generated an increase of 12.5 ± 7.6% (ES = 1.45 ± 0.23) in SJ height, it is obvious that, compared to our study, the participants needed significantly more time for ultimately less improvement as expressed in effect size. Also, the participants of the force group in a prominent study performed a total of eighteen series in one week, while the participants in our study performed ten series per week. Of course, for a complete comparison of these two studies, it is necessary to include all other parameters, but the presented data indicate the purposefulness of future comparisons of different training programs aimed at correcting the deficient component of F-v profile because it is assumed that not every targeted training based on F-v profile is economical. We are of the opinion that in further research it is necessary to thoroughly evaluate all the components that make up targeted training program based on F-v profile (e.g., load intensity, load volume, training frequency, etc.).

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