MAXIMUM POWER TRAINING LOAD DETERMINATION AND ITS EFFECTS ON LOAD-POWER RELATIONSHIP, MAXIMUM STRENGTH, AND VERTICAL JUMP PERFORMANCE

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ABSTRACT

Smilios, I, Sotiropoulos, K, Christou, M, Douda, H, Spaias, A, and Tokmakidis, SP. Maximum power training load determination and its effects on load-power relationship, maximum strength, and vertical jump performance. *J Strength Cond Res* 27(5): 1223–1233, 2013—This study examines the changes in maximum strength, vertical jump performance, and the load-velocity and load-power relationship after a resistance training period using a heavy load and an individual load that maximizes mechanical power output with and without including body mass in power calculations. Forty-three moderately trained men (age: 22.7 ± 2.5 years) were separated into 4 groups, 2 groups of maximum power, 1 where body mass was not included in the calculations of the load that maximizes mechanical power (Pmax − bw, $n = 11$) and another where body mass was included in the calculations (Pmax + bw, $n = 9$), a high load group (HL-90%, $n = 12$), and a control group (C, $n = 11$). The subjects performed 4–6 sets of jump squat and the repeated-jump exercises for 6 weeks. For the jump squat, the HL-90% group performed 3 repetitions at each set with a load of 90% of 1 repetition maximum (1RM), the Pmax − bw group 5 repetitions with loads 48–58% of 1RM and the Pmax + bw 8 repetitions with loads 20–37% of 1RM. For the repeated jump, all the groups performed 6 repetitions at each set. All training groups improved ($p < 0.05$) maximum strength in the semisquat exercise (HL-90%: 15.2 ± 7.1, Pmax − bw: 6.6 ± 4.7, Pmax + bw: 6.9 ± 7.1, and C: 0 ± 4.3%) and the HL-90% group presented higher values ($p < 0.05$) than the other groups did. All training groups improved similarly ($p < 0.05$) squat (HL-90%: 11.7 ± 7.9, Pmax − bw: 14.5 ± 11.8, Pmax + bw: 11.3 ± 7.9, and C: −2.2 ± 5.5%) and countermovement jump height (HL-90%: 8.6 ± 7.9, Pmax − bw: 10.9 ± 9.4, Pmax + bw: 8.8 ± 4.3, and C: 0.4 ± 6%). The HL-90% and the Pmax − bw group increased ($p < 0.05$) power output at loads of 20, 35, 50, 65, and 80% of 1RM and the Pmax + bw group at loads of 20 and 35% of 1RM. The inclusion or not of body mass to determine the load that maximizes mechanical power output affects the long-term adaptations differently in the load-power relationship. Thus, training load selection will depend on the required adaptations. However, the use of heavy loads causes greater overall neuromuscular adaptations in moderately trained individuals.

KEY WORDS muscle power, strength training, power training, squat jump

INTRODUCTION

Muscle power, determined by the force and the velocity of muscle shortening, is considered as an important parameter for success in different sports. Various training methods, such as resistance exercise and plyometrics or a combination of both, have been effective for power development (1,11,18). More specifically, loads of 80–100% of 1 repetition maximum (1RM), for the enhancement of the force component of the power equation, whereas loads of 0–60% of 1RM, for the enhancement of the rate of force development, are recommended when resistance exercises are used for the lower body power training (3,22). Even more, to individualize the training stimulus, a load that maximizes mechanical power output in a specific exercise for each individual should be used for power enhancement (9,24).

A key point in the determination of the load that maximizes mechanical power is whether body mass should be included in the calculation of the force component of the power equation (force × velocity). The inclusion of body mass would increase the total mass values for force calculation, and consequently, power values. The effect would be higher to the power output produced with low loads, because of greater contribution of body mass to the total

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TABLE 1. Maximum strength and vertical jump performance of the 4 groups for the 6-week training program.*

	Pretraining	Posttraining		
Group	Mean ± *SD*	Mean ± *SD*	Effect size	Adjusted means
Half-squat 1RM (kg)				
HL-90% ($n = 12$)	161.25 ± 26.47	185.42 ± 29.65†	0.86	198.12 ± 3.04‡ § ‖
*P*max − bw ($n = 11$)	171.36 ± 27.30	182.96 ± 32.03†	0.39	185.29 ± 3.10‡
*P*max + bw ($n = 9$)	190.56 ± 40.27	203.89 ± 43.64†	0.32	186.53 ± 3.54‡
Control ($n = 11$)	171.36 ± 33.70	170.91 ± 32.23	−0.01	173.24 ± 3.10
Pretraining (covariate)	173.60			
Squat jump (cm)				
HL-90% ($n = 12$)	27.65 ± 4.73	30.70 ± 4.49†	0.66	32.27 ± 0.68‡
*P*max − bw ($n = 11$)	28.45 ± 5.25	32.38 ± 5.90†	0.70	33.24 ± 0.70‡
*P*max + bw ($n = 9$)	32.83 ± 2.96	36.48 ± 3.55†	1.12	33.45 ± 0.82‡
Control ($n = 11$)	28.74 ± 3.59	28.04 ± 3.17	−0.21	28.64 ± 0.70
Pretraining (covariate)	29.42			
Countermovement jump (cm)				
HL-90% ($n = 12$)	32.96 ± 4.37	35.73 ± 4.79†	0.60	37.7 ± 0.75¶
*P*max − bw ($n = 11$)	34.25 ± 4.59	38.05 ± 6.54†	0.67	38.57 ± 0.77‡
*P*max + bw ($n = 9$)	37.98 ± 3.94	41.33 ± 4.82†	0.76	37.7 ± 0.90¶
Control ($n = 11$)	33.7 ± 3.92	33.88 ± 4.99	0.04	35.02 ± 0.77
Pretraining (covariate)	34.72			
Drop jump (cm)				
HL-90% ($n = 12$)	30.99 ± 4.80	33.15 ± 4.50†	0.46	34.73 ± 0.88‡
*P*max − bw ($n = 11$)	32.74 ± 5.53	35.66 ± 5.95†	0.51	35.74 ± 0.91
*P*max + bw ($n = 9$)	35.49 ± 4.46	39.36 ± 5.70	0.77	37.08 ± 1.09‡
Control ($n = 11$)	32.09 ± 6.10	31.92 ± 5.64	−0.03	32.55 ± 0.91
Pretraining (covariate)	32.83			
Drop jump contact time (ms)				
HL-90% ($n = 12$)	247.75 ± 50.35	269.58 ± 59.67	0.40	266.72 ± 11.43
*P*max − bw ($n = 11$)	275.64 ± 55.90	303.09 ± 48.00	0.53	281.51 ± 12.57
*P*max + bw ($n = 9$)	216.75 ± 29.08	212.62 ± 48.48	−0.10	230.58 ± 14.37
Control ($n = 11$)	233.82 ± 61.04	244.73 ± 50.31	0.20	251.22 ± 11.98
Pretraining (covariate)	243.49			
Drop jump RSI ($cm \cdot s^{-1}$)				
HL-90% ($n = 12$)	129.96 ± 32.11	130.82 ± 41.83	0.02	140.10 ± 9.29‖
*P*max − bw ($n = 11$)	123.46 ± 33.76	119.8 ± 23.60	−0.13	134.24 ± 9.89‖
*P*max + bw ($n = 9$)	167.74 ± 38.83	198.81 ± 72.44	0.54	178.04 ± 11.78
Control ($n = 11$)	145.34 ± 42.98	134.14 ± 28.92	−0.31	131.19 ± 9.570‖
Pretraining (covariate)	141.63			

*bw = body weight; RSI =reactive strength index; RM = repetition maximum.
†$p < 0.05$: from pretraining.
‡From control group.
§From *P*max − bw group.
‖From *P*max + bw group.
¶$p = 0.06$ from control group.

mass used for the calculation of force, as compared with the power output produced with higher loads (10). This will change the load-power relationship and accordingly the external load that maximizes mechanical power. Previous studies showed load specificity in the adaptations observed on the force-velocity curve with the greatest increases observed at the portion of the curve with the loads used during training (6,19,23). However, different results were observed in relatively weak individuals (7). The question that arises is whether or not the inclusion of body mass in power calculations for the determination of the optimal load for power training would affect the long-term training adaptations on load-velocity and load-power relationships.

The use of heavy loads (>80% of the 1RM) in the squat exercise has been also found to increase neuromuscular performance (e.g., maximum strength and vertical jump height) (1,5,11,15). It is unknown, however, whether training with heavy loads would have a greater effect on vertical jump performance compared with the load that maximizes mechanical power in the squat or the jump squat exercise

TABLE 2. Maximum mechanical power and the loads that maximized mechanical power, with the inclusion or not of body mass in the calculations, of the 4 groups for the 6-week training program.

	Pretraining	Posttraining		
Group	Mean ± *SD*	Mean ± *SD*	Effect size	Adjusted means
Jump squat maximum power (W) (body mass not included)				
HL-90% ($n = 12$)	872.14 ± 144.46	985.96 ± 132.23*	0.82	1,060.52 ± 23.01†‡
*P*max − bw ($n = 11$)	923.31 ± 111.78	1,035.33 ± 106.94*	1.02	1,024.52 ± 22.98†‡
*P*max + bw ($n = 9$)	967.61 ± 167.30	966.84 ± 210.45	0.00	916.72 ± 25.79
Control ($n = 11$)	926.49 ± 174.25	942.44 ± 159.48	0.10	928.81 ± 22.99
Pretraining (covariate)	911.14			
Jump squat maximum power (W) (body mass included)				
HL-90% ($n = 12$)	1,739.92 ± 225.02	1,830.45 ± 259.00*	0.38	1,890.725 ± 51.00
*P*max − bw ($n = 11$)	1,835.94 ± 183.06	2,035.69 ± 211.47*	1.01	2,015.00 ± 52.60
*P*max + bw ($n = 9$)	1,812.38 ± 240.70	1,905.31 ± 286.39	0.35	1,904.48 ± 58.06
Control ($n = 11$)	1,857.35 ± 282.11	1,906.11 ± 290.08	0.17	1,867.36 ± 52.80
Pretraining (covariate)	1,811.40			
*P*max load (kg) (body mass not included in power calculations)				
HL-90% ($n = 12$)	89.79 ± 13.33	113.13 ± 19.69*	1.39	121.69 ± 4.17†‡
*P*max − bw ($n = 11$)	100.23 ± 15.02	106.82 ± 14.96	0.44	107.5 ± 4.11
*P*max + bw ($n = 9$)	108.56 ± 16.07	108.33 ± 24.24	−0.01	102.7 ± 4.64
Control ($n = 11$)	105.91 ± 24.91	100.91 ± 17.33	−0.23	97.3 ± 4.15
Pretraining (covariate)	101.10			
*P*max load (kg) (body mass included in power calculations)				
HL-90% ($n = 12$)	44.79 ± 16.43	55.83 ± 19.98	0.60	57.26 ± 5.12
*P*max − bw ($n = 11$)	49.77 ± 14.38	49.09 ± 20.71	−0.04	47.99 ± 5.33
*P*max + bw ($n = 9$)	48.33 ± 22.08	42.78 ± 16.93	−0.28	42.41 ± 5.89
Control ($n = 11$)	47.5 ± 18.67	47.27 ± 20.14	−0.01	47.32 ± 5.32
Pretraining (covariate)	47.60			
*P*max load (% 1RM) (body mass not included in power calculations)				
HL-90% ($n = 12$)	56.31 ± 7.49	61.52 ± 9.19	0.62	62.71 ± 2.09‡
*P*max − bw ($n = 11$)	59.04 ± 7.52	59.01 ± 6.53	0.00	58.97 ± 2.15
*P*max + bw ($n = 9$)	58.49 ± 9.99	53.53 ± 7.31	−0.57	53.74 ± 2.38
Control ($n = 11$)	62.02 ± 9.10	59.73 ± 8.51	−0.26	58.36 ± 2.19
Pretraining (covariate)	58.96			
*P*max load (% 1RM) (body mass included in power calculations)				
HL-90% ($n = 12$)	27.62 ± 9.11	30.36 ± 10.47	0.28	30.32 ± 2.74
*P*max −bw ($n = 11$)	29.02 ± 6.38	26.54 ± 9.24	−0.31	26.21 ± 2.87
*P*max + bw ($n = 9$)	25.54 ± 11.01	21.52 ± 8.40	−0.41	21.9 ± 2.18
Control ($n = 11$)	27.45 ± 8.06	27.39 ± 9.57	−0.01	27.38 ± 2.86
Pretraining (covariate)	27.41			

*$p < 0.05$: from pretraining.
†From control group.
‡From *P*max + bw group.

occurring with lighter loads (10–70% of 1RM; 2,9,13,16,17). The identification of the effect that each load has on vertical jump development is of great importance. Indeed, vertical jump is a movement performed in a variety of sports and is widely used for testing muscular power. Even more, the comparison of the effects of the load that maximizes mechanical power, with the inclusion or not of body mass in the calculations, along with a heavy load on the load-velocity and load-power relationships would give further insight into the functional adaptations observed in the neuromuscular system following training with various loads. This would provide valuable information to exercise scientists, coaches, and athletes to get a better insight and design more efficient training programs.

The purpose of this study was to compare the effects of (a) a heavy load (90% of the 1RM), (b) an individual load that maximizes mechanical power output without body mass included in power calculations (moderate loads, 48–58% of the 1RM), and (c) an individual load that maximizes mechanical power output with body mass included in power calculation (low loads, 20–37% of the 1RM) on the development of maximum strength, vertical jump performance and

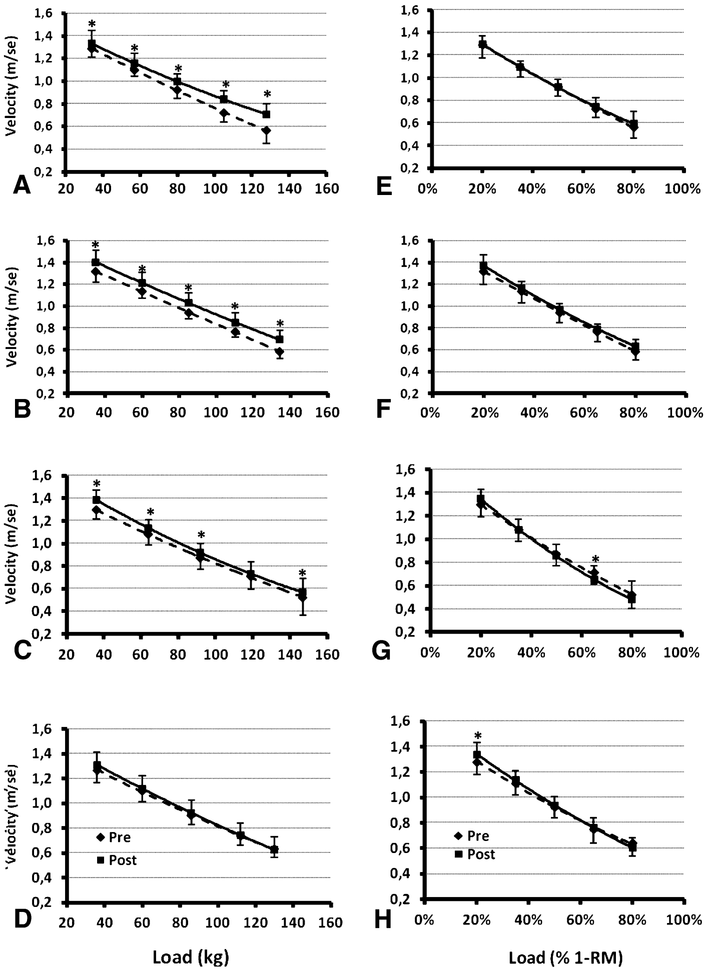

Figure 1. Pretraining and posttraining load-velocity relationships (mean ± *SD*) for the HL-90% (A, E), the *P*max − bw (B, F), the *P*max + bw (C, G), and the Control (D, H) groups. $^*p < 0.05$ from pretraining. Effect sizes for loads 20, 35, 50, 65, and 80% of pretraining 1RM, respectively (A–D): HL90%: 0.39, 0.78, 1.14, 1.5, 1.49 *P*max − bw: 0.76, 0.97, 1.18, 1.24, 1.31. *P*max + bw: 1.13, 0.74, 0.53, 0.17, 0.35 C: 0.4, 0.22, 0.23, 0.12, 0. Effect sizes for loads 20, 35, 50, 65, and 80% of posttraining 1RM, respectively (1E–H): HL90%: 0.1, −0.13, 0, 0.27, 0.29 *P*max − bw: 0.45, 0.24, 0.39, 0.41, 0.57. *P*max + bw: 0.52, 0, −0.1, −0.54, −0.28, C: 0.7, 0.47, 0.37, 0.33, −0.35.

the load-velocity and load-power relationships after a short term resistance training program.

METHODS

Experimental Approach to the Problem

Three training groups ($n = 32$) plus a control group ($n = 11$) were formed to examine the effects of the inclusion or not of body mass in the determination of the load that maximizes mechanical power output in jump squats along with the use of a heavy load on the improvement of muscular strength and power performance. The first training group executed the jump-squat exercise with a heavy load, 90% of 1RM, the second training group with the load that maximized mechanical power with body mass not included in power calculations, and the third training group with the load that maximized mechanical power output with body mass included in power calculation. The training groups followed an adaptation training period for 4 weeks and then a training period for 6 weeks with a training frequency of 2 $\text{d}\cdot\text{wk}^{-1}$. During this time period, the control group did not perform any form of physical training and participated only in the measurements. Semisquat maximum strength, squat jump, countermovement jump (CMJ), and drop jump (DJ) from a 40-cm height, and the load-velocity and load-power relationships in the jump-squat exercise were measured at all groups before and after the training period.

Subjects

Forty-three men (age: 22.7 ± 2.5 years, height: 176.4 ± 6 cm, and body mass: 77.2 ± 8.4 kg) participated in this study after signing an informed consent form, and the experimental protocol was approved by the Institutional Review Board Committee. The subjects were moderately trained executing exercises for all major muscle groups, including the half-squat exercise but not the jump-squat exercise, by lifting moderate loads (50–70% of 1RM) for at least 6 months before the initiation of the study.

Training Program

The training groups followed a 4-week preparatory period targeted to the progressive adaptation of muscle and tendon tissues to resistance exercise workload and familiarize the subjects with the exercises performed during the main training period. During this adaptation period, the subjects executed the leg press, knee extension, knee flexion, half-squat (knee angle 90°), bench press, abdominal exercises, back extensions, and jumping exercises, that is, squat jumps, CMJs, and DJs. During the last 2 weeks, loaded jump squats were included in the training sessions. At each exercise, the subjects performed 2–3 sets of 8–15 repetitions with a load 30–70% of 1RM and

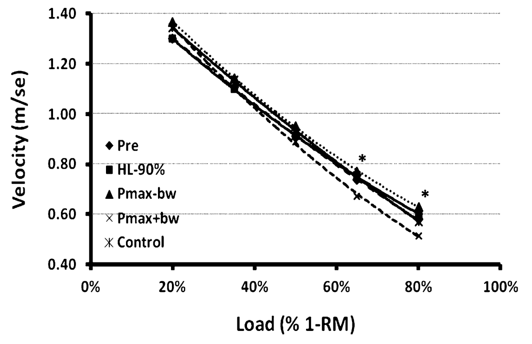

Figure 2. Differences between the HL-90%, *P*max − bw, *P*max + bw, and the Control groups in the load-velocity relationship. Data represent adjusted means as calculated from analysis of covariance (ANCOVA) using pretraining (pre) values as covariates. $^*p < 0.05$ between the *P*max − bw and the *P*max + bw groups.

2–3 minutes of rest between the sets and 3–5 minutes between the exercises. Two exercise sessions per week were performed.

Afterward, the subjects were separated into 3 training groups: (a) a heavy load group (HL-90%, $n = 12$), (b) a maximum power group trained with an individual load that maximized mechanical power output without including body mass in power calculations (*P*max − bw, $n = 11$), and (c) a maximum power group trained with an individual load that maximized power output with body mass included in power calculations (*P*max + bw, $n = 9$). All the groups executed the jump squat and repeated jump with the contrast training method (i.e., alternating sets of jump squats with sets of repeated jumps). Four sets were executed at each exercise during the first week, 5 sets during weeks 2–3, 6 sets during weeks 4–5, and 4 sets during the sixth week. At the jump-squat exercise the HL-90% group performed at each set 3 repetitions with a load of 90% of 1RM, the *P*max − bw group 5 repetitions with loads 48–58% of 1RM (load that maximized mechanical power for each individual), and the *P*max + bw 8 repetitions with loads 20–37% of 1RM. At the repeated-jump, all the groups performed 6 repetitions at each set. A 3-minute rest was allowed between sets and exercises. The subjects were instructed and encouraged to perform each exercise as fast as possible. It should be mentioned that the HL-90% group, actually did not perform a jump squat because it is not possible to execute a jump with such a load. The subjects were instructed to perform the half-squat exercise with the intention to jump and with the movement to end in a plantar flexion. The training program was applied for 6 weeks, 2 times per week.

Each training session started with a general warm-up that included 5 minutes of cycling at 60 W and 5 minutes of stretching of the lower body. Thereafter, a specific warm-up was applied where the subjects executed 2 sets of half-squats with a load equal to 50 and 70% of the training load.

Measurements

All pretraining and posttraining measurements were performed at the same time of day for each subject after 2–3 days of rest.

Half-Squat Maximum Strength. Maximum strength in the half-squat exercise (knee angle 90°) was measured with the 1RM method. Briefly, the subjects warmed up with 5–8 repetitions with a load estimated by the subjects to be approximately 50% of their 1RM. After 2 minutes of rest, 2–4 repetitions were performed with a load 70–80% and 1 repetition with a load 90% of the estimated 1RM. Thereafter, the load increased progressively when the subject performed 1 repetition to reach the maximum where the movement could not be completed with a full range of motion. Between single repetitions, the subjects rested for 3–5 minutes. Two to 3 single trials were required until the 1RM load was reached. The intraclass correlation coefficient (ICC) and the coefficient of variation (CV) of the *SEM* for the measurement of maximum strength were $r = 0.975$ and 2.49%, respectively.

Vertical Jump Performance. Vertical jump was evaluated using a resistive platform connected to a digital timer (Ergojump, Psion CM, MAGICA, Rome, Italy), which recorded flight time and calculated jump height using the formula:

$$h = f_t^2 \times g/8,$$

where h is the jump height, f_t is the flight time, and g is the force of gravity (4). Three forms of vertical jumps were performed, a squat jump (initiated from a knee flexion of 90°; SJ), a CMJ, and a DJ from a height of 40 cm. During the performance of the jumps, the hands of the subjects were placed on the waist. For the execution of the DJ, the subjects were instructed to jump as high as possible with the minimum contact time possible. The contact time of the DJ was also recorded and the reactive strength index (RSI) was calculated as the ratio of DJ height to DJ contact time (centimeters per second). The ICC and the CV of the SEM were $r = 0.971$ and 2.03% for the SJ, $r = 0.956$ and 2.62% for the CMJ, $r = 0.972$ and 2.53% for the DJ height and $r = 0.886$ and 5.51% for the DJ contact time, respectively.

Load-Velocity and Load-Power Relationships. Maximum movement velocity and power output with loads corresponding to 20, 35, 50, 65, and 80% of 1RM was measured during the concentric phase of the loaded jump-squat exercise. Three to 5 trials were performed with each load, until movement velocity did not change >5%, and the best trial was used for further analysis.

Vertical displacement of the bar as a function of time during the jump squat was measured with a linear encoder attached on a belt around the subject's waist. When the subjects moved, a signal was transmitted by the encoder,

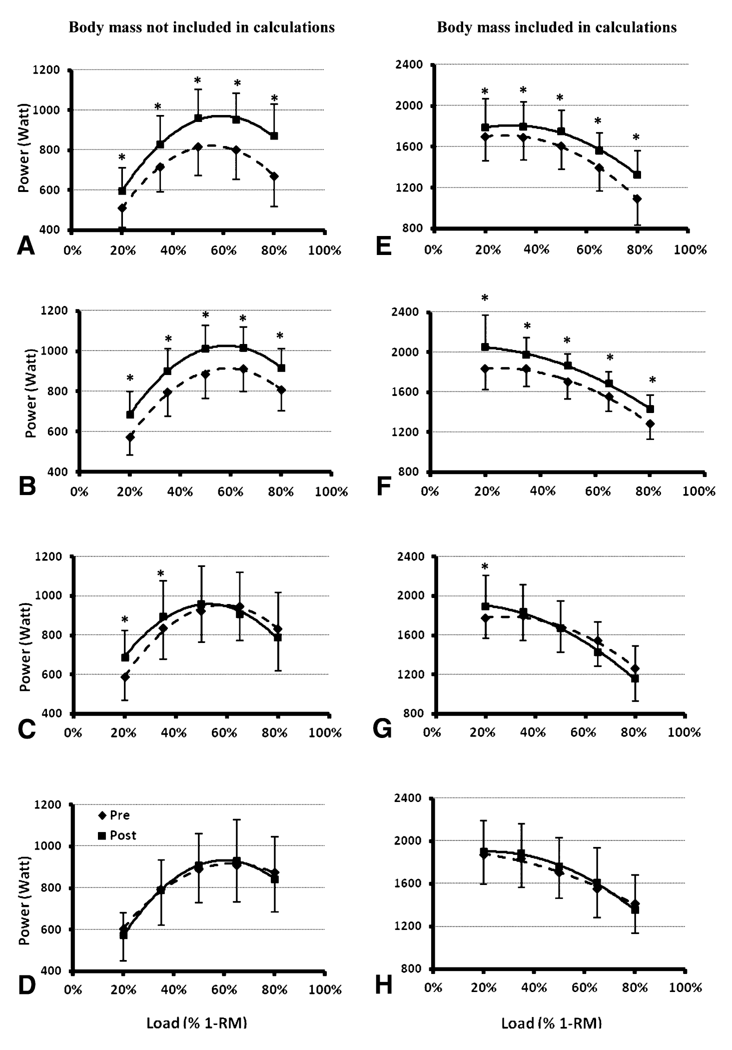

Figure 3. Pretraining and posttraining load (%1RM)-power relationships (mean ± *SD*) with body mass not included in power calculations (A–D) or with body mass included in the calculations (E–H) for the HL-90% (A, E), the *P*max − bw (B,F), the *P*max + bw (C,G), and the control (D,E) groups. $^{*}p < 0.05$ from pretraining. Effect sizes for the 20, 35, 50, 65, and 80% of the 1RM loads, respectively (4–D): HL90%: 0.78, 0.86, 0.99, 1.1, 1.28 *P*max − bw: 1.1, 0.9, 1.04, 0.96, 1.11. *P*max + bw: 0.78, 0.34, 0.22, −0.21, −0.2 C: −0.24, −0.03, 0.13, 0.13, −0.17. Effect sizes for the 20, 35, 50, 65, and 80% of the 1RM loads, respectively (4E–H): HL90%: 0.34, 0.45, 0.67, 0.81, 0.96 *P*max − bw: 0.81, 0.78, 1.13, 0.98, 1.01. *P*max + bw: 0.45, 0.17, 0, −0.42, −0.32 C: 0.11, 0.18, 0.22, 0.17, −0.21.

with a resolution of 0.075 mm, to an A/D converter (Muscle Lab, Ergotest Technology, Langesund, Norway; sampling frequency 100 Hz) interfaced to a PC with a software for data acquisition and analyses (MuscleLab v6.07). This allowed the calculation of the mechanical parameters of velocity, force, and power during movement. Using these data the load-velocity and the load-power curve for each individual was calculated by applying a second degree polynomial model. The obtained curves were used to estimate maximal mechanical power and the corresponding load (MP load) for each individual. For the *P*max + bw group body mass was included in the calculations and for the *P*max − bw body mass was not included. To validate our procedure, preliminary testing was applied. When body mass was not included in the power calculations the ICC and the CV of the *SEM* for the maximal power values were $r = 0.994$ and 1.52%, for the MP load were $r = 0.954$ and 2.97%, and for the power output with loads 20, 35, 50, 65, and 80% of 1RM ranged from $r = 0.963$–0.996 and 1.41–3.49%, respectively. When body mass was included in the power calculations the ICC and the CV of the *SEM* for the maximal power values were $r = 0.966$ and 1.7%, for the MP load were $r = 0.978$ and 4.28%, and for the power output with loads 20, 35, 50, 65, and 80% of the 1RM ranged from $r = 0.952$–0.994 and 1.39–3.64%, respectively.

The same relative load (20–80% of 1RM) was used to define the load-velocity relationship before and after the training period. Furthermore, we estimated the shifts of the load-velocity curve after training using the same absolute loads as before training. Movement velocity with the pretraining loads was estimated by using the second-degree polynomial equation formed with the posttraining data (range: $r^2 = 0.985 - 1$, $SEM = 0.001$–$0.021\ \text{m}\cdot\text{s}^{-1}$, and $SEE = 0.002$–$0.027\ \text{m}\cdot\text{s}^{-1}$). Furthermore, because the main topic in our study is the inclusion or not of body mass in the mechanical power measurement, the load-power curve was estimated twice: one with body mass included in the force component of power equation, and another without body mass. Accordingly, maximal power values and the respective loads were calculated and presented both ways.

Statistical Analyses

The training effects of each group at 1RM, SJ, CMJ, and DJ height, RSI, maximum mechanical power and MP load were examined using a *t*-test for dependent samples. A 2-way analysis of variance (time × load) was used to examine the

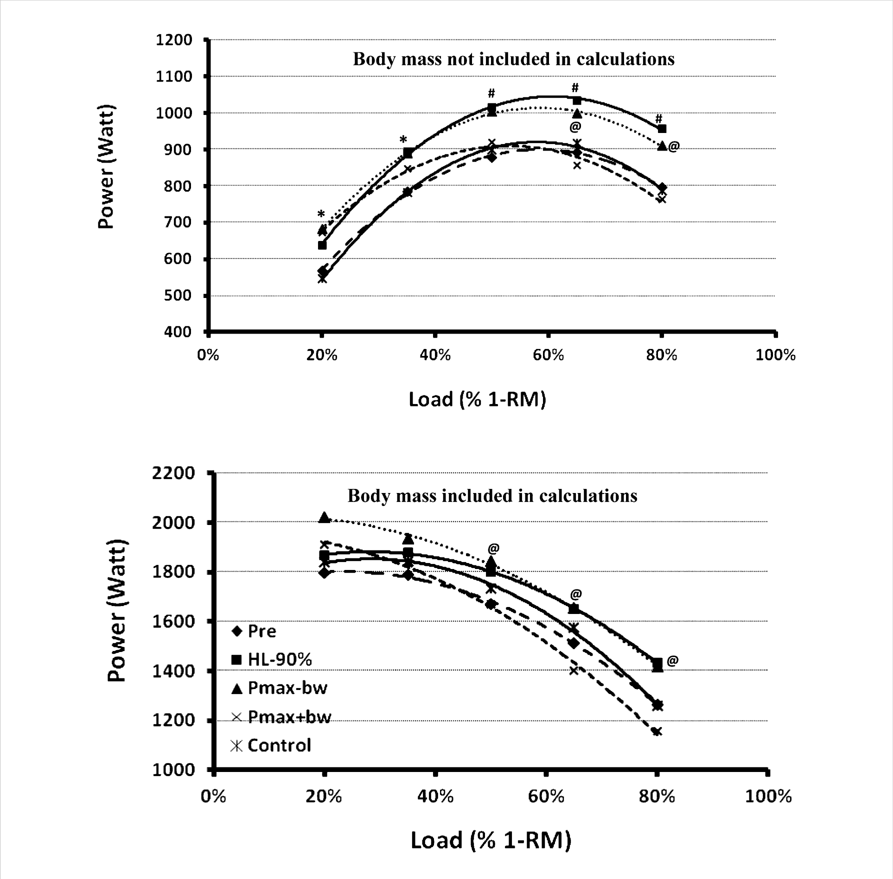

Figure 4. Differences between the HL-90%, *P*max − bw, *P*max + bw, and the control groups in the power-load (%1RM) relationship when body mass was or not included in power calculations. Data represent adjusted means as calculated from analysis of covariance (ANCOVA) using pretraining (pre) values as covariates. *$p < 0.05$ from control group, #$p < 0.05$ from control and *P*max + bw groups, @ from *P*max + bw group.

changes in the load-velocity and load-power relationships with training for each group. The effect size (ES [posttest mean – pretest mean]/*SD*) for the magnitude of treatment effects was determined (8). An analysis of covariance (ANCOVA), using initial values as covariate, was used to determine the differences between groups at the end of the training period. Significant differences between means were located with the Tukey post hoc test. The statistical significance level was set at $p < 0.05$.

RESULTS

Half-Squat 1 Repetition Maximum

Maximum strength in the half-squat exercise increased ($p < 0.05$) in all training groups and at the end of the training was higher ($p < 0.05$) compared with the control group. Furthermore, HL-90% group's maximum strength was higher compared to the *P*max − bw and the *P*max + bw groups (Table 1).

Vertical Jump Performance

The SJ height increased ($p < 0.05$) for the 3 training groups, and it was higher ($p < 0.05$) compared with the control group at the end of training. Similarly, CMJ height increased ($p < 0.05$) for the 3 training groups, and it was higher compared with control group for the *P*max − bw and the HL-90% group ($p < 0.05$) and the *P*max + bw ($p = 0.06$) group. The DJ height increased ($p < 0.05$) for the HL-90% and the *P*max − bw group. However, only the *P*max + bw group differed ($p < 0.05$) from the control group at the end of training. The DJ contact time and DJ RSI did not change significantly ($p > 0.05$) with training, but the *P*max + bw group had higher ($p < 0.05$) RSI values compared with all other groups at the end of training (Table 1).

Jump Squat Maximum Mechanical Power

Maximum mechanical power output in the jump squat exercise increased ($p < 0.05$) with training in HL-90% and the *P*max − bw group and did not change in the *P*max + bw and the control group irrespective of the inclusion or not of body mass in the calculations. At the end of the training period, maximum power output was higher ($p < 0.05$) for the HL-90% and the *P*max − bw group compared with the *P*max + bw and the control group only when body mass was not included in the calculations (Table 2).

Maximum Power Loads

When body mass was not included in the calculation of power the absolute load (kilograms) that maximized mechanical power output increased ($p < 0.05$) with training for the HL-90% group and did not change ($p > 0.05$) for the other groups (Table 2). The relative load (% 1RM) that maximized power output in the jump squat exercise after 6 weeks of training increased ($p = 0.06$) for the HL-90% group and did not change for the other experimental groups (Table 2). At the end of the training period, the absolute MP load (kilograms) was higher ($p < 0.05$) for the HL-90% group compared with the *P*max + bw and the control groups and the relative load (% 1RM) higher from the *P*max + bw group (Table 2). When the body mass was included in the calculations no significant changes ($p > 0.05$) were observed in the loads that maximized mechanical power output.

Load-Velocity Relationship

The HL-90% and the *P*max − bw groups improved movement velocity at all testing loads ($p < 0.05$; Figures 1A, B). The *P*max + bw increased movement velocity with loads of 20, 35, 50, and 80% of pretraining 1RM ($p < 0.05$; Figure 1C), whereas the control group did not improve with any load ($p > 0.05$; Figure 1D). Movement velocity with loads 20, 35, 50, 65, and 80% of posttraining 1RM did not change ($p > 0.05$) for the HL-90% and the *P*max − bw groups (Figures 1E, F). For the *P*max + bw and the control groups, movement velocity at the 20% load increased ($p < 0.05$) with training while for the *P*max + bw decreased ($p < 0.05$) at the 65% load. When an ANCOVA was applied for the analysis of the data, taking pretraining values as covariates, movement velocity with 65 and 80% of the 1RM loads was lower ($p < 0.05$) for the *P*max + bw group than for the *P*max − bw group (Figure 2).

Load-Power Relationship

The HL-90% and the *P*max − bw groups increased power output with loads 20, 35, 50, 65, and 80% of 1RM when body mass was either included in mechanical power calculations or not ($p < 0.05$; Figures 3A, B, E, F). The *P*max + bw group increased power output with loads 20 and 35% of 1RM when body mass was not included in mechanical power calculations and only with a 20% load when body mass was included ($p < 0.05$; Figures 3C, G). No changes in load-power relationship were observed for the control group ($p > 0.05$; Figures 3D, H).

When an ANCOVA was applied for the analysis of the data, with pretraining values as covariates, all training groups presented higher power output with the 20% load compared with the control group after training ($p < 0.05$). With the 35% load, the HL-90% and the *P*max − bw group had higher power values compared with control ($p < 0.05$). With the 50% load, the HL-90% and the *P*max − bw groups achieved higher power outputs compared with the *P*max + bw and control groups ($p < 0.05$). With the 65 and 80% of 1RM loads, the HL-90% group had higher ($p < 0.05$) power output after training compared with the *P*max + bw and control groups and the *P*max − bw group only from the *P*max + bw group (Figure 4A). Furthermore, when body mass was included in the calculations, the *P*max − bw group produced higher power outputs compared with the *P*max + bw group with the 50% load ($p < 0.05$). The HL-90% and the *P*max − bw groups had higher ($p < 0.05$) power output than the *P*max + bw group with the 65 and 80% of 1RM loads (Figure 4B).

DISCUSSION

In this study, we examined the changes in maximum strength, vertical jump performance and the load-velocity and load-power relationship after a training period by performing the jump-squat exercise using (a) a heavy load (90% of the 1RM), (b) an individual load that maximizes mechanical power output without including body mass in power calculations (moderate loads, 48–58% of the 1RM), and (c) an individual load that maximizes mechanical power output with body mass included in power calculation (low loads, 20–37% of the 1RM). The main findings of the study indicate that after a short term training period maximum strength improved more with heavy loads. Squat jump and CMJ height improved similarly with all loads while DJ performance was enhanced only with light loads. The load-velocity and the load-power curves showed a load specificity adaptation. Heavy resistance training improved more the high load portion of the curves, the low resistance training only the low load portion of the curves and the moderate resistance training caused similar adaptations at all portions of the curves (Figures 1 and 3).

Several studies have shown the superiority of heavy resistance loadings for the development of maximum strength (7,12,14). Similarly, in this study the greatest increases in semisquat 1RM by 15.2 ± 7.1% were found in the HL-90% group. It is worth noting, however, that even the *P*max − bw and the *P*max + bw groups, which exercised with loads of 20–58% of 1RM, increased their maximum strength by 6.6 ± 4.7 and 6.9 ± 7.1%, respectively. The ballistic execution of an exercise allows the development of higher forces and muscle activation because of the high acceleration of the movement (13,21). So, the ballistic nature of the jump-squat exercise, performed with low to moderate loads, combined with the moderate pretraining status of the subjects reassures that gains in maximum strength can be achieved with loads lower than maximal. Similarly, other studies have found an increase in maximum strength following ballistic training with loads 15–45% of 1RM (12,19,20). Therefore, low load exercises, performed in a ballistic way, can increase maximum strength in moderately trained individuals. It would be useful to examine what is the effect on well strength trained individuals or if ballistic training with low to moderate loads is of sufficient stimulus to retain maximum strength during in season training. In any case, high load training is the most efficient way for a maximum strength increase.

In this study, we observed load specificity in the adaptations on the load-velocity and the load-power curves. The HL-90% group increased velocity of movement and power output across all loads indicating the importance of strength training for power development. However, the magnitude of the increase was becoming greater as the load of testing was increasing. On the contrary, the *P*max + bw group that trained with low loads (20–37% of the 1RM), improved movement velocity and power output only with low loads, 20 and 35% of the 1RM. The *P*max − bw group, that trained with moderate loads (48–58% of the 1RM), showed an almost similar increase across the load-power curve. Therefore, the appropriate load for the enhancement of the part of the curve that is more related to the performance of an event should be selected for training. These results are in agreement with previous studies that have found a load specificity training effect on the load-velocity and load-power curves in the elbow flexors (19,23). In contrast, Cormie et al. (7) found similar changes in the force-velocity curve after training with loads 75–90 and 0–30% of the 1RM. The use of relatively weak individuals may explain the difference in the results and highlights the need for further study about the effect of strength level and training status on the neuromuscular adaptations with resistance training of various loads.

Despite the differences among the groups in the maximum strength and the load-power curve adaptations, all showed similar improvements in squat and CMJ height. This might be because the training groups had a similar increase in power output with low loads, that is, 20 and 35% of 1RM. The HL-90% and the $P\text{max} - \text{bw}$ groups produced a higher mechanical power output compared with the $P\text{max} + \text{bw}$ group only with moderate and heavy loads, that is, 50, 65, and 80% of 1RM. Furthermore, the HL-90% and the $P\text{max} - \text{bw}$ group improved their maximum power while $P\text{max} + \text{bw}$ group did not. Maybe, squat and CMJ height is more related to the changes in the power output with low loads because the jump itself involves the acceleration of only the body mass. It would have been interesting to measure a performance task that requires high power output when using higher loads. In agreement, Cormie et al. (7) found similar increases in vertical jump performance of relatively weak individuals after training with loads 75–90 and 0–30% of the 1RM. Also, in this study, we tried to equalize training volume among groups by executing a different number of repetitions at each set so the product of sets × reps × load will be approximately the same. Based on the actual data of each training group of the study and using the average load (actually the % of the 1RM express as kilograms to normalize differences between individuals) there was a difference in training volume of 8.5% between the $P\text{max} - \text{bw}$ and the HL-90%, 31% between the $P\text{max} - \text{bw}$ and the $P\text{max} + \text{bw}$ and 24% between the HL-90% group and the $P\text{max} + \text{bw}$ group. These differences are because of the different subjects included at each training group with diverse maximum strength values and maximum power loads. It is unclear, however, if these differences in training volume had an effect on the outcome measures of the study. Nevertheless, other studies have used this approach (7,19,20,24) and yielded acceptable data.

The participants of this study were moderately trained, and it appears that for these groups of individuals it is easier to increase their physical performance by training with a broad range of loads. Well-trained athletes, accustomed to resistance training, required a more specific ballistic power training to improve vertical jump performance than heavy load training (20,21,24). It would be interesting to see how well trained athletes will adapt to different training intensities and with the loads that maximize mechanical power output. Even more, what is the strength level after which an athlete should place more focus on power training and after achieving it which power level should focus again back to strength training?

An advantage of this study is that we applied programs of power training by individualizing the training stimulus using the loads that maximize mechanical power output and measuring this load for each individual separately for the specific exercise (jump squat) used for training. Other studies used either similar loads (as a percentage of the 1RM) for all the subjects to improve performance or based their selection of loads on results of previous studies without measuring the load that maximized power output of the individual (14,19,20,24). However, the maximal power load can range considerably from subject to subject. In this study, for all the subjects, power in the jump squat was maximized at 27.5 ± 8.5% of 1RM with a range of loads 8.6–45.7% of 1RM. Only Cormie et al. (7) used the load that maximized power output in a jump squat for each subject. However, they defined this load by measuring the peak power during the jump squat and not the average power as in this study. When measuring the peak power the load that maximizes mechanical power output is always only the body mass while when measuring the average power the load is heavier as shown in our study. Which method is better to determine the load that maximizes mechanical power output in the jump squat and if this individualization of the training load maximizes training adaptations requires further study.

In this study, we examined how 2 methods of calculating maximum power, that is, the inclusion or not of body mass and the associated optimal load for jump squats, affects strength and power performance after a short-term training program. It is clear from the training loads of the $P\text{max} - \text{bw}$ and the $P\text{max} + \text{bw}$ groups that the inclusion or not of body mass results in completely different optimal loads for jump squats, 20–37 vs. 48–58% of 1RM, respectively. After 6 weeks of training, the 2 groups had similar improvements in semi-squat maximum strength and squat and CMJ performance but different adaptations on the load-velocity and the load-power curve. It would have been interesting to see if the results would be different after a long-term training period or if there would be differences in other performance test, for example, sprinting. It is our belief that body mass should be included in power calculations because it is also accelerated with the bar and the neuromuscular system has to develop the appropriate force to overcome the system mass and not only the bar mass. However, it should be noticed that this method results in low optimal training loads. These loads, in moderately trained subjects, improve maximum strength and vertical jump performance but cause adaptations only on the low load portion of the load-power curve. If an athlete needs improvement in high-velocity movements then this load seems to be the right one. It does not appear to be suitable, however, for power development with higher loads or when aiming the improvement of all portions of the load-power curve. In that case, the calculation of the optimal load without the inclusion of body mass, although theoretically may not be proper, may be a guide for the individualization of the training load. The selection should be based on athlete needs and the training period of the long-term training cycle.

The load that maximizes mechanical power output appears to be a good reference point for designing power training programs. Regular monitoring of the load-power curve adaptations would be needed, however, because the optimal training load may change with training. The results of this study do not show, in general, statistically significant changes mainly because of the applied short-term training program. However, small to moderate changes in the optimal load did occur, and these changes depended on the load used for training. The optimal load for the HL-90% group that trained with heavy loads had a tendency to increase either as an absolute load or as a percentage of the 1RM. On the other hand, the optimal load for *P*max + bw group that trained with low loads had a tendency to decrease either as an absolute load or as a percentage of the 1RM. The optimal load for the *P*max − bw group that trained with moderate loads did not change. It appears that heavy load training, emphasizing maximum strength development, may increase the optimal load for power training whereas low load training, emphasizing velocity of movement, decreases the optimal load. In any case, studies with the application of longer duration training programs and in well-trained athletes should be contacted to examine the above observations.

PRACTICAL APPLICATIONS

The load that maximizes mechanical power appears to be a good reference point for power training. The inclusion of body mass for the determination of the optimal load is the proper method because the athlete applies forces to overcome body mass and bar mass at the same time. This method provides a low load for training, which improves mainly the velocity of movement at the low load portion of the load-power curve. This can be used for the enhancement of the velocity of movement or in training sessions when low stress, as far as intensity is concerned, is required. Although we believe that the proper method is to include body mass for power calculations, when body mass is not included the load that maximizes power output is moderate and using it for training increases all portions of the load-power relationship. This method appears to provide a load that can be used to individualize the training stimulus when power development across a range of loads is necessary. Nevertheless, in moderately trained subjects, heavy load training improves similarly as ballistic power training vertical jump performance and power output across a range of loads and maybe more with heavy ones. Furthermore, training with heavy loads improves to a greater extend maximum strength which may provide a better base for long-term power development. Therefore, heavy load training appears to be a more effective stimulus for moderately trained individuals.

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