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A New Approach to Developing Human Maximal Muscular Force: A Case Study

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ABSTRACT

Milosevic M, Milosevic M, Nemec P, Zivotic D, Izet R. A New Approach to Developing Human Maximal Muscular Force: A Case Study. **JEPonline** 2014;17(5):73-83. The aim of this study was to examined whether human maximal muscular force can be better developed using smaller or larger weights than the maximum. The screening/testing was performed on seven muscle groups based on measurements of a member of the Serbian National Basketball Team. The development of maximal force focused on, and was assessed according to, the following neuromuscular elements: (a) the maximal rate of force development, (b) synchronization and speed in the recruitment of motor units, (c) the maximal force of certain motor unit groups, (d) overall muscle density, (e) intramuscular coordination, and (f) intramuscular coordination through the application of lighter or heavier weights than the established maximum. The study consisted of 42 training sessions. Exercise performance and muscular potential were determined according to descriptive statistical analysis and data-fitting employing the least squares method. The training improvement yield with respect to initial measurement results ranged from 2.56 to 3.37 SD per muscle group or from 25 kg to 130 kg. The development of the potential maximum force per muscle group yielded results ranging from a 91.3% to 99.6% gain in performance. This can be compared to a previous 38% to 72% rate of gain in performance achieved earlier through maximal effort method of training. The obtained results confirm the hypothesis that maximum force can be better developed through the application of a new approach using smaller and larger weights than the previously established maximum or near maximum.

Key Words: Force Maximum, Motor Units, Basketball Center Player, Training Technology.

INTRODUCTION

In the game of basketball, there are situations in which outcomes depend on the maximal force of certain muscle groups. A large number of coaches use weightlifting as a means for developing this force. The main training principle to which the majority of coaches adhere is the physiological size principle that governs motor units' activation (10,22,23). This states that when a basketball player lifts the maximum or near maximum weight, he/she activates the majority of motor units, the fastest motor units are triggered, the discharge frequency is the greatest, and the motor units operate simultaneously (10,22,23). In accordance with the expressed principle, the lifting of maximal or near maximum weights through the maximal effort method (3 - 5 set x relative workload 90% - 100% of 1 RM x rep range 1 to 6) has been recommended in order to best achieve development in maximal muscular force (22,23). However, Carpinelli (6) has challenged such a position, arguing that the same physiological effects can be achieved by using lesser weights. The question is whether the development of maximal force can be achieved through a different approach. In order to address this issue, the following elements were established as the basis for this study:

1. The maximum force that can be generated by muscles in lifting weight (1 RM) depends on the maximal rate of force development, the synchronization and speed of the recruitment of motor units, the maximal force of certain motor unit groups, muscle density, intramuscular coordination, and intermuscular coordination (2,4,12-16,18,20).

2. The development of each value on which the maximum force depends could be achieved through specially designed training programs for lifting weights lighter (30% to 95% 1 RM) or heavier (130% and 150% 1 RM) than the established maximum and by using modern training technology in the application of this proposed new approach (17,19,20). Thus, it is hypothesized that maximal muscle force can be increased by using weights lighter or heavier than the established maximum weight through a special development of the maximal rate of force, the synchronization and speed of the recruitment for motor units, the maximal force of certain motor unit groups, muscle density, intramuscular coordination, and intermuscular coordination (2,4,12-15,18-20).

Therefore, the aim of this study was to examine whether developments in maximal muscular force can be better achieved though using weights lighter or heavier than the maximum. For the programming and control of training, a software hardware system (VAC Bioengineering) was used. The performance of the proposed approach was evaluated by comparing the results achieved by an individual top-level basketball player (player position: center) before and after the implementation of the proposed program.

METHODS

Subject

The dynamics of developing the maximum force will be shown in a basketball center player (height = 2.12 m; weight = 125 kg before treatment, 118 kg after treatment; age = 21 yrs). The subject was a member of the Serbian National Basketball Team for the full 4-yr process during which training through the use of maximal or near maximal resistance was employed in developing maximum force (9,10,23,24). The results of the athlete's development based on these former strategies are shown in Table 3 as the initial condition. The subject gave his informed consent to the procedures of the study. The conditions of the study were approved by the University's Ethics Committee.

Programming and Control of the Training for Maximal Force Development

Testing, programming, and control of the development of maximal force as well as the selected neuromuscular qualities was done using the newly proposed approach, standardized procedures, and a certified hardware and software system (VAC Bioengineering). At the onset of the training process that consisted of one initial and seven transition tests, the maximal force of the following muscle groups (triggered by a particular and identified corresponding exercise) was tested and evaluated using the 1 RM standard: (a) power clean (an integral indicator of back-waist extensors); (b) bench press (arm extensors); (c) half-squat (leg extensors); (d) behind-the-neck press (shoulder and arms extensors); (e) dead lift (back extensors); (f) “good morning” (back extensors); (g) pull-over (shoulder joint flexors); (h) sit-ups (trunk flexors); and (i) step-up (step test - hip and knee extensors).

The previously mentioned neuromuscular elements, as well as weight lifted and weight lifting speed were tested at the beginning of each month (the beginning of the training cycle) for each muscle group (VAC Bioengineering). The testing results were then applied to calculating the status, the potential value of maximum lifted weight, the training time in which a potential maximum can be achieved, and the increase of weights for the monitored muscle groups (Table 3). After each test (every month), a new training program consistent with the presented hypotheses for developing the maximum force of the monitored muscle groups was designed and implemented. The programs aimed to increase results in the rate of force development, maximal force of the certain groups of motor units, the synchronization and speed of the recruitment of motor units, muscle density, intramuscular coordination, and intermuscular coordination (Tables 1 and 2); all towards the primary objective of increasing the maximum force generated by the monitored muscle groups themselves. (1,2,4,7,12-15,17-20).

Table 1. Programming Effects of Training for the Rate of Force Development in One Training Session.

Momentary Effect / Muscle Groups and Exercises	Power Clean	Sit-Ups	Half-Squat	Bench Press	Dead Lift	Torso Rotations
Level of Force Generated in One Repetition (daN)	258	29	305	192	244	
Rate of Force Development in One Repetition – RFD (daN/s)	1984		2178	1628	964	
Time of Achieving RFD (sec)	0.130		0.140	0.118	0.253	
Rate of Change of Force in One Repetition - RCF (daN/s)	5832		7000	4200	1660	
Time of Achieving RCF (sec)	0.124		0.128	0.111	0.132	
Motor Units Recruitment Speed in One Repetition - MURS (absolute value)	10.3		16.6	8.3	6.9	
Time of Achieving MURS (sec)	0.102		0.106	0.098	0.112	
Synchronization of Motor Units in One Repetition (%)	87		89	86	83	
Level of Force Generated per 1 set (daN)	1290	145	1525	960	1220	
Level of Force Generated per 5 sets (daN)	6450	725	7625	4800	6100	
Level of Power Generated per 1 set (kW)	1.3	0.35	1.91	1.46	1.16	0.35
Level of Power Consumed per 1 set (kcal)	18.9	4.7	27	20.6	17.9	6.6
Level of Power Generated per 5 sets (kW)	6.5	1.8	9.6	7.3	5.7	1.7
Total Energy Consumption (kcal)	94.6	23.5	135	103	90	33

Table 2. Physical Work in One Training Session that Caused Programmed Training Effects for the Rate of Force Development.

Values / Muscle Groups and Exercises	Power Pull	Sit-Ups	Half-Squat	Bench Press	Dead Lift	Torso Rotations
Number of Sets	5	5	5	5	5	5
Number of Repetitions per Set	5	60	5	5	5	10
Weight of the Weight Plate (kg)	90		140	100	134	40
Weight Lifting Speed (m/s)	1.68		1.74	1.69	1.7	
Rest Interval between Sets (min)	3	3	3	3	3	3
Weight Lifted per 1 Set (kg)	450		700	500	670	400
Total Weight Lifted (kg)	2250		3500	2500	3350	2000

The programming of the training output was carried out on a monthly basis and was based on the afore mentioned quantified training objectives, the registered changes and effects of training and the training process in accordance with the basketball player's current situation, and the resources and development policy of maximum force (7,17-20). Free weights were used as the basic means of force development. Monthly training sessions were designed in such a way that on Monday in the 1st wk of training the speed of recruitment for motor units was developed, while on Friday the rate of force development was developed (1,17,19,20). During the 2nd wk of training the maximal force of certain motor units groups would be developed on Monday, while on Friday intramuscular coordination in combination with motor unit synchronization were developed (17-20). During the 3rd wk of training the muscle density was developed on Monday, and intermuscular coordination was developed on Friday (7,14,17-20).

Exercise Protocol

The exercise training protocol was carried out twice a week (Monday and Friday), each session lasting 1 hr. At each training 6 muscle groups were prioritized and exercised (3 exercise pairs), in 5 sets of 1 to 5 reps with a rest period of 3 min after each pair had completed its exercise pattern (17,19,20). The number of repetitions per set and the length of rest periods between the sets were determined (using VAC Bioengineering) by the capacity of the subject to perform for a prescribed period of time the prescribed level of the rate of force development, the maximal force of certain motor units groups, muscle density, the level of the synchronization and speed of the recruitment of motor units, and both intramuscular coordination and intermuscular coordination levels in each repetition (2,4,12-14,17-20*).*

The rate of force development, as well as other values on which the maximum force depends, were controlled by the weight and speed of weightlifting (determined by VAC Bioengineering). The following exercise pairs would be performed on Mondays: (a) power clean and sit-ups; (b) half-squat and bench press; and (c) dead lift and torso rotation (barbell with disc weights - 40 kg) (17,19,20). The following exercise pairs would be performed on Fridays: (a) power clean and sit-ups; (b) step-up and behind-the-neck press; and (c) "good morning" and pull-over (17,19,20). Each training session was designed in such way that the participant would perform all the sets and repetitions of the first pair, then the second pair, and finally the third pair (17,19,20).

To develop the speed of recruitment for motor units of the chosen muscle groups the weight of 70% of 1 RM was used. This weight was lifted at the maximum speed of lifting for the particular weight chosen according to the particular participant for 5 sets of 5 repetitions each (4,12,13,15,17,19,20). For the development of the maximal rate of force development the weight of 80% of 1RM was used in 5 sets of 5 reps each, and for muscle density the weight of 90% of 1 RM, in 5 sets, each comprised of 3 repetitions (4,7,12-15,17,19). Lifting was performed at maximum speed in both cases. The development of the maximal force of certain motor units groups, intramuscular coordination and intermuscular coordination was accomplished by varying the weights' heaviness and lifting speed (maximal, submaximal and large (80% of maximal)). The weights of 30%, 40%, 50%, 70%, 75%, 80%, 85%, 90%, 95%, 130% and 150% of 1 RM were employed, and exercises carried out in 5 sets of 1-5 repetitions each (17-20).

Motor unit synchronization development was based on exercises employing the weight of 95% of 1 RM, in 5 sets of 2 repetitions each, done at the maximum speed of lifting of the particular weight for the particular participant (17,19). The development of intramuscular coordination in combination with motor unit synchronization was achieved by combining the lifting of weights of 70%, 75%, 80%, 85%, 90% and 95% of 1 RM. Five sets of 2 to 5 repetitions each were done for each muscle group. Each of the 5 sets for each muscle group was done with each of different weights mentioned above. Immediately following the last repetition of the 5th set, 2 additional series of repetitions were done for each muscle group with a weight of 60% of 1 RM with a 5-sec break between repetitions. Each series was continued until the point at which the participant was unable to lift the weight (17,19). The lifting speed was maximal. The month regiment consisted of 3 wks of the exercise regime, with the 4th-wk set aside for tests and resting (5,17,19). The total regiment comprised 42 trainings (42 hrs of training work, in which the pure time of weight lifting was from 10 to 12 min per session; for the 7th-month duration, a measure of 7 to 8.4 hrs.

Data Analysis

Evaluating the effect of the training on maximum force incorporated the potential maximum, the training duration, and descriptive statistical parameters. To determine the potential (capacity) values of the lifted weight the method of successive measurements has been employed. Repeatedly measured results have been approximated by a second degree polynomial, using the least squares method (11):

$$\mathbf{y = ax^2 + bx + c} \qquad (1)$$

where **y** is the lifted weight in 1 RM expressed in kg, **x** is the time expressed in months, and **a**, **b**, and **c** are polynomial coefficients indicating (a) the speed with which the function increases or decreases, (b) the steepness of the parabola when intersecting the y-axis, and (c) a free member.

The potential value of maximum lifted weight in 1 RM was calculated as follows:

$$\mathbf{y = -(b^2 - 4ac) / (4a)} \qquad (2)$$

The training time in which a potential maximum in 1 RM could be achieved was calculated as follows:

$$\mathbf{x = -(b) / (2a)} \qquad (3)$$

For all of the data descriptive statistics have been performed. So that the training increase in various muscle groups could be compared, it was decided that in addition to registering the absolute and relative measures of these increases. They were also expressed in standard deviations (SD). The training increment for the time of training, for all the muscle groups, was calculated as follows:

$$\mathbf{y = (Diff) / (SD)} \quad (4)$$

where the **y** is the training increment expressed in standard deviations (**SD**), **Diff** = **Max – Min**, where **Max** is the maximum value of the lifted weight in 1 RM expressed in kg, **Min** is the minimum value of the lifted weight in 1 RM expressed in kg, and **SD** is the standard deviation (23).

RESULTS

Table 3 contains the following results for all participant muscle groups and exercises: one-repetition maximum (1 RM) measured initially and after seven monthly training cycles. Estimated potential one-repetition maximum (1 RM) and the number of months needed to reach the value. Table 3 also shows the differences between estimated potential values and the values measured initially and after seven monthly training cycles for all muscle groups and exercises. Finally, Table 3 shows the reached increase after 7 monthly training cycles for all muscle groups and exercises.

Table 3. State, Capacity, and Increase of Weights.

Variables / Muscle Groups and Exercises	Power Clean	Sit-Ups	Half-Squat	Bench Press	Dead Lift	Behind the Neck Press	Pull-Over	Step-Up
Initial State (kg)	90	20	150	90	140	40	70	60
Estimated Potential (capacity) (kg)	125	52	281	130	219	82	117	140
In Time (month)	9	8	8	9	8.7	8	9	8
Starting Level Based on Capacity (%)	72	38	50.3	69.2	63.9	48.8	60	42.8
State After 7 Monthly Training Cycles (kg)	115	50	280	120	200	75	110	130
Reached Level Based on Capacity (%)	92.0	96.1	99.6	92.3	91.3	91.4	94.0	92.8
Increase After 7 Monthly Training Cycles (kg)	25	30	130	30	60	35	40	70
Increase After 7 Monthly Training Cycles (%)	27.8	150	86.7	33.3	42.9	87.5	57.1	116.7

Table 4 shows the descriptive statistics of one-repetition maximum (1 RM) for all the subjects' muscle groups and exercises. Descriptive statistical analysis was performed on the results achieved by the subject throughout eight measurements.

Table 4. Descriptive Statistics.

Muscle Groups and Exercises	Min	Max	Mean	SD	SD/Mean	Diff/SD
Power Clean	90.00	115.00	105.89	7.78	7.1	3.37
Half-Squat	150.00	280.00	238.89	42.78	18.5	2.99
Bench Press	90.00	125.00	111.67	11.38	11.2	2.83
Dead Lift	140.00	200.00	182.78	18.89	10.5	3.16
Behind-the-Neck Press	40.00	75.00	62.77	12.53	20.3	2.79
Pull-Over	70.00	115.00	96.89	17.34	18.4	2.56
Step-Up	60.00	130.00	113.89	22.33	20.5	3.04
Sit-Ups	20.00	50.00	40.50	9.76	24.1	3.07

DISCUSSION

The results (Tables 3 and 4) confirmed the assumption that maximum force can be developed by weights that are smaller (30% to 95% 1 RM) or larger (130% and 150% 1 RM) than the maximum or near maximum (6,17,19,20). The subject took part in the experiment as a top-level basketball player for the full training process. For 4 yrs prior to the study, the subject had worked on the development of force by weightlifting. He had done so using popular recommendations of an exercise regiment utilizing weights at a maximal or near maximal (9,10,22,23). In the preparatory period (pre-season), the subject would have 4 training sessions·wk^{-1}, while during the season 2 training sessions·wk^{-1} (9). In these training sessions, he would do exercises for legs, abdominal muscles, chest and back, shoulders and arms (9). He would perform 3 to 5 sets of 1 to 6 repetitions per set with a 5-min break between sets (9). His multiannual training results are presented in Table 3 as the initial results (1 RM) for each monitored muscle group. The results (Table 3) show that through this exercise regiment the subject achieved 38% to 72% of his potential per monitored muscle group.

The newly proposed training approach whose validity has been documented by this case study correctly applied the size principle in the training programming (6,8), while also introducing innovations (3,17-20). These innovations are reflected in the following: (a) heavier and lighter weights than the maximum were used; (b) the methodology for determining the force maximum potential and the time for achieving were prescribed, thus improving the programming and training control; (c) each training session was programmed and controlled using the hardware - software system VAC Bioengineering; and (d) the training sessions for the maximal rate of force development, the synchronization and speed of the recruitment of motor units, the maximal force of certain motor unit groups, muscle density, intramuscular coordination, and intermuscular coordination were specially programmed and implemented (1,2,7,16-20).

For each training session, the training objectives were quantified in advance and the training effects were calculated (Table 1), as were registered the changes and effects of training and the training process (Table 2) in accordance with the subject basketball player's existent situation. The programmed effects and changes-control were done through monitoring the weight and speed of the weight lifting, the number of repetitions per set, the number of sets, the breaks between sets, the methods of introducing exercises in the training session, etc. (VAC Bioengineering). In comparison to the subject's previous training regiment, the introduced regiment's number of training days per week, pure lifting weight time, and training duration were reduced (17,19,20). The number of sets and repetitions per set was altered (17,19-21). The break duration between sets was decreased (17,19-21). The number of muscle groups treated per session was increased. Instead of the successive introduction of the exercises during training, parallel introduction was applied (17,19,20).

This new approach yielded significantly better results in the maximal force of all the treated muscle groups when compared to the initial results achieved through the conventional approach (Table 3). The subject reduced his body weight from 125 to 118 kg, a measure of 6%. The training increment ranged from 2.56 to 3.37 SD per muscle group (Table 4), or from 25 kg to 130 kg in absolute amounts; that is, from 27.8% up to 150% in relative amounts (Table 3). Power clean increased by 25 kg (a 27.8% improvement, or 3.37 SD), bench press by 30 kg (33%, or 2.83 SD), half-squat by 130 kg (86.7%, or 2.99 SD), behind-the-neck press by 35 kg (87.5%, or 2.79 SD), dead lift by 60 kg (42.9%, or 3.16 SD), pull-over by 40 kg (57.1%, or 2.56 SD), sit-ups by 30 kg (150%, or 3.07 SD), and step-up by 70 kg (116.7%, or 3.04 SD) (Table 3 and 4).

The training increment (Table 4), evaluated using standard deviation (SD), indicates that the applied approach via modern training technology has a relatively equally great influence on the development of maximum force of all muscle groups. For each muscle group, the potential maximal value and the time in which it could be reached were calculated (Table 3). After 42 training sessions, the subject achieved increases of 91.3% to 99.6% of his potential maximum, instead of the 38% to 72% registered in his previous multiannual work. To achieve maximum potential with this type of training applied to 4 muscle groups 1 month is needed, and for an additional 3 groups another 2 months (Table 3). The results obtained indicate that when compared to the classical approach the new approach combined with training technology provided a higher maximum force gain in all of the monitored muscle groups of the monitored subject.

CONCLUSIONS

The results confirm the hypothesis that maximum force can be successfully developed using lighter and heavier weights than the maximum. This was accomplished through individual training session programming that applied modern training technology to develop the rate of force development, the synchronization and speed of recruitment for motor units, the maximal force of certain motor unit groups, muscle density, intramuscular coordination, and intermuscular coordination. After the application of a 7 month exercise program, the subject demonstrated improvement in all measured categories with improvements ranging from 25 kg to 130 kg, or 27.8% to 150%.

After 42 training sessions of applied new training and technology, the subject achieved 91.3% to 99.6% of his potential in lifting the maximum weight in 1 RM, compared to 38% to 72% achieved in his previous multiannual work. To achieve maximum potential with this type of training applied to 4 muscle groups 1 month is needed, and for an additional 3 groups another 2 months. Given that the results of this study have demonstrated a positive effect of the new training regiment on the development of maximum force for a top-level basketball player, it would be of interest to repeat the study on other elite players and examine whether it would lead to similar improvements.

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