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Effects of specific resistance training program on force-velocity relationship

KONSTANTINOS FLESSAS, MARIA KOUMPOULA,
DESPINA TSOPANI, CHARALAMPOS OIKONOMOU

Department of Physical Education and Sport Science, University of Athens

Abstract

Aim: Resistance training is the most famous method for the prevention, rehabilitation of myotendinous injuries and especially for the development of muscle's ability in competitive and recreational sports. The purpose of the present study was to examine the average exerted force $(|\vec{F}|_{mar})$, the mean power consumption (P_{mean}) and the work production on Quadriceps Femoris Muscle of elite athletes, in accordance with joint's knee movement velocity, during eccentric contractions, before and after the application of a specific resistance training program.

Methods: 14 elite athletes participated in this study. Seven of them (training group) performed isometric and eccentric contractions on isokinetic dynamometer before and after the application of specific resistance training program. The other seven athletes (control group) followed the training program of their team and they have participated only to the procedure of measurements.

Results: The results showed, that after the application of the specific training program, the subjects improved significantly ($p < .05$) $|\vec{F}|_{mar}$, P_{mean} ($p < .05$) at high angular velocities of joint's knee movement and maximal isometric exerted force ($|\vec{F}|_{iso}$, $p < .05$).

Conlusion: This study suggests that the application of the specific training program creates adaptations to the subject muscles' which concerns the power consumption ability and the maximal effort activation.

Key Words: *Force-velocity relationship, eccentric action, average force, power consumption, work production, resistance training.*

INTRODUCTION

Muscle strengthening is not only a significant tool in the prevention and rehabilitation of myotendinous injuries but also in the improvement of the performance of athletes (29). The successful performance in most sports depends upon attainment of some threshold level for strength, power and velocity (21). Strength is the ability of neuromuscular system to generate force. The force-velocity relationship together with three types of muscle action: concentric, isometric, eccentric, is described by Hill (18, in vitro). While in vitro, the level of force produced during eccentric action, increases with the increase of the velocity of movement (1 to 1,85 times higher than isometric, 29, 2), In vivo (during voluntary eccentric actions of human muscle) the exerted force is not altered (it maintains a level consistent with that of the isometric) while the speed of the joints increases (6, 8, 10, 31, 32). These results differ when an electrical stimulation is applied to subjects' muscles (9, 33). Research has shown that resistance training is the most widely applied and commonly accepted method of muscle strengthening. There are two major resistance training methods. The first one concerns the use of low resistance – high velocity contractions and the second the use of high resistance – low velocity contractions without any of them to exceeding muscle strengthening (1). While eccentric action is related to a high level of exerted force and myotendinous injuries (12) it is important that athletes in training be prepared for the strenuous load which their muscle system carries while involved in athletic activity (3). Considering power, her expression and development is important from a sports performance perspective. By definition, more power is consuming when the same amount of work is produced in a shorter period of time or when a greater amount of work is produced during the same period of time. In many sport activities such as throwing, jumping, striking and change of directions the time over which athletes can apply force and accelerate their body or other masses is minimal (19). The purpose of this research is to study the average exerted force ($|\vec{F}|_{mar}$), the power consumption (P_{mean}) and the work production (W) on Quadriceps Femoris Muscle of elite athletes, during eccentric actions, before and after the application of a specific resistance training program.

MATERIALS AND METHODS

Participants: Fourteen elite athletes (14) who participated in A1 division in the Greek volleyball, handball and basketball championship (6 volleyball players, 4 basketball players and 4 handball players) took part in the research. Seven (7) of whom undertook a specific resistance training program (training group, 3 volleyball players, 2 basketball players and 2 handball players) while the other seven athletes (control group, 3 volleyball players, 2 basketball players and 2 handball players) followed the training program of their teams. Table 1 shows the anthropometric characteristics.

Table 1. *Anthropometric characteristics of subjects, age (yr), height (cm) and weight (kg). Values, means and SD for training and control group.*

Training Group				Control Group			
Subjects N = 7	Age (yr)	Weight (kg)	Height (cm)	Subjects N = 7	Age (yr)	Weight (kg)	Height (cm)
TRE 1	31.00	85.00	189.00	CON 1	23.00	94.50	197.00
TRE 2	28.00	91.00	196.00	CON 2	28.00	94.00	200.00
TRE 3	21.00	91.50	186.00	CON 3	28.00	84.50	180.50
TRE 4	25.00	84.00	190.00	CON 4	22.00	99.00	206.00
TRE 5	24.00	104.00	207.00	CON 5	22.00	94.00	194.00
TRE 6	23.00	92.00	177.50	CON 6	24.00	80.00	172.00
TRE 7	24.00	105.00	197.00	CON 7	26.00	85.50	190.00
Mean	25.14	93.21	191.79	Mean	24.71	90.21	191.36
SD	3.34	8.34	9.35	SD	2.63	6.87	11.71

Apparatus: The isokinetic dynamometer Kin-Com 2 (Chattanooga Group, Inc., Chattanooga, TN) was used to measure the exerted force of the Quadriceps Femoris Muscle.

Measurements: Average value of force ($|\vec{F}|_{mar}$, N) is the mean of values of force that was measured on the tibia, at a distance of 0,34m from the centre of joint's rotation, per 0.01 s from the beginning of measurement and up to the point where the maximal force was appeared. $|\vec{F}|_{mar}$ calculation concerns the numerical medium value by the beginning of movement until the peak value of force ($|\vec{F}|_{max}$) at the time curve with sampling rate 100 values/s:

$$|\vec{F}|_{mar} \approx \frac{|\vec{F}_1| + |\vec{F}_2| + |\vec{F}_3| + \ldots + |\vec{F}_k|}{k} \quad k \in A$$

were: k = number of moment Force measurements by the beginning of movement until the peak value of force at each angular velocity and $|\vec{F}_k| = |\vec{F}|_{max}$

$|\vec{F}|_{mar}$ was measured during eccentric actions of the left Quadriceps Femoris Muscle in fifteen (15) different (10°/s, 20°/s, 30°/s, 40°/s, 50°/s, 60°/s, 70°/s, 90°/s, 110°/s, 130°/s, 150°/s, 200°/s, 250°/s, 300°/s) angular velocities ($\vec{\omega}$, °/s), of the knee joint. Also the maximal exerted force of the same muscle was measured during isometric action ($|\vec{F}|_{iso}$, N) in the angle of the join at 900 (at 0° we have full knee extension). The exerted force is defined, in the present study, as this force, with the same amount of torque, applied to the tendon of quadriceps femoris muscle and it is measured by Kin-Com, on the tibia, at a distance of 0,34 m from the centre of joint's rotation.

Mean power consumption (P_{mean}, Watt) was also calculated. Power consumption was calculated by the mathematic relation $P = |\vec{F}| \cdot |\vec{V}|$ (gradient product) where $|\vec{F}|$ and $|\vec{V}|$ was the moment measurements every 0.01 s while the Pmean was calculated as the numerical medium value of the moment values of power:

$$P_{mean} \approx \frac{\sum_{i=1}^{n} |\vec{F}_i| \cdot |\vec{V}_i|}{n} \quad n \in A$$

were: n = number of moment measurements at each angular velocity.

The calculation of linear velocity (m/s) was estimated by the mathematic relation:

$$\vec{V} = \vec{\omega} \cdot \vec{R} \quad \text{(inner product)}$$

were: $\vec{\omega}$ is the moment angular velocity converted from deg/s (°/s) in rad/s
$\vec{R}$ is the length of lever arm (m).

Finally the mechanical work production (W, Joule) was calculated. Work production was defined as the integral, according Riemann, of moment values of power in the time that the measurement lasted. Work was calculated with numerical integration according Riemann of values of power sampling in all the length of force-time curve so that are taken into consideration any possible alterations of velocity at the beginning and the end of effort (acceleration and deceleration phases):

$$W = \int_{t=0}^{t=a} P \,.\, dt$$

a = duration of movement
P = consumed power

Measurement Procedure: The measurement procedure was carried out at the National Centre for Athletic Research of Athens, one day prior the beginning and one day after the completion of the resistance program. Each participant was requested to sign a consent form. After a specific warm up protocol the participant sat on the dynamometer chair (the angle formed 110°, angle to the back of the chair) placing his left knee beside the power meter lever. Special straps were used in order for the spine to be stabilized at the chair back, the left thigh to be stabilized on the chair seat and the left tibia to the meter lever arm. A padded inelastic cuff was placed between the meter lever arm and the tibia and the necessary modifications were made so that the meter's rotation axis was aligned with knee joint rotation axle, at the maximum possible grade, relevant to the anatomy of the knee joint. Prior to the beginning of the testing, the weight of the exercised limb was measured with the dynamometer so that the force measurement would be corrected by the inertial force (gravity effect). The position of each participant and the lever arm length were recorded in order to remain the same throughout the testing. The researcher verbally encouraged the participants in order to increase their motivation during the testing. The participants were able to follow their effort on the screen in real time so that they had visual feedback of their performance (28). The lever arm's length remained the same for all participants at 0.34 m. The first recorded measurement concerned the isometric action. Every participant performed the isometric contraction while the lever arm was at the angle of 90o (at 0° we have full knee extension). Before the measurement commence each participant performed 3 trial sub-maximal efforts. After A 90 s rest period, 3 maximal voluntary isometric contractions were performed with a 5s duration and a 90s rest period. Maximal isometric force was determined from the plateau of the force-time curve. The eccentric contractions were performed at different movement velocities of the knee joint starting from the faster (300°/s) and concluding with the slower (10°/s). The participant performed from 2 to 5 sub-maximum efforts under every angular velocity. After a 90 s rest period he performed 3 maximum efforts. The knee joint movement was taking place between the angle of 17° and 90°, meaning that the movement range was 73°. In order for the dynamometer lever arm to start moving, at the angular velocity that it was adjusted to, the athlete, with his knee joint angle at 17°, had to overcome the prearranged force (preload) that was 30% of the average maximum voluntary isometric force while having the knee joint at 90°.

Training Procedure: The training program, which the participants followed , lasted 55 days and included weight lifting (during isotonic contractions) at the kinetic schema (Figure 1) of the measurement procedure at repeated working periods of 10s (set) with equal rest periods and increasing load for each following set (26). The number of sets was 4 (4 sets comprised 1 training cycle). The participant was obliged to carry out 10-12 repetitions at each set during which time no pause was allowed at the edge of the movement (at 90° and 0° of knee joint). These limitations, during the execution of the repetitions of each set, ensured that the training program would take place under greater knee joint angular velocities (180°/s-216°/s). Each session comprised four training cycles and the rest period between the cycles was three minutes. The load of the first set was equal to 30% of the $|\vec{F}|_{iso}$ while the increase in the weight, at each level, was equivalent to 25% of the previous load (Table 2). The participants carried out one session per day.

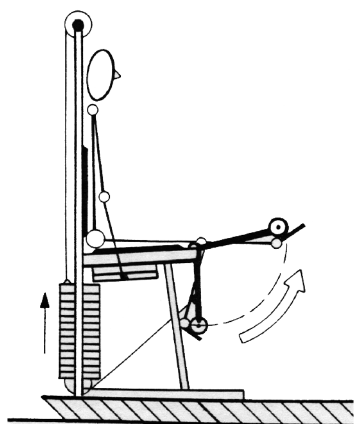

Figure 1: *The kinetic schema of resistance training program using weight machine.*

Table 2. *Resistance training protocol.*

Set		A		B		C		D	
Load (kg)		30% (MMI 90°)		L_A + 25% L_A		L_B + 25% L_B		L_C + 25% L_C	
Exercise period (sec)		10		10		10		10	
Rest period (sec)	0 Time		10		10		10		180
Repetitions		10 - 12		10 - 12		10 - 12		10 - 12	

MMI 90°: maximal exerted isometric force (as measured in Kin-Com) of quatrecips at angle of knee joint of 90°(kg)
L_A: Load of A set equal to 30% of MMI 90°
L_B: Load of B set
L_C: Load of C set

Statistical analysis: Two-way ANOVA (training X velocity) with repeated measurements were conducted in order to evaluate the effects of the training program on each of dependent variables the $|\vec{F}|_{mar}$ the work production (W) and the power consumption (P_{mean}) at the the different angular velocities of the movement. Follow-up analysis to the ANOVA, multiple comparisons with the Bonferroni procedure was used in order to determine which knee joint angular velocities revealed significant statistical differences between measurements before and after the apply of the training program. The follow-up multiple comparisons were taken for the variants for which the ANOVA showed that the training had an effect on the measurements. Simple linear regression analysis was used in order to calculate the regression line of the variants before and after the application of the training program. A paired t-test analysis was used in order to define the effect of the training program on the $|\vec{F}|_{iso}$. A t-test analysis was used in order to define whether the measurements of the $|\vec{F}|_{mar}$, at 300°/s knee's joint movement velocity differ from those of the $|\vec{F}|_{iso}$, during isometric (knee's joint angle 90°) contraction of the same muscle before the training application. A t-test analysis was used in order to define whether the measurements of the $|\vec{F}|_{mar}$, at 300°/s knee's joint movement velocity differ from those of the $|\vec{F}|_{iso}$, during isometric (knee's joint angle 90°) contraction of the same muscle after the training application.

RESULTS

The effects of the training program on Fmar: A significant development ($F = 16.87$, $p < .01$) on $|\vec{F}|_{mar}$ was noted after the application of training program (Figure 2, Table 3). The multiple comparisons with the Bonferroni procedure ($p < .05$) showed that the athletes improved the $|\vec{F}|_{mar}$ after the application of the training program at higher angular velocities of the knee joint, 150°/s, 200°/s, 250°/s (this improvement of $|\vec{F}|_{mar}$ fluctuated between 22.82% to 24.41% at these velocities). There wasn't any significant improvement on $|\vec{F}|_{mar}$ after the application of the training program to the control group.

Table 3. *Mean values of $|\vec{F}|_{mar}$ (N) in different angular velocities ($\vec{\omega}$, °/s) before and after the application of training program for training and control group.*

Training group

	Ang. Veloc	10°/s	20°/s	30°/s	40°/s	50°/s	60°/s	70°/s	80°/s	90°/s	110°/s	130°/s	150°/s	200°/s	250°/s	300°/s
F_{mar}(N)	**BEFORE**															
Mean		744.482	709.605	775.889	845.365	848.642	847.190	852.385	871.218	806.051	738.365	757.062	**680.799**	**672.820**	**686.833**	738.476
SD (±)		154.152	141.636	161.361	146.420	129.625	168.555	148.708	167.890	109.609	138.473	169.414	179.246	195.527	150.923	156.567
F_{mar}(N)	**AFTER**															
Mean		751.791	795.079	913.044	899.864	920.979	909.652	916.798	926.071	904.049	849.934	855.880	**840,95***	**837,05***	**843,57***	861.170
SD (±)		115.868	208.798	197.953	146.412	149.158	161.404	155.977	184.430	128.919	160.319	164.817	171.431	152.110	129.048	119.360

* Alterations in F_{mar} ($p < .05$)

Control group

	Ang. Veloc	10°/s	20°/s	30°/s	40°/s	50°/s	60°/s	70°/s	80°/s	90°/s	110°/s	130°/s	150°/s	200°/s	250°/s	300°/s
F_{mar}(N)	**BEFORE**															
Mean		670.030	638.640	698.300	760.830	763.780	762.470	767.150	784.100	725.450	664.530	681.360	612.720	605.540	618.150	664.630
SD (±)		138.740	127.470	145.220	131.780	116.660	151.700	133.840	151.100	98.650	124.630	152.470	161.320	175.970	135.830	140.910
F_{mar}(N)	**AFTER**															
Mean		682.360	649.410	711.520	773.750	776.090	777.570	780.150	798.110	737.110	664.260	695.990	624.730	606.070	648.640	678.780
SD (±)		168.230	151.360	178.700	163.280	147.770	192.200	164.900	185.150	133.850	162.450	193.110	193.050	205.620	169.900	183.040

Table 4. *Mean values of Mean Power Consumption (P_{mean}, Watt) in different angular velocities ($\vec{\omega}$, °/s) before and after the application of training program for training and control group.*

Training group

	Ang. Veloc	10°/s	20°/s	30°/s	40°/s	50°/s	60°/s	70°/s	80°/s	90°/s	110°/s	130°/s	150°/s	200°/s	250°/s	300°/s
F_{mar}(N)	**BEFORE**															
Mean		–39.160	–76.000	–131.870	–193.060	–241.380	–286.040	–339.100	–369.040	–401.460	–432.650	–536.470	–540.100	–695.370	–746.170	–799.270
SD (±)		9.660	18.580	32.920	44.050	53.170	67.200	81.190	91.720	85.310	103.450	154.390	176.400	218.910	186.230	191.570
F_{mar}(N)	**AFTER**															
Mean		–38.820	–86.950	–150.600	–204.450	–257.670	–310.080	–358.220	–404.770	–454.780	–529.610	–613.92	–664,130*	–858,500*	–895,700*	–938,210*
SD (±)		9.780	25.740	40.220	42.200	56.350	66.380	83.100	100.350	103.63	129.030	155.480	206.110	228.030	179.730	167.19

* Alterations in P_{mean} ($p < .05$)

Control group

	Ang. Veloc	10°/s	20°/s	30°/s	40°/s	50°/s	60°/s	70°/s	80°/s	90°/s	110°/s	130°/s	150°/s	200°/s	250°/s	300°/s
F_{mar}(N)	**BEFORE**															
Mean		–35.240	–68.400	–118.680	–173.750	–217.250	–247.440	–305.190	–332.140	–361.310	–389.38	–482.820	–486.090	–628.830	–671.550	–719.34
SD (±)		8.690	16.720	29.630	39.650	47.860	60.480	73.070	81.650	76.780	93.100	138.950	158.760	197.020	167.600	172.410
F_{mar}(N)	**AFTER**															
Mean		–36.010	–69.650	–121.190	–177.030	–221.31	–262.790	–311.160	–338.500	–368.400	–390.080	–494.440	–496.990	–627.290	–672.880	–735.50
SD (±)		10.660	19.220	35.550	46.600	56.590	73.160	85.420	94.140	94.250	113.800	167.150	183.850	224.300	202.390	215.90

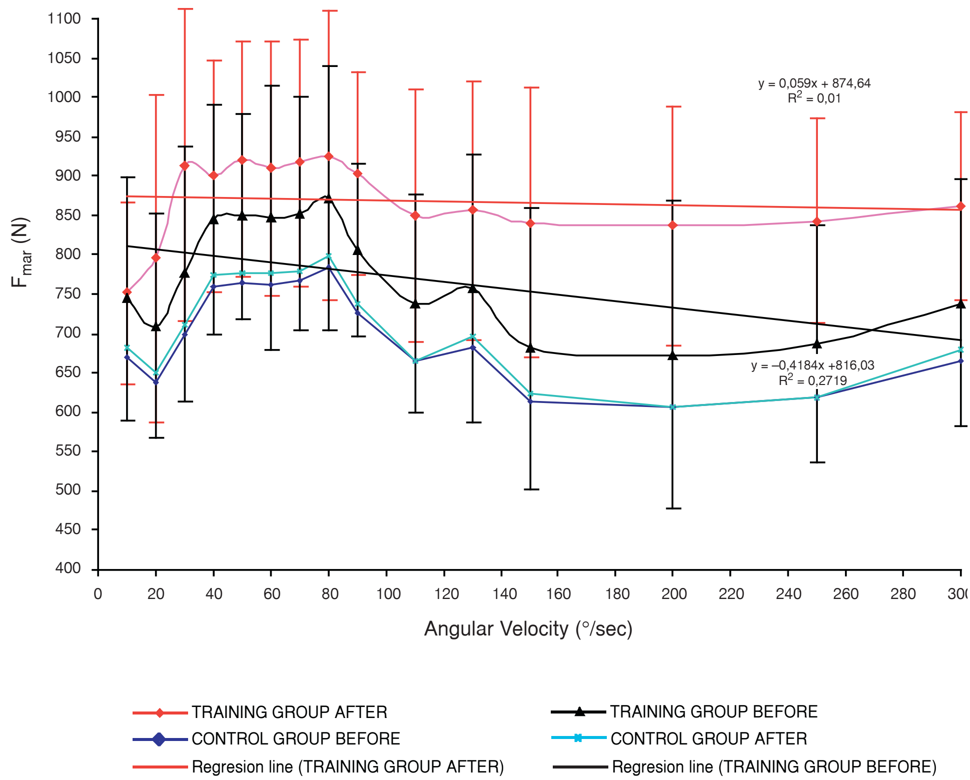

Figure 2: *Relationship of Average Exerted Force ($|\vec{F}|_{mar}$, N) and angular velocity ($\vec{\omega}$, °/s) of knee joint during eccentric actions of quadriceps femoris muscle before and after the application of training program for training and control group. *Significant alterations in $|\vec{F}|_{mar}$ ($p < .05$) after the application of training program. Regression lines for training group before and after the application of training program.*

The effects of the training program on P_{mean}: A significant development ($F = 13.62$, $p < .01$) on Pmean was noted after the application of training program (Figure 3, Table 4). The multiple comparisons with the Bonferroni procedure ($p < .05$) showed that the athletes improved the P_{mean} after the application of the training program at higher angular velocities of the knee joint, 150°/s, 200°/s, 250°/s and 300°/s (this improvement of P_{mean} fluctuated between 20.53% to 25.50% at these velocities). There wasn't any significant improvement on P_{mean} after the application of the training program to the control group.

Table 5. *Mean values of Mechanical Work (W, Joule) in different angular velocities ($\vec{\omega}$, °/s) before and after the application of training program for training and control group.*

Training group

	Ang. Veloc	**10°/s**	**20°/s**	**30°/s**	**40°/s**	**50°/s**	**60°/s**	**70°/s**	**80°/s**	**90°/s**	**110°/s**	**130°/s**	**150°/s**	**200°/s**	**250°/s**	**300°/s**
Work	**BEFORE**															
Mean		–281.1526	–266.7206	–311.6325	–352.9217	–352.1578	–344.7830	–355.1836	–349.4239	–330.8879	–300.6948	–321.5726	–277.9641	–278.4077	–283.1621	–292.015
SD (±)		72.1983	66.3733	72.5204	73.1185	79.8378	72.4620	81.9920	82.2463	75.8133	73.6804	86.6228	86.4179	85.4242	76.6927	76.9954
Work	**AFTER**															
Mean		–277.9723	–315.4658	–346.9532	–366.0810	–355.8065	–363.1459	–363.5848	–355.3213	–353.0395	–338.6857	–347.6457	–329.712	–335.8583	–327.8391	–317.9966
SD (±)		84.3651	108.6756	92.5972	79.0779	79.0989	77.7176	88.7224	90.0678	83.3962	83.3520	86.7225	112.8874	96.3904	70.3108	74.7441

Control group

	Ang. Veloc	**10°/s**	**20°/s**	**30°/s**	**40°/s**	**50°/s**	**60°/s**	**70°/s**	**80°/s**	**90°/s**	**110°/s**	**130°/s**	**150°/s**	**200°/s**	**250°/s**	**300°/s**
Work	**BEFORE**															
Mean		–253.040	–240.050	–280.470	–317.630	–316.940	–310.300	–319.670	–314.480	–297.800	–270.630	–289.420	–250.170	–250.570	–254.850	–262.810
SD (±)		64.980	59.740	65.270	65.810	71.850	65.220	73.790	74.020	68.290	66.310	77.960	77.780	76.880	69.020	69.300
F_{mar} (N)	**AFTER**															
Mean		–285.93	–244.790	–286.69	–323.440	–322.820	–316.230	–325.510	–320.550	–304.310	–270.960	–296.520	–255.200	–250.710	–255.780	–268.790
SD (±)		80.800	70.120	81.820	78.730	83.560	79.190	85.2080	86.850	85.760	76.460	96.440	88.380	86.000	83.300	84.710

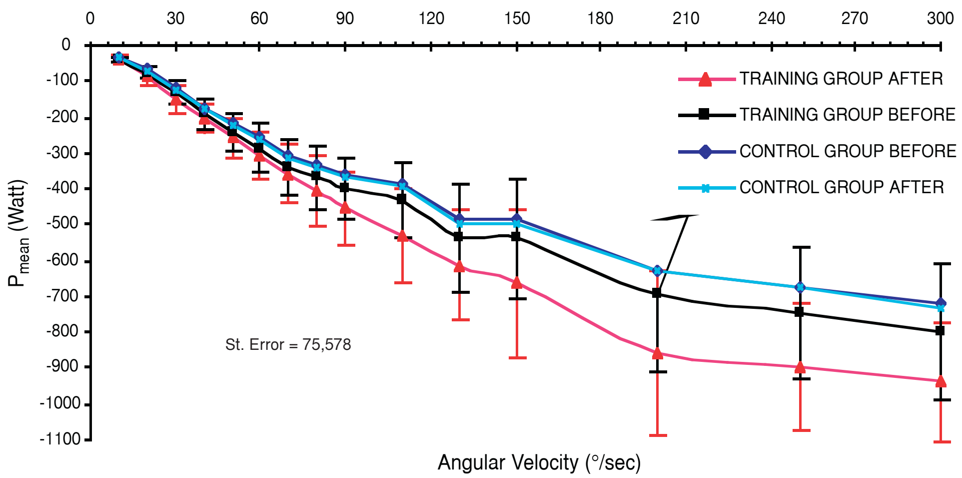

Figure 3: *Relationship of Power Consumption (Pmean, Watt) and Angular Velocity ($\vec{\omega}$, °/s) of knee joint during eccentric actions of quadriceps femoris muscle before and after the application of training program for training and control group. *Significand alterations in Pmean (p,.05) after the application of training program.*

The effects of the training program on W: No significant change in Work production was noted for either group after the application of the training program (Table 5).

The effects of the training program on $|\vec{F}|_{iso}$: The paired t-test ($p < .05$) showed (Table 6) that the $|\vec{F}|_{iso}$ was significantly increased after the application of the training program. Contrary to that, there was not such a difference within the control group.

Comparison between $|\vec{F}|_{mar}$ (300°/s) and $|\vec{F}|_{iso}$ before and after the training program: The paired t-test analysis, showed (Table 7) that in the training group the $|\vec{F}|_{mar}$ at a knee's joint angular velocity of 300°/s was significantly higher from $|\vec{F}|_{iso}$ after the application of the training program. There wasn't any significant difference between $|\vec{F}|_{mar}$ at a knee's joint angular velocity of 300°/s and $|\vec{F}|_{iso}$ before or after the application of the training program to the control group

The effects of the velocity on $|\vec{F}|_{mar}$, W, P_{mean}: There was a significant affect of the knee's joint angular velocity to the P_{mean} ($F = 65.4$). On the contrary, the angular velocity of the knee's joint didn't have any significant affect to the $|\vec{F}|_{mar}$ and W.

Gradients in regression lines of $|\vec{F}|_{mar}$, W, P_{mean}: The analysis of simple linear regression for $|\vec{F}|_{mar}$ showed that there was a positive change 19,330 in the gradient of the regression line (Table 8). The gradient of the regression line did not change significantly for the control group.

DISCUSSION

The hypothesis of the present study was that the athletes, who participated in the specific training program, on the eccentric region of their force-velocity curve, would demonstrate an increase of average exerted force, of power consumption and of work production especially at high knee joint angular velocities. The results showed that there was a positive change (19,33°) in the gradient of the regression line of $|\vec{F}|_{mar}$ (Figure 2, Table 8) with axon (x) of angular velocity after the application of the weight lifting training program. Also there was an increase in $|\vec{F}|_{mar}$ at high angular velocities from 150°/s to 250°/s (Figure 2, Table 3). At the same time there was an increase in $|\vec{F}|_{mar}$ with the increase in angular velocity in an area of force velocity curve which fluctuated from the velocity of 0°/s (isometric action) to the velocity of 900/s beyond that the $|\vec{F}|_{mar}$ became independent of velocity. These findings, that the velocity of 90°/s is a «crucial» value of velocity beyond that there is no increase in force development, are according to the results of the research wherein electrical stimulation of the muscle was applied (9).

The improvement of $|\vec{F}|_{mar}$ after the training program, in the high angular velocities could be due to the fact that the participants trained at these high velocities (180°/s to 216°/s). The alteration in exerted force after isokinetic resistance training in the velocity of the training (4, 5, 11, 20, 25), in slower velocities (22, 23) or in faster ones (7), has been reported in a number of studies (mainly for the concentric action). Kanehisa & Mihashita (20) support that isokinetic resistance training at angular velocities between 180°/s to 240°/s has a significant effect on exerted force at a wider range of velocities (slower and faster than training velocity). Similar results were revealed in the present study, as there is an improvement in $|\vec{F}|_{mar}$ (Figure 2) in the whole range of velocities (not always this improvement to representing statistical significance). Eventually the results about $|\vec{F}|_{iso}$ showed that, in the training group, the $|\vec{F}|_{mar}$ at a knee's joint angular velocity of 300o/s was significantly higher ($p < .05$) from $|\vec{F}|_{iso}$ after the application of the training program (Table 7). These results are in direct opposition to the results of former studies (6, 8, 10, 31, 32) that showed that exerted force during eccentric actions, maintains a level consistent with that force during isometric actions, while the speed of the joints increases. At last an improvement in $|\vec{F}|_{iso}$ was revealed in the present study, after the application of the training program (Table 6). That is in opposition to former studies which did not reveal any effect after the application of isocinetic resistance training with high velocity on the $|\vec{F}|_{iso}$ or revealed a small improvement in $|\vec{F}|_{iso}$ after a high velocity training (vertical jumps) with light weights (20). Of course the training program that is presented in the present study cannot be compared for the type of movement during isokinetic training nor with the training program with weights as in paper of Hakkinen (15).

The most important result of this research is the great improvement in $|\vec{F}|_{mar}$ (oscillated from 20,04% to 23,46% at different velocities) and in $|\vec{F}|_{iso}$ (increased 4,8%) after the application of the training resistance program. In accordance with the American College of Sport Medicine (1) there is a signi ficant diversity in the effect of the training programs analogous to the initial physical status of each participant. Therefore the untrained participants show an increase around 40% in exerted force, after the application of a resistance training program, while high level (elite) competitive athletes around 2% (the training period ranged from 4 weeks to 2 years depending the training protocol). The increases in $|\vec{F}|_{mar}$ and $|\vec{F}|_{iso}$ in the elite group of athletes in the present study is significant not only statistically but also in the absolute improvement of the level of exerted force of the athletes.

The ascertainments of the present study, as far as the comparison of the levels of values of $|\vec{F}|_{mar}$ during eccentric action in relation to that of $|\vec{F}|_{iso}$, without the application of electrical stimulation, are in direct opposition to the results of former studies (10, 16, 8, 32, 7). The stabilizing of exerted force during the eccentric action, at $|\vec{F}|_{iso}$ level (diversification between in vitro και In vivo measurements) has been given by a number of researchers in the mechanisms of the nervous system which restrict the development of the greatest tension of the muscle (in In vivo research) in an effort to protect the muscles from the danger of injury and which it is supposed exists during isometric and slow concentric actions (5, 27, 34). The existence of such protective mechanisms during the eccentric action is not supported by the results of the present study.

The training program didn't influence to the mechanical work production of athletes, possibly due to the short period of application of the training program which was 55 days. Contrary there was a significant alteration in P_{mean} after the application of the training program at the higher angular velocities. This improvement of P_{mean} after the application of the training program, in the high angular velocities, could be due to the fact that the participants trained at these high velocities (180°/s to 216°/s). Alteration in maximal muscular power after the application of resistance program utilizing light to moderate loads at high velocities has been reported by previous studies (16, 17).

Thus, the specific training protocol, which was used in the present study, didn't improve the mechanical work production but improved the rate of this production. The ability for work production in high rates is one of the essential elements of elite athletic performance more than the high work production itself.

Table 6. *Mean values of $|\vec{F}|_{iso}$ and before and after the application of training program for training and control group. *Significant alteration of $|\vec{F}|_{iso}$ (p < .05).*

Training group

	BEFORE (n = 7)	**AFTER** (n = 7)
$|\vec{F}|_{iso}$ ± SD (N)	734,04 ± 144,95	**769,18 ± 140,49***

* Alteration in F_{iso} ($p < .05$)

Control group

	BEFORE (n = 7)	**AFTER** (n = 7)
$|\vec{F}|_{iso}$ ± SD (N)	684,84 ± 122,26	689,30 ± 155,16

Further comparison of the results of the present research with those which use training protocols with resistance is not possible since they refer almost exclusively to the concentric actions while the evaluation of exerted force, power consumption and work production does not occur across the range of the force –velocity and power– velocity curve as in the present study. Also it is difficult to make comparisons in the available bibliography about which resistance training method (high or low velocity) is more effective to strength development. This happens because the researchers are using different experimental procedures or different training protocols for which it is difficult to equate the volume of training, the absolute work and its intensity (24). Also significant is the role played by the initial level of training of the participants and these factors contribute to the lack of an acceptable common method of muscle strengthening (1). Further some researchers (13, 30) support that for the development of exerted force, in high velocity movements, the training should be carried out with high intensity (conscious, fast muscle contractions) independent of the velocity of movement. The adaptations shown by the muscle system of the athletes in the training group in the present study showed results comparable to those of Westing et al (33) and which concerned measurements carried out using a superimposed electrical stimulation and voluntary efforts. It is possible that this equivalence can be associated with the mechanism of activation of the maximal effort which, in the research of Westing et al. (33) is accomplished with the presence of a high potential due to the superimposing of artificial electrical stimulation in the voluntary contraction, while in the present study it is due to the adaptation of the muscle during the training program with significant changes in power and with small intervals for energy recovery (total time in area of 1 min). It is important to be pointed out that the mechanism of power consumption is influenced at the present study and at the study of Westing et al. (33) in positive manner while there is an improvement in the level of values of exerted force after the application of the training program at a wide range of angular velocities. Moreover the level of values of exerted force is higher than the level of isometric force (Table 7, Figure 2). Therefore it is important that training programs follow a design based on significant alterations in power consumption so that the adaptations to the muscle system of the athletes is productive in its use during competitive situations.

Table 7. *Mean values of $|\vec{F}|_{iso}$ and $|\vec{F}|_{mar}$ at 300°/s angular velocity before and after the application of training program for training and control group. *Significant differences between $|\vec{F}|_{iso}$ and $|\vec{F}|_{mar}^{300°/s}$ (p < .05).*

Training group

	BEFORE (n = 7)	**AFTER** (n = 7)
$|\vec{F}|_{mar}$ ± SD (N)	738,48 ± 156.57	**861,17** ± **119,36***
$|\vec{F}|_{iso}$ ± SD (N)	730,71 ± 145,81	765,00 ± 136,11

* Signigicant differences (p < .05)

Control group

	BEFORE (n = 7)	**AFTER** (n = 7)
$|\vec{F}|_{mar}$ ± SD (N)	664,63 ± 140,91	678,78 ± 183,04
$|\vec{F}|_{iso}$ ± SD (N)	684,84 ± 122,26	689,30 ± 155,16

Finally the variables in which the muscle presents adaptations, after the application of the training program, in the present study are: the exerted force, the angular velocity of knee's joint movement and the power consumption (Force X Velocity). The evaluation of such training protocol should be carried out in the future, using assessment's devices, for exerted force and power consumption, in the field, under training loading conditions. The data analysis of the present study was focussed mainly in the precise evaluation of alterations that concerned the measurements of power consumption. An additional purpose was the precise calculation of total mechanical work production at each measurement, so that this work would be possible to be correlated, by future studies, with the work which the muscle consumes internally.

Table 8. *The angles (φ°) and angles alterations of regression lines of $|\vec{F}|_{mar}$ and F – t, with axis (χ) of angular velocity before and after the application of training program for training group.*

Training group

	F_{mar}	P_{mean}	W
Angle $_{AFTER}$ (°)	–3.38	–73.11	–2.35
Angle $_{BEFORE}$ (°)	–22.70	–69.52	8.16
Alternation (°)	19.33	–3.59	–5.81

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Address for correspondence:
Konstantinos Flessas
41 Mitropetrova Str.,
11476, Athens
Greece
e-mail: kflessas@gmail.com