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Original article

The Impact of Resistance Training Program on the Muscle Strength and Bone Density in Adolescent Athletes

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SUMMARY

Strength training and other modes of physical activity may be beneficial in osteoporosis prevention by maximizing bone mineral accrual in childhood and adolescence. This study focuses on the impact of the nine-month long program of resistant exercises with different level of external loads (low, middle and high) on the lower limbs explosive strength and bone tissue density in athletes adolescents aged 17 to 18 years. Sixty healthy, male athletes and non-athletes, divided into experimental (ES, sprinters, N = 45) and control sub-sample (CS, non-athletes, N = 15), were included in study. ES examinees (EG1, EG2 and EG3) were subjected to the program of resistance exercises with low level (60% of the One Repetition Maximum-1RM), middle level (70% 1RM), and high level (85% 1RM) of external loads, respectively. Bone Density values were determined by the use of a clinical sonometer „Sahara" (Hologic, Inc., MA 02154, USA). Explosive strength values of hip extensors and flexors, knee extensors and flexors, and ankle plantar and dorsiflexors were determined by the use of accelerometer „Myotest" (Sion, Switzerland) and the means of Counter Movement Jump without arms swing (CMJ) and half squat. ANOVA method for repeated measures and ANCOVA method were used to determine significant differences and resistance program effects on the lower limbs explosive strength and bone tissue density. Resistance exercise does impact the explosive strength and bone parameters in a way to increase half squat 1RM values, but decreases CMJ values, and increases speed of sound (SOS), broadband ultrasound attenuation (BUA) and bone mineral density (BMD) values in athletes-adolescents, aged 17-18 years.

Key words: **resistance exercise, explosive strength, bone density, sprinters, effects**

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INTRODUCTION

The concept of children and adolescents taking part in different forms of resistance training has been of spiking interest among researchers, clinicians and practitioners (1). Properly designed and supervised resistance training program can boost muscular strength and power (2) and bone mineral accrual in childhood and young adulthood, when bone is changing quickly, which may be beneficial in a prevention of a disease characterized by low bone mass and microarchitectural deterioration called osteoporosis (3) later in life (4, 5). In a systematic evaluation and meta-analysis of 43 intervention studies conducted by Lesinski, Prieske, & Granacher (6), the effects of resistance training on muscular fitness and physical performance in athletes aged 6 to 18 years were taken under a magnifying glass. The results showed that the effects of resistance training on muscle strength and vertical jump performance are moderate, and that high-intensity conventional resistance training (i.e., 80-89% of One Repetition Maximum, i.e., 1 RM) lead to the improvement in muscle strength with respect to lower intensities (i.e., 30-39%, 40-49%, 50-59%, 60-69%, 70-79% of 1 RM). Furthermore, training period longer than 23 weeks with 5 sets per exercise and 6-8 repetitions per set is likely to be the most effective in improving muscle strength. Many studies so far were focused on exercise recommendations, but no studies earlier investigated the effect of strength training on both muscular and skeletal systems. Defining an optimal strength training prescription for promoting both muscular strength and bone gain in young adults is not an easy task because of various intensities and durations of training, age, body composition, sexual dimorphism, nutriation, etc. Also, the transfer of training results in young athletes, i.e., their result improvement in sport discipline should also be considered. Not all studies are going to report positive effects regarding the transfer of training results. It is better to say that young athletes are doing a simple exercise of squatting with a barbell, over a certain period of time. According to Zatsiorsky & Krae-mer (7), it is supposed that the gain is going to be the same for all athletes, for example, 20kg. And let us additionally assume that the gain in bone mineral density (BMD), as measured in heel bone, is relatively the same for all athletes, approximately 1%. In this way, we obtain a clarification related to the transfer of training results, expressed through different exercises, like standing jump, sprint running, and swimming. The gain may be substantial in the standing jump, relatively small in sprint running, and tiny in swimming. Surely, weight lifting is a sport discipline with muscle forces and heavy loads that act on the bone and provoke sufficient osteogenic stimulus for the bone formation. It is at the same time beneficial to muscle strength, BMD, and transfer of training results (8). Older studies have clearly shown the importance of regular physical activity for optimal skeletal growth during the development and maintenance of mineral mass and density in adulthood, although the optimal mode and dose of exercise remain unsure (5).

Although there is a strong unity on the positive effects of physical activity (9-11), not all physical exercises are beneficial to BMD. For example, in research conducted by Korpelainen et al. (12), no effect of long-term impact exercise on bone mass at various skeletal sites in elderly women with low BMD was determined. The same goes when it comes to the research conducted by Vainionpää et al. (13). Regular impact exercise did not cause persistent alterations in bone turnover of women aged 35-40 years, highlighting the necessity of continuous training to achieve bone benefits. Although the findings from exercise trials in men and women are generally similar, showing that resistance training is safe and that it offsets musculoskeletal declines that normally occur with aging, considerably smaller number of prospective studies have been performed in males than in females (5).

In this longitudinal study, there are several questions still to be asked: 1) the importance of strength training for young athletes; 2) lack of previous studies investigating both muscle strength and bone density; 3) determining why it is important to measure bone density especially in young adults. Therefore, the aims of this study were: 1) to quantify the state of lower limbs muscle strength and bone tissue density in sprinters (ES) and their sedentary peers (non-athletes, CS) aged 17 to 18 years; 2) to verify in general if nine-month program of resistance training with different level of external loads (low, middle and high) is beneficial to sprinters aged 17 to 18 years, i.e., their lower limbs muscle strength, and bone tissue density; 3) to figure out the impact of low, middle and high level of external loads separately on the lower limbs muscle strength and bone tissue density in ES.

MATERIALS AND METHODS

PARTICIPANTS

Sixty healthy, male athletes and non-athletes, divided into experimental (ES, sprinters, N = 45) and control sub-sample (CS, non-athletes, N = 15) were included in the study. ES was further divided into three experimental groups, EG1, EG2, EG3 of 15 athletes each, who were training sprint running in athletics club „Prijedor" from the city of Prijedor and athletics club „Banja Luka" from the city of Banja Luka, three years before the start of the study. None of the subjects had any illnesses or used medications that could negatively influence bone metabolism. All subjects signed a written informed consent for the participation in the study, performed in accordance with the ethical standards of the Helsinki Declaration.

EXERCISE PROGRAM

Program of resistance training with different external loads was applied with ES in between the initial and final assessment, in addition to regular athletic training, and for the duration of 9 months. EG1, EG2 and EG3 sprinters were subjected to the program of resistance training with low level (60% 1RM), middle level (70% 1RM) and high level (85% 1RM) of external loads, respectively (Table 1).

In the first five months, the program of resistance training was introduced on Mondays, Wednesdays and Fridays, and was given as follows: warm-up; exercising on the weight machines three times a week, in the gym (five different exercises, three sets within each exercise, rest periods between sets and exercises 1 to 2 min, number of repetitions corresponds to appropriate group, Table 1); cooling down and stretching. The total number of training sessions during this period was 64 (12 in April, 13 in May, 13 in June, 14 in July, and 12 in August). In the last four months, training and program of resistance training was performed on Mondays, and Thursdays, and was given as follows: warm-up; specific, individual work, starting block exit, running techniques (curve and straight running), stride frequency; exercising on the weight machines two times a week, in the gym (four different exercises, three sets within each exercise, rest periods between sets and exercises: 1 to 2 min, the number of repetitions corresponds to the appropriate group, Table 1); easy running and stretching. The total number of training sessions during this period was 36 (9 in September, 9 in October, 9 in November, 9 in December). The total number of training sessions in this nine-month cycle was 100 (one hundred). The program of resistance training included hack squat, leg press, leg extension, lying leg curl, standing calf raises, seated calf raises, and barbell half squat.

Table 1. **Training intensity and number of repetitions**

1.	EG1 = 60%1RM	8 - 12 repetitions
2.	EG2 = 70%1RM	5 - 8 repetitions
3.	EG3 = 85%1RM	2 - 4 repetitions

*Abbrev. 1RM-One repetition maximum

MEASUREMENTS

Anthropometry. Mean values and standard deviations of the anthropometric variables in subjects are presented in Table 2.

Bone densitometry. The research was carried out by using a clinical sonometer „Sahara" (Hologic, Inc., MA 02154, USA), that uses ultrasound to assess bone density of the calcaneus. Data collected by sonographic measuring of the heel bone, as part of the skeleton that is most mechanically loaded during moderate daily and severe training physical activities, can provide a solid approximate value when considering the effects of the programed special exercises. Non-invasive method and the possibility of field work with the device are added benefits that we have opted for in the process of selection of the method to assess bone density (14). In this study, both left and right heel bones were subjected to measurement. Bone density was recorded as SOS, BUA and BMD.

Exercise tests. Muscle strength values of hip extensors and flexors, knee extensors and flexors, and ankle plantar and dorsiflexors were determined by the use of accelerometer „Myotest" (Sion, Switzerland) and the means of Counter Movement Jump without arm swing (CMJ) for the explosive strength and Half Squat (HS) for the maximum strength.

Table 2. **Descriptive statistics of anthropometric parameters**

Variables	EG1	EG2	EG3	CG
Body height (cm)	177.64 ± 8.81/ 177.64 ± 8.81	176.25 ± 6.81/ 177.03 ± 6.98	175.53 ± 4.67/ 175.92 ± 4.94	177.53 ± 5.15/ 177.53 ± 5.15
Body mass (kg)	64.75 ± 11.32/ 65.34 ± 10.59	68.56 ± 8.79/ 68.19 ± 8.32	67.12 ± 7.50/ 68.40 ± 7.03	69.35 ± 7.56/ 68.78 ± 7.65
Body mass index-BMI (kg/m²)	20.47 ± 3.04/ 20.66 ± 2.74	20.47 ± 3.04/ 20.66 ± 2.74	21.75 ± 1.86/ 22.08 ± 1.74	22.02 ± 2.37/ 21.84 ± 2.53

*Abbrev. I/F-Initial/Final measurements

Explosive strength was recorded as HEIGHT (jump height expressed in cm), POWER (jump power expressed in W/kg), FORCE (jump force expressed in N/kg), VELOCITY (jump velocity expressed in cm/s), and maximum strength as HS1RM (one repetition maximum in half squat expressed in kg).

STATISTICAL ANALYSIS

For the statistical analysis and interpretation of the results, statistical package Statistics 13,0 was used. Kolgomorov-Smirnov test (K-S) was used to check for normal distributions.

Table 3. **Descriptive statistics of the muscle strength and bone density parameters**

I/F	EG1	EG2	EG3	CS
HEIGHT(cm)	34.90 ± 5.05 /33.80 ± 4.85	36.99 ± 4.05 /35.15 ± 3.27	39.24 ± 3.87 /34.67 ± 3.95	32.34 ± 4.80 /30.95 ± 3.01
POWER (W/kg)	40.99 ± 7.75 /38.60 ± 7.77	41.51 ± 6.85 /37.63 ± 7.07	41.53 ± 6.37 / 37.25 ±7 .95	44.67 ± 11.21 /48.67 ± 12.40
FORCE(N/kg)	25.29 ± 3.46 /23.82 ± 2.21	25.55 ± 2.93 /25.01 ± 3.15	24.79 ± 3.64 /24.77 ± 3.50	29.40 ± 5.31 /30.34 ± 5.09
VELOCITY (cm/s)	227.47 ± 26.28 /222.74 ± 31.62	230.80 ± 22.37 /219.96 ± 23.25	230.07 ± 24.33 /211.00 ± 34.08	232.33 ± 32.12 /244.36 ± 32.55
HS1RM(kg)	102.22 ± 12.09 /107.47 ± 12.07	110.05 ± 16.55 /127.11 ± 20.53	132.54 ± 11.63 /153.99 ± 9.69	85.67 ± 17.55 /84.17 ± 17.66
SOS_LL(m/s)	1573.12 ± 34. 62 /1586.00 ± 41.66	1579.00 ± 20.05 /1595.54 ± 26.04	1575.57 ± 28.14 /1575.77 ± 26.49	1536.77 ± 18.10 /1547.87 ± 13.58
SOS_RL(m/s)	1572.24 ± 30.50 /1581.58 ± 28. 07	1579.25 ± 25.67 /1593.72 ± 28.87	1579.19 ± 28.22 /1576.53 ± 21.36	1543.30 ± 25.95 /1545.84 ± 18.42
BUA_LL(dB/Mhz)	70.62 ± 23.07 /95.59 ± 23. 88	86.34 ± 14.47 /101.24 ± 13.50	82.09 ± 14.49 /91.78 ± 12.30	64.29 ± 11.75 /76.33 ± 9.97
BUA_RL(dB/Mhz)	70.89 ± 18.98 /92. 83 ± 20. 31	87.55 ± 15.98 /102.65 ± 18.12	84.31 ± 14.33 /91.36 ± 10.47	68.87 ± 14.13 /76.98 ± 9.86
BMD_LL(g/cm²)	.57 ± 14/.67 ±.16	.63 ±.08/.71 ±.10	.61 ±.11/.64 ±.10	.46 ±.07/.52 ±.05
BMD_RL(g/cm²)	.57 ±.12/.65 ±.12	.63 ±.10/.71 ±.12	.63 ±.11/.64 ±.08	.49 ±.10/.52 ±.07

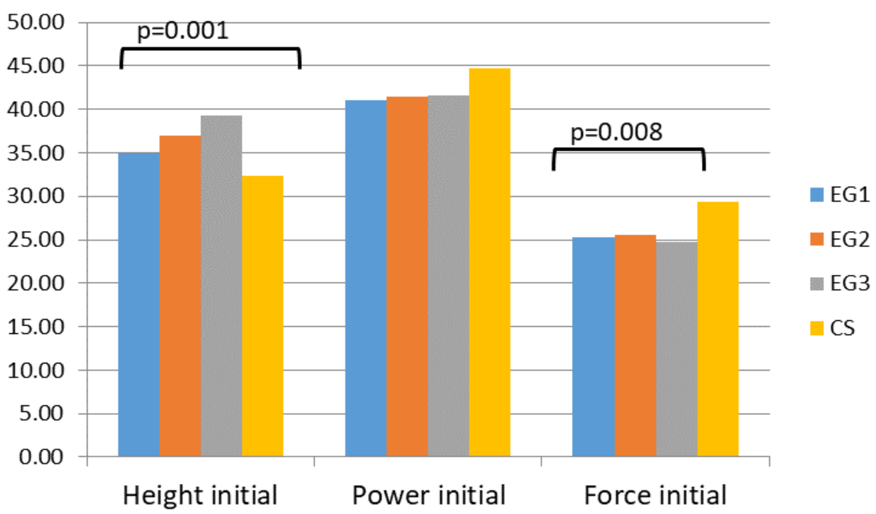
*Abbrev. I/F-Initial/Final measurements; HS1RM-one repetition maximum in half squat; SOS-speed of sound; BUA-broadband ultrasoundattenuation; BMD-bone mineral density; _LL-left leg; _RL-right leg

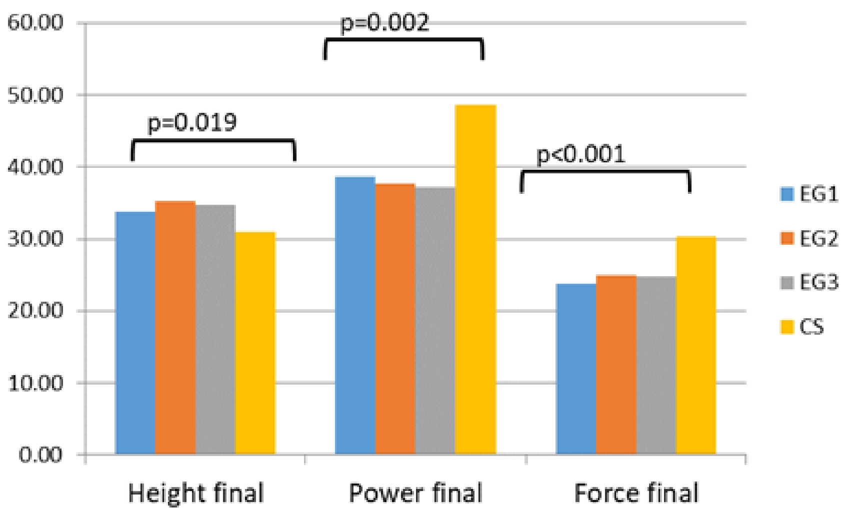
ANOVA method for repeated measures and ANCOVA method were used to determine significant differences and resistance program effects on the lower limb muscle strength and bone tissue density. Results are expressed graphically, with bar charts and significance level set at $p < 0.05$ (15).

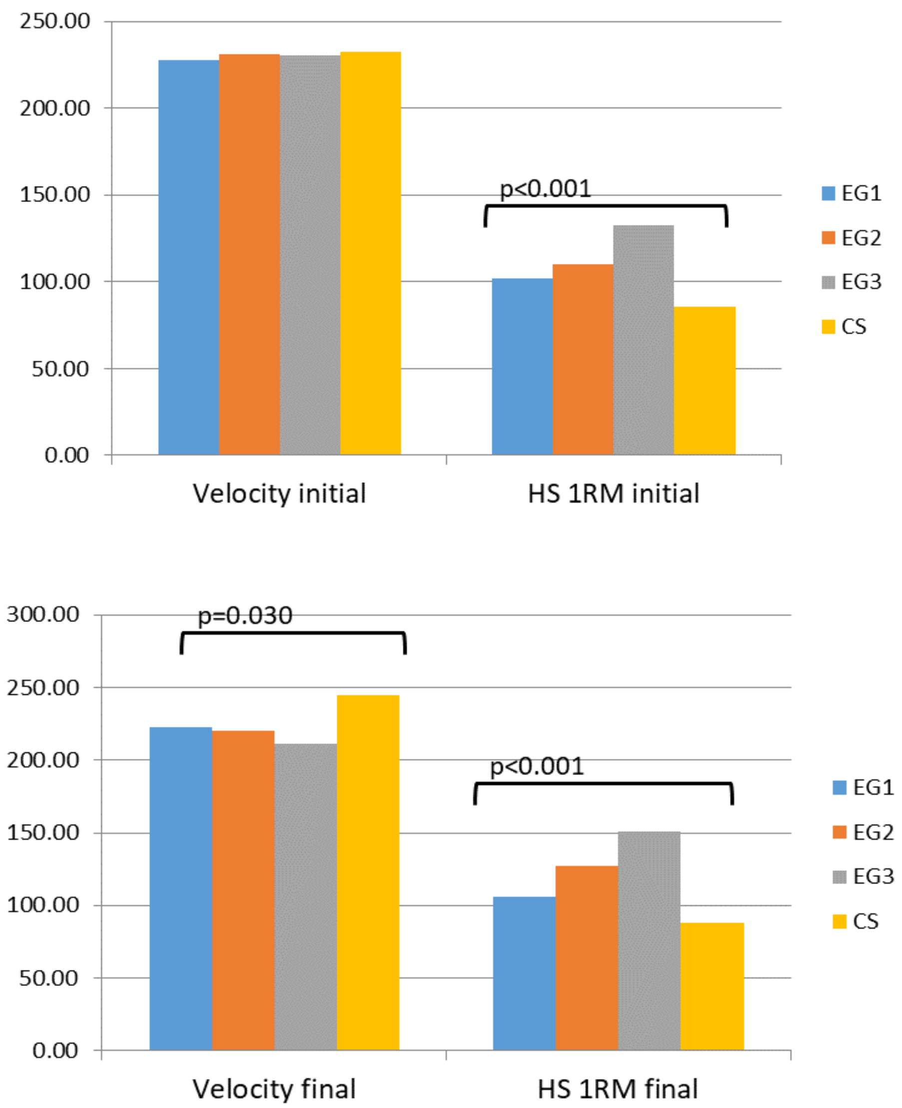
As shown in Table 3, the highest jump HEIGHT mean values at the end of nine-month program are determined for EG2, EG3, EG1, and CS examines, respectively. However, when observing the explosive strength at the initial and the final measurement, mean value of jump HEIGHT decreased in all examinees and the highest decrease was determined in EG3, EG2, EG1 and CS examinees, respectively. The same was observed with the decrease of the jump POWER, jump FORCE, and jump VELOCITY values in all examinees (except for CS examinees). In CS examinees, jump POWER, jump FORCE, and jump VELOCITY values increased, and were determined as the highest in whole sample population. When it comes to the maximum strength, i.e., HS1RM, mean value increased in examinees of ES, and decreased in examinees of CS. The highest HS1RM mean values, as well as an increase is determined in EG1, EG2 and EG3, respectively.

Concerning bone density, there is an increase in all values, both in examinees of ES and CS, with an exception in variable SOS_RL of EG3 that slightly decreased (from 1579.19 ± 28.22 m/s to 1576.53 ± 21.36 m/s). Concerning bone density values at the end of the nine-month experimental program, the highest BMD mean values were determined in EG2, EG1, EG3 and CS examinees, respectively. However, the highest relative incrcredit (%) of BMD mean values were determined in EG1, EG2, CS and EG3, respectively.

Normality tested using K-S shows normal data distribution of all the variables tested both at the initial and the final measurement. Therefore, parametric tests were applied, i.e. ANOVA method for repeated measures, and ANCOVA method.







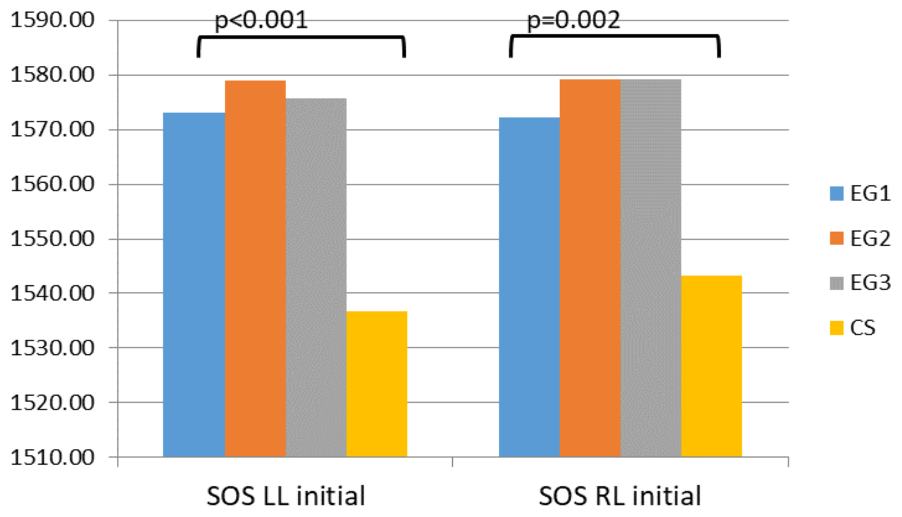
Graph 1. **ANOVA Method-Differences in parameters of muscle strength between sub-samples at the initial and final measurement**

Results of the force, power and velocity are in favor of CS, both at initial and final measurement, with statistical significance for FORCE, $p = 0.008$ at the initial measurement, and for FORCE, $p < 0.001$, POWER, $p = 0.002$, and VELOCITY $p = 0.030$ at the final measurement (Graph 1). Concerning bone tissue density, the obtained results are, as expected, in favor of ES examinees, and with a statistically significant difference, both at initial (SOS_LL, $p < 0.001$, SOS_RL, $p = 0.002$, BUA_LL, $p = 0.002$, BUA_RL, $p = 0.003$, BMD_LL, $p < 0.001$, BMD_RL, $p = 0.002$) and at final (SOS_LL, $p < 0.001$, SOS_RL, $p < 0.001$, BUA_LL, $p = 0.001$, BUA_RL, $p < 0.001$, BMD_LL, $p < 0.001$, BMD_RL, $p < 0.001$) measurement (Graph 2).

Effects of the resistance training, either positive or negative, are absent only in the variables HEIGHT and SOS_LL (Table 4).

DISCUSSION

The main goal of this study was to determine the impact of the nine-month program of resistance training with different levels of external loads (low, middle and high) on the lower limb muscle strength and bone tissue density in 17 to 18-year-young adolescent athletes.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SOS LL initial
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EG1
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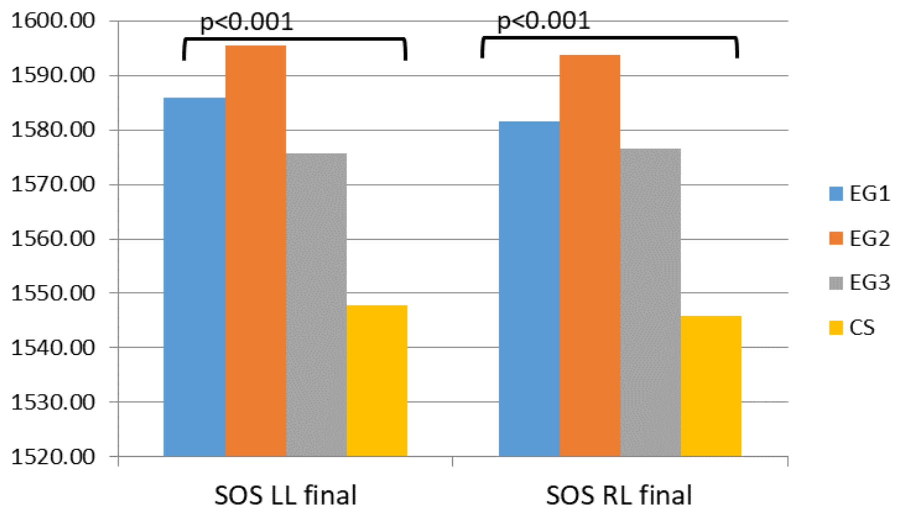
EG3
CS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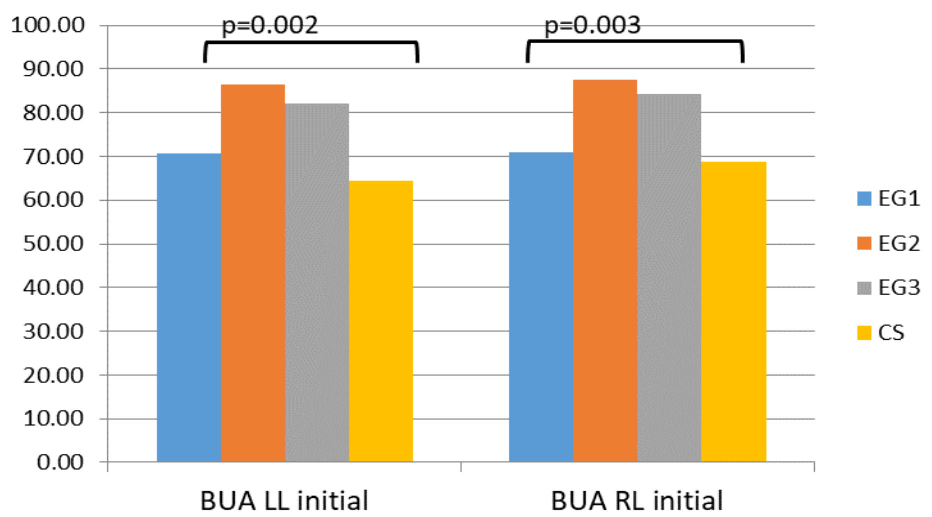
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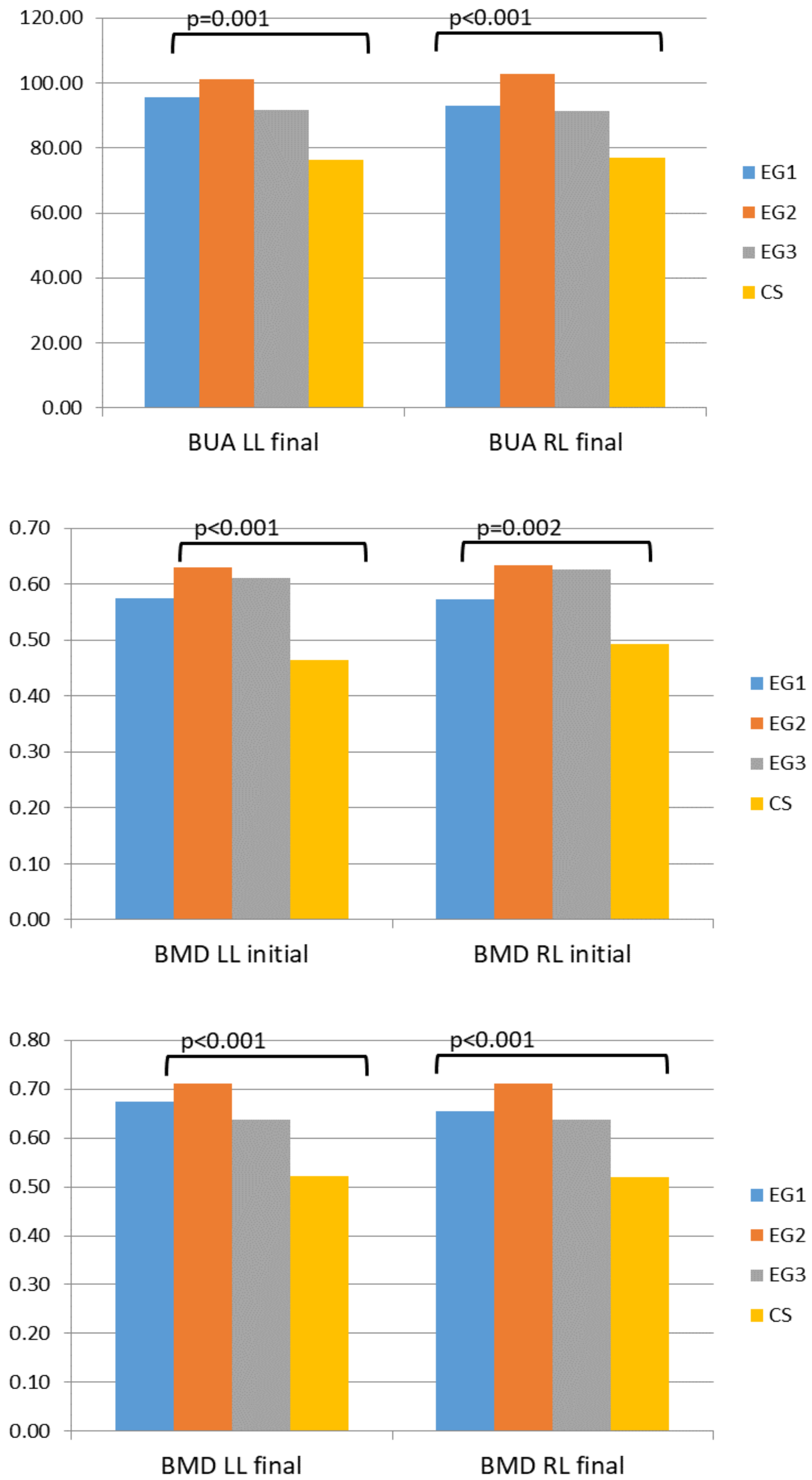

Graph 2. **ANOVA Method-Differences in parameters of bone density between sub-samples at the initial and final measurement**

Table 4. **Resistance program effects**

I/F	EG1	EG2	EG3	CS	sig ANCOVA
HEIGHT (cm)	-3.15%	-4,.97%	-11.65%	-4.30%	0.279
POWER (W/kg)	-5.83%	-9.35%	-10.31%	8.95%	**0.005**
FORCE (N/kg)	-5.81%	-2.11%	-0.08%	3.20%	**0.002**
VELOCITY (cm/s)	-2.08%	-4.70%	-8.29%	5.18%	**0.018**
HS1RM (kg)	5.14%	15.50%	16.18%	-1.75%	**0.000**
SOS_LL (m/s)	0.82%	1.05%	0.01%	0.72%	0.110
SOS_RL (m/s)	0.59%	0.92%	-0.17%	0.16%	**0.004**
BUA_LL (dB/Mhz)	35,36%	17.26%	11.80%	18.73%	**0.010**
BUA_RL (dB/Mhz)	30,95%	17.25%	8.36%	11.78%	**0.004**
BMD_LL (g/cm^2)	17.54%	12.70%	4.92%	13.04%	**0.042**
BMD_RL (g/cm^2)	14.04%	12.70%	1.59%	6.12%	**0.004**

Since the experimental groups performed large volumes of weight-bearing physical activity during a prolonged period of time, with similar biomechanics of movements determined by the weight machines, we assumed that the most significant effects on muscle strength and bone density would have appeared as the consequence of different external loads applied. More precisely, we hypothesized that EG3 (85% 1RM) examinees would benefit the most from programed resistance training, i.e., achieve the maximum muscle strength and bone tissue density, in comparison to EG2 (70% 1RM) and EG1 (60% 1RM) examinees, respectively, over a full 9-month experimental period. To add to it, we hypothesized that ES will have significantly greater results of the maximum muscle strength and bone tissue density than their sedentary peers of CS.

As we mentioned in the previous section Results, force, power and velocity are in favor of CS, both at the initial and final measurement, with statistical significance for FORCE, $p = 0.008$ at the initial measurement, and for FORCE, $p < 0.001$, POWER, $p = 0.002$, and VELOCITY $p = 0.030$ at the final measurement. Although quite unexpectedly, the results can be explained from the biomechanical point of view by two factors. The first factor is related to Myotest system that measures acceleration in the vertical direction and calculates force that comes from the equation $F = ma$, according to Newton's second law. It also calculates velocity by integrating the force over time, and subsequently power by multiplying the calculated force and velocity. Previous studies clearly point to the positive correlation between body mass and muscle power in CMJ (16, 17). Greater mean body mass values in CS, both at the initial and final measurement, could partially explain the obtained difference in force and power, while greater force values could explain consequently greater velocity values of CS. The second factor that is related to jump velocity values brought us to the assumption that experimental program might provoke negative neuromuscular adaptations in ES by decreasing the rate of neural activation of motor units while performing CMJ. On the other hand, when it comes to jump HEIGHT and HS1RM, ES examinees showed significantly better results, as expected: for HEIGHT, $p = 0.001$, and HS1RM $p < 0.001$, at the initial measurement and for HEIGHT, $p = 0.019$, and HS1RM $p < 0.001$ at the final measurement (Graph 1). For that reason, concerning the results of the explosive strength in our study, it seems that the lack of improvement in all measured CMJ variables is a consequence of the lower vertical velocity displacement of ES examinees during the nine-month resistance training program. This fact is supported by the determined decrease in jump VELOCITY (-2.08%, -4.70%, and -8.29% in EG1, EG2, and EG3, respectively), at the end of the study. An earlier work by Duthie, Young, & Aitken (18), pointed out the significance of high velocity displacement during power exercises in improvement of power output. However, it might be that velocity displacement in ES participants was compromised by the resistance training program, that provoked a decrement in the rate of motor units neural activation. According to Noakes (19), the force-velocity characteristics of the neuromuscular system are related to the peripheral neuromuscular factors.

Heterogenity of sample of the examinees showed to be a limiting factor in understanding the results of previous studies dealing with similar thematics. To minimize this dilemma, we homogenized the sample of examinees in relation to sex, age and sport the examinees are engaged in. It is not clear yet what is the most important parameter in enhancing muscle strength and bone density through physical activity. This problem was supported in the study by determined explosive strength values (jump HEIGHT, jump POWER, jump FORCE and jump VELOCITY) that decreased, and by determined maximum strength (HS1RM) and bone density values (SOS, BUA, and BMD) that increased, after the applied experimental program in ES examines.

Two recent studies on resistance training effects need to be mentioned. The first one, conducted by Sander, Keiner, Wirth et al. (20), aimed to examine the influence of periodized strength training for power performance in 134 elite young soccer players. One group (strength training group) was subjected to regular soccer training in addition to strength training twice a week for 2 years. The other group (control group) completed only the regular soccer training. For strength training, both the front squat and the back squat were performed once a week. The subjects were tested on the 1RM of the front and back squat and significantly better performance from the strength training group on 1RM was determined, $p < 0.001$. The second one is a 12-month randomized, clinical trial that included 38 male participants with low bone mass of the hip or spine, aged 43.7 ± 10.1 years, undergoing either resistance training or high-intensity jump training. There were no differences at baseline in age, anthropometric characteristics, nutrient intakes or physical activity between participants that underwent resistance training (RT) or high-intensity jump training group (JUMP). RT participants increased their RM for the squat, lunge, modified deadlift, calf raise, military press and bent-over row at the final assessment by 79, 114, 64, 79, 52, 44%, respectively. JUMP participants increased their vertical jump height by 11% on average at the final assessment. Whole body BMD increased by 0.6% after 6 months both in RT or JUMP participants, relative to pre-treatment, and this increase was maintained at 12 months. Lumbar spine BMD increased both in RT and JUMP participants, while increment of the total hip BMD was determined only in RT participants. One possible explanation is that the participants tended to have lower BMD of lumbar spine than of the total hip prior to the study and, thus, may have had a greater potential to respond to the intervention at the area of the spinal column compared to the area of the hip joint (21).

What is known is that the bone mass increment from physical activity is directly linked to increase in mechanical strain (22). By the same principle, unloading leads to impaired muscle development and lower muscle strength, with subsequent negative effects on bone mass, size, and strength (4). According to Ribeiro-dos-Santos et al. (23), the physical practice in "hypogravity" conditions has potential to decrease bone formation because it decreases the time engaged in weight-bearing activities usually observed in the daily activities of adolescents. Similar assertion can be found in the earlier works of Gómez-Bruton et al. (24) and Ferry et al. (25). We used the above mentioned Frost's theory as a basis for the assumption that the nine-month program of 85%1RM will be of the greatest benefit for bone density. However, the obtained response to different levels of external load have not been typical, in a way that the greatest increment in bone density occurred while conducting resistance program of 60% 1RM and 70% 1RM, and not 85% 1RM. The results obtained in the cross-sectional study by Yung et al. (26), that aimed to investigate bone properties using heel quantitative ultrasound in Chinese male students, athletes and non-athletes (N = 55), aged 18-22 years, are in accordance with the results of our study, when comparing athletes and non-athletes. Namely, significantly higher BUA, and SOS mean values, ($p < 0.05$) were determined in soccer players (137 ± 4.3 dB/MHz; 1575 ± 56 m/s; 544.1 ± 48.4) and dancers (134.6 ± 3.7 dB/MHz; 1538 ± 46 m/s; 503 ± 37) respectively, than in swimmers (124.1 ± 5.1 dB/MHz; 1495 ± 42 m/s; 423.3 ± 46.9) and the sedentary control group (119.9 ± 6.1 dB/MHz; 1452 ± 41 m/s; 369.9 ± 46.4). A trend of a significant linear increase with the weight bearing and high impact exercise was revealed in all QUS parameters ($p < 0.05$). Nilsson et al. (27) conducted a cross-sectional study in order to determine whether present (type and amount) and previous duration of physical activity are associated with trabecular microstructure and cortical cross-sectional area at distal tibia and radius in weight-bearing bone in young men. In this large cohort of young Swedish men, aged 24.1 ± 0.6 years, the degree of mechanical loading due to the type of physical activity was predominantly associated with trabecular microstructure, whereas duration of previous physical activity was mainly related to parameters reflecting cortical bone size in weight-bearing bone. In another noteworthy cross-sectional study of resistance trained male athletes conducted by Nilsson et al. (28), higher grip strength was determined in resistance training men, compared to non-athletes (9.1 % or 0.4 SD, $p < 0.01$), but the bone microstructure or geometry was not significantly higher. However, the differences in areal BMD at the femoral neck and lumbar spine, as well as cortical cross-sectional area and trabecular bone volume fraction were higher in men playing soccer than in non-athletes ($p < 0.001$).

Those findings are in accordance with the results obtained by Maïmoun & Sultan (29) which show that typical responses of bone remodeling to different types of exercise have been difficult to obtain up to now, probably because many factors modify the responses. Those factors may be age-specific (30, 31), sex-specific (32-35) and sport-specific (36-38).

This study is limited by the fact that results are explained mainly from the biomechanical and not physiological angle. There is evidence that an intense exercise bout in male adolescents leads to reductions in anabolic mediators (total IGF-I, bound IGF-I, and insulin) and profound increases in proinflammatory cytokines (IL-6, TNF-α, and IL-1β and in IGF-binding protein-1) (39). Another study limitation is the small number of participants in each group (N = 15). However, the findings might elicit new studies, that will include physiological examination, larger population of athletes, and that will be focusing not only on the impact the resistance training program has on lower limbs explosive strength and bone tissue density but also on the transfer of training results in sprint running.

CONCLUSION

We have revealed that specific, resistance training, nine-month program, impacts muscle strength and bone density parameters in a way to increase maximum strength, i.e. HS1RM values, but decreases explosive strength, i.e. CMJ values (HEIGHT, POWER, FORCE, and VELOCITY), and increases bone density values, i.e. SOS, BUA and BMD values in adolescent athletes, aged 17-18 years. The greatest increment of 16.18% in HS1RM occurred while conducting program of 85%1RM, but the same program provoked the highest decrement of 11.65% in jump HEIGHT, as well. The greatest relative increment of 35.36% and 30.95% in BUA (for the left and right leg, respectively) and 17.54% and 14.04% in BMD values (for the left and right leg, respectively) was determined after conducting resistance program of 60% 1RM, while maximum values of bone density are determined after conducting resistance program of 70%1RM. Significant explosive strength and bone density improvements that are determined at the final measurement in CS participants, in POWER (8.95%), FORCE (3.20%), VELOCITY (5.18%), SOS_LL (0.72%), SOS_RL (0.16%), BUA_LL (18.73%), BUA_RL (11.78%), BMD_LL (13.04%), and BMD_RL (6.12%), might be related in part to natural maturation of adolescent non-athletes. The findings from this study show that resistance training results in important musculoskeletal adaptations in adolescent athletes, and that it can be recommended for the prevention of osteoporosis by maximizing bone mineral accrual during adolescence.

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Uticaj programa vežbi sa opterećenjem na snagu mišića i koštanu gustinu sportista adolescenata

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SAŽETAK

Trening snage i drugi oblici fizičke aktivnosti mogu biti od koristi u prevenciji osteoporoze povećanjem prirasta sadržaja minerala u detinjstvu i adolescenciji. Aktuelno istraživanje je fokusirano na uticaj devetomesečnog programa vežbi, sa spoljašnjim opterećenjem različitog intenziteta (niskog, srednjeg i visokog), na eksplozivnu snagu donjih ekstremiteta i gustinu koštanog tkiva sportista adolescenata uzrasta od 17 do 18 godina. Šezdeset zdravih sportista i nesportista, podeljenih u eksperimentalni (ES, sprinteri, N = 45) i kontrolni subuzorak (CS, nesportisti, N = 15), uključeni su u istraživanje. Ispitanici ES (EG1, EG2 i EG3) su podvrgnuti programu vežbi sa spoljašnjim opterećenjem niskog (60% od jednoponavljajućeg maksimuma (prema engl. One Repetition Maximum-1RM), srednjeg (70%1RM) i visokog (85%1RM) intenziteta, navedenim redosledom. Vrednosti koštano mineralne gustine tkiva (prema engl. Bone Mineral Density-BMD) utvrđene su upotrebom kliničkog sonometra „Sahara" (Hologic, Inc., MA 02154, USA). Vrednosti eksplozivne snage opružača i pregibača u zglobu kuka, zglobu kolena i skočnom zglobu utvrđene su upotrebom akcelerometra „Myotest" (Sion, Švajcarska), posredstvom skoka sa počučnjem (prema engl. Counter Movement Jump bez zamaha ruku - CMJ) i polučučnja sa opterećenjem. Metoda ANOVA za ponovljena merenja i metoda ANCOVA upotrebljene su za utvrđivanje statistički značajnih razlika i uticaja programa na eksplozivnu snagu donjih ekstremiteta i gustinu koštanog tkiva. Vežbe sa spoljašnjim opterećenjem utiču na parametre eksplozivne snage i koštanog tkiva, tako da dovode do uvećanja vrednosti 1RM u polučučnju, ali i umanjenja vrednosti CMJ, kao i uvećanja vrednosti brzine zvuka (prema engl. Speed of Sound-SOS), širokopojasne ultrazvučne atenuacije (prema engl. Broadband Ultrasound Attenuation-BUA) i koštano-mineralne gustine (prema engl. Bone Mineral Density-BMD) kod sportista-adolescenata uzrasta 17-18 godina.

Ključne reči: **vežbe sa spoljašnjim opterećenjem, eksplozivna snaga, gustina koštanog tkiva, sprinteri**