Section: Original Investigation

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Journal: *International Journal of Sports Physiology and Performance*

Acceptance Date: February 5, 2018

DOI: https://doi.org/10.1123/ijspp.2017-0763

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International Journal of Sports Physiology and Performance

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Running head: **Complex training during adolescence**

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Abstract word count: **250**

Text-only word count: **3,329**

Number of Figures and Tables: **8**

Disclosures: nothing to disclose

ABSTRACT

Purpose: To investigate the effect of a complex, short-term strength/power training protocol on performance and body composition of elite early-adolescent soccer players. **Methods**: Twenty-two players (14-15 years) were randomly assigned to (a) an experimental (EG, n=12, participated in a 5-week training protocol with traditional multi-joint power resistance exercises, Olympic-style lifts, plyometric drills and speed work, four times/week) or (b) a control group (CG, n=10). Strength and power performance [jumping, speed, change of direction, repeated sprint ability, endurance, isokinetic strength of knee flexors and extensors, maximal strength in various lifts, speed-endurance) were evaluated pre- and post-training. **Results**: Cessation of training for five weeks in the CG induced a marked performance deterioration (~5-20%). Training not only prevented strength performance deterioration but also increased it (~2-30%). Endurance and RSA declined to a smaller extent in EG compared to CG (15% vs. 7.5%). Isometric strength, and body composition remained unaltered in both groups. **Conclusions**: Results demonstrate that (i) young players exhibit a high level of trainability of their strength/power performance (but not endurance) in response a short-term complex training protocol during early adolescence, (ii) Olympic-style lifts are characterized by increased safety in this age group and appear to be highly effective, (iii) it appears that lifts incorporating a hip thrust result in increased strength of both knee extensors and flexors, (iv) cessation of training for only five weeks results in marked deterioration of strength/power and endurance performance and (v) improvement of strength/power performance may be related to neural-based adaptation since body composition remained unaffected.

Keywords: association soccer, adolescence, weight training, plyometrics, body composition

1. INTRODUCTION

Soccer, an intermittent-type sport, incorporates explosive actions (e.g. sprinting, jumping, tackling, impacts, shooting, changes of direction etc.) that require high power output by lower limb muscles.[1] These powerful muscle actions are pivotal for match performance of adolescent soccer players.[2] Although sprinting represents only a ~3% of the total distance covered in youth matches, it is crucial for ball possession, scoring or allowing opponents to score.[2] Match analysis has shown that the ability to change direction (COD), i.e. the ability to change directions using quick accelerations and decelerations (>2 m/s^2), is an important element for soccer performance with >50 turns recorded per match.[3] Initial acceleration, i.e. a 0-10 m sprint, is also a pivotal physical attribute for young players since the average sprint time/match is 2.3 s suggesting that most sprints are 10-12 m long rendering power development of the lower-limb muscle groups an essential component of athletes' conditioning plan.[4] Improvement of muscle power of lower limb musculature depends on the development of force, velocity or both through independent training.[5]

Implementation of neuromuscular training (i.e. strength, plyometric, sprint training) in peripubertal years is quite effective in promoting the athletic development of youth due to the increased plasticity of the neuromuscular system before, during and after the period of peak height velocity.[6] Strength training (ST) using more traditional power exercises such as the back squat improves kicking force, speed and acceleration in adolescent players even in response to short-term training.[7] These adaptations to strength training are related to an increase of peak ground reaction forces, velocity of movement, muscle mass and bone development.[8]

ST utilizing higher loads at lower velocities with traditional resistance training exercises (e.g. squat) although they are effective in enhancing lower-body strength they may not increase strength optimally at higher velocities characterizing powerful sport movements.[9] The later requires an increase in the rate of force development (RFD) at the ankle, hips and knees which is better developed by exercises using lower resistance and higher velocities.[10] Ballistic, Olympic-style lifts are performed at higher velocities introducing an acceleration of a lighter weight throughout the lift.[11] Although these lifts may result in lower strength development when compared to traditional weight training[12], they induce a higher output in speed-power performance in adolescent athletes[12] with RFD being 4-5-fold greater during these lifts than that measured during a squat.[13] Utilization of both types of exercise may produce the best improvement of power performance due to an increase in both maximal strength and RFD and it represents the most popular practice among high school, college and professional conditioning specialists particularly during off-season training.[14] On the other hand, soccer skills such as ball kicking and sprinting also rely on the utilization of the stretch-shortening cycle (SSC) to produce rapid force.[9] Plyometric training (PT) is highly effective in promoting strength, speed and power performance in youth soccer players[15] whereas its combination with resistance or sprint training may be even more effective.[16] Complex training (CT) is a method used to improve both strength and power combining a resistant exercise of slow velocity and heavy load (e.g. squat) with an exercise of higher velocity, lighter load and a similar biomechanical movement pattern (e.g. plyometric jumps).[17] The available information regarding the responses of soccer players to periodized complex strength/power training during early adolescence is limited. Therefore, this study used a comprehensive set of measurements to evaluate the effects of a 5-week periodized strength/power training program consisting of multi-joint, high-intensity resistance exercises, plyometrics, and speed-endurance drills during off-season on (i) soccer-specific performance and (ii) isometric, eccentric and concentric strength of KE and KF. It was hypothesized that a 5-week complex training program will not change the performance of early adolescent soccer players.

2. Methods

Participants. A power analysis, based on previous studies in youth populations of similar research designs,[15] performed before the study using an effect size >0.55, a probability error of 0.05, and a power of 0.9 for two groups and time points (pre, post) indicated that 16 subjects were the smallest acceptable number of participants to analyze the interaction between group and time points of measurements. Initially, 48 males (13-15 years) were approached but 34 volunteered to participate in this investigation. Participants were included in the study if: 1) had no musculoskeletal injuries for ≥12 months prior to the study; 2) were were early-pubertals (Tanner stage 3); 3) participated in ≥95% of training sessions; 4) participated in organized youth soccer training for ≥6 years; 5) participation in ≥5 practices/week during in-season; 6) had no previous experience of ST with multi-joint exercises; 7) did not consume any medications; 8) medical history (reported by parents/guardians) included no previous growth irregularities. Twenty-two boys met the inclusion criteria and completed the study. Experimental procedures and potential risks, discomforts and benefits were fully explained to all boys, parents/guardians and coaches prior to participation. Signed informed consents were provided by participants' parents and/or legal guardians, the Institutional Ethics Committee approved the study and procedures were in accordance with the Helsinki declaration. Participants' characteristics are shown in Table 1.

Study overview. A randomized, two-group, repeated measures experimental design was employed. Participants were assigned to either a control (CG, N=10, did not train; age 14.1±0.6 years) or an experimental group (EG, N=12 completed training; age 14.3±0.7 years). The study was conducted one week within the off-season period. A familiarization period with experimental/training procedures was utilized to minimize the learning effect error. Four days following familiarization, participants underwent a two-day baseline testing [day 1: anthropometric and strength assessment; day 2: measurement of speed, repeated sprint ability

(RSA), COD, and soccer-specific endurance). Post-training measurements were repeated at the same time and under the same conditions four to five days after the last practice. Participants were instructed to follow their usual daily diet pattern throughout the study.

Training Program

Table 2 highlights study’s training protocol. Training consisted of four training sessions/week for five weeks. Strength training, performed on Mondays and Thursdays, included 13 resistance exercises [squat, Romanian deadlifts (RDL), lounges or step ups, one leg RDL, bench press, rowing or inverse rowing, shoulder press or shoulders extensions, arm curls and dips or push downs). On Tuesdays and Fridays, participants performed complex training (combination of multi-joint Olympic-style lifts, PT and speed work; e.g. barbell cleans, kettlebell snatches, box jumps, speed/power drills) on a soccer pitch. Training followed the model of linear periodization for core ST and PT exercises (intensity increased progressively from 60-70% 1RM in the first week to 80-90% 1RM during in the fifth week for core resistance exercises, from 20 to 40 kg for multi-joint exercises and from 20 cm to 50 cm for plyometric exercises). Sprints were performed at full speed. The intensity for supplementary resistance exercises was set at 60-70% 1RM. 1RM was evaluated every two weeks. Athletes of both groups participated in very light soccer training twice a week. This training consisted of dynamic warm up, technical skill training (10 min), small sided games (5 min) and light scrimmage (15 min). Participants were instructed to fully abstain from any other training and/or strenuous physical activity.

Measurements

Anthropometrics. Body mass was measured to the nearest 0.5 kg (Seca 710, United Kingdom, Birmingham) with subjects wearing the underclothes and bare-footed. Standing height was evaluated to the nearest 0.5 cm (Seca stadiometer 208, United Kingdom, Birmingham). Body composition (% fat), was measured using dual-energy X-ray absorptiometry (DXA) scan (Lunar DPX, General Electric Company) as described.[18] Pubertal development was determined using the Tanner's criteria.[19]

Strength. Isometric strength, concentric peak torque of KF and KE and eccentric peak torque of KF in both dominant and non-dominant leg (dominance was decided based on participants' ball kicking leg) were measured at an angular velocity of 60°/s and 180°/s on an isokinetic dynamometer (Isoforce, TUR Gmbh, Berlin, Germany) as described.[20] The conventional (KF concentric peak torque to KE concentric peak torque) and functional (KF eccentric peak torque to concentric KE peak torque) ratios were then estimated. The intra-class correlation coefficients (ICCs) for repeated measurements was 0.92-0.94. Maximal leg strength was also measured using the 1 Repetition Maximum (1RM) test for barbell back squat and RDL exercises as described.[21] The ICC for test-retest trials was 0.93%.

Performance measurements. Squat (SJ), countermovement (CMJ) and depth (DJ) jumps (ICCs: 0.92-0.95) were utilized to measure jumping performance using an electronic mat to determine vertical displacement (NewTest Ltd., Kiviharjuntie, Finland).[15] Time to complete a 30-m sprint with split time at 10-m was measured using infrared light sensors (NewTest Ltd., Kiviharjuntie, Finland) in two attempts (using a 10 min rest between attempts) with participants wearing soccer shoes on a soccer pitch outdoors (ICC: 0.96).[15] The arrowhead test (ICC: 0.96) was used to measure COD on a 37.1 m course (two attempts were allowed with a 15-min rest in between and the best time was recorded) using infrared light sensors (NewTest Ltd., Kiviharjuntie, Finland) at the starting and finishing point to measure time.[22] RSA was evaluated using infrared light sensors to measure time as previously described.[1] The Yo-Yo intermittent recovery test level 2 (Yo-Yo IR2) was used to measure speed endurance.[1]

Statistical Analyses. Data are presented as means±standard deviation. Data normality was verified by one-sample Kolmogorov–Smirnoff test. Data were analyzed by 2-way (trial X time) repeated measures ANOVA on different time points. For post-hoc analysis, a Bonferonni test was used. Significance set at *P*<0.05. For effect size determination, Eta squared values (η^2) were calculated. The SPSS was used for all analyses (Chicago, IL, USA).

3. Results

There were no differences between groups in all dependent variables examined at baseline. The anthropometric measures (Table 1) remained unaltered throughout the experimental period in both groups.

Performance in squat jump (CG: -6.8%, EG: 5.7%, $F_{(1,20)}$=10.12, p<0.05, η^2=0.35), countermovement jump (CG: -8.2%,; EG: 6.9%, $F_{(1,20)}$=20.67, p<0.05, η^2=0.51) and drop jump (CG: -9%, EG: 10.6%, $F_{(1,20)}$=43.47, p<0.05, η^2=0.7) declined in CG and increased in the EG (Figure 1). 1RM (Figure 1) in squat and RDL decreased in CG (squat: -7.9%, RDL: -13.7%,) and increased in EG (squat: 21.1%, $F_{(1,20)}$=72.86, p<0.05, η^2=0.79; RDL: 29.9%, $F_{(1,20)}$=106.41, p<0.05, η^2=0.84). Fatigue index in RSA and 30-m speed performance remained unaltered in both groups (Figure 2). The 10-m speed performance (Figure 2) declined in CG (-4.6%) and increased in EG (3.6%, $F_{(1,20)}$=57.54, p<0.05, η^2=0.75;). COD (Figure 2) for both sides remained unaltered in CG and increased in EG (left: 0.8%, $F_{(1,20)}$=11.71, p<0.05, η^2=0.37; right: 1.4%, $F_{(1,20)}$=9.16, p<0.05, η^2=0.32). Although speed-endurance (YO-YO IR2, Figure 2) declined in both groups (CG: -15.1%; EG: -7.6%) no statistically meaningful changes were detected.

No changes were noted in isometric peak torque of KF and KE of both limbs in the two groups (Figure 3). Changes in isokinetic strength measures at 60°/s are shown in Figure 4. In dominant limb, concentric peak torque of KF remained unaltered by training in both groups, eccentric peak torque of KF decreased in CG (-6.7%, $F_{(1,20)}$=25.56, p<0.05, η^2=0.56) and increased in EG (5.8%, $F_{(1,20)}$=25.56, p<0.05, η^2=0.56), concentric peak torque of KE decreased in CG (-7.2%; $F_{(1,20)}$=9.92, p<0.05, η^2=0.33) and increased in EG (2.1%; $F_{(1,20)}$=9.92, p<0.05, η^2=0.33) whereas both the conventional and functional ratios (Figure 6) remained unaltered in both groups. In non-dominant limb, concentric peak torque of KF decreased in CG (-7.5%, $F_{(1,20)}$=23.94, $p<0.05$, η^2=0.55) and increased in EG (8.6%, $F_{(1,20)}$=23.94, $p<0.05$, η^2=0.55), eccentric peak torque of KF declined in CG (-6.9%,$F_{(1,20)}$=4.89, $p<0.05$, η^2=0.2) and remained unaltered in EG, concentric peak torque of KE decreased in CG (-19.4%, $F_{(1,20)}$=4.89, $p<0.05$, η^2=0.2) and remained unaltered in EG. In non-dominant limb, the conventional ratio (Figure 6) increased in both groups (CG: 17.9%, EG: 11.2%, $F_{(1,20)}$=8,68 $p<0.05$, η^2=0.31) whereas the functional ratio remained unchanged in both groups.

Changes in isokinetic strength measures at 180°/s are shown in Figure 5. In dominant limb, concentric peak torque of KF remained unaltered in CG and increased in EG (18.2%, $F_{(1,20)}$=23.94p=0.001η^2=0.55), eccentric peak torque of KF decreased in CG (-6.9%, $F_{(1,20)}$=4.89, p=0.04, η^2=0.2) and remained unaltered in EG, concentric peak torque of KE decreased in C (-7.1%; $F_{(1,20)}$=7.18, p=0.014, η^2=0.26) and remained unaffected in EG whereas both the conventional and functional ratios (Figure 6) remained unaltered in both groups at the end of the experimental period. In non-dominant limb, concentric peak torque of KF remained unaltered in CG and increased in EG (17.8%, $F_{(1,20)}$=11.72, $p<0.05$, η^2=0.37), eccentric peak torque of KF declined in CG (-7.6%, $F_{(1,20)}$=7.12, $p<0.05$, η^2=0.26) and remained unaltered in EG, concentric peak torque of KE remained unaltered in both groups, the conventional ratio of KF/KE (Figure 6) increased only in CG (15.3%, $F_{(1,20)}$=11.15, $p<0.05$, η^2=0.35) whereas the functional ratio (Figure 6) remained unaltered in both groups.

4. Discussion

This is the first investigation to study the effects of complex-type exercise training on performance of elite early-adolescent soccer players. Results indicate that (i) five weeks only of off-season detraining in the CG induced a deterioration of speed/power and endurance performance which was more pronounced in eccentric strength of KF and concentric strength of KE; (ii) a five-week periodized complex training program not only attenuated the decline of strength/power performance observed during off-season detraining but also enhanced it; and (iii) deterioration of endurance performance due to off-season detraining cannot be affected by a strength/power training program.

Cessation of training in the CG during off-season resulted in considerable strength detraining of KE and KF strength at low-speed movements. This reduction of KE strength in CG during off-season was greater than that observed to that of KF in both limbs thereby resulting in greater values of conventional and functional ratios in CG. On the other hand, at high-speed movements eccentric strength of KF and concentric strength of KE demonstrated a greater reduction rate during the same time-frame. These findings suggest that strength deterioration during high velocity motions is mainly seen at knee extensions during which KE contract concentrically and KF act eccentrically. This phenomenon is also supported by the fact that maximal strength in two multi-joint exercises that are heavily rely on eccentric strength of KF and concentric strength of KE (i.e. squat and RDL) was reduced by 8-14% in CG. These findings coincide with previous reports suggesting that young athletes may experience a rapid loss of central adaptations initially and of muscle mass later.[23] Since no changes were observed in body composition, a plausible explanation for these reductions of muscle strength is probably a compromised neural input. Detraining effects on performance are related to factors such as maturation, training level, and total training load before training cessation.[24] Short-term detraining in this study induced a decay of maximal force (e.g. 1RM) at a greater extent (8-14% vs. 2-9%) than force during higher velocity movements (e.g. peak torque at 180^{o}/s, jumping, speed and COD). The smaller decline of power performance may be associated with the smaller decay of torque at higher velocities as compared to maximal strength and/or to an upregulation of the expression of fast myosin heavy-chain isoforms in muscle following detraining which may enhance velocity potential to compensate for the reduction in maximal force.[25]

Complex training implemented through a periodized protocol integrating traditional multi-joint strength exercises, Olympic-style lifts, PT and speed drills improved lower limb strength and power of early-adolescent soccer players within only five weeks. Strength increase was more evident at high- vs. low-velocity testing in KF vs. KE probably due to the utilization of lifts and drills requiring a substantial recruitment of KF. 1RM increased by 21-30%, a magnitude of improvement that has been previously reported for youth[26] and may be related to participants' minimal previous involvement with ST.[26] These gains cannot be attributed to an upregulation fat-free mass since body composition remained unchanged suggesting that neural factors have probably contributed to these adaptations within such a short time frame.[23] Furthermore, isokinetic testing revealed that the ratios of peak torques of KF and KE remained unchanged or slightly increased but remained within their physiological range indicating a reduced risk for hamstrings' injury.[20]

Speed improvement (~4%) was of similar magnitude with that usually reported for youth exposed to ST.[27] However, others failed to observe changes in speed despite a rise in muscle power in response to ST.[26] This discrepancy among studies is probably related to differences in the type of exercises used, planes of movements and muscles recruited. We emphasized movement in various planes, recruitment not only of thigh and tibia muscles but also that of the hip at the horizontal vector which seem to be prerequisites for development of speed and acceleration.[28] It appears that exercises emphasizing the recruitment of hip musculature such as dead lifts, lounges, and Olympic style lifts may be well-tolerated and effective for adolescent athletes when used in the context of complex training. However, this type of training failed to improve high-velocity movements, i.e. the sprint time at 30 m. It appears that incorporation of lifts characterized by high-velocity and lighter loads such as the Olympic lifts may be effective for strength/power development of adolescent soccer players during off-season. This type of lifts was found to be more effective than traditional strength exercises four young soccer players.[12]

The complex training protocol used resulted also in improvement of vertical jumping corroborating previous findings in youth.[27] It appears that even a moderate rise in maximal strength is associated with a substantial increase in lower limb muscle power[29] and participants in this study improved both. Maturation could not have affected these results since the controls demonstrated a different response, the training protocol was of a very short duration, and participants were far from their peak growth period.[30]

Training cessation during off-season reduced speed-endurance (15% in YO-YO IR2 and 40% in RSA). Training in EG attenuated the deterioration in YO-YO IR2 performance but not that of RSA. In young men, detraining results in reduced endurance performance mainly due to peripheral adaptations (e.g. reduced capillarization of muscle fibers, substrate utilization, mitochondrial energy capacity, electrolyte regulation) even after only 3-4 weeks of detraining.[31] The complex training model adapted by this study did not affect endurance as it did for strength/power measures indicating a specificity effect.

A number of limitations are associated with this investigation. A lack of measurement of hormonal levels which change abruptly during early adolescence in boys.[32] As such, our results can be extrapolated to other groups such as age-matched female athletes or adults. The training intervention was short-lived (5 weeks/20 training sessions) which might have not allowed participants to fully grasp the squat and/or the hip thrust movements of exercises incorporated in the training program. Changes in acceleration were only assessed and not in maximal speed by using only short-distance sprint testing. Although participants were instructed to abstain from strenuous activities, their daily physical activity was not assessed (e.g. with accelerometry).

5. Practical applications

Early-adolescent soccer players demonstrate an exceptional level of trainability to complex strength/power training during the off-season during which no soccer training was implemented. Specifically, only five weeks of this type of training was able to induce considerable gains in measures of strength, power (approximately 2-30%) and soccer specific performance but not endurance. Olympic-type lifts were well tolerated by young players and may contribute to considerable strength and power gains. This type of training protocol appears to work efficiently when applied according to the linear periodization model that uses a progressive increase of workload. Another major finding of the present study is that cessation of training even for 5-6 weeks may induce marked detraining in strength/power (approximately -5 to -20%) and endurance (approximately -8% to -15%) performance.

6. Conclusions

In conclusion, implementation of a periodized complex training protocol consisting of multi-joint lifts, Olympic-style lifts, plyometrics and speed drills in early adolescent soccer players not only offsets the deleterious effect of cessation of training during off-season on strength/power performance but it may also improve it. These results seem to be related mainly to neural adaptations rather than to an increase in muscle mass.

7. Acknowledgments

The authors wish to thank all the participants, their parents and their coaches for their participation and commitment to the study. This study was supported by departmental funding.

8. Conflict of Interest

No conflicts of interests to declare.

References

1. Mohr, M., et al., Muscle Damage, Inflammatory, Immune and Performance Responses to three Soccer Games in 1 Week in Competitive Male Players. *Eur J Appl Physiol,* 2016;116:179-93.

2. Castagna, C., S. D'Ottavio, and G. Abt, Activity Profile of Young Soccer Players During Actual Match Play. *J Strength Cond Res,* 2003;17:775-80.

3. Dalen, T, et al. Player Load, Acceleration, and Deceleration During Forty-five Competitive Matches of Elite Soccer. *J Strength Cond Res*, 2016;30(2):351–9.

4. Bangsbo, J., L. Norregaard, and F. Thorso, Activity Profile of Competition Soccer. *Can J Sport Sci*, 1991;16:110-6.

5. Martin, R.J., et al., Short-term Peak Power Changes in Adolescents of Similar Anthropometric Characteristics. *Med Sci Sports Exerc*, 2003;35:1436-40.

6. Rumpf, M.C., et al., Vertical and Leg Stiffness and Stretch-shortening Cycle Changes across Maturation During Maximal Sprint Running. *Hum Mov Sci*, 2013;32(4):668-76.

7. Chelly, M.S., et al., Relationships of Peak Leg Power, 1 Maximal Repetition Half Back Squat, and Leg Muscle Volume to 5-m Sprint Performance of Junior Soccer Players. *J Strength Cond Res*, 2010;24:266-71.

8. Behringer, M., et al., Effects of Resistance Training in Children and Adolescents: a Meta-Analysis. *Pediatrics*, 2010;126:e1199-210.

9. Bosco, C., P.V. Komi, and A. Ito, Prestretch Potentiation of Human Skeletal Muscle During Ballistic Movement. *Acta Physiol Scand*, 1981;111:135–40.

10. Thompson, G., et al., Maximal Power at Different Percentages of One Repetition Maximum: Influence of Resistance and Gender. *J Strength Cond Res*, 2007;21:336–42.

11. Newton, R., and W. Kraemer, Developing Explosive Muscular Power: Implications for a Mixed Methods Training Strategy. *Strength Cond*, 1994;16:20–31.

12. Channell, B.T., and J.P. Barfield, Effects of Olympic and Traditional Resistance Training on Vertical Jump Improvement in High School Boys. *J Strength Cond Res*, 2008;22(5):1522-7.

13. MacKenzie, S.J., R.J. Lavers, B.B. Wallace, A Biomechanical Comparison of the Vertical Jump, Power Clean, and Jump squat. *J Sports Sci*, 2014;32:1576-85.

14. Duehring, M.D., C.R. Feldmann, and W.P. Ebben, Strength and Conditioning Practices of United States High School Strength and Conditioning Coaches. *J Strength Cond Res*, 2009;23(8):2188-203.

15. Michailidis, Y., et al. Plyometrics' Trainability in Preadolescent Soccer Athletes. *J Strength Cond Res*, 2013;27:38-49.

16. Fatouros, I.G., et al. Evaluation of Plyometric exercise training, Weight Training and Their Combination on Vertical Jumping Performance and Leg Strength. *J Strength Cond Res*, 2000;14(4):470-6.

17. Baker, D., et al. Acute Effect of Alternating Heavy and Light Resistances on Power Output During Upper-body Complex Power Training. J Strength Cond Res, 2003;17: 493–497.

18. Vlachopoulos, D., et al., Determinants of Bone Outcomes in Adolescent Athletes at Baseline: The PRO-BONE Study. *Med S*ci Sports Exerc, 2017;49(7):1389-96.

19. Tanner, J.M., Growth at Adolescence; With a General Consideration of the Effects of Hereditary and Environmental Factors upon Growth and Maturation from Birth to Maturity. Oxford: Blackwell Scientific Publications, 1962.

20. Draganidis, D., et al., Recovery Kinetics of Knee Flexor and Extensor Strength After a Soccer Match. *PloS one*, 2015;10:e0128072.

21. Sander, A., et al., Influence of a 2-year Strength Training Programme on Power Performance in Elite Youth Soccer Players. *Eur J Sport Sci*, 2013;13:445-51.

22. Lockie, R.G., et al., The Physical and Athletic Performance Characteristics of Division I Collegiate Female Soccer Players by Position. *J Strength Cond Res*, in press, 2016:[Epub ahead of print] Jul 7.

23. Bosquet, L., et al., Effect of Training Cessation on Muscular Performance: a Meta-Analysis. *Scand J Med Sci Sports*, 2013;23:e140-9.

24. Faigenbaum, A.D., et al., Youth Resistance Training: Updated Position Statement Paper from the National Strength and Conditioning Association. *J Strength Cond Res*, 2009;23:S60-79.

25. Andersen, L.L., et al., Changes in the Human Muscle Force-Velocity Relationship in Response to Resistance Training and Subsequent Detraining. *J Appl Physiol*, 2005;99:87-94.

26. Faigenbaum, A.D., et al., Early Muscular Fitness Adaptations in Children in Response to two Different Resistance Training Regimens. *Ped Exerc Sci*, 2005;17:237-48.

27. Behringer, M., et al., Effects of Strength Training on Motor Performance Skills in Children and Adolescents: a Meta-Analysis. *Ped Exerc Sci*, 2011;23:186-206.

28. Randell, A.D., et al., Transference of Strength and Power Adaptation to Sports Performance—Horizontal and Vertical Force Production. *Strength Cond J*, 2010;32:100-6.

29. Meylan, C.M., et al., The effect of Maturation on Adaptations to Strength Training and Detraining in 11-15-year-olds. *Scand J Med Sci Sports*, 2014;24:e156-64.

30. Meyers, R. W., et al. The Influence of Maturation on Sprint Performance in Boys over a 21-Month Period. Med Sci Sports Exerc, 2016;48(12):2555–62.

31. Madsen, K., et al. Effects of Detraining on Endurance Capacity and Metabolic Changes During Prolonged Exhaustive Exercise. *J Appl Physiol*, 1993;75:1444-51.

32. Eliakim, A., and D. Nemet, The Endocrine Response to Exercise and Training in Young Athletes. *Pediatr Exerc Sci*, 2013;25(4):605-15.

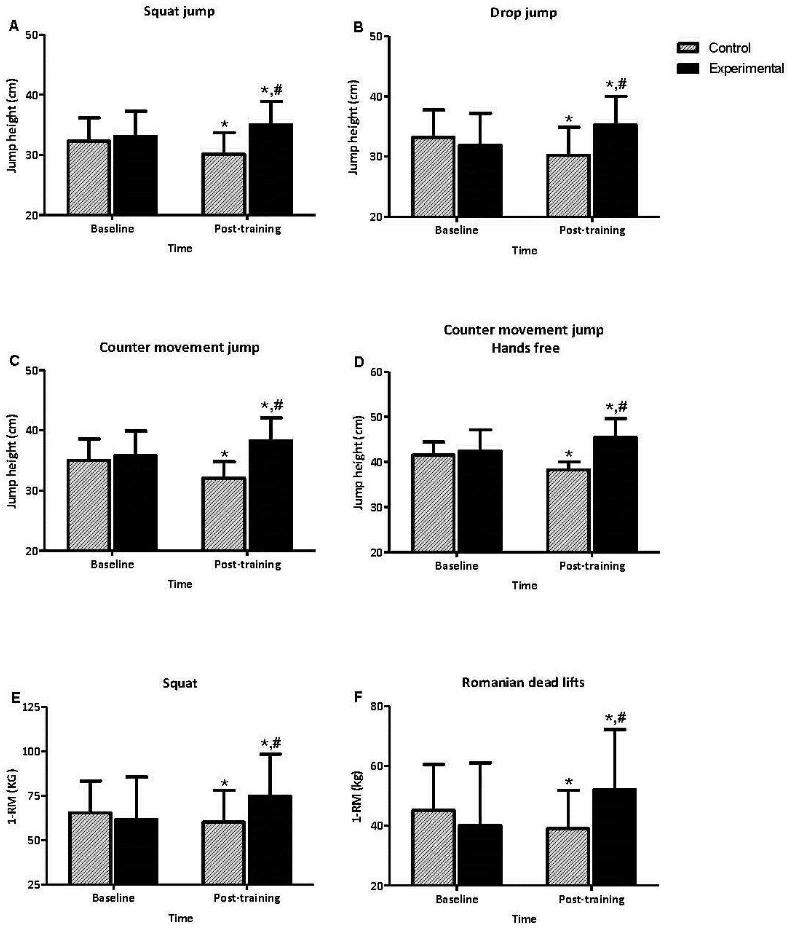

Figure 1. Training-induced changes in strength and power measurements.

1RM, one maximal repetition; *significant difference between pre- and post-training at P<0.05; #significant difference between groups at P<0.05.

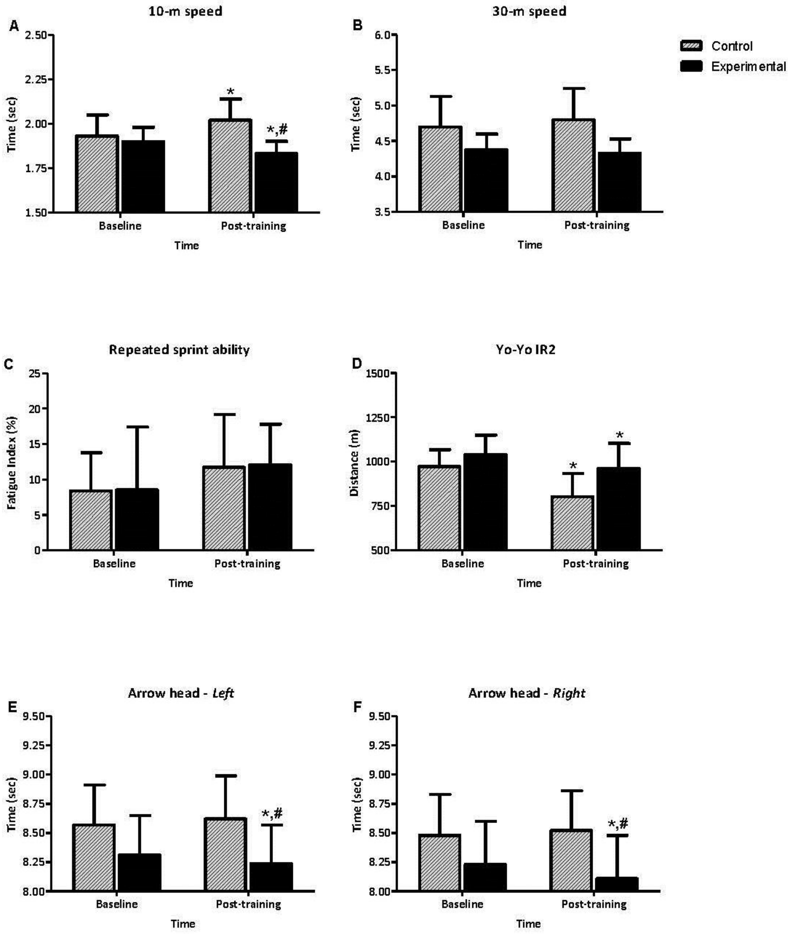

Figure 2. Training-induced changes in speed, speed-endurance and COD measurements.

m, meters; YO-YO IR2, Yo-Yo intermittent recovery test 2; *significant difference between pre- and post-training at P<0.05; #significant difference between groups at P<0.05.

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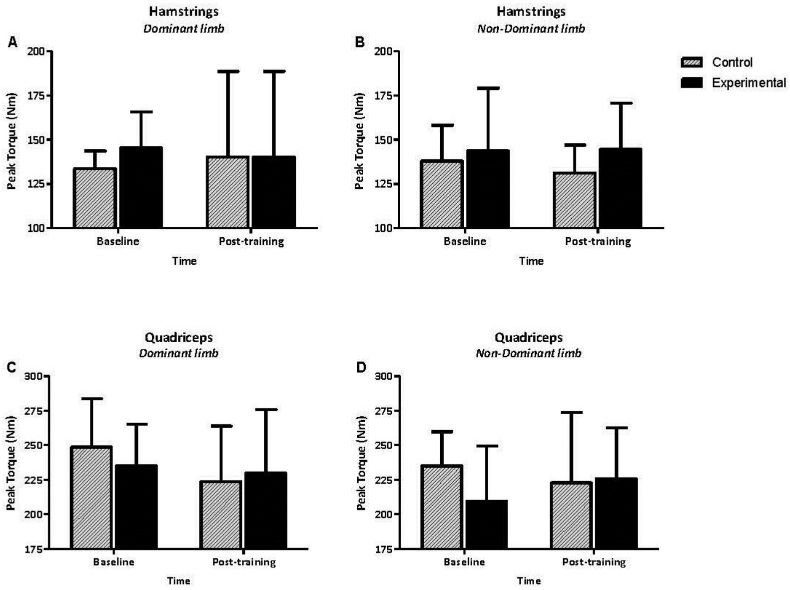

Figure 3. Training-induced changes in isometric peak torque.

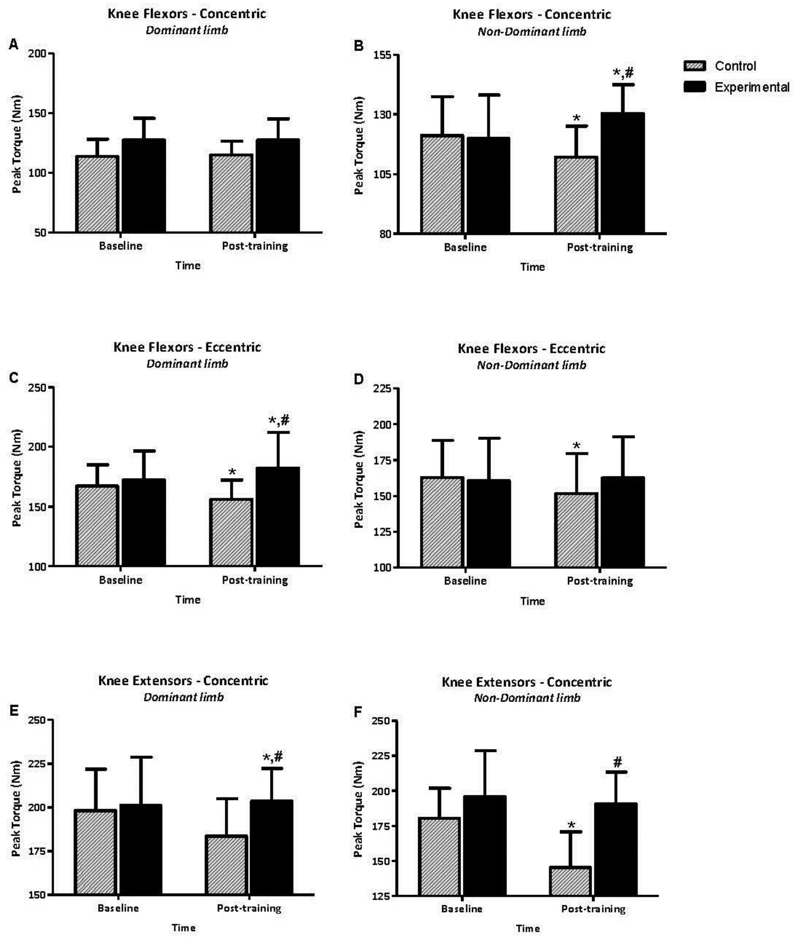

Figure 4. Training-induced changes in isokinetic peak torque of knee flexors and extensors at 60°/s.

*significant difference between pre- and post-training at P<0.05; #significant difference between groups at P<0.05.

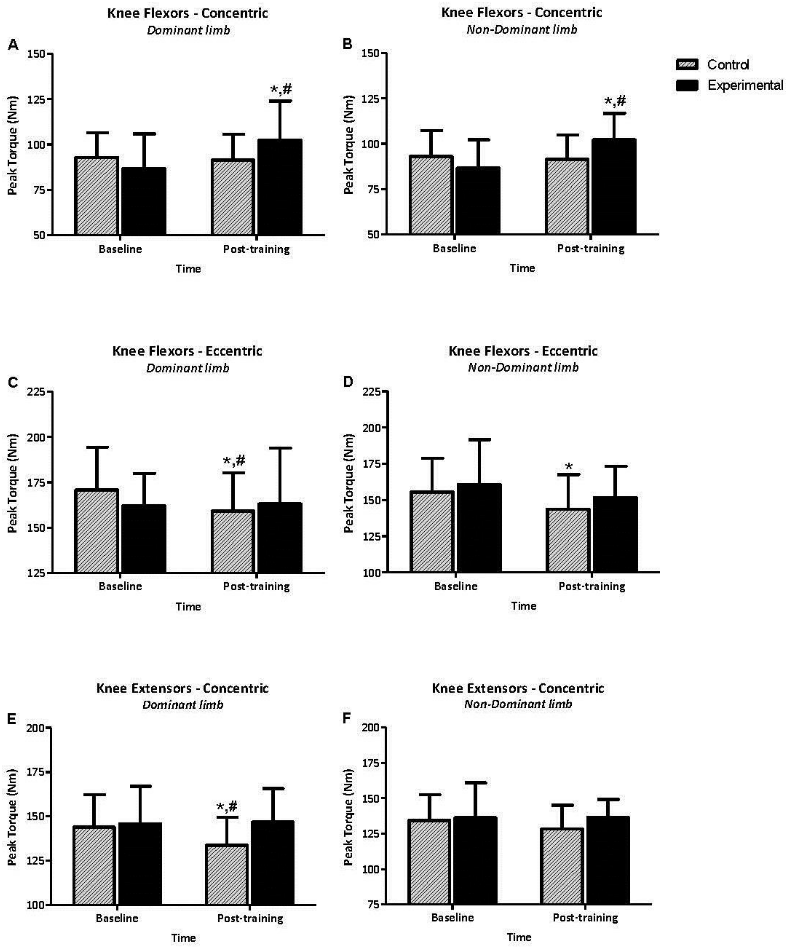

Figure 5. Training-induced changes in isokinetic peak torque of knee flexors and extensors at 180°/s.

*significant difference between pre- and post-training at P<0.05; #significant difference between groups at P<0.05.

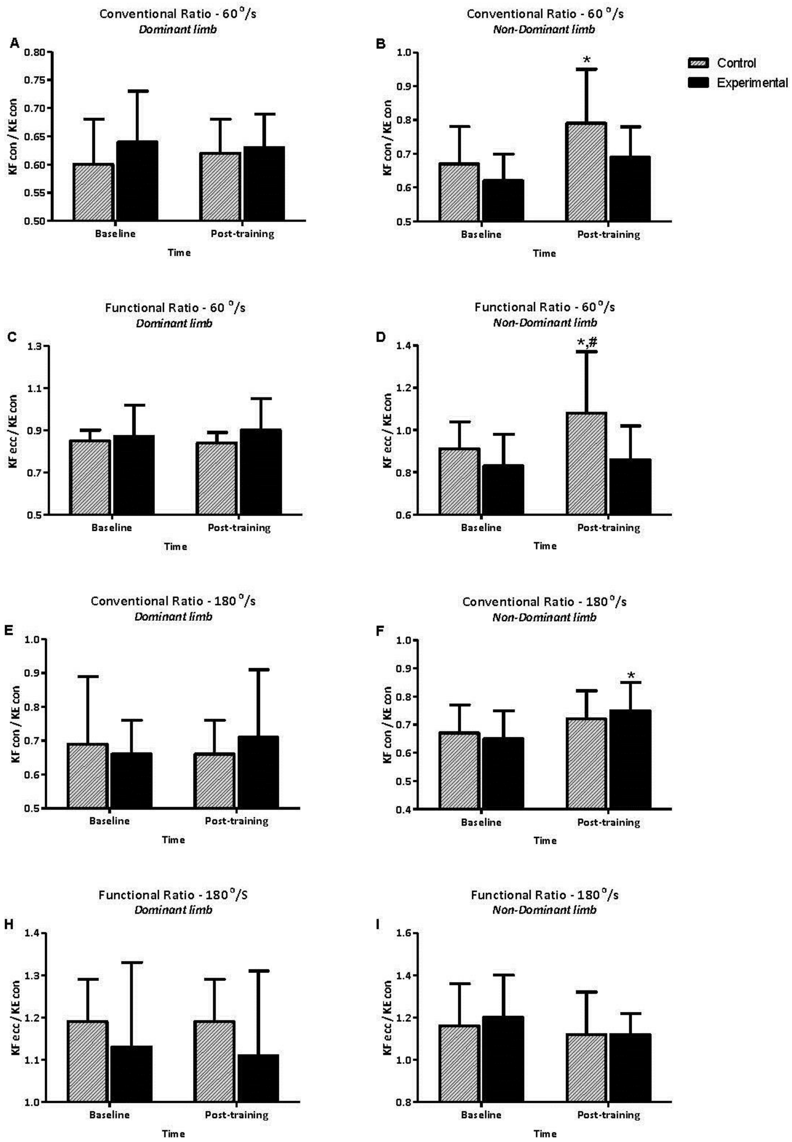

Figure 6. Training-induced changes in conventional and functional rations of knee flexors and extensors at 60°/s and 180 °/s.

KF, knee flexors; KE, knee extensors; *significant difference between pre- and post-training at P<0.05; #significant difference between groups at P<0.05.

Table 1: Anthropometric results.

		Pre-training	Post-training	F, p, η^2
Weight (kg)				$F_{(1,20)}=0.32$
	Control	72.24 ± 8.1	72.06 ± 8.1	$p=0.58$
	Experimental	69.13 ± 5.0	69.1 ± 5.3	$\eta^2=0.05$
Height (m)				$F_{(1,20)}=1.82$
	Control	1.78 ± 0.1	1.78 ± 0.1	$p=0.86$
	Experimental	1.79 ± 0.1	1.79 ± 0.1	$\eta^2=0.08$
BMI (kg m^{-2})				$F_{(1,20)}=0.03$
	Control	22.69 ± 1.9	22.64 ± 2.1	$p=0.18$
	Experimental	21.66 ± 0.9	21.56 ± 1.0	$\eta^2=0.01$
% Body Fat				$F_{(1,20)}=0.22$
	Control	18.18 ± 4.5	18.21 ± 4.3	$p=0.65$
	Experimental	14.26 ± 2.2[#]	13.8 ± 2.7[#]	$\eta^2=0.01$

[*]Significant difference with baseline; [#]significant difference between groups; BMI, body mass index.

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Table 2: The training protocol.

Weeks						
Progressions		1	2	3	4	5
Warm up was the same for all training sessions and consist it of muscle activation, low intensity cardiovascular exercise, dynamic stretching, skills exercise and ball possession games. Total duration was 30 min						
TS 1	Exercises: • Squat • Romanian dead lifts (RDL) • Lounges • One leg –RDL • Bench press • Rowing • Shoulder press • Barbell elbow curls • Dips	Intensity: 60-70% Reps: 10-14 Sets: 2 Rest: 60 s	Squat and RDL* Intensity: 70-80% Reps: 10-12 Sets: 3 Rest: 80 s	Squat and RDL Intensity: 70-80% Reps: 8-10 Sets: 3 Rest: 90 s	Squat and RDL Intensity: 80-85% Reps:6-8 Sets: 3 Rest: 120 s	Squat and RDL Intensity: 80-90% Reps: 6-3 Sets: 2 Rest: 120 s
TS2	Exercises: • Barbell cleans plus 10-20m sprints or agility drills • Kettlebell snatch plus 10-20m sprints or agility drills • Box jumps plus 10m agility drills	Intensity: 20 kg/10 kg/20 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 30 kg/10 kg/30 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 30 kg/10 kg/40 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 40 kg/10 kg/50 cm Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 40 kg/10 kg/50 cm Reps: 6-8 Sets: 3 Rest: 90-120 s
TS3	Exercises: • Squat • RDL • Step ups in box • One leg RDL • Bench press • Inverse rowing • Dumbbells shoulder extensions • Cable elbow flexions	Intensity: 60-75% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL* Intensity: 70-80% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL Intensity: 70-80% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL Intensity: 80-90% Reps: 10-14 Sets: 2 Rest: 60-80 s	Squat and RDL Intensity: 80-90% Reps: 10-14 Sets: 2 Rest: 60-80 s

Weeks						
Progressions		1	2	3	4	5
	• Push downs					
TS4	Exercises: • Power bags jerk plus 10-20m sprints • Kettlebell snatch plus 10-20m sprints • Resistive sprints and sprint (8m+15-20m)	Intensity: 20 kg/10 kg Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 30 kg/10 kg Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 30 kg/10 kg Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 40 kg/10 kg Reps: 6-8 Sets: 3 Rest: 90-120 s	Intensity: 40 kg/10 kg Reps: 6-8 Sets: 3 Rest: 90-120 s
Cool down period consist static stretching exercises for all muscle groups. Total duration was 15 min						
Control group: subjects participated two times per week in light soccer training (5 vs. 5 game on non-consecutive days)						

*For the rest exercises training load was stable throughout the experimental design. TS 1: first training session of the week - strength training in gym; TS2: second training session of the week - Power training in soccer pitch; TS3: third training session of the week - strength training in gym; TS4: fourth training session of the week - Power training in soccer pitch; s, seconds.