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5.2 EFFECTS OF WEIGHT LIFTING TRAINING COMBINED WITH PLYOMETRIC EXERCISES ON PHYSICAL FITNESS, BODY COMPOSITION, AND KNEE EXTENSION VELOCITY DURING KICKING IN FOOTBALL

Abstract

The effects of a training program consisting of weight lifting combined with plyometric exercises on kicking performance, myosin heavy-chain composition (vastus lateralis physical fitness, and body composition (using dual-energy X-ray absorptiometry (DXA) was examined in 37 male physical education students divided randomly into a training group (TG: 16 subjects) and a control group (CG: 21 subjects). The TG followed 6 weeks of combined weight lifting and plyometric exercises. In all subjects, tests were performed to measure their maximal angular speed of the knee during instep kicks on a stationary ball. Additional tests for muscle power (vertical jump), running speed (30 m running test), anaerobic capacity (Wingate and 300 m running tests), and aerobic power (20 m shuttle run tests) were also performed. Training resulted in muscle hypertrophy (+4.3%), increased peak angular velocity of the knee during kicking (+13.6%), increased percentage of myosin heavy-chain (MHC) type Ha (+8.4%), increased 1 repetition maximum (1 RM) of inclined leg press (ILP) (+61.4%), leg extension (LE) (+20.2%), leg curl (+15.9%), and half squat (HQ) (+45.1%), and enhanced performance in vertical jump (all p [less than or equal to] 0.05). In contrast, MHC type I was reduced (-5.2%, p [less than or equal to] 0.05) after training. In the control group, these variables remained unchanged. In conclusion, 6 weeks of strength training combining weight lifting and plyometric exercises results in significant improvement of kicking performance, as well as other physical capacities related to success in football (soccer).

Key words: plyometric training, weight training, vertical jump, 1 RM, MHC, soccer, football.

Resume : Dans cette etude, on analyse l'effet d'un programme d'entrainement constitue d'exercices de musculation et d'exercices pliometriques sur un botte, la composition de la myosine a chaine lourde (vaste externe), la condition physique et la composition corporelle (DXA) chez 37 etudiants en education physique divises aleatoirement en deux groupes dont un s'entrainant (TG, 16 sujets) et l'autre servant de controle (CG, 21 sujets). Le TG s'entraina durant 6 semaines au moyen d'exercices de musculation et d'exercices de pliometrie. Les tests passes par tous les sujets consistent en des mesures de la vitesse angulaire maximale du genou au cours d'un botte du cou-de-pied sur un ballon stationnaire. Les sujets passerent aussi des tests de puissance musculaire (saut vertical), de vitesse de course (sprint sur 30 m), de capacite anaerobie (test de Wingate et course sur 300 m) et de puissance aerobie maximale (test de navette de 20 m). Le programme d'entrainement suscite l'hypertrophie musculaire (+4,3 %) et une augmentation de la velocite angulaire de pointe du genou au cours d'un botte (+13,6 %), du pourcentage de myosine a chaine lourde (MHC) des fibres du type IIa (+8,4 %), de la charge maximale levee (1 RM) au cours d'un developpe incline des jambes (ILP, +61,4 %), de l'extension des genoux (LE, +20,2 %), de la flexion des genoux (+15,9 %), des demi-redressements assis (HQ), +45,1 %) et de la hauteur du saut vertical (toutes les differences significatives a p [less than or equal to] 0,05). Par contre, la quantite de MHC des fibres de type I est diminuee (-5,2 %, p [less than or equal to] 0,05) a la suite du programme d'entrainement. On n'observe aucun changement dans le groupe de controle. En conclusion, un programme d'entrainement d'une duree de 6 semaines et comprenant des exercices de musculation et des exercices pliometriques suscitent une augmentation de la performance au botte et des autres capacites physiques pertinentes an football (soccer).

Mots-cles : entrainement pliometrique, programme de musculation, saut vertical, 1 RM, MHC, soccer, football.

[Traduit par la Redaction]

Introduction

Success in football (or soccer, as it is known in North America) depends on kicking performance (Lees and Nolan 1998), among other factors (Amason et al. 2004). Most studies have concluded that strength training (6-15 weeks duration) improves kicking performance (De Proft et al. 1988; Dutta and Subramanium 2002; Jelusic et al. 1992; Manolopoulos et al. 2006; Manolopoulos et al. 2004), though some investigations have failed to find an improvement (Aagaard et al. 1996; Trolle et al. 1993). The discrepancies between studies may be explained by marked differences in the strength-training program: some investigators have used strength training alone (Aagaard et al. 1996; Trolle et al. 1993) or combined with football-specific training (De Proft et al. 1988; Manolopoulos et al. 2006; Manolopoulos et al. 2004) and loaded kicking movements (Aagaard et al. 1996; Jelusic et al. 1992; Trolle et al. 1993), as well as isokinetic strength training combined with specific training for football kicking (Dutta and Subramanium 2002).

Weight training improves maximal dynamic force (Campos et al. 2002) and plyometric training has positive effects on speed and force of muscle contraction (Malisoux et al. 2006x; Malisoux et al. 2006b; Saunders et al. 2006). Some studies have shown that sprinting and jumping ability may be improved with plyometric training (Diallo et al. 2001; Moore et al. 2005; Rimmer and Sleivert 2000; Siegler et al. 2003), even with only 4 weeks of training (3 sessions/ week) (Impellizzeri et al. 2008). Nevertheless, the effect of this kind of training on other components of physical fitness, particularly peak knee-extension velocity during kicking in football, have not been examined.

Although the efficacy of plyometric training is well established (Bobbert 1990), less is known about the mechanism by which plyometric training may enhance muscle power and sprinting abilities. Muscle power depends on myosin heavy-chain (MHC) composition (Schiaffino and Reggiani 1996). Some studies have shown a decrease in type I and increase of type IIa MHC isoforms with 3 months of training in sprinters using diverse plyometric and strength-training exercises (Andersen et al. 1994b). Plyometric training alone has been reported to elicit an increase of MHC IIa (Malisoux et al. 2006x). In contrast, Andersen et al. (1994x) reported a reduction in type Ha muscle fibers (using traditional myofibrillar ATPase histochemistry) without significant changes in the proportion of MHC isoforms (determined by electrophoresis) with 3 months of strength training in soccer players. In general, most studies report a shift in MHC composition from IIx to IIa combined with no change (or reduction) of MCHI with strength training (Campos et al. 2002; Putman et al. 2004; Raue et al. 2005). It remains unknown if vastus lateralis MHC composition may be affected by 6 weeks of strength training combined with plyometric exercises.

Thus, we hypothesized that the combination of weight lifting with plyometric training would promote an improvement in knee-extension velocity during kicking in football, as well as an improvement in vertical jump and running speed, while eliciting an enhancement of type Ha and a reduction of type I MHC composition.

Therefore, the aim of this study was to determine whether a 6-week strength-training program combining weight lifting and plyometric exercises elicits the appropriate adaptations to improve kicking velocity and performance in other skills relevant to football success, such as sprinting capacity, jumping, and endurance. Another aim of this study was to determine if this training program has other potential beneficial effects on physical performance and body composition that could be of benefit for football players.

Materials and methods

Subjects

Forty-two physical education students were randomly assigned to a strength-training group (TG) (n = 16; age, 23.4 [+ or -] 0.5 years; height, 174.9 [+ or -] 1.7 cm; body mass, 71.2 [+ or -] 1.9 kg (all mean [+ or -] SEM)) and control group (CG) (n = 21; age, 24.3 [+ or -] 0.5 years; height, 177.0 [+ or -] 1.5 cm; body mass, 75.7 [+ or -] 2.5 kg (all mean [+ or -] SEM)). Five subjects were excluded from the training group due to failure in accomplishing the training program and (or) performance tests. The data reported correspond to the 16 subjects that finished the study.

Their usual physical activity was limited to some participation in sports and exercises related to their studies, but none had been doing strength training during at least the last 6 months. Subjects did not train or perform any kind of intense or unusual physical activity during the 24 h before the test and subjects were always tested in the morning. Subjects were informed about the aims, benefits, and risks of the study, which was approved by the Ethical Committee of the University of Las Palmas de Gran Canaria and performed in accordance with the Helsinki Declaration of 1975 in regards to the conduct of clinical research. All volunteers provided their written consent before participating in the study.

Training program

The TG followed a periodised 6-week training program consisting of 3 sessions/week, scheduled on Monday, Wednesday, and Friday. During the training, they executed bilateral plyometric exercises combining unloaded drop jumps from a height of 40-60 cm and explosive hurdle jumps, using 5 hurdles spaced 1 m apart at a height of 50 cm. After the completion of the plyometric exercises they performed the weight lifting part of training, consisting of bilateral inclined leg press (ILP), leg extension (LE), half squat (HQ), and leg curl (LC). The intensity, repetitions, and sets per sessions are described in the Table 1. The subjects were instructed to jump as high as possible over the hurdles during plyometric training and to minimize contact time with the ground as much as possible and to lift the load as quickly as possible during weight lifting. The weight lifting training was not technically explosive, i.e., no release of the weight occurred, but the subjects were encouraged to do the exercises quickly. After 3 weeks of training 1 RM tests were performed and the absolute training load was adjusted accordingly. The CG did not perform any kind of training.

Tests

Tests were carried out over 5 days. The first testing day started with the determination of body composition and kicking performance, followed by the assessment of jumping performance and maximal dynamic strength. On a different day, sprint performance and anaerobic capacity were assessed. The anaerobic capacity tests were started at least 30 min after the sprint tests. The next day, the Wingate test was carried out. The 4th and 5th testing days were used to determine the maximal aerobic power and to obtain a muscle biopsy, respectively.

Lower-limb lean mass

Lean mass of the lower limbs (lower limb mass--[lower limb fat mass + lower limb bone mass]) was assessed by dual-energy X-ray absorptiometry (DXA) (QDR-1500, Hologic Corp., Software version 7.10, Waltham, Mass.) as reported in Calbet et al. (2001) and Ara et al. (2006). DXA equipment was calibrated using a lumbar spine phantom and following the manufacturer's guidelines. Subjects were scanned in the supine position and the scans were performed in high resolution. Lower-limb lean mass (kg) was calculated from the regional analysis of the whole-body scan and was considered equivalent to the lower-limb muscle mass (Perez-Gomez et al. 2008). The coefficient of variation for the assessment of lower limb lean mass in young volunteers (n = 9) with repositioning was 1.5% (Calbet et al. 1998).

Kicking performance

A telemetric electrogoniometer (Gait Analysis System, Mie Medical Ma 695110, Leeds, UK) was firmly attached to the lateral aspect of the right knee centred on the condyle--tibial joint line to measure angular velocity of the knee joint during a maximal instep kick. In addition, an accelerometer (Kistler 8632C50, Winterthur, Switzerland) was also firmly attached to the medial aspect of the tibia with tape, just below the tibial tuberosity and used to identify the time at which the leg impacted the football (Mikasa, Official size 5, Hiroshima, Japan) during kicking. The knee angular velocity reached just 10 ms before impact was taken as the maximal knee extension velocity. All data were sampled at 1000 Hz and recorded on a PC using a data acquisition system (MacLab/8e, ADInstruments Pty. Ltd., Castle Hill, Australia). Subjects performed 3 maximal instep kicks on a stationary ball, as quickly as possible, without any special attention to the accuracy of the kick. The supporting leg was situated 10 cm to the side and 10 cm behind the ball. The best of the three trials was selected as the representative value of the kicking performance. The intraclass correlation coefficient [alpha] (Cronbach) for the peak knee angular velocity in 14 subjects was 0.98.

Maximal dynamic force (1 RM)

Maximal strength was assessed using the 1 RM of ILP, LE, HQ, and LC exercises. For the ILP and HQ, subjects were required to lower the load so that 90[degrees] of knee flexion was achieved. For the LE, each participant lifted the weight to the full extension of the knee. For the LC, each subject lifted the device until contact with the thigh. Before the first 1 RM attempt subjects warmed up by doing 10 min of stationary cycling followed by 10 repetitions with approximately 50% of perceived maximum load. Then, subjects performed 4-5 lifting attempts with progressively heavier loads until the 1 RM was determined. To minimize fatigue, 3-5 min resting periods were allowed between attempts.

Muscle biopsies

Needle muscle biopsies were obtained from the middle section of the vastus lateralis muscle under local anaesthesia without suction, but with mild pressure on the lateral aspect of the thigh. Biopsies before and after the 6-week period were obtained from 25 of the subjects (15 from the TG and 10 from the CG). The muscle samples were immediately mounted with Tissue-Tek and frozen in isopentane cooled with liquid nitrogen, and stored at -80 [degrees]C. MHC analyses were performed on the muscle biopsies using sodium dodecylsulfate polyacrylamide gel electrophoresis (SDSPAGE), as reported by Larsson et al. (2002). From each biopsy 20-40 serial cross sections (10 pm) were cut and placed in 200-500 [micro]L of lysing buffer and heated for 3 min at 90 [degrees]C. Between 2 and 12 [micro]L of the myosin-containing samples were loaded on a SDS-PAGE Gels were run at 70 V for 43 h at 4 [degrees]C. Subsequently, the gels were Coomassie stained and MHC isoform bands (I, Ila, IIx) were determined based on known migration patterns and quantified with Un-scan-it gel software (Orem, Utah). A representative example is depicted in Fig. 1.

Vertical jump performance

The forces generated during vertical jumps were measured with a force plate (Kistler, Winterthur, Switzerland), as reported in Ara et al. (2006). During the jumps, the subjects were asked to keep their hands on their hips and to minimize horizontal and lateral displacement. They were aware that the jumps had to be executed explosively to achieve maximum height. Two kinds of jumps were performed: squat jumps (SJs), in which countermovement was not permitted, and countermovement jumps (CMJs), in which subjects were asked to perform a countermovement from standing, intending to reach knee-bending angles of around 90[degrees] just before impulsion A digital goniometer (Lafayette Instrument Company, Lafayette, Ind.) was used to verify that knees were bent at 90[degrees] before jumping for the SJ. The vertical velocity at takeoff (VT), height jumped (VJH), the mean rate of force development (RFD), positive impulse (PI), mean power (MP), maximal instantaneous power (MIP), and maximal instantaneous vertical velocity (MIV) generated were determined in the best of the 3 trials for SJs and CMJs. The RFD was obtained by linear regression of the force--time relationship during the impulse phase of the SJ and CMJ between 25% and 75% of the peak force. The intraclass correlation coefficients a (Cronbach) for VT, VJH, RFD, PI, MP, MIP, and MIV during the SJs were 0.98, 0.98, 0.88, 0.99, 0.86, 0.99, and 0.99, respectively, in 10 subjects who repeated the jumps 3 times. The corresponding intraclass correlation coefficients for the same variables during the CMJs were 0.99, 0.99, 0.88, 0.99, 0.97, 0.99, and 0.99, respectively.

All-out 30 s sprint test (Wingate test)

Wingate tests were performed on a modified mechanically braked ergometer (Monark 818E, Monark AB, Vargerg, Sweden) equipped with an SRM power meter (Schoberer, Germany) with a braking load equivalent to 10% of body mass (Calbet et al. 2003). Peak power output (PPO) was recorded as the highest work output performed during a 1 s interval of the test, and mean power output (MPO) was recorded as the average power developed during the 30 s period. The intraclass correlation coefficient a (Cronbach) for MPO and PPO was 0.98, in 19 subjects assessed in our laboratory twice in a single day (Calbet et al. 1997).

Running sprint tests

Following an individual warm-up, subjects performed 3 maximal indoor short sprint trials, each separated by at least 5 min. The time required to cover 30 m was recorded with photoelectric cells (General ASDE, Valencia, Spain). The timer is automatically activated when the subject crosses the first cell, and every 5 m thereafter. The subjects were encouraged to run as fast as they could. A standing start was used and the best of the 3 trials was selected as the representative value of this test (Vicente-Rodriguez et al. 2004). The intraclass correlation coefficient [alpha] (Cronbach) for the running times at 5, 10, 15, 20, 25, and 30 m were 0.91, 0.97, 0.98, 0.99, 0.99, and 0.99, respectively, in 14 physical education students who repeated the test 3 times.

Anaerobic capacity

An all-out 300 m running test was used to estimate the anaerobic capacity, since the anaerobic metabolic pathways contribute more than 50% to the overall energy expenditure during all-out exercise tests with a duration between 30 and 60 s (Calbet et al. 1997; Calbet et al. 2003; Medbo and Tabata 1993). The test was performed on a 400 m track, and the time was recorded manually with a digital stopwatch.

Aerobic maximal power

The maximal oxygen uptake (V[O.sub.2 max]) was estimated using the maximal multistage 20 m shuttle run (Leger et al. 1988). Subjects were required to run back and forth on a 20 m course and be on the 20 m line at the same time that a beep was emitted from an audiotape. The frequency of the sound signals increased in such a way that running speed started at 8.5 km*[h.sup.-1] and was increased by 0.5 km*[h.sup.-1] each minute. The time during which the subjects were able to run was recorded to calculate V[O.sub.2 max]. This test has a test--retest reliability coefficient of 0.95 for adults (Leger et al. 1988).

Statistical analysis

Mean and standard error of the mean (SEM) are given as descriptive statistics. To identify potentially significant group by time interactions, separate 2 x 2 (group x time) analyses of variance (ANOVA) with repeated measures were used. When the group by time interaction was statistically significant, post hoc pairwise comparisons were performed using the Tukey's post hoc test. The relationship between variables was assessed by linear regression analysis and Pearson's correlation coefficient was calculated. SPSS software (SPSS Inc., Chicago, Ill.) was used for the statistical analysis. Statistical significance was set at p [less than or equal to] 0.05.

Results

Body composition

The subject's physical characteristics are summarized in Table 2. Training resulted in an enlargement in lower limb lean mass, which was significantly greater than the small increase observed in the control group (ANOVA group x time interaction: p = 0.05).

Kicking performance, vertical jump, and maximal dynamic force (1 RM)

Kicking performance, vertical jump, and maximal dynamic force values pre- and post-training are presented in Table 3. Significant improvements were obtained in the maximal angular velocity of the knee in the experimental group (from 21.9 [+ or -] 1.3 before training to 24.5 [+ or -] 1.2 rads-1 after training, p [less than or equal to] 0.01), whereas no significant changes were observed in the control group (ANOVA group x time interaction: p [less than or equal to] 0.001). However, there was no correlation between the increments in angular velocity of the knee and the changes in performance in the other variables assessed in this study.

Strength training also resulted in improvements in countermovement jump vertical velocity at takeoff, height jumped, maximal instantaneous vertical velocity, and maximal instantaneous power.

The experimental group improved 1 RM performance in inclined leg press, leg extension, and half squat.

Wingate and running tests

There were no significant effects of strength training in any of the variables analysed during the Wingate tests and running tests. The data are presented in Table 4.

Myosin heavy-chain isoform distribution

Strength training resulted in an increased amount of MHC type IIa (+8.4%, p [less than or equal to] 0.05; ANOVA group x time interaction: p [less than or equal to] 0.05) and a reduction in the amount of MHC type I (-5.2%, p [less than or equal to] 0.05; ANOVA group x time interaction: p = 0.05) (Table 5). No significant correlations were observed in the training group between the change in MHC type IIa composition and the improvement of kicking performance, jumping performance, and maximum dynamic strength.

Discussion

The main finding of this study was that 6 weeks of strength training consisting of weight lifting combined with plyometric exercises in the same training session significantly improved kicking performance, vertical jump, and maximal dynamic force (1 RM) in physical education students; however, the training failed to increase running velocity or predicted maximal aerobic power. These effects were associated with greater lean mass in the lower extremities, higher proportion of MHC type IIa, and reduction of MHC type I.

The maximal knee angular velocities observed in this study ranged between 21.3 and 24.5 rad*[s.sup.-1, and are similar to those reported by Lees et al. (2005) but a little lower than those recorded by Manolopoulos et al. (2006) in football players. In general, kick performance has been determined by measuring the distance reached by the ball after kicking (De Proft et al. 1988), or by the velocity of the ball after it has been hit (Aagaard et al. 1996; Trolle et al. 1993). In theory, the velocity of the ball may vary depending on the characteristics of the ball and the technique of kicking. In addition to these factors, the kicking distance depends also on the take-off angle of the ball, wind direction, air density (altitude), and the amount of imparted spin. Thus, to better isolate the effect of the strength-training program on the capacity to kick the ball harder, we measured the angular speed of the knee, which is the main factor determining the velocity of the ball (Dorge et al. 1999; Lees and Nolan 2002). We did not assess, however, the process of transfer of energy from proximal (upper leg) to distal (lower leg) segments, which is also crucial in imparting a high velocity to the ball (Dorge et al. 1999; Wickstrom 1975).

Kicking performance has been related to leg muscle strength (De Proft et al. 1988; Dutta and Subramanium 2002; Jelusic et al. 1992; Manolopoulos et al. 2004). De Proft et al. (1988) noted that after a specific leg strength-training program during a full football season the concentric strength of the knee increased and kick performance (measured as kicking distance) improved (De Proft et al. 1988). They also reported that the correlations between leg strength and kick performance improved from the beginning to the end of the season in adolescent football players. In the present investigation, both kicking performance and vertical jump were improved with strength training. However, in contrast to De Proft et al. (1988), we did not observe a significant correlation between vertical jump and peak knee angular velocity during kicking in adults.

The results of the present study are consistent with previous research in which vertical jump performance was improved following a training program combining weight lifting and plyometric exercises (Adams et al. 1992; Bauer et al. 1990; Fatouros et al. 2000; Ingle et al. 2006; Lyttle et al. 1996; Moore et al. 2005). A close analysis of the effects observed in both types of vertical jump shows the specificity of this training program (Morrissey et al. 1995; Sale and MacDougall 1981). Training resulted in improvements of vertical velocity at take off, vertical jumping height, maximal instantaneous vertical velocity, and maximal instantaneous power during the countermovement jumps, but not during the squat jumps. This specificity of training is likely the reason why no improvements were observed in running speed or cycling power (Wingate tests) with this training program. Indeed, Young et al. (2001) noted that the best training to improve performance in a 30 m sprint test was training over a similar distance without changes of direction. In soccer, part of training is usually devoted to sprinting exercises; this may be reason why some studies report improvement in sprinting performance with 4 weeks of plyometric training (Impellizzeri et al. 2008) and with 3 months of weightlifting combined with plyometric exercise (Moore et al. 2005). Our results combined with previous studies indicate that strength training alone or combined with plyometric exercises may fail to enhance sprint performance without adding some sprint-specific training.

Myosin heavy chain (MHC) isoforms determine the contractile and energetic properties of human muscles fibre types (Bottinelli and Reggiani 2000). Despite the significant increment in MHC isoform type IIa in the experimental group there was no correlation between the increment in MHC isoform type IIa and the increment in the angular velocity of the knee, the maximal dynamic force, or height jumped. Our results are in agreement with those of Andersen et al. (1994b), who reported an increase of MHC IIa and a reduction of MHC I after 3 months of training in sprinters who used a combination of strength, plyometric, and sprint-specific exercises. Other researchers have also reported an increase in MHC type IIa isoform with plyometric training alone (Malisoux et al. 2006x) or combined with weightlifting exercises (Liu et al. 2003).

The study by Liu et al. (2003) is comparable to ours, since they also studied the effect of 6 weeks of strength training on physical education students. In the latter, 12 subjects performed combined strength training consisting of weight lifting and plyometric exercises, while the other 12 subjects only trained with weight-lifting exercises (Liu et al. 2003). The reduction in MHC type I observed in the present investigation agrees with that reported by Liu et al. (2003) in the triceps brachii when strength training is combined with plyometric training.

In contrast to our results, Aagaard et al. (1996) and Trolle et al. (1993) did not find improvements in kicking performance after knee-extension strength training. Several reasons could explain the differences; the participants of our study were physical education students, whereas the studies of Aagaard et al. (1996) and Trolle et al. (1993) used elite football players. It is likely that football players already possess a high kicking performance with less potential for improvement. The action of kicking requires a complex series of synergistic movements that are difficult to replicate with simple strength-training movements (Bangsbo 1994). An important difference between the studies of Aagaard et al. (1996) and Trolle et al. (1993) with respect to that of De Proft et al. (1988) is that in the latter study the football players carried out strength training in addition to their ordinary football training, whereas in the former studies only strength training was used. Thus, it appears that combining strength training with technical training involving the actual motor tasks is necessary to improve kicking in professional football players. A difference between our study and those of Aagaard et al. (1996) and Trolle et al. (1993) was that these investigators applied only high resistance, low resistance, or loaded kicking movements in the training process, whereas we combined weight lifting with explosive actions (plyometric leg exercises) in the same session. Thus, the stimulus for our participants may have been higher and more specific than for the football players in the studies of Aagaard et al. (1996) and Trolle et al. (1993). A further difference between these studies and ours was that our participants performed maximal instep kicks as quickly as possible with no regard for accuracy or direction of the kick, whereas their football players shot towards a handball goal and only shots within the goal posts were accepted. This criterion may have limited the players' ability to use all of their kicking potential, though admittedly this should have affected the kicking performance pre- and post-training similarly.

Limitations

The experimental design used did not allow us to distinguish between the effects of the strength and plyometric components of the training program. Another limitation is that it is uncertain if athletes with high experience in strength training or footballers would respond in the same way as our physical education students. It remains to be determined what is the optimal duration and combination of weightlifting and plyometric exercise for an optimal improvement of kicking performance, power, and sprinting ability.

Conclusions

The present results indicate that, in physical education students, 6 weeks of strength training combining weight lifting and plyometric exercises is associated with improvements in angular velocity of the knee during a kick, one repetition maximum (1 RM) in leg extension, inclined leg press, leg curl, and half squat, and vertical velocity at takeoff, height jumped, maximal instantaneous vertical velocity, and power in a countermovement jump. This training also elicited muscle hypertrophy, and increased and decreased the amount of MHC type IIa and I, respectively, within skeletal muscle. Further studies are needed to ascertain if similar results may be achieved in football players.