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ORIGINAL ARTICLE

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Strength training effects on physical performance and serum hormones in young soccer players

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Abstract To determine the effects of simultaneous explosive strength and soccer training in young men, 8 experimental (S) and 11 control (C) players, aged 17.2 (0.6) years, were tested before and after an 11-week training period with respect to the load-vertical jumping curve [loads of 0–70 kg (counter-movement jump CMJ0–70)], 5- and 15-m sprint performances, submaximal running endurance and basal serum concentrations of testosterone, free testosterone and cortisol. In the S group, the 11-week training resulted in significant increases in the low-force portion of the load-vertical jumping curve (5–14% in CMJ0–30, $P < 0.01$) and in resting serum total testosterone concentrations (7.5%, $P < 0.05$), whereas no changes were observed in sprint running performance, blood lactate during submaximal running, resting serum cortisol and resting serum free testosterone concentrations. In the C group, no changes were observed during the experimental period. In the S group, the changes in CMJ0 correlated ($P < 0.05$–0.01) with the changes in the 5-m ($r = 0.86$) and 15-m ($r = 0.92$) sprints, whereas the changes in CMJ40 correlated negatively with the changes in the testosterone:cortisol ratio ($r = -0.84$, -0.92, respectively, $P < 0.05$). These data indicate that young trained soccer players with low initial strength levels can increase explosive strength by adding low-frequency, low-intensity explosive-type strength training. The inverse correlations observed between changes in CMJ40 and changes in the testosterone:cortisol ratio suggest that a transient drop in this ratio below 45% cannot always be interpreted as a sign of overstrain or neuroendocrine dysfunction.

Keywords Soccer · Strength training · Endurance · Vertical jump · Testosterone

Introduction

Soccer is a high-intensity, intermittent exercise that relies predominantly on aerobic energy pathways (Ekblom 1986) and places considerable demands on the neuromuscular and the hormonal systems (Bangsbo 1994; Ekblom 1986). The ability of the neuromuscular system to produce maximal leg power output appears to be important in soccer because one of the main physiological differences between soccer players of different levels seems to be the ability to develop maximal strength (Wisloff et al. 1998) and muscular power (Cometti et al. 2001; De Proft et al. 1988) with high contraction velocities while executing the numerous explosive bursts of activity required during a game, such as jumping, tackling, kicking, heading, turning and short-distance sprinting. Although few studies have examined the effects of low-volume strength training in soccer players (De Proft et al. 1988; Andersen et al. 1992; Aagaard et al. 1994; Taiana et al. 1992), such studies have shown that, after several weeks of heavy-resistance training, there is an increase (De Proft et al. 1988; Andersen et al. 1992) or no change (Taiana et al. 1992) in knee extensor isokinetic strength and an increase in dynamic non-isokinetic knee extension strength (Aagaard et al. 1994), but no improvements in vertical jump performance (De Proft et al. 1988; Taiana et al. 1992). To date no investigations have been directed toward determining the effects of low-volume, explosive-type strength training on vertical jump and sprint performance in soccer players. Therefore, it remains to be determined whether a low-volume, explosive-type strength training program is effective for highly trained soccer players.

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Endurance shares importance with strength and power development in soccer because previous investigations have indicated a positive relationship between endurance capacity and performance results in elite soccer (Wisloff et al. 1998) and because enhanced aerobic endurance improves soccer performance (Helgerud et al. 2001). Further, preparation for soccer competition stresses the hormonal system (Bangsbo 1994) and involves intense training programs with multiple goals of increasing strength, endurance running and game skills. This may interfere with explosive force development because of the interference effects of the endurance training (Andersen et al. 1992; Gorostiaga et al. 1999; Hickson 1980). In addition, the large amount of time devoted to improving the other fitness components might increase the training stress and elicit an imbalance between anabolic and catabolic metabolism.

To our knowledge, no studies have been directed toward determining the effects of simultaneous strength and soccer training on endurance running and serum anabolic and catabolic hormones. We hypothesized that soccer training combined with a progressive, explosive-type strength training should result in significant improvements in neuromuscular performance, with no interference with the development of endurance running and with the adaptations of the endocrine system. The purpose of the present study was thus to examine the effects of 11 weeks explosive-type strength training combined with soccer training on the load-vertical jumping height curve and sprint and endurance running performance, on resting serum concentrations of testosterone, free testosterone and cortisol and on possible interrelationships between training induced changes in vertical jumping height, sprint running performance and serum hormone concentrations.

Methods

Subjects

A group of 21 young male subjects (mean age 17.2 years; range 16–18.5), volunteered to participate in the study with the informed consent of their parents. All were regional soccer players from the same team. At the conclusion of the subsequent playing season, the team was ranked as the best year-matched team in the region. Their experience in soccer was at least 5 years. None of the subjects had any background in regular strength training. Subjects were grouped into pairs, both members of the pair being matched on vertical jumping, 15-m sprint running time, blood lactate running at 13 km h^{-1}, resting serum testosterone levels, soccer skills and player field position. The matched pair was then randomly assigned to a control group (C, $n=11$) or a strength training group (S, $n=10$). Over the experiment, two individuals withdrew from the study through illness. The program was thus completed by 11 subjects in the C group and 8 subjects in the S group. All the subjects were familiarized with the testing protocol, as they had been previously tested on several occasions during the season with the same testing procedures. The mean (SD) physical characteristics of the C and S groups were: age, 17.2 (0.7) and 17.3 (0.5) years; height, 175.1 (5.4) and 177.4 (4.9) cm; body mass, 66.8 (6.0) and 70.3 (6.7) kg, respectively. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee responsible.

Experimental design

In this study a prospective, longitudinal design was undertaken to examine the effect of explosive-type strength training on the physical performance and serum hormones of soccer players. A control group and an explosive-type strength training group were used to examine this question over the course of 11 weeks of training and soccer competition. This approach allowed us to control directly and to monitor carefully the training and status of each subject in the study to gain insights into the efficacy of this type of strength training. The data can be generalized only to the type of population examined in the context of the world of competitive soccer. The experimental period lasted 11 weeks, from September to December, 2 weeks after the end of the 4-week pre-competitive mesocycle, during the first of the three 10- to 14-week competitive mesocycles. A regular week of training consisted of four 1.5-h practice periods and one game. About 1 h of each practice was organized as playing sessions, whereas the physical conditioning part without ball lasted 25 min. Twice a week, the physical conditioning training consisted of a circuit-training program of muscle endurance and stretching training traditionally used by the soccer coaches during the season. The exercises (abdominal and back muscle endurance, some callisthenics, jumping and running exercises) were performed for 15–60 s per set at a low speed and were interspaced by stretching exercises for the calf, quadriceps, hamstring, leg adductor and deep abdominal muscles. Once a week, training without the ball consisted of running for 25 min at a speed near the individual anaerobic threshold. In the last training session of the week, training without the ball consisted of 15 min warm-up and speed-training exercises. All subjects were tested before and after the 11-week experimental period using identical protocols. The S group was also tested for muscle strength, sprint velocity and blood hormone levels after 4 and 8 weeks of strength training. Tests were carried out after 2 days of minimal physical activity, on 2 consecutive days, in a fixed order.

Testing schedule

All players were tested on the same day and the tests were performed in the same order. During the first testing occasion, each subject was tested for sprint running and counter-movement jumps (CMJ) on the contact platform without loads and with various extra loads of 20, 30, 40, 50, 60 and 70 kg, loaded on a barbell kept on the shoulders. In the second test session, each subject was tested for endurance running. Training was integrated into the test-week schedules.

Sprint running testing

Sprint tests and the CMJ were performed in an indoor court. The sprint test consisted of three maximal sprints of 15 m, with a 90-s rest period between each sprint. During the 90-s recovery period, the subjects walked back to the starting line. Running time was recorded using photocell gates (Newtest, Oulu, Finland) placed 0.4 m above the ground, with an accuracy of 1 ms. The subjects commenced the sprint when ready from a standing start, 0.5 m behind the start. Stance for the start was consistent for each subject. The timer was activated automatically as the subject passed the first gate at the 0-m mark and split times were then recorded at 5 and 15 m. In repeated determinations of sprint running time, the coefficient of variation including both biological and methodological variables was less than 1.5%.

Jumping test

Ten min after the end of the sprint test, each subject performed maximal CMJ on a contact platform (Newtest) with and without various extra loads. The subjects were asked to perform a maximal CMJ on the contact platform from a standing position with a preparatory movement from the extended leg position down to the 90-degree knee flexion, followed by a subsequent concentric action. In these jumping conditions without an extra load, the subjects were instructed to keep their hands on the hips throughout the entire jump and to minimize lateral and horizontal displacement during performance. In the CMJ jumps performed with various extra loads, the subjects gripped their hands on the barbell at the width of the shoulders and loads of 20, 30, 40, 50, 60 and 70 kg were used. The subjects were also instructed to land on the contact platform in a position similar to that of the take-off. The jumping height was calculated from the flight time. Two to three maximal jumps in each attempt were recorded interspersed with approximately 10 s rest and the best performance was used for further analysis. Further analysis was carried out of the load-vertical jumping height relationships, which have also been demonstrated to characterize the force-velocity relationship in CMJ jumps (Viitasalo 1985). The test-retest reproducibility of such jumping performances is very high ($r = 0.90–0.97$) (Komi and Bosco 1978).

Endurance running test

The endurance running test was performed in the second test session, at the same time of day and on an outdoor, artificial-grass soccer pitch. Each subject performed a three-stage submaximal discontinuous running test, around the soccer pitch (100×50 m), with a 3-min rest between each run. The running velocity and time for the three stages were 12 $\text{km}\cdot\text{h}^{-1}$ (10 min), 13 $\text{km}\cdot\text{h}^{-1}$ (10 min) and 14 $\text{km}\cdot\text{h}^{-1}$ (5 min), for the first, second and third stage, respectively. To assure a constant velocity for each running stage, the subjects were instructed to pace their running evenly by following an audio signal connected to a pre-programmed computer (Balise Temporelle, Bauman, Switzerland). During the test, heart rate was recorded every 15 s (Polar Vantage NV, Polar Electro, Finland) and averaged for the last 60 s of each stage. Immediately after each exercise stage, capillary blood samples for the determination of lactate concentrations were obtained from a hyperaemic earlobe. Samples for the whole blood lactate determination (100 µl) were deproteinized, stored at 4 °C, and analysed (YSI 1500, Yellow Springs Instruments, Yellow Springs, Ohio, USA) within 5 days after completing the test. The blood lactate analyser was calibrated after every fifth blood sample dosage with three known controls (5, 15 and 30 mM). In repeated determinations of submaximal blood lactate, the coefficient of variation was less than 3%.

Analytical methods

The subjects reported to the laboratory and sat quietly for 10–15 min before giving a blood sample. Venous blood samples were obtained from the antecubital vein at rest between 8 and 9 a.m., after 12 h fasting and 2 days of minimal physical activity Concentrations of serum total testosterone, free testosterone and cortisol were determined. Blood samples were taken at the same time of day to reduce the effects of diurnal variation on hormonal concentrations. The samples for hormone analysis were centrifuged and the serum removed and frozen at −20 °C for later analysis. Serum cortisol and testosterone were determined by radioimmunoassay. Serum testosterone, free testosterone and cortisol concentrations were measured using reagent kits (Coat-A-Count Total/Free testosterone TKTT11CS, Diagnostic Products, Los Angeles, Calif., USA; GammaCoat Cortisol Radioimmunoassay Kit, DiaSorin, Stillwater, Minn., USA). The sensitivity of the total testosterone and free testosterone assay was 0.14 nM and 0.15 pg/ml respectively. The sensitivity of the cortisol assay was 0.21 µg/dl. The coefficient of intra-assay variation was 5% and 4% and that of interassay variation 5.9% and 3.7% for the total and free testosterone respectively. The respective values were 6.6% and 8.8% for the cortisol assay. All samples were analysed according to the instructions of the manufacturers.

Periodized explosive resistance training program

The strength training program in the S group consisted of two training sessions each week over an 11-week period. These explosive strength training sessions lasted 25–30 min and replaced the part of the training session without the ball performed by the C group on these days, consisting of circuit training programs of muscle endurance and stretching training. The main exercises of the explosive-strength training sessions were the full squat-lift, power clean, vertical CMJ to box, hurdle vertical jumps and sprint runs. Table 1 shows in detail the exercises, weekly frequency, number of repetitions, number of sets and the exercise intensities (in kilograms) of the explosive-strength training program. Approximately 2-min rest periods were allowed between each set and each exercise. During the squat lifts and power clean exercises, the subjects were instructed carefully to perform all the concentric leg extensions at the highest possible speed, starting from the flexed position to reach the full extension of 180°, against the resistance determined by the weight plates added to both ends of the bar. This type of strength training was developed because it has been shown that training with light loads performed at maximal speeds is the most effective way to enhance muscular power and speed (Kraemer and Ratamess 2000, Wilson et al. 1993). This type of strength training induces only minor hypertrophic muscular changes (Häkkinen et al. 1985) that should not interfere with the development of aerobic endurance (Paavolainen et al. 1991, 1999). The eccentric actions were performed at low velocity during the “lowering” phase of the movement. The subjects of the S group also performed some light strengthening exercises (with loads of 40–60% of one maximum repetition) for the trunk and arm muscles and some stretching exercises for the calf, quadriceps, hamstring, leg adductor and deep abdominal muscles to prevent injuries. A trained researcher supervised each workout session carefully and recorded the compliance and individual workout data during each training session.

Table 1 Schedule of exercises, weekly training frequency (*WTF*), number of sets (*Sets*), number of repetitions (*Reps*), intensity (*I*), and distance (*D*) during the 11-week periodized explosive-type strength training program (*CMJ* counter-movement jump)

Exercises	Weeks 1–4					Weeks 5–8					Weeks 9–11				
	WTF (days/week)	Sets	Reps	*I* (kg)	*D* (m)	WTF (days/week)	Sets	Reps	*I* (kg)	*D* (m)	WTF (days/week)	Sets	Reps	*I* (Kg)	*D* (m)
Squat lifts	2	2–3	6	20–38		2	3	3–4	30–46		1	3	2–3	36–52	
Power clean	2	4	4	16–24		2	3–4	3	20–28		1	3	3	26–28	
Maximal CMJ to box	1	3	5–6		-	1	3–5	5–8			-	-	-	-	
Repeated Sprint runs	1	1	3–5		40	1	1	2–5		15–40	1	1	2–3		15–30
Hurdles Vertical Jumps	-	-	-		-	-	-	-	-		1	3	4		

Statistical methods

Data are given as means and standard deviations (SD), and standard methods were used to calculate Pearson's product moment correlation coefficient. A *t*-test for unpaired samples indicated that there were no baseline differences among the two groups' initial body mass, strength, sprint performance, endurance running and blood hormonal measures. Corresponding pre-and post-training values for all measured variables were compared using ANCOVA. For this purpose, pre-training values were used as covariates so that the effects of the covariance could be observed. The effects of training in the S group before and after 4, 8 and 11 weeks of training were tested by one-way ANOVA with repeated measures design, using the Greenhouse-Geisser correction procedure and Scheffé's test to establish the significance of differences between weeks. $P \leq 0.05$ was regarded as significant. Observed statistical power was above 0.80 for all variables, except serum testosterone (0.69) and running velocity (0.73).

Results

Body mass, body height and compliance

Body height increased during the 11-week training period in the S group: from 177.5 (4.9) to 178.0 (4.8) cm; $P < 0.05$ and in the C group: from 175.1 (5.4) to 175.7 (5.7) cm; $P < 0.01$. The increase in body height during the course of the training did not differ significantly between the subject groups. No significant changes were observed for body mass after the 11-week training period for either group: from 70.3 (6.7) to 71.9 (6.6) kg and from 66.8 (6.0) to 67.8 (6.5) kg, in the S and C groups respectively. To be considered compliant and remain in the study, subjects had to attend a minimum of 80% of the training sessions and competitions. There was no difference in training compliance in both groups. In the S group, the subjects attended on average 1.78 (0.20) sessions per week (range 1.36–1.91) of the possible two weekly strength training sessions.

Vertical jumping performance

In the S group, the 11-week explosive strength training resulted in great increases, primarily in the low-force portions of the load-vertical jumping height curve (Fig. 1A). The greatest increases in the vertical jumps were observed at CMJ0 (5.1%; $P < 0.01$), CMJ20 (7.5%; $P < 0.01$) and CMJ30 (13.9%; $P < 0.01$). The improvements become gradually smaller near the high-force portions of the curve and were no longer significant for CMJ40 (7.4%; $P = 0.06$), CMJ50 (6.8%; $P = 0.18$) and CMJ60 (11%; $P = 0.06$). Of note is the near-significant effect for CMJ40 and CMJ60 ($P = 0.06$). No significant changes were observed in the C group in the load-vertical jumping height curve throughout the experimental period (Fig. 1B). When the data were analysed by ANCOVA using the pretraining vertical jump values as the covariate, the increase in vertical jumping height observed for CMJ20, CMJ30, CMJ40, CMJ50 and CMJ60 during the 11-week training period was significantly higher ($P < 0.05$–0.01) in the S group than in the C group.

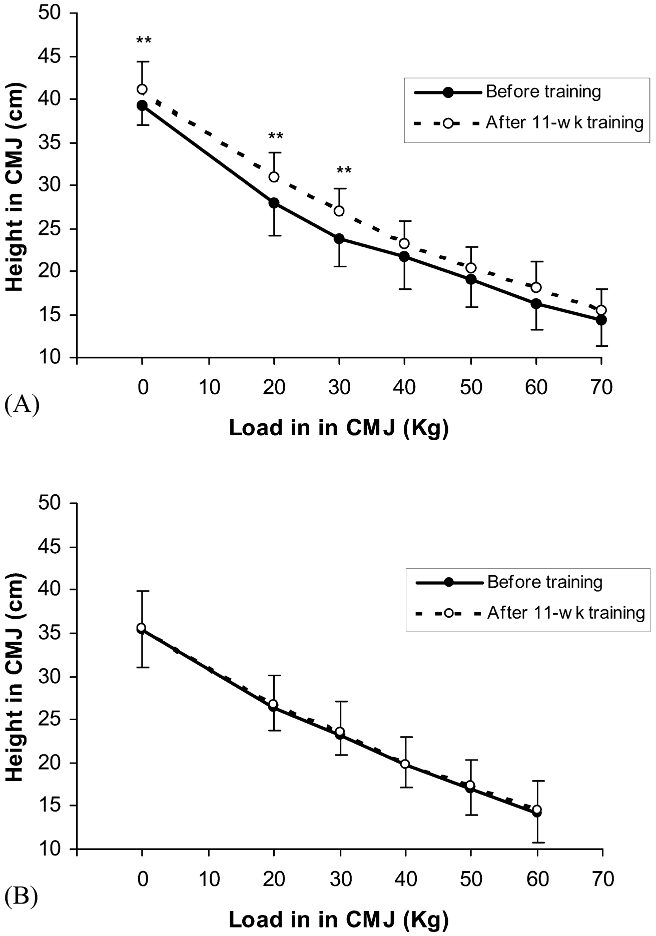

Fig. 1 Load-vertical jumping height curve in the explosive-type strength training (S) group (**A**) and the control (C) group (**B**) before and after 11 weeks training period. (*CMJ* counter-movement jump). Means (SD) $n = 8$ (S) and 11 (C); $^{**}P < 0.01$ week 0 vs. week 11

Training-induced changes in CMJ0 and CMJ20 at weeks 0, 4, 8 and 11 for the S group and at weeks 0 and 11 for the C group are shown in Fig. 2. The above-mentioned increase in CMJ0 observed between weeks 0 and 11 in the S group occurred mainly during the first 4 weeks of training ($P < 0.01$) with no further improvement between weeks 4 and 8 and even a significant decrease between weeks 4 and 11 ($P < 0.05$, Fig. 2A). Similar trends were observed in CMJ20 (Fig. 2B) in the S group.

Sprint runs

Figure 3 shows the training-induced changes of running times for 5 and 15 m in both groups. There were no significant changes in running times for 5 and 15 m in either group after the 11-week training period. The response patterns for the 5-m running times in the group S

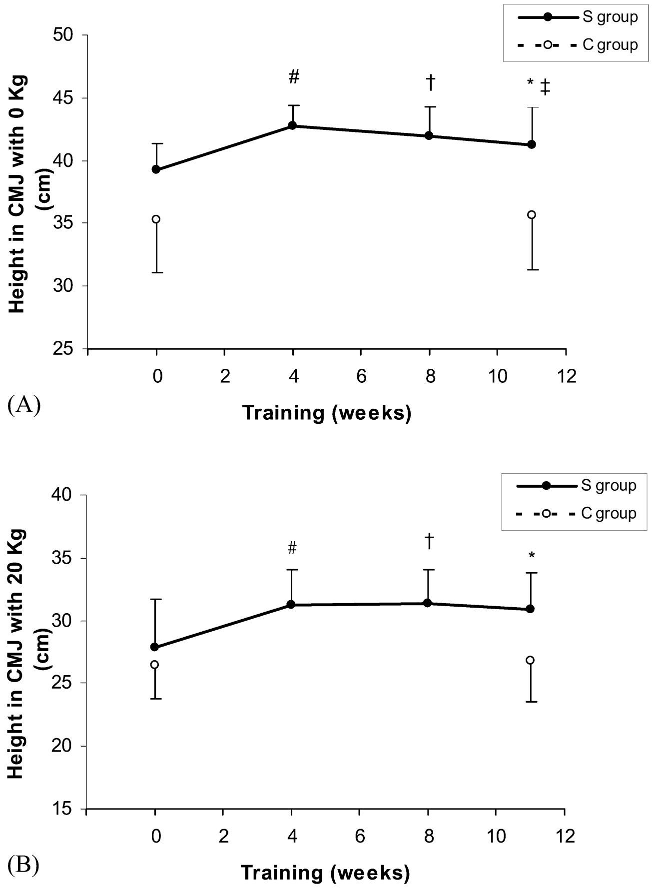

Fig. 2 Height jumped in a CMJ with 0 kg load (CMJ0, **A**) and CMJ20 (**B**) at 0, 4, 8 and 11 weeks of the training period in the S group and at weeks 0 and 11 in the C group. Means (SD); $n=7$–8 (S) and 11 (C). $P<0.05$ between $^{\#}$weeks 0 and 4, †weeks 0 and 8, *weeks 0 and 11 and ‡weeks 4 and 11 in S

at weeks 0, 4, 8 and 11 show that during the first 4 weeks of training there was a significant decrease in the 5-m time: from 0.96 (0.03) to 0.95 (0.04) s; $P<0.05$. No differences were observed in the S group between weeks 0 and 8 or weeks 0 and 11 in the 5-m times or at any point in the 15-m running times.

Relationships between explosive strength and running velocity

Significant correlations were observed in the S group between the individual relative changes in the height of rise in CMJ0 and the individual relative changes in the average running velocity over 15 m during the first 4 weeks of training ($r=0.92$; $P<0.01$; Fig. 4), as well as between the individual relative changes in the height of rise in CMJ0 and the individual relative changes in average running velocity over 5 m between weeks 4 and 8 ($r=0.86$; $P<0.05$). No significant correlations were observed between weeks 8 and 11 in S or weeks 0 and 11 in the C group.

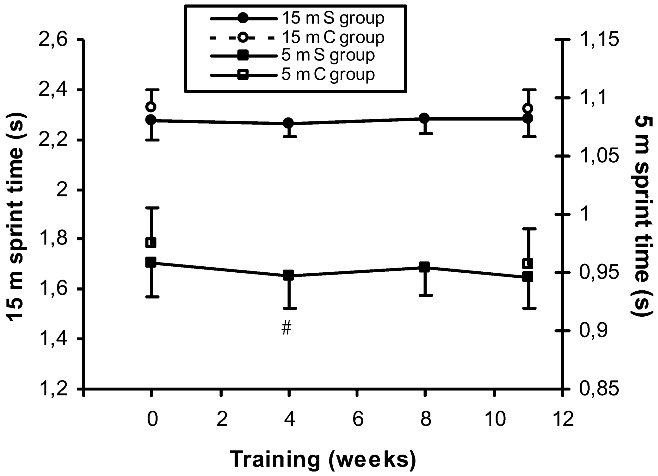

Fig. 3 Five- and 15-m run times at weeks 0, 4, 8 and 11 in the training period in the S group and at weeks 0 and 11 in the C group. Means (SD); $n=7$–8 (S) and 11 (C); $^{\#}P<0.05$ between weeks 0 and 4 in S

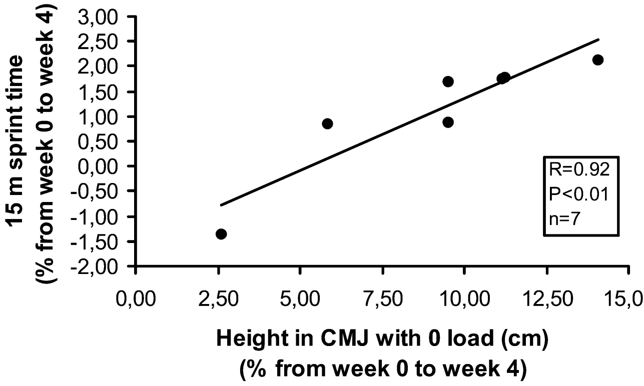

Fig. 4 Relationships between the individual percentage changes in CMJ0 and the individual percentage changes in 15-m average running velocity during the first 4 weeks of the 11-week training period in the S group (*n* number of subjects)

Endurance running test

The data for average blood lactate concentrations and average heart rate values during the endurance running test at weeks 0 and 11 are presented in Table 2. No changes were observed in mean blood lactate concentration and heart rate in either group during the training period.

Serum hormone concentrations

The response patterns of resting serum concentrations of testosterone in both groups during the experimental period are presented in Fig. 5. During the 11 weeks of training, serum testosterone increased significantly in the S group (7.5%; $P<0.05$). The increase occurred mainly between weeks 4 and 11, whilst serum testosterone tended to decrease (non-significantly) between weeks 0 and 4.

Table 2 Mean (SD) blood lactate concentrations and heart rates during the endurance running test, before and after 11 weeks of training in the explosive strength training (*S*) and control (*C*) groups

Running Velocities Group		$13\ \mathrm{km{\cdot}h^{-1}}$		$14\ \mathrm{km{\cdot}h^{-1}}$	
		Blood lactate (mM)	Heart rate (bpm)	Blood lactate (mM)	Heart rate (bpm)
C	Week 0	4.5 (3.0)	182 (3)	3.9 (0.7)	185 (4)
	Week 11	5.3 (5.0)	181 (9)	3.9 (1.1)	182 (7)
S	Week 0	4.2 (2.4)	180 (9)	4.8 (2.1)	182 (7)
	Week 11	4.5 (2.0)	177 (2)	5.2 (2.0)	182 (5)

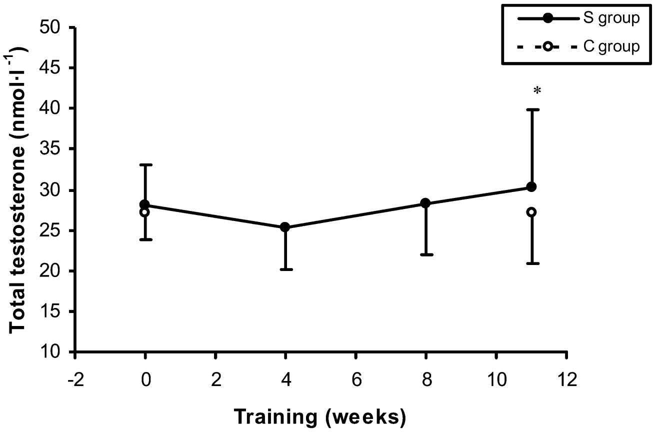

Fig. 5 Resting serum testosterone at weeks 0, 4, 8 and 11 in the training period in the S group and at weeks 0 and 11 in the C group. Means (SD); $n=7$–8 (S) and 11 (C). $^{*}P<0.05$ between weeks 0 and 11 in S

No significant changes in resting serum testosterone concentrations were observed in the C group. During the 11-week training period, no significant changes were observed for cortisol in either group: from 431 (149) nM at week 0 to 393 (86) nM at week 11 and from 476 (107) nM at week 0 to 501 (87) nM at week 11 in S and C groups, respectively. However, ANCOVA showed that serum cortisol concentrations decreased in S and increased in C group ($P<0.05$) during the training period. The response pattern of the serum testosterone:cortisol ratio was similar to the response patterns of serum testosterone in both groups: from 0.07 (0.03) at week 0 to 0.09 (0.06) at week 11 and from 0.06 (0.02) at week 0 to 0.06 (0.02) at week 11 in S and C groups, respectively, although the differences were not significant. There were no significant changes in serum concentrations of free testosterone in either group: from 93.6 (18) pM at week 0 to 97.7 (34) pM at week 11 and from 95 (32) pM at week 0 to 103 (28) pM at week 11 in S and C groups, respectively.

Relationships between serum hormone concentrations and explosive strength

No significant correlations were observed between the individual changes in explosive strength and the individual changes in serum hormone concentrations from weeks 0 to 11 in either group. However, significant inverse correlations were observed in the S group between the individual relative changes in the height of rise in CMJ40 and the individual relative changes in the serum testosterone:cortisol ratio, from weeks 0 to 4 ($r=-0.84$; $P<0.05$; Fig. 6A), from weeks 4 to 8 ($r=-0.90$; $P<0.05$; Fig. 6B) and from weeks 8 to 11 ($r=-0.92$; $P<0.01$; Fig. 6C). The individual relative changes in the serum testosterone:cortisol ratio between weeks 8 and 11 also correlated inversely in the S group with individual relative changes in CMJ20 ($r=-0.81$; $P<0.05$), as well as in CMJ30 ($r=-0.82$; $P<0.05$) and CMJ50 ($r=-0.83$; $P<0.05$).

Discussion

The primary results of the present study demonstrated that soccer training combined with a progressive, 11-week explosive-type strength training including full squat, power clean, vertical jumps and sprinting exercises resulted in significant improvements in the low-load portions of the load-vertical jumping height curve. This finding is consistent with previous observations of training-induced specificity caused by traditional explosive strength training in which high contraction velocities with low loads are used (Häkkinen and Komi 1985).

Improvements in explosive force production during explosive-type strength training result primarily from significant increases in the neural activation of the trained muscles, probably related to training-induced increases of number and/or firing frequencies of active motor units and/or changes in the recruitment pattern of the motor units, primarily in the fast-twitch muscle fibres (Häkkinen and Komi 1985). The present improvement in the vertical jump performance suggests that young, trained soccer players with low initial strength levels can increase explosive strength by adding a low-frequency, low-intensity, explosive-type strength training program that accounts for a very low percentage of the total, predominantly aerobic, soccer training. Further, this type of strength training program seems to be more effective in transferring the neural adaptations made during strength training to vertical jump development than other strength training programs using heavy resistance loads (Taiana et al. 1992; Gorostiaga et al. 1999).

During the first 4 weeks of training, there was a significant improvement in the 5-m sprint performance in the S group. This improvement in short-distance sprint

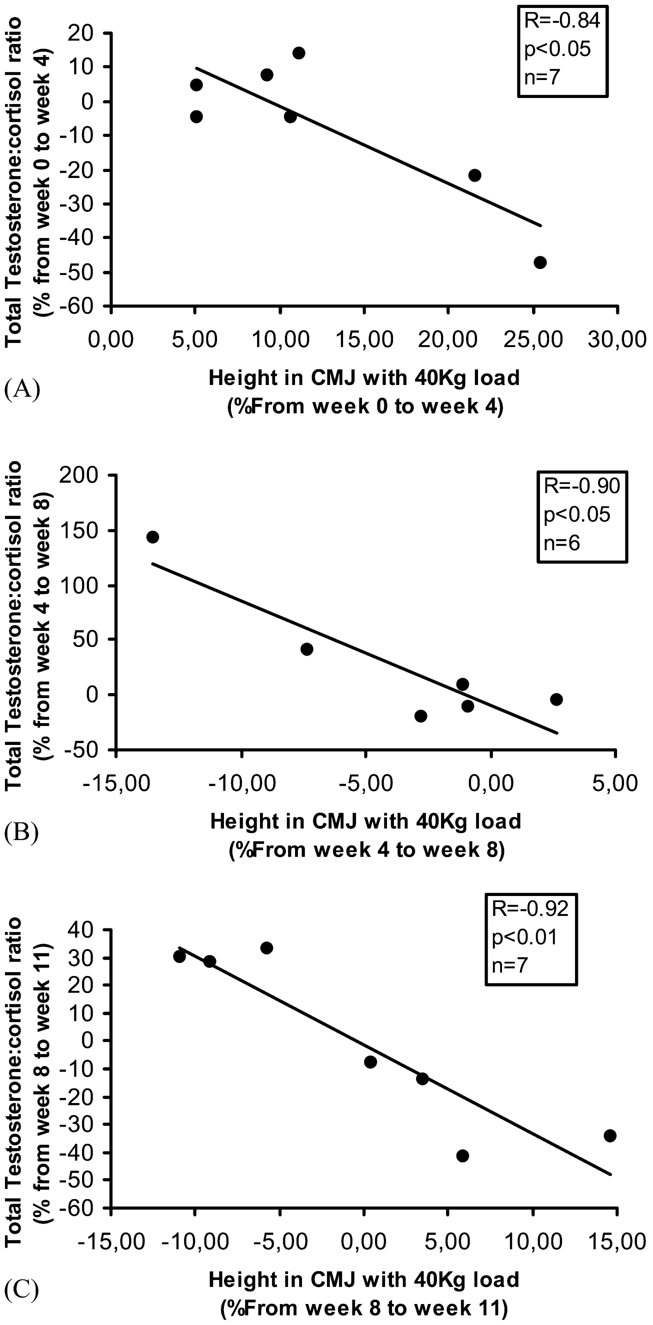

Fig. 6 Relationships between the individual percentage changes in the height of rise in CMJ40 and the individual percentage changes in the resting serum testosterone:cortisol ratio between weeks 0 and 4 (**A**), weeks 4 and 8 (**B**) and weeks 8 and 11 (**C**) in the S group (*n* number of subjects)

performance occurred concomitantly with the largest increases observed in the vertical jump values. These results agree with the limited number of studies that have analysed the effects of different strength training programs on sprint performance (Delecluse et al. 1995). These studies have noticed that explosive-type strength training can be effective for improving short-distance sprint performance. The importance of increasing leg muscular strength and power for improving short-distance sprint performance has been emphasized by biomechanical analyses of sprinting. These analyses have shown that short-distance sprints are highly dependent on the athlete's ability to generate powerful extensions of the knee extensors, the hip extensors and the plantar flexors muscles (Frick et al. 1995). In addition, in the present study, significant correlations were observed in the S group between the individual relative changes in the height of rise in the CMJ0 and the individual relative changes in 5 and 15-m average sprint running velocity during the first 8 weeks of the training period. It indicates that those soccer players with higher increases of vertical jump at 0 kg may be more likely to produce major sprint performance gains than those with lower increases of vertical jumping performance. The relationships observed between vertical jump and sprint performances gains suggest a possible transfer from the gain in leg explosive strength into enhanced sprint performance.

After large increases during the initial 4 weeks of strength training, a plateau phase in the vertical jump and short-distance sprint performance values was observed between weeks 4 and 11 of training in the S group. The observation that during the latter 7 weeks of training, vertical jump and sprint performance values increased at a diminished rate, or even slightly decreased, may be related to the pretraining status of the subject, an insufficient strength stimulus (i.e. decrease in strength training frequency and volume during the last weeks of training) (Table 1), resulting in limited stimulation toward further increases in vertical jump and sprint performance, a lack of variation in the strength training program and/or to the principle of diminishing returns, whereby initial improvements in muscular function are easily invoked, but further improvements are progressively harder to achieve.

Several studies have investigated the effects of concurrent strength and endurance training on endurance performance, but the results are conflicting (Dudley and Djamil 1985; Hickson 1980; Andersen et al. 1992; Rusko and Bosco 1987; Paavolainen et al. 1991, 1999; Gorostiaga et al. 1999). Differences in strength training programs, the subject's initial physical fitness and the means of estimating endurance could explain the controversy. Indeed, earlier observations based on experiments in which heavy-resistance strength training predominated and in which the subjects were previously untrained and maximum O_2 uptake ($\dot{V}O_{2\ max}$) was the criterion of endurance, have shown that concurrent strength and endurance training do not affect the development of endurance (Dudley and Djamil 1985; Hickson 1980). Other studies have used previously-endurance-trained subjects (soccer players, handball players and endurance-trained subjects), and the criteria of endurance were the blood lactate concentration response to submaximal exercise [a more sensitive parameter than $\dot{V}O_{2\ max}$ for detecting changes in endurance performance (Weltman 1995)], or other markers of muscle respiratory capacity. These studies have found that heavy-resistance training (Andersen et al. 1992; Gorostiaga et al. 1999) or low-resistance, low-velocity strength training (Rusko and Bosco 1987) interfere with optimal development of endurance capacity in soccer players (Andersen et al. 1992), handball players (Gorostiaga et al. 1999) and endurance trained subjects (Rusko and Bosco 1987).

However, when explosive-type strength training is combined with endurance training in previously endurance trained subjects, strength training does not interfere with the development of endurance performance in cross-country skiers (Paavolainen et al. 1991) and endurance trained runners (Paavolainen et al. 1999). These results agree with the present study, in which there were no changes in blood lactate during submaximal running in either group during the experiment. The similar pattern response in submaximal blood lactate values observed in both groups suggests that concurrent explosive-type strength training and soccer training did not interfere with the development of endurance. It is likely that the minor hypertrophic muscular changes that occur with explosive-type strength training are not sufficient to induce a decrease in mitochondrial density and oxidative potential that is observed in hypertrophic muscles of heavy-resistance-trained subjects (Tesch 1988). This observation can be considered as advantageous in soccer, because muscular strength and power can be increased without a corresponding decrease in endurance running.

Circulating testosterone and cortisol have been proposed as physiological markers for men and women to evaluate the anabolic-catabolic status of the body (Kraemer 2000) and have been used as an index of training adaptations of the endocrine system (Kraemer et al. 1995). During the present study, the combination of explosive-type strength training to the soccer training resulted in changes in endogenous hormone production, observable primarily as an increase in resting serum concentrations of testosterone and some reduction in the resting concentration of cortisol in the S group compared with the C group. Increases in resting serum concentrations of testosterone (Staron et al. 1994) and decreases in serum concentrations of cortisol (Staron et al. 1994; Kraemer et al. 1995) have occurred during some long-term, normal strength training programs. Training-induced increases in resting testosterone concentrations may reflect increased anabolic-androgenic activity (Kraemer 2000), may mediate increases in myosin heavy chain (MHC) protein isoforms for the working muscle (Staron et al. 1994) and may improve the neural adaptations that occur for strength gain (Kraemer 2000). Because of the catabolic role of cortisol, a decrease in cortisol over the course of a strength training program may reflect a decreased level of tissue breakdown and contribute to the overall enhancement of the anabolic environment with training (Kraemer et al. 1998). Therefore, the present increase in resting serum testosterone and decrease in serum cortisol found in the S group could suggest a training-induced increase in anabolic androgenic activity. However, due to limitations in the study design, namely, the hormonal values of the C group were obtained only for the first and last tests, and the fact that the slight increase (7.5%) in resting serum testosterone of the S group did not exceed its normal biological or circannual variations, the present results of serum hormone concentrations should be interpreted with great caution.

It has been claimed that a balance between the anabolic and catabolic activity is represented by the so-called testosterone:cortisol ratio or the free testosterone:cortisol ratio (Vervoorn et al. 1991). It has been suggested that these ratios should be useful parameters in indicating the overall training stress and the early detection of an imbalance between anabolic and catabolic metabolism (Adlercreutz et al. 1986). In the present study significant inverse correlations were observed in the S group between the individual relative changes in the height of rise in CMJ40 and the individual relative changes in the serum testosterone:cortisol ratio between weeks 0 and 4, weeks 4 and 8 and weeks 8 and 11. It indicates that those subjects with a larger decrease in the testosterone:cortisol ratio may be more likely to produce major explosive strength gains than those with smaller decreases in the testosterone:cortisol ratio. This is a surprising finding because a decrease in the testosterone:cortisol ratio has been associated with a disturbance in the anabolic-catabolic balance, which may express itself in decreased performance (Hoogeveen and Zonderland 1996; Adlercreutz et al. 1986). Thus, Adlercreutz et al. (1986) introduced the criterion that a condition of overstrain or over-reaching and decreased performance might exist in long-distance runners when a decrease in the testosterone:cortisol ratio of 30% or more is observed. However, some authors have demonstrated the usefulness of the relative criterion of 30% in detecting decreased performance (Vervoorn et al. 1991; Hoogeveen and Zonderland 1996; Fry et al. 2000; Häkkinen et al. 1987). These authors have found a decrease in the testosterone:cortisol ratio or the free testosterone:cortisol ratio to be associated with an increase (Hoogeveen and Zonderland 1996; Vervoorn et al. 1991; Fry et al. 2000) or no change in performance (Häkkinen et al. 1987). For instance, Fry et al. (2000) have observed inverse correlations between individual changes in weightlifting performances and individual changes in resting testosterone:cortisol values in 14 non-elite junior weightlifters during 1 week of high training volume. Hoogeveen and Zonderland (1996) have found that after 3 months of endurance training in ten professional cyclists, maximum workload on a cycle-ergometer increased, but the mean resting testosterone:cortisol ratio decreased by 26% (more than 30% in six of the ten cyclists). The present results agree with those of Hoogeveen and Zonderland (1996) and Fry et al. (2000) and suggest that a transient drop in the testosterone:cortisol ratio below 45% cannot be interpreted as a sign of overstrain or neuroendocrine dysfunction and may not be associated with decreased performance. Indeed, in some circumstances it may be related to a temporary positive stress stimulus and may even be expressed in a beneficial effect on performance (Hoogeveen and Zonderland 1996).

In summary, the present study indicates that soccer combined with an explosive-type strength training results in significant enhancements in the low-force portions of the load-vertical jumping height curve as well as in the running sprint performance over 5 m, with no interference with the development of endurance running. The combination of explosive strength training and soccer training increased resting serum concentrations of testosterone and reduced the resting concentrations of cortisol somewhat. The individual changes observed in vertical jumping correlated positively with the individual changes in 5 and 15 m sprint running velocities but correlated negatively with changes in serum testosterone:cortisol ratios. The present improvement in the vertical jump performance suggests that young trained soccer players with low initial strength levels can increase explosive strength by adding a low-frequency, low-intensity explosive-type strength training program that accounts for a very low percentage of the total, predominantly aerobic, soccer training. The inverse correlations observed between changes in vertical jump performance and changes in the testosterone:cortisol ratio suggest that a transient drop in this ratio below 45% cannot always be interpreted as a sign of overstrain or neuroendocrine dysfunction.

Declaration The experiments comply with the current laws of the country in which the experiments were performed.

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