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Early Phase Changes by Concurrent Endurance and Strength Training

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ABSTRACT

To compare regimens of concurrent strength and endurance training, 26 male basketball players were matched for stature, body composition, and physical activity level. Subjects completed different training programs for 7 weeks, 4 days per week. Groups were as follows: (a) the strength group (S; $n = 7$) did strength training; (b) the endurance group (E; $n = 7$) did endurance training; (c) the strength and endurance group (S + E; $n = 7$) combined strength and endurance training; and (d) the control group (C; $n = 5$) had no training. The S + E group showed greater gains in $\dot{V}O_2max$ than the E group did (12.9% vs. 6.8%), whereas the S group showed a decline (8.8%). Gains were noted in strength and vertical jump performance for the S + E and S groups. The S + E group had better posttraining anaerobic power than the S group did (6.2% vs. 2.9%). No strength, power, or anaerobic power gains were present for the E and C groups. We conclude that concurrent endurance and strength training is more effective in terms of improving athletic performance than are endurance and strength training apart.

Key Words: strength, endurance, power, body composition

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Introduction

Strength, endurance, and power are major components of athletic performance. Athletes focus their attention on these physical components during preseason training. Sport experts often wonder whether or not noncombined endurance and strength training is more effective than a concurrent training program (9). Strength training causes fiber hypertrophy, decreased capillary density, and increased ratio of fast-twitch fibers to slow-twitch fibers (23, 30). On the other hand, endurance training increases capillary density and decreases the ratio of fast-twitch fibers to slow-twitch fibers (19, 31, 33, 34). In theory, concurrent strength and endurance training leads to an antagonistic effect.

There is a lack of agreement in the related literature. Published books and fitness guides advise trainers and athletes to train for strength, power, and endurance simultaneously (6). Volpe et al. (35) stated that the running regimen followed by previously sedentary female subjects did not interfere with leg strength gains. There is evidence in the literature that maximal strength training improves the double-poling performance by improved work economy in cross-country skiers (15). Moreover, some authors believe that regimens of concurrent strength and endurance exercise in previously untrained individuals can be advantageous in terms of aerobic power (7, 8, 18). Rosler et al. (28) concluded that endurance training ''contributed'' to the development of strength. Gettman et al. (10) reported no interference between force and endurance from a concurrent strength and endurance training program. Additionally, some studies report short- and long-term endurance benefits via combined endurance and strength training (12, 13, 14).

In contrast, Sale et al. (29) believe that simultaneous strength and endurance training may result in an ''antagonism'' of the training responses. Kraemer et al. (21) concluded that the combination of strength and endurance training results in an attenuation of muscle and power improvements. Nelson et al. (25), along with Moroz and Houston (24), state that simultaneous strength and endurance training inhibits strength development. Endurance training causes a decrease of muscle fiber size, which consequently leads to an obstruction of strength development (19, 33). Furthermore, combined endurance and strength training over a period of 8 weeks resulted in improvements concerning endurance and upper-body strength only. However, strength gains were compromised when combined training was carried out in the same muscle group (11). Bishop et al. (2) concluded that a 12-week high-resistance, low-repetition program did not improve endurance performance. Several other authors claimed to have recorded an interference of endurance training in strength and power gains (5, 16, 22, 26, 27).

The experimental design of this paper is similar to that of other papers (11). However, the time schedule of this investigation covered only a 7-week training program (preseason training). This period of time is shorter than the majority of other training regimens in similar studies (11, 21, 29, 35), and it represents only the initial physiologic adaptations (32). There are limited data available regarding trained subjects (and even less concerning athletes) providing information about the physiologic compatibility of simultaneous strength and endurance training. The matched athletes of this investigation were active individuals, and they did participate in the same sport. The experimental personnel of this study decided to consider (a) the sport-specific requirements by applying sport-specific exercises; (b) the training status of each athlete; and (c) the importance of adequate rest periods, which were relative to the specific training phase of the macrocycle (i.e., maximum strength, power, and muscular endurance phase). Thus, the purpose of this study was to examine the effects of strength and endurance training separately and simultaneously (with regard to power, endurance, and strength) by taking all of the above parameters into serious consideration.

Methods

Experimental Approach to the Problem

Although a longer period of training would be more appropriate and suitable for safer conclusions, we have restricted our study to a period of 7 weeks (maximum strength phase, power development phase, and muscular endurance phase). This specific amount of time is usually the time that covers the preseason preparation. Another issue that deserves a brief comment is the absence of invasive diagnostic procedures in this study; this was mainly to avoid psychological discomfort of the subjects.

The experimental personnel measured the following criterion measures for each subject: (a) 1-repetition-maximum (1-RM) tests for half squat, bench press, lateral pull down (front), and leg press. 1RM effort represents the heaviest weight that can be lifted through a full range of motion for 1 repetition. Moreover, the 4 resistance exercises were chosen because they belong to the exercise group with the greatest amount of stimulation within each target muscle group (3). (b) Anaerobic capacity, via the well-known Wingate anaerobic test. (c) Maximum aerobic capacity. The ''One Mile Walk Test'' by Kline et al. (20) was used. The specific test is an accepted indirect method for the estimation of $\dot{V}O_2max$. Cross-validation analysis yielded a correlation of $r = 0.88$ between observed and estimated $\dot{V}O_2max$. (d) Anaerobic power. An additional index of anaerobic power is the vertical jump test.

In conclusion, the criterion measures of this investigation cover a wide spectrum of the physiologic assessment of human fitness. In this way, more reliable conclusions about the early phase changes caused by simultaneous strength and endurance training can be extracted.

Subjects

Twenty-six undergraduate college-age male members of basketball teams were recruited for this study. Initially, the sample size was 30 subjects. Four subjects could not continue the training program because of injury. All participants were fully informed about the requirements and potential risks of the study, and all signed an institutionally approved informed consent document to participate. Furthermore, subjects were matched within approximately 2 cm (at the nearest centimeter) for stature using a portable stadiometer, 2 kg for body mass (beam balance scale, Seca Corporation, Hanover, MD), 2% for lean body mass, and for relative physical activity level. Physical activity level was evaluated from an activity level questionnaire that assessed mode, frequency, and duration of the training performed by the subjects of this investigation. Percentage of body fat was estimated by the ''Tanita'' percentage body fat determination and skin-fold caliper (Yuhasz technique and calculations) (4). Because the results of ''Tanita'' and skin-fold caliper approached a correlation of 0.89, we used the average value of the 2 methods in order to determine percentage of body fat of the subjects. The same member of the experimental personnel performed all skin-fold measurements.

Subjects were not involved in any kind of individual or team training 5 weeks prior to the start or during the present study. The participants in running sessions run on grass. All trainees were instructed to follow their usual dietary habits. The consumption of any dietary supplements was prohibited. Experimental personnel did a dietary plan check every day. A day of rest was given to every group after each training session. Subjects were rested for 7 days prior to the retest. We believed that this amount of time would be adequate for residual fatigue caused by the training program to be excluded. Day 1 and day 2 of the test and retest determinations were 48 hours apart. The order of the test and retest procedure is presented in Table 1. Pretraining scores of the 4 groups differed significantly for bench press, leg press, and maximum aerobic capacity. However, 2-tailed *t*-tests showed no significant differences between the strength and strength + endurance groups and between the endurance and the strength + endurance groups for bench press and lateral pull down (front), and for $\dot{V}O_2max$, respectively. Experienced conditioning coaches supervised the whole training program.

Table 1. Test and retest order and schedule.*

Day	Test	Retest
1	(a) Vertical jump, (b) Wingate	(a) Vertical jump, (b) Wingate
2	(a) 1RM efforts, (b) 1-mile walk	(a) 1RM efforts, (b) 1-mile walk

* 1RM = 1-repetition maximum.

Training Program

Participants were divided into 4 groups. (a) The strength group (n = 7) completed a strength training program for 7 weeks (4 times per week) (Table 2). The start of each training session was in the morning. During week 4, 5 subjects also performed plyometrics, which included front cone hops, diagonal cone hops, lateral cone hops, tuck jump with knees up, incline push-up depth jump, and handstand depth jump (each drill consisted of 2 sets of 15 repetitions, with a 2-minute rest between sets), plus a 1RM reevaluation (week 4). (b) The endurance group (n = 7) was trained for 7 weeks, 4 times per week (Table 3). Each training session began in the morning. During the whole 7-week program, heart rate was monitored by a polar watch-telemetry system. (c) The strength and endurance group (n = 7) performed a combined strength and endurance program for 7 weeks (4 times per week). The endurance training program was set in the morning, and the strength training session was scheduled 7 hours after the completion of the endurance training. The endurance and strength training of this specific group was identical to the respective training regimens of the endurance and strength groups. (d) The control group (n = 5) did not train at all. Members of the control were restricted from any kind of endurance or strength training. They were allowed to participate only in recreational activities such as golf, tennis, and table tennis.

Table 3. Regimen of endurance training.*

Week	Regimen
1	5 miles at 70% HRmax
2	8·200 m (stride/1.5-min interval), 8·100 m (stride/45-s interval), 8·200 m (stride/1.5-min interval), and 8·100 m (stride/45-s interval)
3	8·200 m (stride/1-min interval), 8·100 m (stride/30-s interval), 8·200 m (stride/1-min interval), and 8·100 m (stride/30-s interval)
4	8·200 m and 8·100 m at 85% HRmax (1-min interval)
5	6·100 and 5·200 at 90% HRmax (30-s interval), 4·300 and 3·400 m full-speed runs (45-s interval), and 2·500 m full-speed runs (1-min interval)
6	2·100 and 2·80 m (stride/30-s interval), 10·50 m full-speed runs (30-s interval), 2·100 and 2·80 m (stride/30-s interval), and 10·30 m full-speed runs (30-s interval)
7	4·100 and 4·200 m full-speed runs (30-s interval), 3·300 and 3·400 m (stride/45-s interval), 2·500 m (stride/1-min interval), 2·300 and 2·400 m full-speed runs (45-s interval), and 3·100 and 3·200 m full-speed runs (30-s interval)

* HRmax = maximal heart rate.

Physical characteristics of all studied subjects are presented in Table 4.

Test-Retest Determinations

Power and Speed. (a) In the vertical jump, jump height was measured by a force platform (Kistler). Subjects completed a double leg/free arm swing jump. The best performance out of 3 trials was recorded. (b) For the Wingate Anaerobic Test (WanT), the resistance to pedaling was based on body mass and was calculated as 0.075-kg resistance per kilogram body mass. Resis-

Table 2. Resistance training for strength and strength + endurance groups.*

Exercises	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Half squat	75/6, 2 sets 80/4, 1 set	85/5, 2 sets 90/4, 4 sets	90/4, 2 sets 95/3, 2 sets	70/6, 4 sets	70/8, 4 sets	40/30, 3 sets	40/40, 3 sets
Bench press	80/6, 2 sets 85/4, 1 set	85/5, 2 sets 90/4, 3 sets	90/4, 2 sets 95/4, 1 set	70/5, 5 sets	70/7, 5 sets	40/30, 3 sets	40/40, 3 sets
Leg press	75/6, 2 sets 80/4, 1 set	85/5, 2 sets 90/4, 4 sets	90/4, 2 sets 95/3, 2 sets	70/6, 4 sets	70/8, 4 sets	40/30, 3 sets	40/40, 3 sets
Lateral pull down (front)	80/6, 2 sets 85/4, 1 set	85/5, 2 sets 90/4, 4 sets	90/4, 2 sets 95/4, 1 set	70/5, 5 sets	70/7, 5 sets	40/30, 3 sets	40/40, 3 sets

* For all exercises, the numerator represents the load in percentage of 1-repetition maximum, and the denominator indicates the number of repetitions. During weeks 1, 2, and 3, the speed of execution was slow (maximum strength phase). Rest interval was 4 minutes. During weeks 4 and 5, the speed of execution was fast (power development phase). Rest interval was 3 minutes. During weeks 6 and 7, the speed of execution was medium to fast (muscular endurance phase). Rest interval was 3 minutes.

Table 4. Pretraining descriptive statistics of subjects divided by training groups.

	Endurance	Strength	Endurance + strength	Control
Age (y)	22.4 ± 0.53	22.2 ± 0.38	22.6 ± 0.79	22.2 ± 0.45
Body mass (kg)	86.2 ± 0.69	85.4 ± 0.54	86.1 ± 0.69	86.6 ± 0.55
Stature (cm)	189 ± 0.82	188 ± 0.90	188 ± 0.53	189 ± 0.45
Body fat (%)	10.3 ± 0.39	10.7 ± 0.61	10.3 ± 0.48	10.9 ± 0.24
Number of subjects	7	7	7	5
Questionnaire*				
Question 1	2.3 ± 0.49	2.3 ± 0.49	2.3 ± 0.49	2.2 ± 0.45
Question 2	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00
Question 3	2.0 ± 0.00	2.0 ± 0.00	2.0 ± 0.00	2.0 ± 0.00
Question 4	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00
Question 5	1.0 ± 0.00	1.0 ± 0.00	1.0 ± 0.00	1.0 ± 0.00
Question 6	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00

* The values for the questionnaire results ranged from 1 to 5.

tance was applied within 3 seconds after initial inertia and unloaded frictional resistance of the ergometer had been overcome. The test was performed (after a 3-minute warm-up) on a mechanically braked cycle ergometer (Monarch). The procedure took place twice, pre- and posttraining. Furthermore, all participants followed a familiarization procedure with the lab apparatus.

1RM effort was calculated in half squat, bench press, leg press, and lateral pull down.

Maximum Aerobic Capacity: 1-Mile Walk. Participants had to walk a mile as fast as possible without running (20). The average heart rate of the last complete minute was recorded. Maximum aerobic capacity values were calculated in milliliters per kilogram per minute. Subjects performed the test twice (pre- and posttraining) on a measured track.

Table 5. Test-retest reliability.

Criterion measures	Reliability coefficients means (r)
Half squat	0.40
Bench press	0.42
Leg press	0.34
Lateral pull down	0.35
Percentage body fat	0.55
Wingate	0.94
$\dot{V}O_2$max	0.40
Vertical jump	0.62

Statistical Analyses

Student's t-test for paired data was used in order to detect possible significant differences between test and retest scores. All criterion measures were compared (pretraining) with the aid of 1-way analysis of variance, and if significant, Tukey's post hoc test was used. In addition, test-retest reliability was applied for evaluating the quantitative extent of relationship and association between the 2 sets of scores for each criterion measure. Level of significance was set at $p \leq 0.05$.

Results

Reliability coefficients means for the 8 criterion variables are displayed in Table 5. They ranged from $r = 0.34$ (leg press) to $r = 0.94$ (Wingate Test).

The intragroup differences concerning total energy intake were not found to be statistically significant (at $p < 0.05$), according to the everyday dietary plan check. Furthermore, no significant differences existed in all pretraining key anthropometric variables.

Although no significant differences were found between the 4 groups in pretraining values for squat, lateral pull down (front), Wingate test, and vertical jump, significant differences were present in pretraining values for bench press, leg press, and $\dot{V}O_2$max values. Tukey's post hoc test revealed that the source of significance of pretraining scores for bench press and lateral pull down was the endurance group, whereas the pretraining $\dot{V}O_2$max values differed significantly for the strength group.

According to the level of statistical significance ($p < 0.05$), no significant pre- to posttesting differences were found regarding strength and power for the endurance group, except from the 1RM effort for lateral pull down (front). The difference reached 2.7% (Table 6). As for endurance, a statistically significant increase of 6.8% for maximal aerobic capacity was noted (Table 7). In addition, there appeared to be a significant decrease between pre and post values in percentage of body fat (10.3 ± 0.39% vs. 9.8 ± 0.74%) and body weight (86.2 ± 0.69 kg vs. 83.5 ± 2.29 kg) (Table 8).

Statistically significant differences were present for the strength group, first and foremost concerning strength. More specifically, significant increases of

16.1%, 23.6%, 8.4%, and 17.1% were present for 1RM squat, bench press, leg press, and lateral pull down (front), respectively (Table 6). Vertical jump and Wingate pre-post values also showed statistically significant differences (53.1 ± 2.67 cm vs. 58.7 ± 1.88 cm and 1,084 ± 87.5 W vs. 1,117 ± 74.7 W) (Table 7). Posttraining $\dot{V}O_2$max values revealed a significant decrease compared with the pretraining values (57 ± 1.97 ml·kg·min^{-1} vs. 52 ± 3.03 ml·kg·min^{-1}) (Table 7). Also, in regard to the strength group, a significant reduction took place for percentage of body fat (15%), according to the posttraining tests. A nonsignificant decrease occurred for body weight (2.4%) (Table 8).

The strength + endurance group revealed statistically significant pre- to posttesting scores for 1RM squat (18.9%), bench press (23.1%), leg press (6.5%), and lateral pull down (front) (22.4%) (Table 6). Further significant improvements were noted for vertical jump (53.3 ± 3.14 cm vs. 59.6 ± 2.37 cm), Wingate (1,064 ± 95.9 W vs. 1,134 ± 84.6 W), and maximum aerobic capacity (54 ± 1.57 ml·kg·min^{-1} vs. 62 ± 1.91 ml·kg·min^{-1}) (Table 7). Pre- and posttesting also showed significant attenuation in body fat (15.5%) and body weight (4.3%) (Table 8).

Comparisons of the strength group with the strength + endurance group indicated a statistically significantly better posttraining testing performance for the strength group in 1RM leg press (2.25% difference) and a greater extent of improvement for 1RM bench press (23.6% vs. 23.1%). On the other hand, there was a significant ''superiority'' in the strength + endurance group for 1RM squat (4.5%), lateral pull down (front) (5.6%), vertical jump (1.5%), Wingate (1.5%), and $\dot{V}O_2$max (16.1%). Finally, the strength + endurance group revealed a statistically significant lower posttraining value for percentage body fat compared with the endurance group (11.35% difference).

The control group was used for comparison reasons. It showed a statistically nonsignificant pre- to posttraining decline in all strength (unless for the 1RM leg press), endurance, and power parameters. Moreover, the control group showed a nonsignificant increase in the percentage of body fat and body weight.

Discussion

The findings of the present study showed that concurrent strength and endurance training results in significant increases in power, strength, and endurance.

Strength training alone significantly improves power and strength, but it significantly reduces maximum aerobic capacity, either because of the lack of aerobic training or because of the decrease of the oxidative potential per total muscle mass (34). The significant decline of $\dot{V}O_2$max is not consistent with other studies suggesting that strength training alone can maintain endurance (11, 21) or even has the potential

Table 6. Mean values (1-repetition maximum) and standard deviations for squat, bench press, leg press, and lateral pull down for groups pre- and posttraining.

Groups	Pretest				Posttest†			
	Half squat (kg)	Bench press (kg)	Leg press (kg)	Lateral pull down (kg)	Half squat (kg)	Bench press (kg)	Leg press (kg)	Lateral pull down (kg)
Control	100.6 ± 1.34	85.2 ± 0.44	220.0 ± 1.48	70.6 ± 0.89	100.2 ± 1.48 (0.4)	82.8 ± 2.16 (2.8)	210.6 ± 3.64* (4.3)	70.2 ± 3.56 (0.6)
Endurance	102.4 ± 1.71	82.4 ± 0.97	210.6 ± 4.99	68.9 ± 0.90	100.8 ± 0.89 (1.6)	82.4 ± 2.57 (0.1)	215.5 ± 3.10 (2.3)	70.8 ± 1.57* (2.7)
Strength	100.8 ± 2.34	84.4 ± 0.53	220.5 ± 2.43	70.8 ± 1.06	120.2 ± 1.38* (16.1)	110.5 ± 2.14* (23.6)	240.7 ± 4.88* (8.4)	85.4 ± 0.97* (17.1)
Strength + endurance	102.1 ± 2.34	85.2 ± 1.34	220.0 ± 2.00	70.2 ± 2.49	125.9 ± 5.27* (18.9)	110.8 ± 3.93* (23.1)	235.3 ± 3.98* (6.5)	90.5 ± 2.22* (22.4)

† Numbers in parentheses represent the percentage change between pre- and posttraining test scores.
* Significant difference, $p < 0.05$, between pre- and posttraining testing.

Table 7. Mean values and standard deviations for vertical jump, Wingate, and $\dot{V}O_2max$ for groups pre- and posttraining.

Group	Pretest			Posttest†		
	Vertical jump (cm)	Wingate (W)	$\dot{V}O_2max$ (ml·kg·min^{-1})	Vertical jump (cm)	Wingate (W)	$\dot{V}O_2max$ (ml·kg·min^{-1})
Strength + endurance	53.3 ± 3.14	1,064 ± 95.9	54 ± 1.57	59.6 ± 2.37* (10.6)	1,134 ± 84.6* (6.2)	62 ± 1.91* (12.9)
Control	52.2 ± 2.16	841 ± 92.4	54 ± 1.81	51.2 ± 1.30 (1.9)	839 ± 124.1 (0.25)	52 ± 3.39 (3.8)
Endurance	51.4 ± 2.81	1,074 ± 81.1	55 ± 2.64	51.3 ± 3.16 (0.2)	1,105 ± 87.8 (2.8)	59 ± 0.90* (6.8)
Strength	53.1 ± 2.67	1,084 ± 87.5	57 ± 1.97	58.7 ± 1.88* (9.5)	1,117 ± 74.7* (2.9)	52 ± 3.03* (8.8)

† Numbers in parentheses represent the percentage change between pre- and posttraining test scores.
* Significant difference, $p < 0.05$, between pre- and posttraining testing.

Table 8. Pre- and posttraining mean values and standard deviations for body composition parameters.

Group	Pretest		Posttest†	
	Percentage body fat	Weight (kg)	Percentage body fat	Weight (kg)
Control	10.9 ± 0.24	86.6 ± 0.55	11.4 ± 0.55 (4.4)	88.8 ± 2.28 (2.5)
Endurance	10.3 ± 0.39	86.2 ± 0.69	9.8 ± 0.74* (4.9)	83.5 ± 2.29* (3.1)
Strength	10.7 ± 0.61	85.1 ± 0.69	9.1 ± 0.44* (14.9)	83.1 ± 2.26 (2.4)
Strength + endurance	10.3 ± 0.48	86.1 ± 0.69	8.7 ± 0.50* (15.5)	82.4 ± 2.87* (4.3)

† Numbers in parentheses represent the percentage change between pre- and posttraining test scores.
* Significant difference, $p < 0.05$, between pre- and posttraining testing.

to produce small but significant increases in $\dot{V}O_2max$ (12, 14). The strength group followed a resistance program that was divided into 3 weeks of maximum strength training, 2 weeks of explosive power training, and 2 weeks of muscular endurance training. Additionally, during weeks 4 and 5, the participants of the strength group experienced plyometric training. The 2-week high-repetition, low-resistance training program (muscular endurance) along with the plyometrics did not prevent the decline of maximum aerobic capacity. Posttraining scores of the strength group (related to power and strength components) seem to be similar to previous findings in the literature (2, 3, 11, 13, 17, 21). Members of the strength group also experienced significantly reduced levels of body fat. The decreased fat levels of this study appear to have a greater magnitude than in previous studies (14.9% vs. 7.8%) (11). On the other hand, the nonsignificant reduction of body weight contrasts with previous findings, where an increase in body weight was noted (11, 29). In our opinion, plyometric training could be the minor cause for body weight attenuation. However, the major cause for this specific body weight alteration should be the low-resistance, high-repetition strength training program during weeks 6 and 7. Another issue also deserves a brief comment. Vertical jump performance was improved without any specific jump training. Previous studies claimed that this phenomenon was due to the squat exercise (11, 18). Leg press and plyometrics might also contribute to this increase. Furthermore, Hennessy and Watson (11) believe that the improvement of vertical jump found by Hunter and his colleagues (18) was due to the low vertical jump scores prior to training (approximately 44 cm). Nevertheless, the vertical jump performance prior to training of the current investigation (53.1 cm) seems to be similar to the equivalent pretraining scores of the Hennessy and Watson study (54.2 cm) (11).

Endurance training alone significantly improved maximum aerobic capacity, as expected. However, posttraining values for the endurance group in this study were lower than in other investigations (6.8% vs.

10.8%) (11). Aerobic exercise is also responsible for the reduction of body weight and percentage of body fat for the members of the endurance group. Endurance training causes physiologic and biochemical changes in skeletal muscles. It favors slow-twitch fibers and causes an increase in capillary density (31). Thus, the deterioration of the other training parameters included in this study seems to be a reasonable consequence of the lack of specific training. The significant increase in 1RM lateral pull down can only be explained as resulting from chance.

Lack of exercise—because the energy intake, which was monitored via the daily dietary plan recall, showed no difference between groups—is responsible for the nonsignificant increase (4.4%) in percentage of body fat and body weight (2.2%) for the control group. In addition, the complete absence of any kind of exercise caused a nonsignificant reduction in the retest values for Wingate, vertical jump, and strength (apart from leg press). Finally, the control group averaged a decreased maximum aerobic capacity, partly because of the body weight increase and mainly because of the lack of aerobic exercise.

Concurrent strength + endurance training promoted significant gains in strength, power, and $\dot{V}O_2$max as well. Simultaneous strength and endurance training seems to be more beneficial than strength and endurance training on different days. As far as we know, fatigue or anticipation reduced neither the amount of training volume nor the effort applied by the participants, in contrast to what was hypothesized in previous studies (21, 29). Volpe et al. (35) presented significant improvements from pretraining levels in low body strength for the strength and endurance group. Hennessy and Watson (11) reported that simultaneous strength and endurance training resulted in upper-body strength gains only. In contrast, Kraemer et al. (21) concluded that concurrent strength and endurance training might produce smaller muscle strength and power increases than strength training alone. Moreover, evidence in the literature supports the idea of interference effects during concurrent strength and endurance training (16, 25), whereas other authors reported an interference effect of endurance training on strength development (7, 11, 12, 18). The findings of this study suggest upper- and lower-body strength gains, including vertical jump. The strength and endurance group also revealed a significantly better posttraining endurance performance. Previous articles in the literature also reported an improved level in endurance via strength training (12, 13, 14, 21). In addition, Hennessy and Watson (11) presented that the endurance group of their investigation did not demonstrate a greater improvement in $\dot{V}O_2$max values over and above the strength and endurance group. The results of this investigation indicate that the strength and endurance group had higher posttraining values for maximum aerobic capacity than the endurance group. Moreover, the strength and endurance group averaged lower posttraining levels of percentage body fat than the strength or endurance groups. The results of the current study also indicate a significant improvement in WanT for the strength group. Not only was this improvement replicated in the strength and endurance group, but its magnitude was also greater.

It is possible that the central nervous system is better adapted to concurrent strength and endurance training. It is supported that this kind of training also serves as a better stimulus for the oxidative enzyme of citrate synthase, with no obvious reason (29). Perhaps a better recruitment of the energy reserves takes place, caused by the increased energy demands from the simultaneous training stimuli. Kraemer et al. (21) used an invasive diagnostic procedure in order to investigate the compatibility of high-intensity strength and endurance training. In contrast to our results, an interference of power and strength development with this type of training was present. The explanation for this difference, as Sale et al. (29) also believe, might be the training modes, intensity, and frequency of the training regimens. For instance, the participants of this study did not experience supersets of paired exercises as in the Kraemer et al. (21) study. Hence, one should not disregard the fact that the functional efficiency of the concurrent strength and endurance training might depend partly or exclusively on the quality of the training program (based on the sport-specific requirements and the amount of rest between the training sessions) according to the specific training phase (i.e., maximum strength, power, and muscular endurance phase).

During this study—as in most studies investigating simultaneous strength and endurance training—members of the strength and endurance group experienced greater total training volumes compared with the strength group. Previous authors reported the possibility of overtraining as a result of simultaneous strength and endurance training (21, 25). All subjects were further monitored for a period of 9 months concerning overtraining effects. It is encouraging that especially the members of the strength + endurance group did not experience overtraining syndrome, injuries, or deterioration regarding their sport-specific skills.

One last point that needs to be made concerns the validity of the extracted conclusions. The training status of the trainees plays an important role. The lower the activity level, the more substantial the effect in endurance and strength development and vice versa (1, 7, 12, 13, 18).

In conclusion, the results of the current study indicate that a well-designed concurrent strength and endurance training that follows the principles of specificity and overload and that ''realizes'' the possibility of fatigue and anticipation can lead to the concomitant development of strength, power, and endurance.

Practical Applications

A 7-week strength training similar to the one used in this study will likely have an additive effect on strength, power, and speed. In contrast, a significant reduction in $\dot{V}O_2$max was noted. Reduction of percentage of body fat can be also expected. However, it is not completely clear whether the strength training program of the current study will lead to an increase of body weight or not. One possible explanation could be the plyometric training along with the 2-week low-resistance, high-repetition training program.

Endurance training alone for 7 weeks leads to an augmentation of aerobic capacity, as expected. Moreover, an attenuation of body weight and percentage of body fat takes place. No changes for speed, power, and strength should be expected because of the absence of specific training.

It seems that the concurrent strength and endurance regimen of this investigation does not have any antagonistic effect. It resulted in significant increases regarding power, strength, and maximum aerobic capacity. However, during a simultaneous strength and endurance training program, it is important to take in serious consideration first of all the sport-specific requirements, the training status of each athlete, and the importance of adequate rest periods, in order for injuries and overtraining to be avoided.

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