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Concurrent Training and Detraining: The Influence of Different Aerobic Intensities

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Abstract

Sousa, AC, Neiva, HP, Gil, MH, Izquierdo, M, Rodríguez-Rosell, D, Marques, MC, and Marinho, DA. Concurrent training and detraining: the influence of different aerobic intensities. *J Strength Cond Res* XX(X): 000–000, 2018—The aim of this study was to verify the effects of different aerobic intensities combined with the same resistance training on strength and aerobic performances. Thirty-nine men were randomly assigned to a low-intensity group (LIG), moderate-intensity group (MIG), high-intensity group (HIG), and a control group. The training program consisted of full squat, jumps, sprints, and running at 80% (LIG), 90% (MIG), or 100% (HIG) of the maximal aerobic speed for 16–20 minutes. The training period lasted for 8 weeks, followed by 4 weeks of detraining. Evaluations included 20-m sprints (0–10 m: T10; 0–20 m: T20), shuttle run, countermovement jump (CMJ), and strength ($1RM_{est}$) in full squat. There were significant improvements from pre-training to post-training in T10 (LIG: 4%; MIG: 5%; HIG: 2%), T20 (3%; 4%; 2%), CMJ (9%; 10%; 7%), $1RM_{est}$ (13%; 7%; 8%), and oxygen uptake ($\dot{V}O_2max$; 10%; 11%; 10%). Comparing the changes between the experimental groups, $1RM_{est}$ gains were significantly higher in the LIG than HIG (5%) or MIG (6%). Furthermore, there was a tendency for higher gains in LIG and MIG compared with HIG, with "possibly" or "likely" positive effects in T10, T20, and CMJ. Detraining resulted in performance decrements, but minimal losses were found for $\dot{V}O_2max$ in LIG (−1%). Concurrent training seems to be beneficial for strength and aerobic development regardless of the aerobic training intensity. However, choosing lower intensities can lead to increased strength and is recommended when the cardiorespiratory gains should be maintained for longer.

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Introduction

Concurrent training (CT) is widely described in the literature as an effective training method for improving aerobic capacity, muscle strength, and power (18,28). However, combining resistance and aerobic training has been reported to attenuate the training response induced by either type of training alone (13,14). This interference phenomenon (13) seems to be associated with a greater inhibitory effect on strength development than on aerobic capacity when CT is conducted (22). Nevertheless, some studies have shown no antagonistic effects on strength (30) or aerobic performance (33) after CT compared with performance after either form of stand-alone training. This fact could be due to the physiological adaptations induced by CT, which seem to be dependent on the order, volume, and intensity of the stimulus applied during the training session (28).

Notably, a variety of CT protocols have been assessed in previous research (28,41). In fact, the benefits and limitations of training sequence and the effects on health and performance have already been well-documented (3,24). However, only a few studies have focused on the training intensity distribution during CT, which seems to be a major issue when programming aerobic and resistance training (RT) simultaneously (4,7,40). Some authors have suggested that the intensity during aerobic training is a possible cause of interference when aerobic training is combined with RT, pointing out that interference only occurs at intensities close to the maximal oxygen uptake ($\dot{V}O_2max$) (4,7). Indeed, Chtara et al. (4) found interference in the strength and power gains when aerobic exercise was performed at a velocity associated with $\dot{V}O_2max$ ($v\dot{V}O_2max$). In another study, De Souza et al. (7) investigated the acute effects of 2 aerobic exercises (aerobic threshold vs. $v\dot{V}O_2max$) on maximal dynamic strength (1 repetition maximum test [1RM]) and local muscular endurance (number of repetitions at 80% of

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1RM) and found that only the higher intensity aerobic exercise impaired local muscular endurance. It seems that a more pronounced chronic interference effect occurs in higher rather than lower aerobic intensities; however, these studies only focused on acute but not long-term effects.

To the best of our knowledge, only Fyfe et al. (12) compared different intensities of aerobic training during a short-term CT program regimen. Despite the gains observed after 8 weeks of different CT protocols, these authors suggested that CT incorporating either high-intensity (120–150% of the lactate threshold intensity) or moderate-intensity (80–100% of the lactate threshold intensity) aerobic stimulation similarly attenuates improvements in maximal lower-body strength compared with RT alone. Importantly, only moderate and high intensities were studied, and 2 different methods of training were compared simultaneously (interval and continuous), thus affecting the conclusions obtained. Considering that a better understanding of the effects of CT with different aerobic intensities seems necessary, the primary purpose of the current study was to analyze the effect of 3 CT programs that only differed in the intensity of the aerobic training program on performance in vertical jumping, sprint, leg strength, and aerobic capacity.

Another issue regarding CT is the effect caused by interruptions in training programs. This detraining (DT) period usually occurs during a season because of injuries or even recovery from a previous training period (34,35). Understanding the effect of DT may be important to better understand previous adaptations caused by CT and thus essential in the design of efficient training programs. Several authors have reported a decrease in strength gains and aerobic capacity previously acquired after a reduction in muscular activity associated with a reduction or cessation of training (9,10). Unfortunately, the effects of DT after a CT period are still poorly studied in the literature, especially when different intensities are applied. Recently, Sousa et al. (40) verified that different 8-week RT programs with different loads combined with low-intensity aerobic training improved strength and aerobic capacities. However, 4 weeks of DT resulted in detrimental effects for all different intensities used during RT. Nevertheless, DT-induced changes caused by a CT program may be related to multiple factors (17,31), and the aerobic training intensity used during the training period may be essential. Therefore, the second aim of this study was to analyze the effects of a 4-week DT period after CT programs comprising different aerobic intensities.

Methods

Experimental Approach to the Problem

When properly combined, CT can produce benefits in both strength and aerobic performance, but the distribution of the training intensities must be carefully planned. The latest research on this problem focused on the loading magnitude of RT; however, this question has yet to be solved regarding the aerobic component of CT. An experimental research design was used to compare the effects of 3 concurrent resistance and aerobic training programs only differing in training intensity used during aerobic training (80% maximal aerobic speed [MAS] vs. 90% MAS vs. 100% MAS) on physical performance and the DT adaptations. Higher aerobic intensities were hypothesized to compromise strength gains during the CT period and result in higher performance impairments after the DT period.

The participants were randomly assigned to the experimental groups performing RT combined with aerobic training of different intensities, while those assigned to the control group (CG) merely undertook daily-life activities (without training). All experimental groups performed the CT training program twice a week for 8 weeks. Strength performance seems to be negatively affected by previous aerobic exercitation (37); therefore, the literature recommends that intrasession exercise sequences should consist of resistance followed by aerobic training. Resistance training was the same across the experimental groups, consisting of full squat (FS) (70–85% of 1 repetition maximum: $1RM_{est}$), jumps, and sprints and designed based on recent evidences (40).

All subjects were evaluated in 2 sessions separated by a 48-hour rest interval. During the first testing session, the participants performed 20-m sprints and a 20-m shuttle run test. During the second testing session, subjects executed the countermovement jump (CMJ) test and an isoinertial strength assessment in the FS exercise. During the 2 weeks preceding this study, 4 preliminary familiarization sessions were undertaken to ensure properly executed technique in both the FS and CMJ exercises. To evaluate the DT effects, the same tests were performed after 4 weeks of training cessation. Throughout this period, the participants were asked to refrain from participating in regular exercise programs aimed at developing or maintaining strength and aerobic capacity.

Subjects AU3

Thirty-nine physically active men volunteered to participate in this study. Participants were physically active sport science students with RT experience ranging from 6 months to 2 years (at least 2 sessions per week). After an initial AU4 evaluation, the participants were matched according to their estimated MAS in the shuttle run exercise and then randomly assigned to 4 groups depending on the training intensity used during aerobic training as follows: a low-intensity group (LIG, 80% MAS), a moderate-intensity group (MIG, 90% MAS), a high-load group (high-intensity group [HIG], 100% MAS), and a CG. Because of injury or illness, 3 participants from the CG were absent from the post-testing sessions. Thus, of the 39 initially enrolled participants, only 36 successfully completed the entire study. The subjects' characteristics are displayed in Table 1. All participants were T1 informed about the experimental procedures and potential

TABLE 1. Subject characteristics.*†

Variable	Group LIG ($n = 10$)	MIG ($n = 10$)	HIG ($n = 10$)	CG ($n = 6$)
Age (y)	21.2 ± 1.5	21.0 ± 2.0	21.1 ± 2.2	20.7 ± 2.3
Height (m)	1.80 ± 8.1	1.77 ± 4.3	1.75 ± 4.7	1.80 ± 0.1
Body mass (kg)	72.5 ± 8.5	74.5 ± 9.1	72.4 ± 9.1	70.1 ± 4.8

*LIG = low-intensity group; MIG = moderate-intensity group; HIG = high-intensity group; CG = control group.
†Values are mean ± *SD*.

risks before they provided their written informed consent. The investigation was conducted in accordance with the Declaration of Helsinki and was approved by the local research ethics committee. AU5

Procedures

The variables were assessed before (Pre), after the 8-week training period (Post 1), and after the 4-week DT period (Post 2) in 2 sessions separated by a 48-hour rest interval. Testing sessions were performed at the same time of day for each participant under the same environmental conditions (~20° C and ~60% humidity). Body mass and height (Seca Instruments, Ltd, Hamburg, Germany) were measured before the warm-up protocol in the first testing session. Strong verbal encouragement was provided during all tests to motivate participants to give maximal effort.

Sprints. Each participant performed three 20-m sprints separated by a 3-minute rest. Photocell timing gates (Brower photocells; Wireless Sprint System, USA) were placed at 0, 10, and 20 m, so that the times needed to cover 0–10 m (T10) and 0–20 m (T20) could be determined. A standing start with the lead-off foot placed 1 m behind the first timing gate was used. The average of the best 2 sprints was used for the analysis. Warm-up consisted of 5 minutes of running at a self-selected intensity, 5 minutes of joint mobilization exercises, followed by several sets of progressively faster 30-m running accelerations. Reliability for T20 as measured by the coefficient of variation was 3.7%, whereas the intraclass correlation coefficient was 0.94 (95% confidence interval: 0.91–0.97).

Shuttle Run Test. The 20-m multistage shuttle run test was administered according to the original version described by Léger (27). The initial running velocity was set at 8.5 $km \cdot h^{-1}$ and was gradually increased in 0.5 $km \cdot h^{-1}$ each minute (27). The test ended when a participant failed to reach the appropriate marker in the allotted time twice or could no longer maintain the pace. The number of laps completed was recorded. $\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$) was calculated based on the MAS reached before participants were unable to keep up with the audio recording, as follows: $-27.4 + 6 \times$ MAS (27).

Vertical Jump Test. The jump height was determined using a contact mat connected to an electronic power timer, control box, and handset (Globus Ergojump, Italy). After AU6 a specific warm-up consisting of 2 sets of 10 squats without load and 5 CMJs (20 seconds rest interval), each participant performed 3 maximal CMJs with their hands on their hips, separated by 1-minute rests. The highest value was recorded for the subsequent analysis. The intraclass correlation coefficient was 0.98 (95% confidence interval: 0.97–0.99), and the coefficient of variation was 2.9%.

Isoinertial Strength Assessment. A Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain) was used for this test. A detailed description of the testing procedures used in this study was recently reported elsewhere (15,38). The initial load was set at 17 kg and progressively increased in 10-kg increments until the attained mean propulsive velocity (MPV) was ~1.00 $m \cdot s^{-1}$ (range 0.95–1.05 $m \cdot s^{-1}$) (15). The participants performed 3 repetitions with each load, with 3-minute recovery. A linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) was used to register bar velocity. The $1RM_{est}$ was calculated for each individual from the MPV attained against the heaviest load (kg) lifted in the progressive loading test, as follows: $(100 \times \text{load})/(-5.961 \times MPV^2) - (50.71 \times MPV) + 117$ (38).

Training Program. The descriptive characteristics of the training programs completed by each group are presented in Table 2. The RT session comprised FS, CMJ, and sprint exercises and 2- to 3-minute rest periods were allowed between each set and exercise. The participants were instructed to perform all exercises at maximal intended velocity to obtain the highest possible gains (36). The loads used by each participant in the FS were assigned according to $1RM_{est}$ obtained in the initial isoinertial squat strength assessment. Thus, the relative intensity of the FS exercise progressively increased from 70 to 85% $1RM_{est}$ for all 3 T2

Table 2. Characteristics of the training program performed by the LIG, MIG, and HIG groups.*

Exercise	Sessions														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Full squat (% 1RM: S × R)	70:3 × 8	70:3 × 8	70:3 × 8	75:3 × 8	75:3 × 8	75:3 × 6	80:3 × 5	80:3 × 5	80:3 × 5	85:3 × 5	85:3 × 5	85:3 × 5	80:3 × 5	80:3 × 5	75:3 × 8
CMJ (S × R)	2 × 5	2 × 5	2 × 5	2 × 5	2 × 5	2 × 5	2 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	2 × 5
Sprint (S × D), m	2 × 30	2 × 30	2 × 30	3 × 30	3 × 30	3 × 30	3 × 20	3 × 20	3 × 20	4 × 20	4 × 20	4 × 20	3 × 20	3 × 20	2 × 20
20-m shuttle run (S × T), min	4 × 4	4 × 4	4 × 4	4 × 4	5 × 4	5 × 4	5 × 4	5 × 4	5 × 4	5 × 4	5 × 4	5 × 4	5 × 4	5 × 4	5 × 4
LIG (%MAS)	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
MIG (%MAS)	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
HIG (%MAS)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

*1RM = 1 repetition maximum; S × R: sets × repetitions; S × D: sets × distance; S × T: sets × time; CMJ = countermovement jump; LIG = low-intensity group; MIG = moderate-intensity group; HIG = high-intensity group; %MAS = percentage of the maximal speed reached for each participant during the 20-m multistage shuttle run test.

experimental groups. Because strength was expected to increase with training, an intermediate strength assessment was performed after 4 weeks of training to perform the necessary load adjustments for each participant.

Aerobic training was performed 20 minutes after the participants completed the RT to guarantee that required intensities were performed properly (40). This consisted of 16–20 minutes performing the 20-m shuttle run exercise until reaching 80% (LIG), 90% (MIG), or 100% (HIG) of the maximal individual speed (MAS) reached during the 20-m multistage shuttle run test. As for RT, participants were assessed in the 20-m shuttle run test after 4 weeks of training to perform the necessary adjustments for each participant. At least 2 trained researchers supervised each workout session and recorded the individual workout data during each training session. All participants were instructed to maintain their normal daily activities throughout the study. The participants did not undertake any additional strength or aerobic training activities during the testing, training, and DT periods.

Statistical Analyses

The values of each variable are presented as mean ± *SD*. Homogeneity of variance across groups (LIG vs. MIG vs. HIG vs. CG) was verified using the Levene test, whereas the normality of distribution of the data was examined with the Shapiro-Wilk test. Data for all variables analyzed were homogeneous and normally distributed ($p > 0.05$). A 4 (group: LIG, MIG, HIG, CG) × 3 (time: Pre, post 1, post 2) repeated-measures analysis of variances was calculated for each variable. Sphericity was checked using Mauchly's test. Percentage of change for each variable within and between groups was calculated and a 1-way analysis of variance was conducted to examine between-group differences with Tukey post hoc comparisons (LIG vs. MIG vs. HIG vs. CG) to clarify the interaction. In addition to this null hypothesis testing, the data were assessed for clinical significance using an approach based on the magnitudes of change (19). The effect sizes (ESs) were calculated using Cohen's *d* (10) to estimate the magnitude of the training effect on the selected strength variables within each group. The threshold values for assessing the magnitudes of the standardized effects were 0.20, 0.60, 1.20, and 2.00 for small, moderate, large, and very large magnitudes, respectively (19). Probabilities were also calculated to establish whether the true (unknown) differences were lower than, similar to, or higher than the smallest worthwhile difference or change (0.2 multiplied by the between-subject *SD*) (19). The quantitative chances of obtaining higher or lower differences were evaluated as follows: 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and 99%, almost certain. If the chances of having higher or lower values than the smallest worthwhile difference were both >5%, the true difference was assessed as unclear. Inferential statistics based on the interpretation of the magnitude of effects were calculated using a purpose-built spreadsheet for the analysis of controlled trials (20). The

TABLE 3. Changes in neuromuscular performance variables from pre-training to post-training and detraining period for each experimental group.*†

				Pre vs. Post 1			Pre vs. Post 2			Post 1 vs. Post 2		
Variable	Pre	Post 1	Post 2	*p*	Δ (±90% CI)	ES	*p*	Δ (±90% CI)	ES	*p*	Δ (±90% CI)	ES
Low-intensity group												
T10 (s)	1.95 ± 0.08	1.88 ± 0.08	1.89 ± 0.08	0.001	−3.7 ± 2.0	0.76	0.003	−3.1 ± 1.7	0.63	0.980	0.6 ± 0.4	0.13
T20 (s)	3.32 ± 0.15	3.23 ± 0.17	3.26 ± 0.15	0.002	−2.8 ± 1.3	0.54	0.049	−1.9 ± 0.9	0.37	0.863	0.9 ± 0.6	0.17
CMJ (cm)	34.7 ± 4.1	37.9 ± 5.4	36.7 ± 4.8	0.000	8.9 ± 3.6	0.64	0.004	5.6 ± 1.6	0.41	0.048	−3.0 ± 2.5	0.23
$1RM_{est}$ (kg)	82.4 ± 21.7	92.2 ± 21.1	84.7 ± 18.9	0.000	12.8 ± 3.2	0.40	0.217	3.6 ± 3.2	0.12	0.000	−8.1 ± 2.3	0.28
$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})	41.4 ± 8.0	45.5 ± 8.0	45.5 ± 7.5	0.000	10.3 ± 4.1	0.47	0.000	10.5 ± 5.9	0.48	1.000	0.2 ± 5.1	0.01
Moderate-intensity group												
T10 (s)	1.95 ± 0.14	1.86 ± 0.13	1.92 ± 0.10	0.000	−5.1 ± 2.5	0.87	0.111	−1.7 ± 1.6	0.30	0.000	3.2 ± 1.9	0.57
T20 (s)	3.28 ± 0.20	3.16 ± 0.17	3.23 ± 0.16	0.000	−3.7 ± 1.9	0.65	0.046	−1.5 ± 0.9	0.26	0.031	2.1 ± 1.5	0.38
CMJ (cm)	33.5 ± 6.0	36.9 ± 6.6	35.2 ± 6.4	0.000	10.3 ± 2.0	0.49	0.012	5.2 ± 1.9	0.26	0.003	−4.6 ± 1.8	0.24
$1RM_{est}$ (kg)	83.4 ± 21.3	89.3 ± 21.7	81.0 ± 21.6	0.000	7.4 ± 1.6	0.25	0.184	−3.1 ± 1.9	0.11	0.000	−9.7 ± 2.2	0.36
$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})	42.5 ± 8.7	46.9 ± 7.3	44.7 ± 7.4	0.000	11.3 ± 4.7	0.47	0.072	5.9 ± 4.8	0.25	0.005	−4.8 ± 1.2	0.22
High-intensity group												
T10 (s)	1.96 ± 0.11	1.92 ± 0.11	1.96 ± 0.11	0.261	−1.6 ± 0.6	0.26	1.000	0.3 ± 1.1	0.05	0.013	1.9 ± 0.9	0.31
T20 (s)	3.34 ± 0.18	3.27 ± 0.15	3.31 ± 0.15	0.014	−2.1 ± 0.9	0.41	0.731	−0.9 ± 0.8	0.17	0.384	1.2 ± 0.5	0.23
CMJ (cm)	33.6 ± 4.7	36.1 ± 4.5	35.8 ± 4.0	0.000	7.4 ± 2.5	0.49	0.002	6.6 ± 2.2	0.45	1.000	−0.7 ± 1.6	0.05
$1RM_{est}$ (kg)	84.0 ± 19.1	90.8 ± 20.5	81.5 ± 19.0	0.000	8.1 ± 1.6	0.30	0.155	−3.1 ± 3.3	0.12	0.000	−10.4 ± 2.5	0.42
$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})	42.0 ± 8.4	46.1 ± 7.7	43.1 ± 7.8	0.000	10.3 ± 3.7	0.45	0.766	2.9 ± 2.3	0.13	0.005	−6.7 ± 1.6	0.32

*Pre = initial evaluation; Post 1 = evaluation after training period; Post 2 = evaluation after detraining period; Δ = percentage of change; ES = intragroup effect size; CI = confidence interval; T10 = 10-m sprint time; T20 = 20-m sprint time; CMJ = countermovement jump; $1RM_{est}$ = estimated 1 repetition maximum; $\dot{V}O_2max$ = estimated maximal oxygen uptake.

†Data are mean ± *SD*.

TABLE 4. Changes in neuromuscular performance variables from initial evaluation (pre) to final evaluation (post) between groups.*†

	Changes observed for post 1 vs. Pre				
	p	Δ (±90% CI)	ES	Percent changes of better/trivial/worse effect	
T10‡					
LIG vs. CG	0.015	4.6 ± 3.9	0.86	99/1/0	Very likely
MIG vs. CG	0.002	5.8 ± 3.9	0.81	100/0/0	Almost certainly
HIG vs. CG	0.269	2.7 ± 3.9	0.41	94/6/0	Likely
LIG vs. MIG	0.775	−1.2 ± 3.4	0.19	7/44/49	Unclear
LIG vs. HIG	0.404	2.0 ± 3.4	0.36	78/21/1	Likely
MIG vs. HIG	0.073	3.2 ± 3.4	0.46	91/9/0	Likely
T20					
LIG vs. CG	0.365	1.8 ± 3.0	0.33	82/18/0	Likely
MIG vs. CG	0.095	2.6 ± 3.0	0.47	92/8/0	Likely
HIG vs. CG	0.702	1.2 ± 3.0	0.23	59/41/0	Possibly
LIG vs. MIG	0.816	−0.8 ± 2.6	0.15	6/53/41	Unclear
LIG vs. HIG	0.912	0.6 ± 2.6	0.12	31/66/3	Possibly
MIG vs. HIG	0.429	1.5 ± 2.6	0.27	63/35/2	Possibly
CMJ‡					
LIG vs. CG	0.038	7.2 ± 6.9	0.43	89/11/0	Likely
MIG vs. CG	0.011	8.6 ± 6.9	0.41	94/6/0	Likely
HIG vs. CG	0.043	5.7 ± 12.6	0.33	79/21/0	Likely
LIG vs. MIG	0.931	−1.3 ± 6.0	0.08	2/81/17	Likely trivial
LIG vs. HIG	0.889	1.6 ± 6.0	0.10	28/68/4	Possibly
MIG vs. HIG	0.559	2.9 ± 6.0	0.16	34/66/0	Possibly
$1RM_{est}$‡					
LIG vs. CG	0.000	13.7 ± 5.3	0.40	100/0/0	Almost certainly
MIG vs. CG	0.001	8.2 ± 5.3	0.25	87/13/0	Likely
HIG vs. CG	0.000	8.9 ± 5.3	0.29	95/5/0	Very likely
LIG vs. MIG	0.014	5.5 ± 4.6	0.17	33/67/0	Possibly
LIG vs. HIG	0.043	4.7 ± 4.6	0.15	34/66/0	Possibly
MIG vs. HIG	0.968	−0.8 ± 4.6	0.03	0/100/0	Most likely trivial
$\dot{V}O_2max$‡					
LIG vs. CG	0.148	7.8 ± 9.6	0.52	98/2/0	Very likely
MIG vs. CG	0.082	8.8 ± 9.6	0.54	98/2/0	Very likely
HIG vs. CG	0.151	7.7 ± 9.6	0.37	94/6/0	Likely
LIG vs. MIG	0.986	−1.0 ± 8.3	0.04	6/80/14	Unclear
LIG vs. HIG	1.000	0.0 ± 8.3	0.00	7/85/7	Unclear
MIG vs. HIG	0.985	1.1 ± 8.3	0.04	13/82/5	Unclear

*CI = confidence interval; LIG = low-intensity group; MIG = moderate-intensity group; HIG = high-intensity group; CG = control group; T10 = 10-m sprint time; T20 = 20-m sprint time; CMJ = countermovement jump; $1RM_{est}$ = estimated 1 repetition maximum; $\dot{V}O_2max$ = estimated maximal oxygen uptake; Δ = percentage of change between groups; ES = intergroup effect size.

†All differences are presented as improvements for the first group compared with the second group (i.e., LLG vs. CG), so that negative and positive differences are in the same direction.

‡Statistically significant interaction "time × group": ** $p < 0.01$.

statistical analyses were performed using SPSS software version 18.0 (SPSS, Inc., Chicago, IL, USA). Statistical significance was established at the $p \leq 0.05$ level.

RESULTS

There were no significant differences between groups at baseline for any analyzed variable. The mean values, percentage of change, and intragroup ES for all variables analyzed during Pre, post 1, and post 2 are reported in Table 3.

T3

All the experimental groups showed significant improvements ($p < 0.05$–0.001) in all the variables assessed, except the T10 in HIG (Table 3). No changes took place in the CG. The intragroup ES for LIG ranged from small (T20, $1RM_{est}$, and $\dot{V}O_2max$) to moderate (T10 and CMJ). For MLG, the standardized effects were small (CMJ, $1RM_{est}$, and $\dot{V}O_2max$) and moderate (T10 and T20), whereas for HLG, the qualitative outcome relative to ES was small for all the variables analyzed.

After the training period, statistically significant "time × group" interactions were observed for T10 ($p < 0.01$), CMJ

($p < 0.01$), $1RM_{est}$ ($p < 0.01$), and $\dot{V}O_2max$ ($p < 0.01$), whereas there was no interaction in T20 ($p = 0.137$). Table 4 compares the changes from Pre to Post 1 between the LIG, HIG, MIG, and CG. When compared with CG, all the experimental groups (LIG, MIG, and HIG) showed significantly greater percent of changes from Pre to post 1 in CMJ ($p < 0.05$), $1RM_{est}$ ($p \leq 0.001$), and $\dot{V}O_2max$ ($p < 0.05$). The LIG and MIG also showed greater percentage of changes than CG in T10 ($p < 0.05$–0.01). Comparing the changes observed in the experimental groups, greater changes were found in $1RM_{est}$ for the LIG compared with MIG and HIG ($p < 0.05$), with "possibly" better changes. Furthermore, it seems that there was a tendency for higher gains in LIG and MIG compared with HIG, with "possibly" or "likely" positive effects in T10, T20, and CMJ.

After 4-week DT period, most of the variables analyzed showed an important detriment effect for all the experimental groups. A significant performance decrement was experienced for MIG in all the variables assessed between post 1 and post 2 (Table 3). The LIG group showed significant lower values in CMJ ($p < 0.05$) and $1RM_{est}$ ($p < 0.001$) after the rest period, whereas HIG showed significant performance losses in T10 ($p < 0.05$), $1RM_{est}$ ($p < 0.001$), and $\dot{V}O_2max$ ($p < 0.01$). In addition, no significant differences were found between the 3 trained groups and the CG at post 2 for any variable.

Discussion

The current study aimed to verify the effects of different aerobic training intensities combined with the same RT on strength and aerobic performances. All experimental groups showed improvements in the assessed variables, specifically the jump, sprint running, maximal strength, and $\dot{V}O_2max$. Thus, aerobic training programs with LIG, MIG, or HIG seem to be equally effective for producing gains in strength and aerobic fitness. Curiously, the LIG showed higher gains in maximal strength compared with the HIG and MIG. In addition, a cessation period of 4 weeks of training resulted in decreased performances. Nevertheless, the LIG showed smaller performance decrements during this period. These findings reveal that, although all the aerobic training intensities result in improvements, the lower intensity tend to result in higher gains after training and minor losses after DT.

The goal of CT is to maximize the benefits associated with both aerobic and RT usually achieved by single-mode training. There are many sports where a combination of both are required for successful performance (5). However, combining these 2 exercitation modes, resistance and aerobic, is challenging. Several studies have shown that there is an interference effect, for instance, blunting power and/or strength gains when aerobic exercises are added to an RT program (12). These mechanisms are not well-understood but comprise several factors that affect acute and chronic fatigue and exercise anabolic responses (5). Thus, the influence on either fatigue or the anabolic response could be caused by the load magnitude, which, for instance, is mainly influenced by the intensity of exercitation. A previous study from our laboratory (40) analyzed the effects of different resistance intensities during a CT program on strength and aerobic performance. Despite similar improvements, RT with medium and high loads (>55% $1RM_{est}$) was suggested to increase changes in explosive efforts such as short runs and CMJ. Nevertheless, the interference effect of aerobic training intensity is still unknown.

In this study, the 3 different aerobic intensities added to the same RT program showed significant improvements in all variables assessed, with the exception of the short run (T10) in the HLG. This effort lasted for less than 2 seconds, and some interference effect of the higher aerobic intensity could be speculated to exist during training. In fact, previous research has suggested that aerobic training during CT can impair ballistic and strength adaptations (29). Accordingly, the evaluated variables that demanded a higher participation of type II muscle fibers, such as short sprints, showed a higher percentage of change when training with lower aerobic intensities, but not with higher aerobic intensities.

Aerobic training has been reported to cause deterioration in the capacity of the neuromuscular system to generate force (18). However, with the addition of explosive exercises along with FS, executing all at the maximal intended velocity may attenuate the interferences on CMJ and short-run adaptations. In the current study, a higher aerobic stimulation intensity seems to be associated with fewer gains. Comparing the changes from pre-training to post-training between groups, we found no significant differences in T10, T20, or CMJ. Nevertheless, there was a slight trend toward a greater intragroup ES in the LIG and MIG than in the HIG in T10, T20, and CMJ. These higher probabilities of better effects (Table 4) for the lower intensities showed a tendency for the existence of interference effects according to aerobic intensities.

The gains in $1RM_{est}$ were lower than those reported by previous studies (~20%) that assessed the effects of CT on strength (30,40), perhaps because of the use of only one resistance exercise (FS) in this study. However, a similar magnitude of improvements was found when using a similar RT protocol during CT (40). Interestingly, those that trained with lower aerobic intensities (LIG) showed possibly better $1RM_{est}$ results after 8 weeks of CT. Previous research observed that high-intensity aerobic training (e.g., repeated sprints; high-intensity interval training) when performed concurrently with resistance exercises attenuated the anabolic response (6). Higher aerobic intensities seem to increase glycogen depletion predominantly in type II muscle fibers (14), which may intensify residual fatigue (21) and inhibit central regulators of cellular activity, such as activated protein kinase (8). Protein kinases play critical roles in regulating growth and reprogramming metabolism, and with their increased inhibition, muscle regeneration and training adaptations can be compromised (32).

The training period resulted in similar improvements in $\dot{V}O_2max$ for all experimental groups (10–11%), agreeing with previous researches on CT (7–18%) (19). Unclear inferences were found between groups, showing the level of similarity between the gains in $\dot{V}O_2max$. This fact is curious because the only thing that changed during the training program was the intensity of aerobic training, and this would be expected to change the $\dot{V}O_2max$ adaptations. Moreover, previous studies found that different training intensities showed dissimilar cardiorespiratory fitness changes (1,25). Particularly, the $\dot{V}O_2max$ responses seem to be dependent on the intensity of training in the context of single-mode exercise (1,25). A CT regimen has been previously shown to stimulate cardiorespiratory adaptation through elevation of $\dot{V}O_2max$ (2,16). The combination of the 2 modes of exercise, especially when aerobic exercitation follows RT, causes metabolism to increase aerobic needs and the cardiovascular system to adapt concordantly (39,42). However, to our knowledge, the current study was the first to analyze different intensities during aerobic training when combined with RT, using the same method of exercitation, and reporting no different gains in response.

The DT period resulted in a reduction in most of the variables analyzed in the experimental groups. The training adaptations persisted longer after the LIG program, with no significant declines in T10, T20, or $\dot{V}O_2max$. Several studies using a CT program have shown that sprint times of 10, 20, and 30 m remained unchanged or slightly decreased after a DT period (31). By contrast, previous evidence has reported relevant $\dot{V}O_2max$ declines (4–14%) with short-term training cessation in trained and untrained individuals (34). The current findings associated with $\dot{V}O_2max$ in the MIG and HIG were supported by those observations. The training cessation caused significant losses in T10, $1RM_{est}$, and $\dot{V}O_2max$ in the HIG and in all variables in the MIG. The LIG was the only group in which $\dot{V}O_2max$ did not diminish after the DT period, suggesting higher chronic adaptations. By contrast, strength variables ($1RM_{est}$ and CMJ) decreased in this training program after DT. Countermovement jump performance depends largely on the maximal strength of leg extensors (11), and thus, a reduction in the $1RM_{est}$ due to the strength loss that usually occurs without training could be also reflected in CMJ. Interestingly, despite the reduction in $1RM_{est}$ in the HIG, there was not a reduction in CMJ. This lack of an effect of DT could be because of the specific neuromuscular demands of the type and intensity of the aerobic exercise. The aerobic exercise used required a constant and rapid change in running direction. When the running intensity is higher, there is a greater change in acceleration to stop, change direction, and start running again. This change in acceleration could lead to an increased solicitation of the neuromuscular system and overload during the CT period in the HIG. Therefore, different rates of adaptation and high-intensity training could be required for extra recovery and to attain better CMJ performance between the second and third evaluations.

Several limitations should be addressed to this study. One of the main limitations of the study was the small number of subjects in each group; thus, we cannot be sure that the differences within and between the groups would have been clearer with a greater number of participants. In addition, the study evaluated the effects of aerobic and RT consisting of lower-limb exercitation only, which may have constituted a limitation in improving and maintaining the strength gains after the CT period. However, the main aim was to analyze the training and DT effects of an RT program combined with 3 different aerobic training regimens. We chose not to include additional resistance exercises to avoid increasing the number of confounding factors, such as the number of exercises, rest time, type of exercises, or fatigue accumulation, following the example of previous studies (40). Finally, analyzing the responses of different participants, such as women only, would be interesting, and further investigations should be developed in this regard.

In brief, the results of this study indicated that 8 weeks of RT programs combined with aerobic training with low, moderate, and high intensities improved strength and aerobic capacities regardless of the intensity used during aerobic exercitation. A remarkable contribution of this study is that the LIG was the one with the highest gains in maximal strength compared with the HIG and MIG. Moreover, the impairment caused by the 4 weeks of DT seemed to have less impact in the LIG, with higher maintenance of previous gains, especially regarding cardiorespiratory fitness.

Practical Applications

The results suggested that performing the same RT followed by aerobic training with low, moderate, or high intensities is beneficial for strength and aerobic development in healthy adults. Furthermore, choosing lower intensities during aerobic training (i.e., <80% MAS) can lead to increased strength gains in explosive efforts. These aerobic intensities should also be used during CT when the gains in cardiorespiratory fitness should be maintained for longer periods after training cessation. These findings should be considered to design CT programs for competitive and noncompetitive sports to efficiently integrate both resistance and aerobic regimens in the same training session.

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