

ORIGINAL ARTICLE

Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity

M Chtara, K Chamari, M Chaouachi, A Chaouachi, D Koubaa, Y Feki, G P Millet, M Amri

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See end of article for authors' affiliations

Correspondence to:
K Chamari, National Center of Medicine and Sciences in Sports, Physiology Department, Unité de Recherche "Evaluation, Sport, Santé", BP 263, Ave Mohamed Ali Akid, El Menzah 1004, Tunisia; karimchamari@gmx.net

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Aim: To examine the effects of the sequencing order of individualised intermittent endurance training combined with muscular strengthening on aerobic performance and capacity.

Methods: Forty eight male sport students (mean (SD) age 21.4 (1.3) years) were divided into five homogeneous groups according to their maximal aerobic speeds ($\dot{V}O_{2MAX}$). Four groups participated in various training programmes for 12 weeks (two sessions a week) as follows: E (n = 10), running endurance training; S (n = 9), strength circuit training; E+S (n = 10) and S+E (n = 10) combined the two programmes in a different order during the same training session. Group C (n = 9) served as a control. All the subjects were evaluated before (T0) and after (T1) the training period using four tests: (1) a 4 km time trial running test; (2) an incremental track test to estimate $\dot{V}O_{2MAX}$; (3) a time to exhaustion test (t_{lim}) at 100% $\dot{V}O_{2MAX}$; (4) a maximal cycling laboratory test to assess $\dot{V}O_{2MAX}$.

Results: Training produced significant improvements in performance and aerobic capacity in the 4 km time trial with interaction effect ($p < 0.001$). The improvements were significantly higher for the E+S group than for the E, S+E, and S groups: 8.6%, 5.7%, 4.7%, and 2.5% for the 4 km test ($p < 0.05$); 10.4%, 8.3%, 8.2%, and 1.6% for $\dot{V}O_{2MAX}$ ($p < 0.01$); 13.7%, 10.1%, 11.0%, and 6.4% for $\dot{V}O_{2MAX}$ (ml/kg^{0.75}/min) ($p < 0.05$) respectively. Similar significant results were observed for t_{lim} and the second ventilatory threshold (% $\dot{V}O_{2MAX}$).

Conclusions: Circuit training immediately after individualised endurance training in the same session (E+S) produced greater improvement in the 4 km time trial and aerobic capacity than the opposite order or each of the training programmes performed separately.

The development of the various components of muscular strength is now integrated into the training programmes of various endurance disciplines. The high level of velocity and power sustained and the imposed changes in pacing require emphasis on muscular preparation. Various studies have shown the benefit of adding strength training to improve endurance performance.^{1–4}

Theoretically, training induced muscle adaptations are divergent and can even be antagonistic to improvements in strength^{5–7} or endurance.^{8–9} Strength training has been reported to cause muscle fibre hypertrophy, associated with an increase in contractile protein, proportional to an increase in maximal contractile force.¹⁰ Strength training also reduces mitochondrial density and decreases the activity of oxidative enzymes, which can impede endurance capacity, but has minimal effect on capillary density or the conversion from fast (type II) to slow twitch (type I) fibre types.^{8–10} In contrast, endurance training usually induces little or no muscle hypertrophy, but increases the mitochondrial content, citric acid enzymes, oxidative capacity, and the possibility of muscle fibre conversion from fast to slow twitch.^{8–11} The interference between endurance and strength training can be explained by the followings factors: (a) the inability of muscle to adapt optimally to two different stimuli because of simultaneous requests from different energy pathways during the same session^{7–12}; (b) muscle tiredness resulting from the preceding training^{13–14}; (c) the type, nature, and specific mode of strength and aerobic training¹⁵ as well as the physical fitness and age of the athletes^{2–3–12}; (d) the volume, frequency, and intensity of training may also influence the degree of incompatibility observed^{9–12}; (e) finally, the sequencing order—that is, the order in which endurance and strength training are carried out—may also have an effect on the training induced adaptations.^{10–16–18} However, only a few

studies have reported whether strength training should precede or follow endurance training when both are performed in the same session.^{17–18} Previous investigations on the effects of concurrent training have used various sequences: (a) periods of several weeks of strength training before endurance training or endurance training before strength training^{5–19–20}; (b) alternating training days during the training period^{10–16}; (c) alternating the sequences during the training sessions.^{17–18} In the latter studies, aerobic capacity improved. However, to the best of our knowledge, there are no studies on the effect of the sequence order of concurrent training in the same session on endurance performance.

Therefore the objectives of this study were firstly to examine the effects of concurrent strength and endurance training on aerobic performance, and secondly to determine if the order of training within the same session produces different changes in endurance performance.

METHODS

Subjects

Forty eight male sports students participated in the study. They did not do any physical activity outside of their studies (about 15 hours of multiple activities a week). All subjects gave written consent after having being informed about the study protocol, without being informed of the goal of the study. The study protocol was approved by the National University ethics committee. Anthropometric characteristics were as follows: mean (SD) age 21.4 (1.3) years; height 178.2 (5.7) cm; body mass 72.1 (6.3) kg; percentage body fat 14.7 (3.0)%. Mean (SD) aerobic maximal speed ($\dot{V}O_{2MAX}$) and maximum oxygen consumption ($\dot{V}O_{2MAX}$) were 16.16 (0.85) km/h and 50.60 (4.24) ml/kg/min respectively. The subjects were divided into five homogeneous groups according to their $\dot{V}O_{2MAX}$.

Protocol

Four groups participated in various training programmes for 12 weeks (two sessions a week) as follows: group E ($n = 10$), running endurance training; group S ($n = 9$), strength circuit training; groups E+S ($n = 10$) and S+E ($n = 10$) combined the two training methods in different orders during the same training session. Group C ($n = 9$) served as a control. Before (T0, February) and after (T1, May) the training period, each subject performed the same evaluation protocol including anthropometric, field, and laboratory tests. The subjects did not perform any intense physical activity during the 24 hours preceding each test.

Physiological measurements

The subjects had field and laboratory tests during which they were greatly encouraged to reach their maximal performance.

Field tests

- (1) A 4 km time trial: this consisted of covering 4 km in the minimum time on a 400 m athletic track. The test was preceded by a standardised 20 minute warm up period.
- (2) A progressive Vam-eval track test for the measurement of maximal aerobic speed ($v\dot{V}O_{2MAX}$).²¹ This test consisted of a running trial around a 200 m track calibrated by reference marks placed every 20 m. A tape recorder emitted sound signals, which indicated the speed to be achieved. The speed was low at the beginning (8 km/h) and increased by 0.5 km/h each minute. The last stage reached and completed by the subject corresponded to his maximal aerobic speed ($v\dot{V}O_{2MAX}$), which is considered an indicator of aerobic power.^{21 29}
- (3) A constant velocity test to exhaustion (t_{lim}) at 100% $v\dot{V}O_{2MAX}$.²² It was carried out on the same 200 m track with 20 m reference marks. The subject carried out a 15 minute warm up at 60% of $v\dot{V}O_{2MAX}$. Then in 20 seconds, he reached his $v\dot{V}O_{2MAX}$ and tried to maintain it for as long as possible. The assessor emitted sound signals, which indicated the speed to be achieved, thanks to a stop watch which allowed adjustable countdowns to the nearest 1/100 seconds to be set. These countdowns and corresponding sound signals allowed the subject to maintain the imposed speed by reaching the successive marks for each sound signal. During the last two tests, heart rate (HR) was continuously recorded, using a heart rate monitor (Polar Accurex Plus, Kempele, Finland) set at a recording frequency of 0.2 Hz (five second intervals). At T1, the subjects performed the t_{lim} test with the same $v\dot{V}O_{2MAX}$ as at T0. All the tests were performed in the morning (9–11 am). The external temperature varied between 25°C and 30°C.

Laboratory testing

A continuous incremental test was carried out on an ergocycle (Ergoline type 800, Bitz, Germany). Laboratory testing was carried out from 2 to 5 pm (temperature 21 (1)°C). Before each test, the subjects had a clinical examination and resting electrocardiogram to check their health status. The test protocol was personalised by individualised increments.²³ Cardiorespiratory variables were determined using a breath by breath system (ZAN 680, Oberthulba, Germany) allowing continuous measurement of HR, oxygen uptake, and lung ventilation. Before each test, the gas analysers were calibrated with gases of known concentration, and the ventilatory membrane with a 1 litre syringe. HR was determined from a six lead electrocardiograph with 12 derivations. HR and the respiratory data were provided once every 30 seconds, with the values averaged over the last 10 respiratory cycles on a sliding technique basis.²⁴ Classical criteria of attainment of $\dot{V}O_{2MAX}$ were observed in all subjects.^{7 8} The highest HR attained at exhaustion was considered to be HR_{max} . Respiratory compensation threshold (Th_{2vent}) was calculated by the method of Beaver *et al.*²⁵ $\dot{V}O_{2MAX}$ was expressed classically and according to allometric scaling to avoid underestimation in heavy subjects and overestimation in light subjects.^{26–28}

Training programmes

Endurance training (E)

This was carried out on a 200 m track calibrated by 20 m reference marks. It included five successive fractions. Each fraction consisted of one period of exercise at 100% of $v\dot{V}O_{2MAX}$ and one period of active recovery at 60% of $v\dot{V}O_{2MAX}$. The duration of each period was equal to half of the individual t_{lim} duration.²⁹ An assessor emitted sound signals, which indicated the speed to be achieved. Thereafter, the intensities of the periods of exercise and recovery were alternatively readjusted (+5%) when the HR measured at the end of the fifth fraction of a given training session was lower by 10–12 beats/min with respect to the first session performed at that particular intensity.

Strength training (S)

The programme was divided into four periods of three weeks each. During the first two periods, the general objective was the development of strength endurance. The exercises included total and segmentary movements of upper limbs, trunk and lower limbs (abdominal strengthening, hip extension with 15 kg, back extensors, half squats with 20 kg, forward alternated arm flexions with 5–10 kg, forward walking slits with 20 kg). As far as periods 3 and 4 are concerned, particular emphasis was put on the development of explosiveness. The choice of the exercises mainly focused on the muscular chains particularly involved in running—

Table 1 Strength training programme

	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Duration of cycle (weeks)	3	3	3	3
Main objective	Strength endurance	Strength endurance	Explosivity	Explosivity
Number of exercises per circuit	6	6	6	6
Number of circuit revolutions (series)	4	4	4	4
Work/rest (s)	30/30	40/20	30/30	40/20
Inter-series recovery (min)	2	2	2	2
Total duration of the session (min)	30	30	30	30

Table 2 Physical and physiological characteristics before and after 12 weeks of training

	VO ₂ MAX		t _{lim} (s)	vVO ₂ MAX (km/h)	Th ₂ vent		HR _{max} (beats/min)
	l/min	ml/kg/min			ml/kg ^{0.75} /min	ml/kg/min	
E (n = 10)							
Before	3.80 (0.53)	49.84 (3.06)	312.20 (68.01)	16.17 (1.06)	1.47.13 (10.29)	38.90 (2.60)	187.50 (6.26)
After	4.22 (0.53)**	54.73 (3.42)**	394.2 (53.9)**	17.52 (0.72)**	1.62.03 (10.46)**	44.71 (2.40)**	187.88 (6.06)
S (n = 9)							
Before	3.41 (0.35)	50.08 (4.89)	280.89 (55.58)	16.12 (0.50)	1.43.82 (14.18)	39.08 (3.26)	190.38 (9.10)
After	3.69 (0.30)**	53.00 (4.05)**	326.67 (57.88)**	16.38 (0.41)*	1.53.09 (11.77)**	42.33 (2.86)**	191.25 (7.55)
S+E (n = 10)							
Before	3.75 (0.24)	51.15 (3.45)	274.90 (63.30)	16.16 (1.02)	1.49.58 (8.20)	39.63 (2.34)	187.75 (9.02)
After	4.20 (0.20)**	56.61 (2.03)**	346.00 (39.50)**	17.48 (0.79)**	1.66.05 (3.54)**	45.96 (1.67)**	188.75 (7.92)
E+S (n = 10)							
Before	3.65 (0.42)	51.29 (1.60)	312.70 (57.01)	16.18 (0.91)	1.48.83 (6.53)	40.25 (0.93)	187.13 (7.61)
After	4.16 (0.38)**	58.27 (1.90)**	417.01 (38.02)**	17.86 (0.45)**	1.69.24 (4.54)**	48.92 (1.77)**	188.25 (5.78)
C (n = 9)							
Before	3.67 (0.34)	50.65 (6.34)	253.89 (51.01)	16.14 (0.78)	1.47.73 (17.22)	38.66 (4.06)	191.25 (9.59)
After	3.68 (0.28)	50.51 (4.71)	247.56 (50.52)	16.18 (0.75)	1.47.51 (12.96)	38.70 (3.68)	191.63 (8.72)

*p<0.05, **p<0.01, significantly different from before training. vVO₂MAX, Lowest velocity associated with VO₂MAX; t_{lim}, time to exhaustion at vVO₂MAX; VO₂MAX, maximal oxygen uptake; Th_{2,vent}, second ventilatory threshold or respiratory compensation threshold; HR_{max}, maximal heart rate.

that is, lower limbs (drop jumps from a plinth (0.30–0.60 m), hops, jumps over hurdles (0.50–0.70 m), single leg hops, single leg bonds, multi-jumps). The subjects were trained by short interval circuits (30–30 seconds and 40–20 seconds). The warm up lasted about 15–20 minutes. Recovery between the circuits was set at two minutes, and the total session was about 30 minutes (warm up excluded). Exercise intensity was individual, as each subject was asked to perform an optimal number of repetitions per set, inducing fatigue on the one hand, and allowing him to complete the entire training session on the other. In parallel, throughout the training period, the exercises were made harder by increasing hurdle and plinth heights and jumps and bond length. Table 1 presents the programme as it was carried out.

The weekly inter-session interval was three days. Groups E and S trained on Mondays and Thursdays, and groups E+S and S+E trained on Tuesdays and Fridays.

Statistical analysis

Paired *t* tests were used to determine the significance of differences in the measured variables after training. When the normality test failed, a Mann-Whitney rank sum test was performed between pre-training and post-training variables. The data were then analysed using multivariate analysis of variance with repeated measures. Because of the slight differences in the initial groups, analysis of covariance with the pre-test values as the covariate was used to determine significant differences between the post-test adjusted means in the groups. The results are presented as means (SD). p<0.05 was accepted as significant.

RESULTS

4 km time trial performance

The 4 km performance had improved significantly after training (table 2). The improvements were as follows: group E+S = 8.57%; group E = 5.69%; group S+E = 4.66%; group S = 2.47%. The inter-group comparison shows that group E+S had significantly higher averaged adjusted values than the E, S+E, and S groups (p<0.05) (fig 1).

Variables of aerobic capacity

The multivariate analysis of variance showed a significant interaction (p<0.001) between the two principal factors (group × time) for the maximal aerobic speed, t_{lim} performance, VO₂MAX (l/min, ml/kg/min, and ml/kg^{0.75}/min), and the respiratory compensation threshold (ml/kg/min and %VO₂MAX). After the 12 weeks of training, all physiological variables studied had improved significantly (p<0.001), except HR_{max}. Moreover, a significant effect of the group factor was observed (p<0.001). No changes were observed for the control group (table 2).

The univariate analysis of variance showed that training induced significant improvements in vVO₂MAX for the four experimental groups: 10.38% for E+S, 8.35% for E, 8.17% for S+E, and 1.61% for S. E+S had significantly higher averaged adjusted values than the other groups (p<0.01) (fig 2A).

Training induced significant improvements in t_{lim} performance for the four experimental groups: 28.22% for E+S, 21.13% for E, 20.80% for S+E, and 11.28% for S. The E+S group had significantly higher averaged adjusted values than the other groups (p<0.02) (fig 2B).

Absolute (l/min) and scaled (ml/kg^{0.75}/min) VO₂MAX had improved significantly. The improvements in absolute VO₂MAX (l/min) were 14.05% for E+S, 11.96% for S+E, 11.05% for E, and 8.29% for S. The improvements in scaled VO₂MAX (ml/kg^{0.75}/min) were 13.71% for E+S, 11.01% for S+E, 10.13% for E, and 6.45% for S. For absolute VO₂MAX (l/min), groups E+S, E, and S+E showed comparable adjusted averaged values, whereas for scaled VO₂MAX (ml/kg^{0.75}/min),

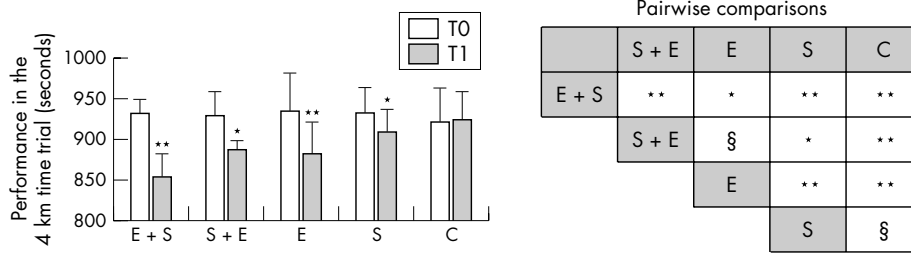


Figure 1 Changes in the 4 km time trial after training. E+S, Endurance followed by strength training; S+E, strength followed by endurance training; E, endurance training only; S, strength training only; C, control group. §Non-significant difference; *significant difference, $p < 0.05$; **significant difference, $p < 0.01$.

group E+S showed significantly higher averaged adjusted values ($p < 0.04$) (fig 3).

$\text{Th}_{2\text{vent}}$ increased by 21.54% and 6.96% for the E+S group, 14.93% and 4.77% for the E group, 15.99% and 4.75% for the S+E group, and 8.30% and 2.26% for the S group, when expressed in ml/kg/min or $\dot{V}O_{2\text{MAX}}$ respectively. The E+S group had significantly higher averaged adjusted values than the E ($p < 0.001$) and S+E ($p < 0.03$) groups.

DISCUSSION

This study confirms that concurrent strength and endurance training produces improvements in aerobic capacity and endurance performance. However, the improvements are greater when, in the same session, the endurance training precedes the strength training.

Endurance training alone

This study confirms that intermittent sessions using running velocity close to $v\dot{V}O_{2\text{MAX}}$ are effective in improving aerobic power.^{30,31} These modifications are accompanied by an improvement in the 4 km test trial performance (table 2). This type of session, in which periods of high and moderate intensity are alternated, allows high intensities to be maintained for longer than a continuous training session.

Strength training alone

The use of short intermittent strength exercises was shown to affect aerobic capacity: the increase in $\dot{V}O_{2\text{MAX}}$ observed during this study was close to that noted previously (8–10%)^{10,12} but is greater than that found in other studies.^{5,32,33} The magnitude of cardiorespiratory adaptation depends primarily on the intensity, duration, and frequency of the exercise.¹¹ If the intensity of work during strength training is not sufficient, oxygen consumption remains very low—that is, only 45% $\dot{V}O_{2\text{MAX}}$.³² To reach a positive effect, it seems that a minimal level of intensity of 50% $\dot{V}O_{2\text{MAX}}$ has to be attained.³⁴ Furthermore, the training duration was only 15 minutes three times a week. Of the other studies that did not show cardiorespiratory improvement with strength training, that of Hickson⁵ was composed of traditional strength exercises including short series (five repetitions, with heavy loads of >80% of maximum) and long (three minutes) rests. It is clear that this type of training does not fulfil the commonly acknowledged requirements of duration and intensity for endurance work. In this context, this study of strength training allowed long duration exercises which certainly helped to improve aerobic capacity. Lastly, the optimal duration for improvements in $\dot{V}O_{2\text{MAX}}$ with strength training has been reported to be 10–12 weeks,^{5,10,12,32} but significant improvement has also been noted with a shorter period—that is, seven weeks.³³

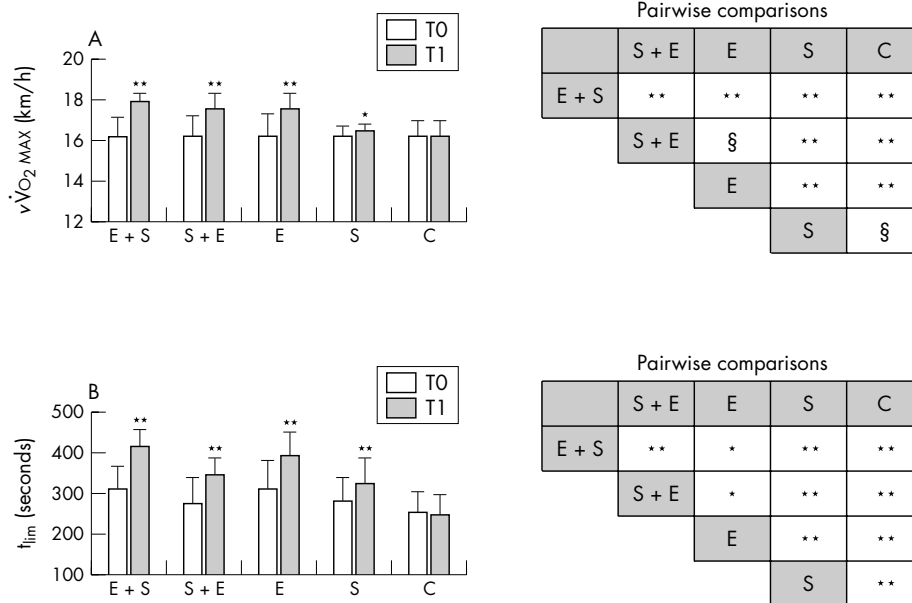


Figure 2 Changes in (A) the velocity associated with $\dot{V}O_{2\text{MAX}}$ (km/h) and (B) the time to exhaustion at $\dot{V}O_{2\text{MAX}}$ (t_{lim}) after training. E+S, Endurance followed by strength training; S+E, strength followed by endurance training; E, endurance training only; S, strength training only; C, control group. §Non-significant difference; *significant difference, $p < 0.05$; **significant difference, $p < 0.01$.

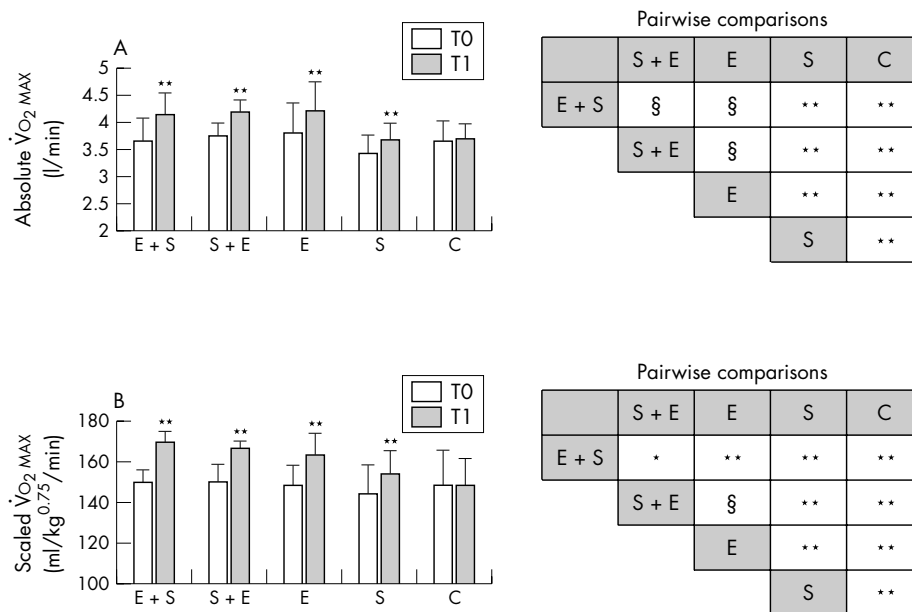


Figure 3 Changes in (A) absolute $\dot{V}O_{2\text{MAX}}$ (l/min) and (B) scaled $\dot{V}O_{2\text{MAX}}$ (ml/kg^{0.75}/min) after training. E+S, Endurance followed by strength training; S+E, strength followed by endurance training; E, endurance training only; S, strength training only; C, control group. §Non-significant difference; *significant difference, p<0.05; **significant difference, p<0.01.

Concurrent strength and endurance training

The concurrent training in this study produced significant improvements in the 4 km performance as well as aerobic capacity (table 2). This confirms the efficiency of this method in trained and non-trained subjects.^{1-4 12 33 35} Tanaka and Swensen¹ suggested that runners and cyclists may improve endurance performance by resistive weight training, because of increases in the size of type I fibres and changes in type II subtype ratios and myofibril contractile properties. These changes may allow a subject to exercise for longer at a given submaximal work rate by reducing the force contribution from each active myofibre or by using fewer myofibrils. In conjunction, the myofibre changes may also allow the recruitment of the less efficient type II fibres to be delayed.¹ Hoff *et al*³ reported a considerable increase in endurance performance as the result of strength training in cross country skiers, which made them stronger, more powerful, and, especially, more economical. Paavola² showed that endurance performance can be increased by adding explosive strength training (33% of training time) to classic endurance training. Balabinis *et al*³³ concluded that concurrent training was more effective in terms of performance increase than strength and endurance training alone. Lastly, McCarthy *et al*¹² and Marcinik *et al*³⁵ showed that heavy resistance strength training led to lower lactataemia at a given intensity, because of a reduction in intrafibre pressure, partly explaining the improvement in submaximal endurance performance.

Concurrent training versus endurance or strength training

Absolute (l/min) and relative (ml/kg^{0.75}/min) $\dot{V}O_{2\text{MAX}}$ had improved considerably after the various training programmes (table 2). For absolute $\dot{V}O_{2\text{MAX}}$, the E+S, E, and S+E groups showed comparable adjusted average values, whereas relative $\dot{V}O_{2\text{MAX}}$ had increased more in the E+S group than the other groups (fig 3). This shows that expressing $\dot{V}O_{2\text{MAX}}$ appropriately is paramount as it may allow smaller changes to be observed. The improvements in the combined groups were slightly higher than those observed in previous studies using similar concurrent training.^{7 10 14 17} In contrast with our

study, no changes in $\dot{V}O_{2\text{MAX}}$ were observed in previous studies.^{2-3 5 9 32} These differences can be explained by the training programmes (form, intensity, frequency, and duration), the initial level, and the age and sex of the subjects. Other mechanisms may be involved, including particularly the conflict between the physiological adaptations, in addition to muscular hypertrophy which produces an increase in body mass.⁶

$\dot{V}O_{2\text{MAX}}$ had improved notably more for the E+S group than the E and S+E groups (fig 2A). Millet *et al*³ showed that, in triathletes, $\dot{V}O_{2\text{MAX}}$ increased by 6.7% (p<0.01) in a combined group and did not change in an endurance group (2.6%). Paavola² also reported an increase in $\dot{V}O_{2\text{MAX}}$ (p<0.05) in a combined group and not in an endurance group and suggested that it was mainly due to a change in lower limb power and strength.

Endurance and strength training sequencing

The most important finding of this study was that the intra-session order of strength and endurance training influences the training induced adaptations. The improvement in $\dot{V}O_{2\text{MAX}}$ (ml/kg/min) was greater in the E+S group than in the S+E group (13.6% v 10.7%) (table 2). Previous studies have examined the effects of intra-session sequence order of strength and endurance training on aerobic adaptations. Collins and Snow¹⁷ showed that the training sequence did not have any effect on the change in $\dot{V}O_{2\text{MAX}}$. Gravelle and Blessing¹⁸ reported that concurrent training limited the increase in $\dot{V}O_{2\text{MAX}}$ when endurance training preceded strength training compared with strength before endurance training (5.3% v 8.0%) in female students. It was argued that, when strength training was preceded by acute bouts of endurance and exhaustive dynamic resistance exercise, the subsequent strength training intensity was impaired, resulting in less strength improvement. The authors stressed the fact that it is still not known if the reverse was true. Our results may be partly explained by fatigue resulting from the strength training which may have influenced at least the physiological adaptations to endurance training,¹⁸ despite the fact that, from the training records, the endurance training intensity was not modified. Any possible effect of

What is already known on the topic

Recent studies have shown that adding strength training to endurance training improves both aerobic capacity and endurance performance. However, the effects on endurance performance of the order in which the two types of training are performed in the same session have not been studied.

What this study adds

Endurance training followed by strength training produced greater improvements in endurance performance and aerobic capacity than the reverse order or if the training methods were performed separately.

fatigue has probably been counterbalanced by the positive effects of concurrent strength training,^{2,3} as the S+E group showed similar improvement in aerobic capacity and performance to the E group. However, it seems that the best sequence for aerobic adaptations consists of endurance training with no preceding fatigue followed by the strength circuit training with its well known effects on endurance performance and capacity.

To our knowledge, this study is the first to show the effects of intra-session sequence of training on endurance performance. As the S+E group improved all aspects of aerobic fitness, we can assume that the first activity (strength training) induced muscular fatigue which reduced the effectiveness of and/or physiological adaptations to the second activity (endurance training). Other factors such as endocrinal changes or alterations in the recruitment of the driving units may also be the origin of the differences observed.⁶

CONCLUSION

The intra-session order of strength and endurance training influenced the adaptive responses to them. Improvement in endurance performance and aerobic capacity was significantly greater when, in the same session, the endurance training preceded the strength training rather than the other way around or if each of the training methods was performed separately.

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Authors' affiliations

M Chtara, M Chaouachi, M Amri, Laboratoire de Physiologie de la Nutrition, Faculté des Sciences de Tunis, El Manar, Tunisia
K Chamari, A Chaouachi, D Koubaa, National Center of Medicine and Sciences in Sports (NCMSS), El Menzah, Tunisia
G P Millet, UPRES 37-59, Faculty of Sports Sciences, University of Montpellier, Montpellier, France
Y Feki, Institut Supérieur du Sport et de l'Éducation Physique, Ksar Said, Tunisia

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