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

M Chata, K Chamari, M Chaouachi, A Chaouachi, D Koubaa, Y Fekri, G P Millet, M Amri

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 (\(v\text{VO}_2\text{MAX}\)). 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 \(v\text{VO}_2\text{MAX}\); (3) a time to exhaustion test \(t\text{lim}\) at 100% \(v\text{VO}_2\text{MAX}\); (4) a maximal cycling laboratory test to assess \(v\text{VO}_2\text{MAX}\).

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 \(v\text{VO}_2\text{MAX}\) (p<0.01); 13.7%, 10.1%, 11.0%, and 6.4% for \(v\text{VO}_2\text{MAX}\) (ml/kg0.75/min) (p<0.05) respectively. Similar significant results were observed for \(t\text{lim}\) and the second ventilatory threshold (\%\(v\text{VO}_2\text{MAX}\)).

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 pace require emphasis on muscular preparation. Various studies have shown the benefit of adding strength training to endurance training; S (n = 9), strength circuit training; E (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 \(v\text{VO}_2\text{MAX}\); (3) a time to exhaustion test \(t\text{lim}\) at 100% \(v\text{VO}_2\text{MAX}\); (4) a maximal cycling laboratory test to assess \(v\text{VO}_2\text{MAX}\).
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 (vVO2MAX). 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 (vVO2MAX), which is considered an indicator of aerobic power.

(3) A constant velocity test to exhaustion (tlim) at 100% vVO2MAX. 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 vVO2MAX. Then in 20 seconds, he reached his vVO2MAX 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 tlim test with the same vVO2MAX 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. 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. Classical criteria of attainment of V˙O2MAX were observed in all subjects. The highest HR attained at exhaustion was considered to be HRmax. Respiratory compensation threshold (Th2vent) was calculated by the method of Beaver et al. V˙O2MAX was expressed classically and according to allometric scaling to avoid underestimation in heavy subjects and overestimation in light subjects.

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˙O2MAX and one period of active recovery at 60% of V˙O2MAX. The duration of each period was equal to half of the individual tlim duration. 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>
<thead>
<tr>
<th>Table 1</th>
<th>Strength training programme</th>
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<tbody>
<tr>
<td></td>
<td>Cycle 1</td>
</tr>
<tr>
<td>Duration of cycle (weeks)</td>
<td>3</td>
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<tr>
<td>Main objective</td>
<td>Strength endurance</td>
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<tr>
<td>Number of exercises per circuit</td>
<td>6</td>
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<tr>
<td>Number of circuit revolutions (series)</td>
<td>4</td>
</tr>
<tr>
<td>Work/rest (s)</td>
<td>30/30</td>
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<tr>
<td>Inter-series recovery (min)</td>
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<tr>
<td>Total duration of the session (min)</td>
<td>30</td>
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Table 2: Physical and physiological characteristics before and after 12 weeks of training

<table>
<thead>
<tr>
<th>Variables of aerobic capacity</th>
<th>4 km time trial (s)</th>
<th>$vO_2^{MAX}$ (km/h)</th>
<th>$t_{lim}$ (s)</th>
<th>$O_2^{MAX}$ (l/min)</th>
<th>$O_2^{MAX}$ (ml/kg/min)</th>
<th>$O_2^{MAX}$ (ml/kg$^{0.75}$/min)</th>
<th>$%O_2^{MAX}$</th>
<th>$HR_{max}$ (beats/min)</th>
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<tbody>
<tr>
<td>E (n = 10)</td>
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<tr>
<td>Before</td>
<td>934.2 (47.3)</td>
<td>16.17 (1.06)</td>
<td>312.20 (68.01)</td>
<td>3.80 (0.53)</td>
<td>49.84 (3.06)</td>
<td>417.13 (10.29)</td>
<td>38.90 (2.60)</td>
<td>187.50 (6.26)</td>
</tr>
<tr>
<td>After</td>
<td>881.0 (39.2)**</td>
<td>16.22 (1.03)**</td>
<td>326.07 (53.9)**</td>
<td>4.22 (0.53)**</td>
<td>54.73 (3.2)**</td>
<td>416.03 (10.4)**</td>
<td>39.02 (2.6)**</td>
<td>186.71 (6.4)**</td>
</tr>
<tr>
<td>S (n = 10)</td>
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<tr>
<td>Before</td>
<td>931.1 (32.8)</td>
<td>16.12 (0.50)</td>
<td>280.89 (55.58)</td>
<td>3.41 (0.35)</td>
<td>50.04 (3.4**</td>
<td>143.82 (11.72)</td>
<td>39.08 (2.6)**</td>
<td>187.21 (7.9)</td>
</tr>
<tr>
<td>After</td>
<td>886.0 (11.3)****</td>
<td>17.48 (0.79)**</td>
<td>346.00 (39.50)</td>
<td>4.20 (0.20)**</td>
<td>56.61 (2.03**)</td>
<td>166.05 (3.54**)</td>
<td>42.33 (2.8)**</td>
<td>187.85 (7.9)</td>
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<td>S+ (n = 10)</td>
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<tr>
<td>Before</td>
<td>932.7 (17.1)</td>
<td>16.71 (0.91)</td>
<td>312.70 (57.01)</td>
<td>3.45 (0.42)</td>
<td>50.29 (1.60)</td>
<td>148.83 (6.53)</td>
<td>39.64 (2.4)**</td>
<td>187.13 (7.61)</td>
</tr>
<tr>
<td>After</td>
<td>852.3 (29.5)****</td>
<td>17.86 (1.45)**</td>
<td>417.01 (38.02)**</td>
<td>4.16 (0.38)**</td>
<td>58.27 (1.90*)</td>
<td>169.24 (4.54**)</td>
<td>48.92 (1.77)</td>
<td>188.25 (5.78)</td>
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<tr>
<td>C (n = 9)</td>
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<tr>
<td>Before</td>
<td>920.8 (42.3)</td>
<td>16.14 (0.78)</td>
<td>253.89 (51.01)</td>
<td>3.67 (0.34)</td>
<td>50.56 (6.64)</td>
<td>147.73 (17.22)</td>
<td>38.66 (4.06)</td>
<td>191.25 (9.59)</td>
</tr>
<tr>
<td>After</td>
<td>852.3 (35.2)</td>
<td>16.18 (0.75)</td>
<td>247.56 (50.52)</td>
<td>3.68 (0.28)</td>
<td>50.51 (4.71)</td>
<td>147.51 (12.96)</td>
<td>38.70 (3.68)</td>
<td>191.63 (8.72)</td>
</tr>
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$p<0.05$, $**p<0.01$, significantly different from before training.

$O_2^{MAX}$, lowest velocity associated with $O_2^{MAX}$; $t_{lim}$, time to exhaustion at $vO_2^{MAX}$; $O_2^{MAX}$, maximal oxygen uptake; $\%O_2^{MAX}$, second ventilatory threshold or respiratory compensation threshold; $HR_{max}$, maximal heart rate.
group E+S showed significantly higher averaged adjusted values (p<0.04) (fig 3).
Th2vent 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 %Vo2max 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 Vo2max are effective in improving aerobic power. 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 Vo2max observed during this study was close to that noted previously (8–10%) but is greater than that found in other studies. The magnitude of cardiorespiratory adaptation depends primarily on the intensity, duration, and frequency of the exercise. If the intensity of work during strength training is not sufficient, oxygen consumption remains very low—that is, only 45% Vo2max. To reach a positive effect, it seems that a minimal level of intensity of 50% Vo2max has to be attained. 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 Hickson 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 Vo2max with strength training has been reported to be 10–12 weeks, but significant improvement has also been noted with a shorter period—that is, seven weeks.
Intra-session sequencing of concurrent training

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. Tanaka and Swensen 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. Hoff et al. 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. Paavolainen et al. showed that endurance performance can be increased by adding explosive strength training (33% of training time) to classic endurance training. Balabinis et al. concluded that concurrent training was more effective in terms of performance increase than strength and endurance training alone. Lastly, McCarthy et al. and Marcinik et al. 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/kg0.75/min) \( \text{VO}_{2\text{MAX}} \) had improved considerably after the various training programmes (table 2). For absolute \( \text{VO}_{2\text{MAX}} \), the E+S, E, and S+E groups showed comparable adjusted average values, whereas relative \( \text{VO}_{2\text{MAX}} \) had increased more in the E+S group than the other groups (fig 3). This shows that expressing \( \text{VO}_{2\text{MAX}} \) 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. In contrast with our study, no changes in \( \text{VO}_{2\text{MAX}} \) were observed in previous studies. 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.

\( \text{VO}_{2\text{MAX}} \) had improved notably more for the E+S group than the E and S+E groups (fig 2A). Millet et al. showed that, in triathletes, \( \text{VO}_{2\text{MAX}} \) increased by 6.7% (p<0.01) in a combined group and did not change in an endurance group (2.6%). Paavolainen et al. also reported an increase in \( \text{VO}_{2\text{MAX}} \) (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 \( \text{VO}_{2\text{MAX}} \) (ml/kg/min) was greater in the E+S group than in the S+E group (13.6% ± 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 Snow showed that the training sequence did not have any effect on the change in \( \text{VO}_{2\text{MAX}} \). Gravelle and Blessing reported that concurrent training limited the increase in \( \text{VO}_{2\text{MAX}} \) when endurance training preceded strength training compared with strength before endurance training (5.3% ± 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, despite the fact that, from the training records, the endurance training intensity was not modified. Any possible effect of

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**Figure 3** Changes in (A) absolute \( \text{VO}_{2\text{MAX}} \) (l/min) and (B) scaled \( \text{VO}_{2\text{MAX}} \) (ml/kg0.75/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.

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<th>Pairwise comparisons</th>
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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.

**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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