Concurrent Strength and Endurance Training of the Elbow Extensors

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Reference Data

ABSTRACT
The purpose of this investigation was to determine the effects of 7 weeks of concurrent strength and endurance training on the triceps brachii. Fifteen fit subjects were randomly allocated to endurance (TE), strength (TS), or concurrent (TC) training groups. Endurance training involved five 5-min bouts of incremental arm cranking at between 40 and 100% of peak arm ergometer oxygen consumption (PVO₂). Strength training involved two 30-s sets of maximal isokinetic contractions at 4.16 rad · sec⁻¹. The TC group completed both strength and endurance training, PVO₂ and strength assessments were conducted prior to and following 2, 5, and 7 weeks of training. Isokinetic strength (T30) was determined 0.52 rad (30°) from full extension for 10 angular velocities between 0.52 and 5.20 rad · sec⁻¹. Two weeks of training significantly increased T30 at all contractile speeds for the TS, TE, and TC conditions. T30 was further increased at all contractile speeds at Weeks 5 and 7 for the TE and TC groups, respectively. Seven weeks of training significantly increased PVO₂ in the TE and TC conditions, but not in the TS group.

Key Words: interaction, isokinetic, arm ergometry

Introduction
Athletes are often required to complete training in several conditioning modalities simultaneously. Over the last decade several researchers have investigated the effects of concurrent strength and endurance training (8, 10, 12, 16, 19, 23). Concurrent training has adversely affected the development of strength (as determined by maximal isokinetic and isoinertial measures) or V̇O₂max in some (8, 10, 12, 19) but not all investigations (15, 23).

Inhibition in the development of V̇O₂max in the latter half of the concurrent training study of Nelson et al. (19) appeared to be due to the dilution of mitochondrial density (18). However, the mechanisms underlying the impaired strength development reported by Craig et al. (18), Dudley and Djamil (10), and Hickson (12) are not known. The hypothesized mechanisms can be categorized as either acute or chronic. The acute hypothesis contends that the endurance element of concurrent training reduces tension developed in the strength element of concurrent training, and this attenuation in training performance in turn reduces the development of strength (8). This scenario is consistent with the belief that tension is the critical factor in strength development (4).

Recently, data collected in our laboratory provided some support for the acute hypothesis, with isokinetic strength being found to be significantly compromised by preceding endurance activity (1). Alternatively, the inhibition in strength development following concurrent training may be due to some chronic process altering the neuromuscular adaptations normally associated with the strength training element of concurrent training. Possibilities that have been suggested include fast twitch (FT) to slow twitch (ST) fiber type transitions, fiber atrophy, the development of inefficient patterns of motor unit recruitment, and suboptimal endocrine status (7, 11, 17).

To date, all the concurrent training studies have involved the conditioning of the quadriceps femoris muscle group (3, 8, 10, 12, 14, 15, 19, 23). There is a need, however, to determine whether interactions similar to those reported for the quadriceps femoris occur in other muscle groups. In this investigation the study of Dudley and Djamil (10) was essentially replicated, with the single exception that the triceps brachii and not the quadriceps femoris was investigated. Dudley and Djamil (10) reported that 7 weeks of concurrent training inhibited isokinetic strength development of the quadriceps femoris at contractile speeds greater but not less than 1.68 rad · sec⁻¹. V̇O₂max development was not affected by concurrent training. The purpose of this investigation was to determine whether the pattern of isokinetic strength and PVO₂ development of the triceps brachii was similar to that reported for the quadriceps femoris following 7 weeks of concurrent strength and endurance training.
Methods

Subjects
Nine male and 6 female exercise leaders volunteered for the study (2). The regular duties of these exercise leaders were limited to instructing exercise to music classes and counseling clients. None had been involved in upper body exercise programs for at least 6 months prior to the study. While exercise to music did occasionally involve arm activity, it did not mimic the strength and endurance training activities used in this study. Participants refrained from vigorous arm activity for the period of study (e.g., swimming, rowing, gymnastics). Subjects were randomly allocated to one of three training conditions: strength training (TS; 4 males, 1 female), endurance training (TE; 2 males, 3 females), or concurrent strength and endurance training (TC; 3 males, 2 females). The study conformed to the Australian National Health and Medical Research Council’s guidelines for research with human subjects.

Experimental Design
The testing and training procedures for this study were similar in virtually all respects to the procedures of Dudley and Djamil (10), the major difference being that the elbow extenders rather than the leg extensors were studied. All subjects were familiarized with the strength and endurance assessment procedures 2 days prior to initial assessment. PVO₂ and isokinetic strength were measured before (Week 0) and after 2, 5, and 7 weeks of training. All strength and endurance assessments were conducted on a Monday following a 60- to 72-hr period in which subjects refrained from all upper body exercise. These precautions were to minimize any residual fatigue that may have resulted from such activity. Strength measurements (7 to 9 a.m.) always preceded endurance measurements (11 a.m. to 5 p.m.) by approximately 4 hrs. Additionally, subjects were assessed at the same time of day to minimize any diurnal influences. Although there was no formal dietary control, subjects were asked not to change their general eating pattern over the period of the study.

Measurement of Endurance
Assessment of PVO₂ was conducted on a Monark arm ergometer (Vanber, Sweden) at a cranking cadence of 100 rpm. Each minute of the workload was increased by 15 watts from an initial level of 15 watts until the nominated workload could not be maintained.

During testing the subjects sat on a chair adjacent to the ergometer, with feet flat on the floor and shoulders at the level of the crank axle. The distance between the chair and table was such that when the crank was at its most distal point from the subjects, the elbow was fully extended and parallel with the floor. The table, chair, and ergometer were all anchored, but the subjects themselves were not restrained. Subjects were instructed to use elbow extensors and flexors while cranking, and to minimize shoulder involvement.

Exhaled gases were directed via a one-way breathing valve (Hans Rudolph, model 2700, Kansas City) to a Mijnhardt 4 Oxycon (Ojijk, Holland) on-line automated gas analysis system. Expired gases were analyzed in the final 30 sec of each minute during the PVO₂ assessment. Calibration procedures were conducted prior to and following each test. Calibration of the oxygen analyzer was made against room air and gases with 0.00 and 15.2% O₂, while the carbon dioxide analyzer was calibrated against room air and a gas with 4.1% CO₂. These gravimetric gases were purchased from and certified by Commonwealth Industrial Gases Ltd., Australia. The ventilometer was calibrated with a 1-liter calibration syringe (Vitalograph, Birmingham, England). The volumes of air used for calibration ranged from 5 to 150 L. Heart rate was assessed from chest electrodes by Polar Electro Sports Tester Units (Finland).

Measurement of Strength
Tests for elbow extension strength were completed on a Cybex II isokinetic dynamometer (Lumex Corp., Bay Shore, NY). The dynamometer had force transducers externally mounted at the axis of rotation with a reported error rating of 1% (P. Henke, personal communication, 1988). Calibration using known external loads (1–100 kg) was carried out prior to all measurement occasions.

The nondominant arm only was assessed, as it was less likely to be inadvertently used in extraneous activity when compared with the dominant arm. Strength was determined for a joint angle 0.52 rad (30°) from full extension (T30) (10, 20). Bobbert and van Ingen Schenau (5) have suggested that torques gathered 0.52 rad from full extension are not influenced by isometric precontraction of the agonists immediately prior to the test. Furthermore, the measurement of T30 eliminated the confounding influence of impact artifact. There was no gravitational correction. The subjects were urged to contract maximally throughout the full range of movement.

T30 was determined for a range of contractile speeds between 0.52 and 5.20 rad·sec⁻¹ so that torque/contractile speed curves could be developed. To minimize any possible order effect, such as fatigue, the order in which contractile speeds were tested was randomized for each individual but was consistent between measurement occasions. The contractile speeds assessed were 0.52, 1.04, 1.56, 2.08, 2.60, 3.13, 3.64, 4.16, 4.68, and 5.20 rad·sec⁻¹. For test speeds in excess of 1.56 rad·sec⁻¹, subjects completed five repetitions with maximal effort at each contractile speed, while for speeds less than this they completed three maximal contractions. The mean of the two greatest T30 values was used for analysis. The two strongest repetitions were usually the first two repetitions. Prior to testing, the subjects were allowed to complete several warm-up contractions at contractile speeds between 2.08 and
3.64 rad · sec⁻¹. A standard 60-sec recovery period was allowed between these warm-up contractions and the maximal contractions associated with each test speed.

During testing the dynamometer was adjusted so that it stood at its minimum height. The subject lay in a supine position on the upper body exercise table (UBXT) adjacent to the dynamometer, and was positioned so that the center of rotation of the elbow joint corresponded with the center of rotation of the dynamometer. To minimize arm and shoulder girdle involvement, the arm was strapped to a supporting pad. The upper arm was abducted so that the angle between the arm and trunk was 0.78 rad. The distance between the medial epicondyle of the humerus and anterior superior iliac spine was the same at all measurement occasions. The forearm was held in the supinated position by a molded brace. The trunk of the subject was anchored to the UBXT by a waist strap. The knees were flexed at 1.56 rad over the end of the UBXT. The feet were placed on a foot rest. The lever arm (L-shaped adaptor and fixed hand grip) of the dynamometer was held by the hand in a supinated position. The endpoints of the range of movement for the forearm corresponded with full extension and full flexion (=2.35 rad). The positioning of the hand piece and the length of the lever arm were constant at all times for each subject.

Training
Subjects completed three supervised training sessions each week—Monday, Wednesday, and Friday—for the 7 weeks of the investigation. On the Monday of Weeks 2 and 5, endurance training followed PVO₂ testing for the TE and TC groups, with the PVO₂ assessment being substituted for the first endurance training repetition. The results of the PVO₂ assessments for Weeks 0, 2, and 5 were used to develop the workloads for endurance training for the weeks to the next test occasion. On Wednesday and Friday, endurance training was scheduled for the convenience of the subjects (11 a.m. to 5 p.m.). Strength training was held between 7 and 9 a.m. each training day.

Endurance training was performed on an arm cranking ergometer (Monark, Vanber, Sweden). Subjects were positioned in the manner described for endurance testing. A training session consisted of five 5-min work bouts interspersed with 5-min recovery periods. The cranking cadence was 100 rpm at all times. The first minute of every work bout was at a workload requiring 40% PVO₂. For each of the subsequent 3 min, the resistance was increased by the equivalent of 20% PVO₂. For the final 2 min of each work bout the subjects worked at loads equivalent to PVO₂. If during a work bout a subject indicated he or she was having difficulty maintaining the nominated workload, the resistance was reduced to that of the preceding workload. In such situations the laboratory assistant urged the participant to complete the work bout. Every work bout of a training session was completed. There was no warm-up, as this was provided in the initial minutes of the first work bout. Subjects were regularly reminded of the need to use elbow extendors and flexors while cranking and to minimize shoulder involvement.

Strength training was conducted on a Cybex II isokinetic dynamometer (Lumex Corp., Bay Shore, NY). The positioning of the subjects during training was as described for strength testing. Training consisted of maximal elbow extensions and flexions at the contractile speed of 4.16 rad · sec⁻¹. The subject completed as many repetitions as possible (=22) in each of the two 30-s strength training intervals for each limb. There was a 2-min recovery period after each strength training set. During a strength training session both arms were trained, but not bilaterally. A record was kept so that the left arm was trained first on one training occasion and second on the next. The two training intervals for one arm preceded those of the other arm. In the 2-min period between training for each arm, the UBXT was appropriately repositioned. Subjects completed approximately six warm-up contractions at the training speed prior to the first set for each arm.

The TC group completed both the endurance and strength training programs just described. Strength and endurance training was completed on the same day, with strength training preceding endurance training. There were at least 2 hours, and often several, between strength and endurance training.

Statistical Analysis
Descriptive statistics (mean, SD) for each dependent variable were determined following each measurement occasion. Consideration was given as to whether parametric procedures should be used, as the training groups were small and data were not always normally distributed. Parametric procedures were selected on two grounds: first, Keppel (17) concluded that even the most abnormal distribution of small samples (N = 3–5) only marginally increased the risk of type I error. Second, the Levine test indicated that the variances within each training condition were similar for all dependent variables (17). Thus, analysis of variance (ANOVA) was used to compare dependent variable scores. However, the small number of subjects and the uneven distribution of males and females between training conditions precluded the identification of gender specific effects.

A 0.05 level of significance was adopted and the Neuman Keul procedure was used where post hoc analysis was necessary. A two-way ANOVA (Group × Measurement occasion) was used to compare PVO₂ data. In the case of T30, only intragroup differences were examined, using a two-way ANOVA (Speed × Measurement occasion) (24). To minimize experimentwise error associated with the T30 analyses, the Bonferroni correction was applied, which reduced the alpha level to 0.016. All statistical analyses were performed.
Table 1

<table>
<thead>
<tr>
<th>Training condition</th>
<th>TS</th>
<th>TE</th>
<th>TC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>27.0</td>
<td>6.7</td>
<td>26.4</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>69.0</td>
<td>12.7</td>
<td>60.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.3</td>
<td>11.7</td>
<td>171.5</td>
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</table>

Figure 1. The torque/contractile speed curves for the strength (TS) condition prior to (W0) and after 2 (W2), 5 (W5), and 7 (W7) weeks of training. *Significantly different from W0 (p < 0.05).

using StatView 512+ (Brain Power Inc., Calabasas, CA) computer package on a Macintosh Classic personal computer.

Results

Subjects
The 9 male and 6 female subjects presented a range of ages (18–38 yrs), masses (47.0–81.0 kg), and heights (153.5–186.5 cm) (Table 1). There were no significant differences in age, mass, and height between the TS, TE, and TC groups. Mass did not change significantly over the training period for any of the training groups.

Changes in T30
In all of the training conditions, neither the main effect for contractile speed (TS p = 0.95, TE p = 0.97, TC p = 0.97) nor the interaction between measurement occasion and contractile speed (TS p = 0.95, TE p = 0.98, TC p = 0.65) were significant. However, the main effect for measurement occasion was significant in all three training conditions (TS p = 0.0001, TE p = 0.0001, TC p = 0.0001). This significant main effect for measurement occasion for the TS, TE, and TC groups is depicted by 2nd-degree polynomials in Figures 1 to 3, respectively. Subsequent post hoc analysis indicated that in all training conditions, T30 was greater at Weeks 2, 5, and 7 than at Week 0. In addition, T30 at Week 5 was greater than at Week 2 for the TE group, while for the TC group T30 at Week 7 was greater than at Week 2.

Aerobic Capacity
The main effect for measurement occasion (p = 0.0001) and the interaction between training condition and measurement occasion (p = 0.0025) for PVO2 were significant. Subsequent post hoc analysis indicated a number of intra- and intergroup differences for PVO2. There were significant differences in PVO2 between the groups at Week 0 (TS > TC > TE) (Table 2). For the TS group, PVO2 did not change significantly over the training period (Table 2). However, for the TE and TC conditions PVO2 at Weeks 2, 5, and 7 were significantly greater than at Week 0 (Table 2). At Week 7 there was no significant difference in PVO2 between training conditions (Table 2).
Table 2

<table>
<thead>
<tr>
<th></th>
<th>Week 0</th>
<th>Week 2</th>
<th>Week 5</th>
<th>Week 7</th>
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<tbody>
<tr>
<td><strong>TS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.87&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>2.91</td>
<td>2.90</td>
<td>2.86</td>
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<tr>
<td>SD</td>
<td>0.83</td>
<td>0.94</td>
<td>0.96</td>
<td>0.87</td>
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<tr>
<td><strong>TE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.08</td>
<td>2.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.86&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SD</td>
<td>0.68</td>
<td>0.88</td>
<td>1.02</td>
<td>1.05</td>
</tr>
<tr>
<td><strong>TC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.49&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.20&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>3.06&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SD</td>
<td>0.84</td>
<td>0.74</td>
<td>1.00</td>
<td>0.84</td>
</tr>
</tbody>
</table>

<sup>a</sup>Significantly greater than Week 0 (<p < 0.05); <sup>b</sup>significantly different from TE (<p < 0.05); <sup>c</sup>significantly different from TC (<p < 0.05).

Discussion

The purpose of this investigation was to determine whether the pattern of isokinetic strength and PVO<sub>2</sub> development of the triceps brachii were similar to that reported for the quadriceps femoris following 7 weeks of concurrent strength and endurance training. Dudley and Djamil (10) reported that concurrent training inhibited T30 development of the quadriceps femoris at high contractile speeds (>1.68 rad·sec<sup>-1</sup>). However, there was no evidence of T30 development being inhibited in the triceps brachii by a similar concurrent training regimen. In fact, the TC, TS, and TE groups all presented significant isokinetic strength developments. Neither in this investigation nor that of Dudley and Djamil (10) was there evidence of concurrent training inhibiting PVO<sub>2</sub> development.

Strength Development

Just 2 weeks training of the triceps brachii by the TS group increased T30 at all contractile speeds (Figure 1). However, T30 was not further increased by 5 more weeks of training. This contrasts with the quadriceps femoris in relation to both the pattern and duration of strength development (6, 10). T30 development appeared to occur simultaneously at all contractile speeds for the triceps brachii. In contrast, Caiozzo et al. (6) reported that increments in T30 for the quadriceps femoris following 4 weeks of training at 4.19 rad·sec<sup>-1</sup> were limited to contractile speeds greater than 1.68 rad·sec<sup>-1</sup>. However, an additional 3 weeks of training saw significant T30 development also occurring at contractile speeds less than 1.68 rad·sec<sup>-1</sup> (10). Thus the triceps brachii did not present the same pattern of T30 development as the quadriceps femoris (i.e., adaptations at speeds greater than 1.68 rad·sec<sup>-1</sup> preceding adaptations at less than 1.68 rad·sec<sup>-1</sup>). It is not readily apparent why the pattern of isokinetic strength development for the triceps brachii and quadriceps femoris should differ. The data of Caiozzo et al. (6) and Dudley and Djamil (10) also suggest that isokinetic training of the quadriceps femoris at 4.19 rad·sec<sup>-1</sup> results in an overload that produces strength development for at least several weeks. However, 2 weeks of such isokinetic training of the triceps brachii produced the same magnitude and pattern of T30 development as did 7 weeks of training (Figure 1). Perhaps the greater absolute tensions developed during the training of the quadriceps femoris extended the duration of adaptive responses. The absolute torque generated by the quadriceps femoris during training was approximately three times greater for the leg (≈100 Nm) than for the elbow (≈32 Nm) extensors. This differential was maintained when torque was expressed as proportion of body weight (triceps brachii − 0.5 Nm·kg<sup>-1</sup>; quadriceps femoris − 1.6 Nm·kg<sup>-1</sup>).

Interestingly, there was significant T30 development at all speeds for the TE group (Figure 2). There has been little research on the effects of endurance training on strength development. Rosler et al. (21) reported that peak isokinetic torque and power during leg extension were increased at the contractile speeds approximating the pedal cadence used in cycle training. However, T30 adaptations in this investigation were not limited to contractile speeds approximating the cadence of arm cranking. T30 was not assessed for the endurance group of Dudley and Djamil's (10) study. However, endurance training did not change one-repetition maximum (1-RM) values in the study by Hickson (12).

Sale et al. (22) have reported that endurance training involving six 3-min bouts of cycling at VO<sub>2</sub>max enhanced 1-RM strength and increased the cross-sectional areas of muscle as well as FT and ST fibers. The increased strength reported by Sale et al. (22) may be partially attributed to fiber and/or gross muscle hypertrophy. In contrast, the endurance subjects of Hickson (12) and Craig et al. (8) reported neither changes in thigh girth nor in 1-RM strength with training. Perhaps 1-RM strength may increase when endurance training produces increments in the cross-sectional area of fibers and/or the gross muscle. However, this does not appear to be the case for isokinetic strength.

Nelson et al. (19) reported strength development at 3.13 rad·sec<sup>-1</sup> and significant ST, FT<sub>A</sub>, and FT<sub>B</sub> fiber hypertrophy following endurance training. However, endurance training did not increase peak torques at 0.52 and 1.04 rad·sec<sup>-1</sup>. The increments in strength reported in this investigation and that of Sale et al. (22) following endurance training may be due in part to the muscle tensions developed when working at rates approximating PVO<sub>2</sub> representing an overload. However, Hickson's (12) subjects also worked at or near PVO<sub>2</sub> with no strength development.
Isokinetic strength development occurred in the TE groups after only 2 weeks of training. It is not known whether this rapid T30 development is typical, as no other study, to our knowledge, has assessed isokinetic strength after 2 weeks of endurance training. Interestingly, the endurance training appeared to increase T30 for the first 5 weeks of training (i.e., T30 at Week 5 was greater than Week 2) (Figure 2). Further research is required to clarify the mechanisms underlying the rate and pattern of T30 development presented in the TE condition.

Similar concurrent training regimens produced differing patterns of T30 development for the arm and leg extensors (10). T30 development was evident at contractile speeds faster and slower than 1.68 rad · sec⁻¹ in the TC group (Figure 3). In the Dudley and Djamil (10) investigation there was an inhibition in strength development at contractile speeds greater than 1.68 rad · sec⁻¹. Thus, concurrent training that inhibited strength development at high contractile speeds in the leg did not do so in the arm. In fact, concurrent training appeared to enhance T30 development in the triceps brachii. T30 continued to increase beyond Week 2 in the TC condition (Figure 3), in contrast to the TS group (Figure 1). Further research is required to determine why concurrent training produced different patterns of strength adaptation in the quadriceps femoris and triceps brachii.

The similarity of the strength training regimen used in the present study and that by Dudley and Djamil (10) to resistance training practices of athletes must be questioned. This regimen has a greater endurance element than that typically used by athletes. Perhaps this endurance element partially explains why the T30 development of the TS group was less than in the TE and TC conditions. Furthermore, the endurance element of the strength training protocol may limit the application of these results to athletes completing typical training programs.

To date the inhibition of strength development following concurrent strength and endurance training (8, 10, 12) has often been thought to be due to what Craig et al. (8) described as a chronic mechanism (7, 11, 16). That is, some chronic process associated with concurrent training compromises the neuromuscular adaptations normally associated with the strength training element of concurrent training. For example, concurrent training may produce a FT to ST fiber type transition or fiber atrophy (11, 16). However, Craig et al. (8) suggested that the development of strength may be inhibited by an acute process, specifically residual fatigue. This hypothesis contends that the ability to perform strength training is compromised by concurrent endurance training. That is, the endurance training prior to resistance training attenuates the tension developed in strength training and, over time, strength development in the concurrent condition is less than in states with no residual fatigue. Unfortunately, these data do not clarify whether the inhibition of strength development following some concurrent training investigations (8, 10, 12) was due to acute and/or chronic mechanisms.

Development of Aerobic Capacity
There was a significant and similar increase in PVO₂ with training for the TC and TE groups (Table 2). Thus there was no evidence of endurance development being inhibited in the TC group. Once again this format of endurance training was found to be effective in enhancing peak VO₂. The 28% increment in PVO₂ for the TE and TC groups was similar to that reported in studies involving the larger muscle mass of the legs (Cunningham et al. [9], 23%; Dudley and Djamil [10], 17%; Hickson et al. [13], 39%; Hickson [12], 23%).

Strength training did not influence PVO₂ values, which was consistent with the findings of Hickson and colleagues (12, 14) (Table 2). Unfortunately, Dudley and Djamil (10) did not measure peak VO₂ of their strength group. The influence of strength training on the peak VO₂ measures of Sale et al. (23) were confused by one of the subject’s limbs being a control condition and the other an experimental condition. Consequently, the peak VO₂ scores of one limb may have been contaminated by the central adaptations induced by the other limb. Thus it was not clear whether changes in peak VO₂ were the result of strength training, endurance training, or concurrent training in the Sale et al. (23) investigation.

Nelson et al. (19) reported that VO₂max development was inhibited in the latter weeks (11–20) of concurrent training. This inhibition was attributed to the dilution of mitochondrial volume density (18). It is possible that PVO₂ may have been inhibited had the duration of concurrent training been extended. Like this study, in the Nelson et al. (19) investigation strength training preceded endurance training. Perhaps Craig et al.’s (8) acute hypothesis (see preceding section) should be considered in relation to Nelson et al.’s (19) findings. That is, over time (>10 weeks) the preceding strength training may compromise the performance of subsequent endurance training.

The TS, TE, and TC groups presented different PVO₂ scores prior to training (Table 2), but these differences did not appear to influence the experiment. The absence of PVO₂ adaptation in the TS group was consistent with the literature. However, the absence of PVO₂ adaptation in the TS group may have been due to the fact that subjects had already fulfilled their potential for these developments. That is, there would have been no change in PVO₂ for this group regardless of the form of training undertaken. This explanation appeared unlikely upon closer examination of the results. For example, there were individuals in the TS group who had initial PVO₂ scores and fiber compositions similar to those of subjects in other training conditions. These similar TE and TC subjects did adapt to endurance training while their contemporaries in the TS condition did not.
In summary, the endurance, strength, and concurrent regimens all produced T30 adaptations at all contractile speeds. But there were differences in the duration of time that each training regimen was effective in increasing T30. Similarly, the endurance training regimen was effective in enhancing $\dot{V}O_2$ in both the TE and TC groups. $\dot{V}O_2$ development did not appear to be inhibited by concurrent training. The limitations of this work call for its extension to a larger number of subjects and a greater variety of training regimens. Specifically, future work should investigate strength and endurance training with greater and lesser muscle tensions, respectively.

Practical Applications

These data suggest that when endeavoring to simultaneously develop endurance ($\dot{V}O_2$) and strength (isokinetic), different training periodizations may need to be used for the legs (quadriceps femoris) and arms (triceps brachii). It is not yet known what would be the optimal structure for such periodizations. Nor is it known whether the differences between limbs manifest themselves with different training regimens or other indices of strength and endurance. However, this study illustrates our limited understanding of concurrent strength and endurance training and the need for more research in the area. Such research may facilitate the optimal development of strength and endurance in the training macrocycles of an athlete.

References


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