A Review: The Effects of Combined Strength and Endurance Training on Strength Development

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ABSTRACT

Concurrent strength and endurance training reportedly compromises strength gains and the ability to produce explosive movements. Possible reasons for compromises in strength-power adaptations with concurrent training are an increased likelihood of overtraining; differences in the organization of neuromuscular recruitment patterns; alterations in the concentrations of various hormones and differences in activation or repression of various anabolic/catabolic processes at the muscular level; and shifts in protein isoforms such as myosin. Recent research suggests that strength training may enhance endurance performance, although there are reasons to believe that resistance training can also be detrimental. Further research is necessary to determine the extent to which strength adaptations are compromised with concurrent training, and the mechanism(s) by which combined training negatively affects strength. It is recommended that the training of athletes takes into account the physiological demands of the sport and unique needs of the individual athlete in designing a training program in order to optimize performance.

KEY WORDS: Concurrent training, aerobic training, anaerobic training.

Introduction

The adaptive responses by the physiological systems of the body to physical training, including the neuromuscular system, are directly related to the training stimulus. Aerobic exercise, which involves prolonged muscular work, increases aerobic capacity through numerous adaptations at the cardiorespiratory and muscular levels (7, 17). Changes in skeletal muscle include increases in myoglobin content, capillary density and enzymes of the citric acid cycle and electron transport system; however, strength increases little or not at all (1, 7, 14).

Strength training, involving intermittent exercise of short duration using high resistance, results in muscle hypertrophy and increased strength (20, 22, 24), with little or no change in VO₂ max (16, 19). Circuit weight training using lighter resistances, a higher number of repetitions per set, and shorter rest periods results in increases in VO₂ max of approximately 5 to 10 percent, and improvements in strength of 7 to 32 percent (12). This review will focus on traditional heavy resistance training rather than circuit weight training. Because the training stimuli and adaptive responses to endurance and heavy resistance training are very different and many sports require some combination of strength and anaerobic or aerobic conditioning, it is important to understand the effects of combined training on the development of strength and endurance. Furthermore, many coaches continue to use aerobic conditioning in training strength-power athletes. This review examines the available data regarding the effects of concurrent training on endurance and strength adaptations to these training protocols.

Review of Literature

Combined strength and endurance training compromised strength gains compared with strength training alone (14). In this study, the strength-trained group weight trained five days per week for 10 weeks. The training program was designed specifically to increase leg strength, and all exercises were done
using as much weight as possible. The endurance-trained group exercised six days a week, alternating cycling and running. Cycling consisted of six 5-minute work bouts at an intensity that approached \( \text{VO}_2 \text{ max} \). The running program involved running as fast as possible for up to 40 minutes by the end of the study. The combination-trained group performed both the strength and endurance training regimens. Strength was measured with a one repetition maximum (1 RM) parallel squat.

Maximal squat in the strength-trained and combination-trained groups increased at approximately the same rate during the first seven weeks of training, and continued to increase in the strength-trained group throughout the entire 10 weeks of training (Figure 1). After 10 weeks, the strength-trained group showed a 44 percent gain in the 1 RM squat. In the combination-trained group, strength leveled off between the seventh and eighth weeks and declined thereafter. The combination-trained group had a 34 percent gain in strength after seven weeks, but at 10 weeks strength was only 25 percent greater than pretraining levels. The maximal squat of the endurance-trained group was unchanged. Thigh girth increased in the strength-trained and combination-trained groups, but not in the endurance-trained group. \( \text{VO}_2 \text{ max} \), whether measured on a cycle ergometer or treadmill, increased to a similar extent in the endurance-trained and combination-trained groups. The strength-trained group had a small but statistically significant increase in absolute \( \text{VO}_2 \text{ max} \) when measured on a cycle ergometer, but relative \( \text{VO}_2 \text{ max} \) was unchanged due to an increased body weight.

Dudley and Djamil (5) examined the effects of simultaneous strength and endurance training on torque at a specific joint angle for various contraction velocities using an isokinetic dynamometer, and on peak \( \text{VO}_2 \) measured on a cycle ergometer. Twenty-two previously untrained males and females trained for seven weeks. Strength training consisted of two 30-second bouts of maximal voluntary knee extensions at 4.19 rad/sec\(^{-1} \) (240 deg/sec\(^{-1} \)) on a Cybex II (Lumex Corp., Bayshore, New York) isokinetic dynamometer. Endurance training consisted of five 5-minute bouts of cycling at an intensity designed to elicit peak cycle ergometer \( \text{VO}_2 \) at 4 to 5 minutes, with rest intervals of 5 minutes between work bouts. The strength-trained and endurance-trained groups exercised three days per week. The combination group trained six days weekly, alternating strength and endurance training days.

The endurance-trained and combination-trained groups increased peak \( \text{VO}_2 \) approximately 18 percent. The strength-trained group had increases in angle-specific torque at angular velocities from 0.00 to 4.19 rad/sec\(^{-1} \). The combination-trained group increased torque only at lower angular velocities (up to 1.68 rad/sec\(^{-1} \)). It was concluded that concurrent training for strength and endurance does not affect gains in peak \( \text{VO}_2 \), but compromises the ability to produce

<table>
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<th>Group IS</th>
<th>Group C</th>
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Values are means ±SE.

**Figure 1.** Maximal Squat Increase through 10 Weeks of Training

**Table 1.** Percent Improvement in Peak Torque at Various Velocities of Contraction. Reprinted with permission from Dudley, et al. (5)
force at the high-velocity, low-force region of the force-velocity curve. It was suggested that combined training hinders strength gains by altering intrinsic muscle properties or affecting the adaptability of neural factors other than those that limit force in the high-force, low-velocity region of the force-velocity relationship.

A closer inspection of the data shows that strength gains may have been compromised by combined training at slow contraction velocities as well as fast contraction velocities (Table 1). In the statistical analysis, within group, pre- to posttraining differences in torque were compared. It would have been more appropriate to compare the changes in torques between the strength-trained and combination-trained groups. For an isometric contraction, the strength-trained group increased torque 38.4 Nm compared to a 26.1 Nm gain in the combination-trained group—a difference of 12.3 Nm. At a contraction velocity of 4.19 rad·sec⁻¹, the strength-trained group increased torque 10.4 Nm compared to a minimal gain in the combination-trained group—a difference of approximately 10 Nm. Numerically, the strength-trained group had greater absolute and relative improvements in angle-specific torque at every angular velocity tested compared with the combination-trained group. While it is possible that a neural factor is the mechanism limiting strength gains, it is likely to be operative at both slow and fast contraction velocities.

The low-frequency, repetitive nature of muscle fiber recruitment during endurance training may restrain explosive muscular contractions such as jumping requires (25). Limitations in the ability to develop force during muscular contractions involving high-velocity movements could hinder power production during various lifts such as power cleans. Thirty-six males, 30 to 71 years of age, ran an average of 4 kilometers daily for 18 weeks. Vertical jump (VJ) height decreased approximately 8 percent to 18 percent in the subjects 40 to 60 years of age. In subjects aged 30 to 39 and 60 to 69 years, VJ height declined slightly. The group with the greatest improvement in \( \dot{V}O_2 \) max and running time to exhaustion had the largest decrement in VJ height. No statistical analysis was reported, therefore the conclusions from this study must be interpreted cautiously.

Callister et al. (2) reported decreases in average jump power during the last two 15-second intervals of a 60-second jump test in a sprint-trained group, and during the last 15-second interval in an endurance-trained, and a sprint-and-endurance-trained group. These authors questioned the validity of using a jump test as a marker for changes in performance ability. Komi et al. (20) reported a decline in VJ height after eight weeks in subjects training with light weight, fast movements and explosive-type jumps. After 16 weeks, VJ height had returned to pretraining values. This suggests that with an increased training volume, performance ability on some tests may decline until muscular adaptations occur in response to the greater training load. The impaired jumping ability in distance runners (3) can be reversed with detraining (4), suggesting that a high volume of training or a neuromuscular factor that is altered as a result of endurance training limits ability to develop force during high-velocity movements.

It is apparent that endurance training may limit the ability to produce force (5, 14) and explosive movements (3, 25). Since the metabolic and neuromuscular demands placed on skeletal muscle by endurance and strength training result in specific biochemical adaptations, it might be expected that both strength and endurance would be compromised by combination training, especially in elite athletes. However, the addition of heavy resistance training to the training routines of well-trained cyclists and runners improved endurance performance (15). (Mean \( \dot{V}O_2 \) max determined on a treadmill was 60.2 ml·kg⁻¹·min⁻¹.) Strength training consisted of 5 sets of 5 repetitions for the squat, 3 sets of 5 repetitions for knee extensions and flexions, and 3 sets of 25 repetitions for toe raises. Subjects lifted three days per week and used as much weight as possible for each exercise. After 10 weeks of strength training, 1 RM squat was increased an average of 27 percent. \( \dot{V}O_2 \) max was unchanged by heavy resistance training during cycling and treadmill running. Short-term endurance was increased by 11 percent and 13 percent during cycling and running, respectively. Cycling time to exhaustion at 80 percent of \( \dot{V}O_2 \) max increased 20 percent, while performance times for the 10 km run were unchanged. The authors stated that there were no changes in total body mass, thigh girth or muscle fiber size; therefore, any potential negative influences on performance did not represent limiting factors to the results. The strength gains likely reflect learning specific activation and motor unit recruitment patterns rather than intramuscular adaptations (15). It was concluded that certain types of endurance performance, especially those requiring fast-twitch fiber recruitment, could be improved by strength training.

There was no evidence of muscle hypertrophy, which may be detrimental to endurance performance, in the study by Hickson's group (15). Mitochondrial volume density declined following resistance training when muscle hypertrophy occurred (22, 23). After six months of heavy resistance training, mitochondrial volume density of the triceps muscle declined 26 percent, and the mitochondrial-to-myofibrillar volume ratio decreased 25 percent (23). Mean muscle fiber cross-sectional area increased 33 percent for fast twitch and 27 percent for slow twitch fibers. Assuming that
mitochondrial volume density reflects the oxidative potential of the muscle, heavy resistance training may be detrimental to endurance performance by decreasing oxidative potential per total muscle mass. MacDougall et al. (22) reported a lower mitochondrial volume density in the triceps brachii of a group of bodybuilders and powerlifters compared to untrained controls. The mitochondrial volume density of the controls declined with six months of weightlifting, and was similar to that of the bodybuilders and powerlifters.

Staron et al. (27) reported a 34 percent greater volume-percent mitochondria in the vastus lateralis muscle of weightlifters compared with sedentary controls. A group of distance runners had a 73 percent greater volume-percent mitochondria compared with the control group, and a 22 percent higher volume-percent mitochondria than the weightlifters. The difference between the runners and lifters was due to a 24 percent greater volume-percent mitochondria in the type Ila fibers of the runners, and no differences for the type I and Iib fibers. The discrepancy between these studies may be due to the methods used to determine volume-percent mitochondria (27). Although the effect of heavy resistance training on mitochondrial volume density requires further study, strength training is beneficial to endurance performance if hypertrophy is avoided (15).

**Possible Mechanisms for Compromised Adaptations with Combined Training**

The ability of the muscles to produce force is affected by an interaction of neural, mechanical and muscular factors (8). Alterations in any of these factors could result in compromised strength gains. Since strength training can benefit endurance performance (15), this section focuses primarily on possible mechanisms for compromises in strength adaptations with concurrent strength and endurance training. Understanding these mechanisms may help in designing programs for optimal performance.

Since subjects training for strength and endurance were exercising at a greater volume compared with subjects training only for strength or endurance, the compromise in strength gains may be due to overtraining. Overtraining is a decline or lack of improvement in physical performance, accompanied by underlying physiological changes resulting from a high volume and/or intensity of training without adequate recovery over a relatively long time period. For example, in the study by Hickson (14), the reduction in strength after seven weeks of training in the strength and endurance group may have been due to the high volume of training. However, the increase in cycle ergometer work during training was similar for the groups that trained for endurance or strength and endurance, and gains in aerobic power were not compromised in the combination-trained group (14). Furthermore, the studies of Hickson (14) and Dudley and Djamil (5) obtained similar results with different total training volumes (6). It is unlikely that the compromised strength gains were due to overtraining.

The studies of Dudley and Djamil (5) and Ono et al. (25) suggest that the compromise in the ability to produce force during high velocity movements are due to differences in the pattern or efficiency of motor unit recruitment during strength or endurance training. As discussed earlier, strength may be compromised at all velocities of contraction as a result of combination training. The demands placed on the neuromuscular system during endurance or resistance training exercise require different patterns of motor unit activation. During endurance exercise, the slow twitch (type I) fibers are recruited repetitively over a prolonged period. With high-intensity endurance exercise, such as in the study of Dudley and Djamil (5), marked recruitment of the fast twitch fibers would probably occur since subjects cycled at a workload that elicited VO2 max within four to five minutes. During strength training exercise, muscular contractions requiring high force or power output result in the recruitment of slow (type I) and fast twitch (type Ila, Iib) muscle fibers. Concurrent strength and endurance training may hinder organization of efficient motor unit recruitment patterns necessary for forceful muscular contractions at the level of the peripheral or central nervous system.

Shifts in skeletal muscle myosin isoforms may be a factor in the compromised strength gains with concurrent training. Fiber type transformation may be possible with prolonged and intense endurance training, resulting in a conversion of fast to slow myosin isoforms (10, 18, 26). Alterations of the myosin isoforms from fast to slow isoforms would hinder maximal power output ability. Furthermore, a greater degree of hypertrophy of fast twitch compared with slow twitch muscle fibers following strength training has been reported (22). Training-induced transformation of slow twitch to fast twitch fibers is difficult to achieve, since between training sessions the slow twitch fibers are continuously stimulated by the typical low-frequency pattern of the slow motoneuron. This influence is much stronger than the one imposed by the short, high-frequency bursts of stimulation during training. Therefore, changes induced by anaerobic or strength training are restricted to adaptations in metabolic function and fiber size (18). Changes in myosin isoforms are an important factor to consider in the training of elite athletes, especially in sports requiring various degrees of strength-power and endurance.

The endocrine system plays an important role in regulating growth and development (11), and in the acute responses and chronic adaptations to exercise
training. It was suggested that endocrine responses during strength training may be related to the trainability status of an individual (13). In elite olympic-style weightlifters, individual changes in the serum testosterone-to-sex hormone-binding globulin ratio were positively related to changes in strength. In contrast, male distance runners had lower total and free testosterone concentrations compared with a control group (28). Acute responses and longer term alterations in testosterone concentrations as a result of endurance or strength training may result in compromised strength gains, since changes would ultimately affect muscle growth-related processes. Changes in the levels of other hormones, such as cortisol and thyroxine, may affect strength gains (or expression of strength). This area requires further investigation before any conclusions can be reached.

The mechanisms by which the training stimulus is transduced to biochemical adaptations is unclear. Strength training places a large amount of tension on the muscle fibers. Calcium and high intramuscular tension may play an important role in activating or repressing various growth-related processes (9). Endurance training does not result in high tension development but stimulates oxidative metabolism to a greater extent. Therefore, these two types of training may activate various anabolic or catabolic processes to different degrees, which are modulated by endocrine responses to exercise and training. It is difficult to reach any firm conclusions as to the cause of compromised strength gains with combined training based on current evidence.

**Practical Applications**

The question that arises for the coach or athlete is whether or not a strength-power athlete should engage in aerobic training, or if an athlete in aerobic sports should strength train. Heavy resistance training increased cycling and running times to exhaustion in subjects training only for strength (16) and in individuals training for strength and endurance (15). Supplementing an endurance training program with strength training may enhance performance in endurance events in which a substantial recruitment of fast twitch muscle fibers is required (15), or in which a kick-finish is important (6). Strength training may help prevent injuries in endurance athletes (21). Strength training may hinder endurance performance by diluting mitochondrial volume density if muscle hypertrophy occurs (22, 23).

Apparently it is detrimental for strength-power athletes to perform endurance activities (5, 14). Many coaches believe that athletes need an aerobic base for conditioning for strength-power sports. For a football game, the length of a play is very brief, requiring quick bursts of energy. The primary energy systems used are the phosphagen and glycolytic systems. Aerobic capacity is not a limiting factor in football performance. High volume weight training may help increase muscular endurance and delay fatigue during a game. Conditioning should involve interval-type training over a short distances (less than 400 meters).

Many sports (e.g. wrestling, 1,500-meter run) require utilization of aerobic and anaerobic metabolism. For athletes in these sports, training should stress the various energy systems to the same extent that they are used in competition. For sports such as wrestling, interval-type training may be the best way of improving cardiorespiratory endurance, while high-volume weight training can improve strength and muscular endurance.

In summary, it is apparent that aerobic training inhibits or interferes with strength development (5, 14), while strength training can be beneficial to endurance performance (15). The following recommendations are proposed: (a) the athlete and coach should be aware of the concept of training specificity, i.e., training must emphasize the energy systems used in competition; (b) to increase muscular endurance, high-volume weight training should be undertaken instead of moderate or long distance running or cycling; (c) running should be limited to interval training of short distances and high intensity for athletes in sports that are primarily anaerobic; and (d) endurance athletes can benefit from strength training for injury prevention and enhanced performance.

**References**