Chapter II

REVIEWS OF RELATED LITERATURE

Capitalizing on the reviews of expert researchers can be fruitful in providing helpful ideas and suggestions keeping this in mind the research scholar made an attempt to go through the related literatures available in the libraries of Department of Physical Education and Sports Sciences, Acharya Nagarjuna University, Andhra Pradesh.

The research scholar scanned the literature and research work, published so far here and abroad, on the allied field and physical education and sports. Extensive studies regarding exercise science, different exercise programme and their development, hygienic, therapeutic and other values use of big muscles activities and sports culture is available in research journals. But comparatively very few studies are reported regarding high intensity interval training, the relative studies found from various sources, which the scholar has come across, are cited below.

Importance of combined training to sports and games

Kilinc (2008) studied the effects of an intensive combined training program based on the pretest scores of a university women's basketball team on their physical, physiological, biomotoric, and technical features. Twenty-four university volunteers were equally divided into two groups: an
experiment group (intensive combined training group) and a control (technical training) group. The 10-week intensive combined training program was performed on the experiment group according to their pretest outcomes. Before and at the end of each period of training, which was scheduled four times a week, the physical, physiological, biomotoric, and technical performance of each subject were determined. With respect to the pre- and posttest measurements, the basketball group showed significant differences ($p < 0.05$) in girth measurements (shoulder, waist, hip, arm, thigh, and calf), in skinfold measurements (percent body fat), in physiological measurements (vital capacity and forced vital capacity), in biomotoric tests (right-left hand grip, dynamic and countermovement jump, sit-up, push-up, 1500-m endurance), and in technique tests (free and inside shooting). The researcher concluded that a 10-week intensive combined training program performed on university women basketball players had a significant effect on improving their physical, physiological, biomotoric, and technical features. It proved to be highly recommendable for female basketball players who are preparing for short-term tournaments; the basketball group in this study won a championship.

**Combined effect of endurance and strength training on motor fitness variables**

Holviala *et al.* (2012) examined the effects of 21-week twice weekly strength (ST), endurance (ET) and combined (ST + ET 2 + 2 times a week) (SET) training on neuromuscular, endurance and walking performances as
well as balance. 108 healthy men (56.3 ± 9.9 years) were divided into three training (ST; n = 30, ET; n = 26, SET; n = 31) groups and controls (C n = 21). Dynamic 1RM and explosive leg presses (1RMleg, 50%1RMleg), peak oxygen uptake using a bicycle ergometer (VO₂peak), 10 m loaded walking time (10WALK) and dynamic balance distance (DYND) were measured. Significant increases were observed in maximal 1RMleg of 21% in ST (p < 0.001) and 22% in SET (p < 0.001) and in explosive 50%1RMleg of 7.5% in ST (p = 0.005) and 10.2% in SET (p < 0.001). VO₂peak increased by 12.5% in ET (p = 0.001) and 9.8% in SET (p < 0.001). Significant decreases occurred in 10WALK in ST (p < 0.001) and SET (p = 0.003) and also in DYND of -10.3% in ST (p = 0.002) and -8% in SET (p = 0.028). The changes in C remained minor in all variables. They concluded that ST and SET training produced significant improvements in maximal and explosive strength, walking speed and balance without any interference effect in SET. Significant but moderate relationships were observed between strength and dynamic balance and walking speed, while no corresponding correlations were found in the ET group.

Ferrauti, Bergermann and Fernandez-Fernandez (2010) investigated the effects of a concurrent strength and endurance training program on running performance and running economy of middle-aged runners during their marathon preparation. Twenty-two (8 women and 14 men) recreational runners (mean ± SD: age 40.0 ± 11.7 years; body mass index 22.6 ± 2.1 kg·m⁻²) were separated into 2 groups (n = 11; combined endurance running
and strength training program [ES]: 9 men, 2 women and endurance running [E]: 7 men, and 4 women). Both completed an 8-week intervention period that consisted of either endurance training (E: 276 ± 108 minute running per week) or a combined endurance and strength training program (ES: 240 ± 121-minute running plus 2 strength training sessions per week [120 minutes]). Strength training was focused on trunk (strength endurance program) and leg muscles (high-intensity program). Before and after the intervention, subjects completed an incremental treadmill run and maximal isometric strength tests. The initial values for VO$_2$peak (ES: 52.0 ± 6.1 vs. E: 51.1 ± 7.5 ml·kg$^{-1}$·min$^{-1}$) and anaerobic threshold (ES: 3.5 ± 0.4 vs. E: 3.4 ± 0.5 m·s$^{-1}$) were identical in both groups. A significant time × intervention effect was found for maximal isometric force of knee extension (ES: from 4.6 ± 1.4 to 6.2 ± 1.0 N·kg$^{-1}$, p < 0.01), whereas no changes in body mass occurred. No significant differences between the groups and no significant interaction (time × intervention) were found for VO$_2$ (absolute and relative to VO$_2$peak) at defined marathon running velocities (2.4 and 2.8 m·s$^{-1}$) and submaximal blood lactate thresholds (2.0, 3.0, and 4.0 mmol·L$^{-1}$). Stride length and stride frequency also remained unchanged. Their results suggest no benefits of an 8-week concurrent strength training for running economy and coordination of recreational marathon runners despite a clear improvement in leg strength, maybe because of an insufficient sample size or a short intervention period.

Rønnestad and Mujika (2013) studied the effect of combining endurance training with heavy or explosive strength training on endurance
performance in endurance-trained runners and cyclists. Running economy is improved by performing combined endurance training with either heavy or explosive strength training. However, heavy strength training is recommended for improving cycling economy. Equivocal findings exist regarding the effects on power output or velocity at the lactate threshold. Concurrent endurance and heavy strength training can increase running speed and power output at $\text{VO}_{2\text{max}}$ ($V_{\text{max}}$ and $W_{\text{max}}$, respectively) or time to exhaustion at $V_{\text{max}}$ and $W_{\text{max}}$. Combining endurance training with either explosive or heavy strength training can improve running performance, while there is most compelling evidence of an additive effect on cycling performance when heavy strength training is used. They suggested that the improved endurance performance may relate to delayed activation of less efficient type II fibers, improved neuromuscular efficiency, conversion of fast-twitch type IIX fibers into more fatigue-resistant type IIA fibers, or improved musculo-tendinous stiffness.

Gergley (2009) examined the effect of two different modes of lower-body endurance exercise (i.e., cycle ergometry and incline treadmill walking) on lower-body strength development with concurrent resistance training designed to improve lower-body strength (i.e., bilateral leg press 1 repetition maximum [RM]). Thirty untrained participants (22 men and 8 women, ages 18-23) were randomly assigned to one of 3 training groups (resistance only [R], $N = 10$; resistance + cycle ergometry [RC], $N = 10$; and resistance + incline treadmill [RT], $N = 10$). The 3 training groups exercised twice per week for 9 weeks. The reduced frequency of exercise treatments were
selected specifically to avoid overtraining for in-season athletes attempting to maintain offseason conditioning. Body mass and body composition measurements were taken pre- and post-training. Before training began, 3 weeks of training, 6 weeks of training, and after training, the participants also performed a 1RM test for lower-body strength. Analysis of variance comparisons with repeated measures revealed the following statistically significant changes (alpha = 0.05) in the 3 training groups over time: (a) when men and women were combined, body mass of R was significantly greater than RC and RT post-training; (b) body mass of men only was significantly greater than RC and RT post-training; (c) body composition of men only was significantly smaller for RC and RT compared with R; (d) when men and women were combined, percent change in strength revealed significantly greater gains in R compared with RT at 6 weeks; (e) when men and women were combined, percent change in strength revealed significantly greater gains in R compared with RC and RT post-training; (f) percent change in strength for men only was significantly greater for R compared with RT at 3 weeks; (g) percent change in strength for men only was significantly greater for R compared with RC and RT at 6 weeks, and RC was significantly greater than RT at 6 weeks; (h) percent change in strength in men only was significantly greater for R compared with RC and RT post-training, and RC was significantly greater than RT post-training; and (i) percent change in strength in women was significantly greater in R compared with RT post-training. The findings of the investigation confirmed previous studies that
reported attenuated strength development with concurrent resistance and endurance training compared with resistance-only training. More importantly, the study indicated that the mode of endurance exercise in concurrent training regimens may play a role in the development of strength. Specifically, there seemed that cycling was superior to treadmill endurance training for an individual with the goal of developing strength in a multijoint movement (i.e., leg press or squat) in the lower-body because it more closely mimics the biomechanical movement of these exercises.

Levin, Mcguigan and Laursen (2009) investigated the effect of concurrent resistance and endurance cycle training on physiologic and performance parameters of cyclists. Before and after a 6-week training intervention period, 14 well-trained male cyclists completed a maximal graded exercise test, a 30-km dynamic cycling test with 3 intermittent 250-m and 1-km sprints, and a 1 repetition maximum (1RM) squat test for the assessment of lower-limb strength. Subjects were allocated into 2 groups: a resistance training group (RT; n = 7) that completed a 6-week undulating, periodized resistance training program (3/wk) in conjunction with their regular cycle training and a control group (CON; n = 7) that maintained their usual cycle training. Upon completion of the training intervention, there was no change in graded exercise test parameters in either group, but the RT group showed a significantly greater increase in 1RM squat strength compared with CON (p < 0.05). Moreover, the change in 30-km time trial and sprinting performance did not differ between RT and CON, except for the final 1-km
sprint where the percent change in 1-km final sprint performance was greater in CON (+11%) compared with RT (-5%). They concluded that concurrent resistance and endurance training in well-trained cyclists enhanced 1RM strength, it did not improve overall cycle time trial performance and in fact was shown to reduce 1-km final cycle sprint performance compared with a CON group performing their normal cycle training.

Bell et al. (2000) investigated the effect of concurrent strength and endurance training on strength, endurance, endocrine status and muscle fibre properties. A total of 45 male and female subjects were randomly assigned to one of four groups; strength training only (S), endurance training only (E), concurrent strength and endurance training (SE), or a control group (C). Groups S and E trained 3 days a week and the SE group trained 6 days a week for 12 weeks. Tests were made before and after 6 and 12 weeks of training. There was a similar increase in maximal oxygen consumption (VO2max) in both groups E and SE (P < 0.05). Leg press and knee extension one repetition maximum (1 RM) was increased in groups S and SE (P < 0.05) but the gains in knee extension 1 RM were greater for group S compared to all other groups (P < 0.05). Types I and II muscle fibre area increased after 6 and 12 weeks of strength training and after 12 weeks of combined training in type II fibres only (P < 0.05). Groups SE and E had an increase in succinate dehydrogenase activity and group E had a decrease in adenosine triphosphatase after 12 weeks of training (P < 0.05). A significant increase in capillary per fibre ratio was noted after 12 weeks of training in group SE. No changes were observed
in testosterone, human growth hormone or sex hormone binding globulin concentrations for any group but there was a greater urinary cortisol concentration in the women of group SE and decrease in the men of group E after 12 weeks of training (P < 0.05). Their findings would support the contention that combined strength and endurance training can suppress some of the adaptations to strength training and augment some aspects of capillarization in skeletal muscle.

Shaw, Shaw and Brown (2009) compared the effects of 16 weeks of resistance training and concurrent resistance and endurance training on muscular strength development in 38 sedentary, apparently healthy males (25 yr +/- 8 mo). Subjects were age-matched and randomly assigned to either a control (Con) group (n = 12), resistance training (Res) group (n = 13), or concurrent resistance and endurance training (Com) group (n = 13). After 16 weeks, no changes were found in the strength of the subjects in the Con group. Resistance training and concurrent resistance and endurance training significantly (p < or = 0.05) improved strength in all of the 8 prescribed exercises. Their data also indicated that 16 weeks of concurrent resistance training and endurance training was as effective in eliciting improvements in strength as resistance training alone in previously sedentary males. As such, concurrent resistance and endurance training does not impede muscular strength gains and can be prescribed simultaneously for the development of strength in sedentary, apparently healthy males and thus may invoke all the physiologic adaptations of resistance and endurance training at once.
Santos et al. (2012) compared the effects of an 8-week training period of resistance training alone (GR), or combined resistance and endurance training (GCOM), followed by 12 weeks of detraining (DT) on body composition, explosive strength, and VO₂max adaptations in a large sample of adolescent school boys. Forty-two healthy boys recruited from a Portuguese public high school (age: 13.3 ± 1.04 years) were assigned to 2 experimental groups to train twice a week for 8 weeks: GR (n = 15), GCOM (n = 15), and a control group (GC: n = 12; no training program). Significant training-induced differences were observed in 1- and 3-kg medicine ball throw gains (GR: +10.3 and +9.8%, respectively; GCOM: +14.4 and +7%, respectively), whereas no significant changes were observed after a DT period in both the experimental groups. Significant training-induced gains in the height and length of the countermovement (vertical-and-horizontal) jumps were observed in both the experimental groups. No differences were perceived after a DT period in lower limb power. Time at 20 m decreased significantly for both intervention programs (GR: -11.5% and GCOM: -12.4%, <0.00), but either GR or GCOM groups kept the running speed after a DT period of 12 weeks. After training, the VO₂max increased only significantly for GCOM (4.6%, p = 0.01). A significant loss was observed after a DT period in GR but not in GCOM. Performing resistance and endurance training in the same workout does not impair strength development in young school boys. As expected, strength training by itself does not
improve aerobic capacity. Their results also suggest that training program effects even persist at the end of the DT period.

Wong et al. (2010) examined the effect of concurrent muscular strength and high-intensity running interval training on professional soccer players' explosive performances and aerobic endurance. Thirty-nine players participated in the study, where both the experimental group (EG, n = 20) and control group (CG, n = 19) participated in 8 weeks of regular soccer training, with the EG receiving additional muscular strength and high-intensity interval training twice per week throughout. Muscular strength training consisted of 4 sets of 6RM (repetition maximum) of high-pull, jump squat, bench press, back half squat, and chin-up exercises. The high-intensity interval training consisted of 16 intervals each of 15-second sprints at 120% of individual maximal aerobic speed interspersed with 15 seconds of rest. EG significantly increased (p < or = 0.05) 1RM back half squat and bench press but showed no changes in body mass. Within-subject improvement was significantly higher (p < or = 0.01) in the EG compared with the CG for vertical jump height, 10-m and 30-m sprint times, distances covered in the Yo-Yo Intermittent Recovery Test and maximal aerobic speed test, and maximal aerobic speed. High-intensity interval running can be concurrently performed with high load muscular strength training to enhance soccer players' explosive performances and aerobic endurance.

Balabinis et al. (2003) compared regimens of concurrent strength and endurance training, 26 male basketball players were matched for stature, body
composition, and physical activity level. Subjects completed different training programs for 7 weeks, 4 days per week. Groups were as follows: (a) the strength group (S; n = 7) did strength training; (b) the endurance group (E; n = 7) did endurance training; (c) the strength and endurance group (S + E; n = 7) combined strength and endurance training; and (d) the control group (C; n = 5) had no training. The S + E group showed greater gains in VO$_2$ max than the E group did (12.9% vs. 6.8%), whereas the S group showed a decline (8.8%). Gains were noted in strength and vertical jump performance for the S + E and S groups. The S + E group had better post training anaerobic power than the S group did (6.2% vs. 2.9%). No strength, power, or anaerobic power gains were present for the E and C groups. They concluded that concurrent endurance and strength training is more effective in terms of improving athletic performance than are endurance and strength training apart.

Santtila, Kyröläinen and Häkkinen (2009) examined the effect of 8-week endurance-based military training period interferes with muscle strength development in the conscripts (n = 72) compared with that caused by sport-related military training with added strength training (ST) or endurance training (ET). More specifically, we examined the effects of these 3 training modes on maximal isometric force, maximal rate of force development (RFD), electromyography (EMG), and muscle thickness of the lower and upper extremities. The measurements included isometric force-time parameters of leg and arm extensors and EMG activity from the vastus lateralis, vastus medialis, rectus femoris, and triceps brachii muscles. The 8-
week basic training period combined with added ST and ET significantly improved maximal bilateral isometric force of the arm extensors in ST by 11.8% (p < 0.001), ET by 13.9% (p < 0.001), and normal training (NT) by 7.8% (p < 0.05). Strength training and ET showed significant increases in maximal EMG activity of the trained arm muscles. A significant increase was observed in maximal RFD of the upper extremities only in ST by 28.1% (p < 0.05). Both ST and ET increased their maximal leg extension strength by 12.9% (p < 0.01) and 9.1% (p < 0.05), respectively, whereas no significant change occurred in NT (5.2%, p = 0.45). No significant changes were observed in the shape of the force-time curves of leg extensors. No increases occurred in muscle thickness either in the lower or upper extremities. The BT training with a large amount of endurance-based military training interfered with strength development, and especially, explosive power development of the lower extremities in the ST group. The optimal improvements in neuromuscular characteristics may not be possible without some decreases in the amount of the endurance-based military training and/or some increases in the amount of the maximal/explosive strength training during the BT.

Mikkola et al. (2007) examined the effects of concurrent endurance and explosive strength training on electromyography (EMG) and force production of leg extensors, sport-specific rapid force production, aerobic capacity, and work economy in cross-country skiers. Nineteen male cross-country skiers were assigned to an experimental group (E, n = 8) or a control group (C, n = 11). The E group trained for 8 weeks with the same total
training volume as C, but 27% of endurance training in E was replaced by explosive strength training. The skiers were measured at pre- and post training for concentric and isometric force-time parameters of leg extensors and EMG activity from the vastus lateralis (VL) and medialis (VM) muscles. Sport-specific rapid force production was measured by performing a 30-m double poling test with the maximal velocity (V_{30DP}) and sport-specific endurance economy by constant velocity 2-km double poling test (CVDP) and performance (V_{2K}) by 2-km maximal double poling test with roller skis on an indoor track. Maximal oxygen uptake (VO_{2max}) was determined during the maximal treadmill walking test with the poles. The early absolute forces (0-100 ms) in the force-time curve in isometric action increased in E by 18 +/- 22% (p < 0.05), with concomitant increases in the average integrated EMG (IEMG) (0-100 ms) of VL by 21 +/- 21% (p < 0.05). These individual changes in the average IEMG of VL correlated with the changes in early force (r = 0.86, p < 0.01) in E. V_{30DP} increased in E (1.4 +/- 1.6%) (p < 0.05) but not in C. The V_{2K} increased in C by 2.9 +/- 2.8% (p < 0.01) but not significantly in E (5.5 +/- 5.8%, p < 0.1). However, the steady-state oxygen consumption in CVDP decreased in E by 7 +/- 6% (p < 0.05). No significant changes occurred in VO_{2max} either in E or in C. The concurrent explosive strength and endurance training in endurance athletes produced improvements in explosive force associated with increased rapid activation of trained leg muscles. The training also led to more economical sport-specific performance. The improvements in neuromuscular characteristics and
economy were obtained without a decrease in maximal aerobic capacity, although endurance training was reduced by about 20%.

Marta et al. (2013) compared the effects of an 8-weeks training period of resistance training alone (GR), combined resistance and endurance training (GCON) and a control group (GC) on explosive strength and VO$_2$max in a large sample of prepubescent boys and girls. 125 healthy children (58 boys, 67 girls), aged 10-11 years old (10.8±0.4 years) were assigned into 2 training groups to train twice a week for 8 weeks: GR (19 boys, 22 girls), GCON (21 boys, 24 girls) and a control group (GC: 18 boys, 21 girls; no training program). A significant but medium-sized increase from pre- to the post-training in the vertical jump (Effect size=0.22, F=34.44, p<0.01) and VO2max (Effect size=0.19, F=32.89, p<0.01) was observed. A significant large increase in the 1 kg (Effect size=0.53, F=202.17, p<0.01) and 3 kg (Effect size=0.48, F=132.1, p<0.01) ball throwing, standing long jump (Effect size=0.53, F=72.93, p<0.01) and running speed (Effect size=0.45, F=122.21, p<0.01) was also observed. The training group (GR and GCON) and sex factors did not significantly influence the evolution of strength variables from pre- to the post-training. The VO$_2$max increased significantly only in GCON. Concurrent training is equally effective on training-induced explosive strength, and more efficient than resistance training only for VO$_2$max, in prepubescent boys and girls. This should be taken into consideration in order to optimize strength training school-based programs.
Häkkinen et al. (2003) investigated the effects of concurrent strength and endurance training (SE) (2 plus 2 days a week) versus strength training only (S) (2 days a week) in men [SE: n=11; 38 (5) years, S: n=16; 37 (5) years] over a training period of 21 weeks. The resistance training program addressed both maximal and explosive strength components. EMG, maximal isometric force, 1 RM strength, and rate of force development (RFD) of the leg extensors, muscle cross-sectional area (CSA) of the quadriceps femoris (QF) throughout the lengths of 4/15-12/15 (L(f)) of the femur, muscle fibre proportion and areas of types I, IIa, and IIb of the vastus lateralis (VL), and maximal oxygen uptake (VO\(_2\max\)) were evaluated. No changes occurred in strength during the 1-week control period, while after the 21-week training period increases of 21% (p<0.001) and 22% (p<0.001), and of 22% (p<0.001) and 21% (p<0.001) took place in the 1RM load and maximal isometric force in S and SE, respectively. Increases of 26% (p<0.05) and 29% (p<0.001) occurred in the maximum iEMG of the VL in S and SE, respectively. The CSA of the QF increased throughout the length of the QF (from 4/15 to 12/15 L(f)) both in S (p<0.05-0.001) and SE (p<0.01-0.001). The mean fibre areas of types I, IIa and IIb increased after the training both in S (p<0.05 and 0.01) and SE (p<0.05 and p<0.01). S showed an increase in RFD (p<0.01), while no change occurred in SE. The average iEMG of the VL during the first 500 ms of the rapid isometric action increased (p<0.05-0.001) only in S. VO\(_2\max\) increased by 18.5% (p<0.001) in SE. Their data did not support the concept of the universal nature of the interference effect in strength development and
muscle hypertrophy when strength training is performed concurrently with endurance training, and the training volume is diluted by a longer period of time with a low frequency of training. However, the results suggested that even the low-frequency concurrent strength and endurance training leads to interference in explosive strength development mediated in part by the limitations of rapid voluntary neural activation of the trained muscles.

McCarthy, Pozniak and Agre (2002) examined the muscle morphological and neural activation adaptations resulting from the interaction between concurrent strength and endurance training. Thirty sedentary healthy male subjects were randomly assigned to one of three training groups that performed 10 wk of 3-d x wk(-1) high-intensity strength training (S), cycle endurance training (E), or concurrent strength and endurance training (CC). Strength, quadriceps-muscle biopsies, computed tomography scans at mid-thigh, and surface electromyogram (EMG) assessments were made before and after training. The result of their study showed that S and CC groups demonstrated increases (P < 0.0001) in both thigh extensor (12 and 14%) and flexor/adductor (7 and 6%) muscle areas. Type II myofiber areas similarly increased (P < 0.002) in both S (24%) and CC (28%) groups, whereas the increase (P < 0.004) in Type I area with S training (19%) was also similar to the nonsignificant (P = 0.041) increase with CC training (13%). Significant increases (P < 0.005) in maximal isometric knee-extension torque were accompanied by nonsignificant (P <or= 0.07) increases in root mean squared EMG amplitude of the quadriceps musculature for both S and C groups. No
changes ($P > 0.38$) in the EMG/torque relation across 20 to 100% maximal voluntary contractions occurred in any group. A small 3% increase ($P < 0.01$) in thigh extensor area was the only change in any of the above variables with E training. They concluded that 3 days per week concurrent performance of both strength and endurance training does not impair adaptations in strength, muscle hypertrophy, and neural activation induced by strength training alone. Results provide a physiological basis to support several performance studies that consistently indicate 3 days per week concurrent training does not impair strength development over the short term.

Rønnestad, Hansen and Raastad (2012) compared the effect of 12 weeks of strength training combined with a large volume of endurance training with the effect of strength training alone on the strength training adaptations. Well-trained cyclists with no strength training experience performed heavy strength training twice a week in addition to a high volume of endurance training during a 12-week preparatory period ($S + E; n = 11$). A group of non-strength trained individuals performed the same strength training as $S + E$, but without added endurance training ($S; n = 7$). Thigh muscle cross-sectional area, 1 repetition maximum (1RM) in leg exercises, squat jump performance, and peak rate of force development (RFD) were measured. Following the intervention period, both $S + E$ and $S$ increased 1RM strength, thigh muscle cross-sectional area, and squat jump performance ($p < 0.05$), and the relative improvements in $S$ were greater than in $S + E$ ($p < 0.05$). $S$ increased peak RFD while $S + E$ did not, and this improvement
was greater than in S + E (p < 0.05). To the best of their knowledge, this is the first controlled study to demonstrate that the strength training response on muscle hypertrophy, 1RM strength, squat jump performance, and peak RFD is attenuated in well-trained endurance athletes during a period of concurrent endurance training.

McGawley and Andersson (2013) study aimed to quantify the effects of concurrent high-intensity run-based training (HIT) and strength- and power-based training (STR) on soccer-specific performance, and investigate the order effect of completing HIT and STR either first or second within training sessions. Eighteen semi- and fully-professional players completed a battery of field- and gym-based tests before and after a 5-week pre-season training intervention. Players were pair-matched and completed 3 sessions per week of HIT followed by STR (n=9) or STR followed by HIT (n=9). ANCOVA tests revealed no differences between groups for changes in any of the measures (p>0.05). However, a training effect was observed for all measures (p<0.05), with 10-m sprint, 6×30-m repeated sprint, 40-m agility and Yo-Yo test performances improving by 1.8±2.6%, 1.3±1.8%, 1.0±1.5% and 19.4±23.4%, respectively (n=18). They concluded that there was a positive effect of the concurrent training approach on key measures of soccer performance, but the order of completing HIT and STR appears inconsequential to performance adaptations.
Combined effect of endurance and strength training on physiological variables

Glowacki et al. (2004) tried to determine whether endurance and resistance training performed concurrently produces different performance and physiologic responses compared with each type of training alone. They selected untrained male volunteers, who were randomly assigned to one of three groups: endurance training (ET, N = 12); resistance training (RT, N = 13); and concurrent training (CT, N = 16). The following measurements were made on all subjects before and after 12 wk of training: weight, percent body fat, peak oxygen consumption (VO₂peak), isokinetic peak torque and average power produced during single-leg flexion and extension at 60 and 180 degrees⁻¹, one-repetition maximum (1RM) leg press, 1RM bench press, vertical jump height, and calculated jump power. Their results showed that weight and lean body mass (LBM) increased significantly in the RT and CT groups (P < 0.05). Percent body fat was significantly decreased in the ET and CT groups. VO₂peak was significantly improved only in the ET group. Peak torque during flexion and extension at 180 degrees⁻¹ increased in the RT group. Improvements in 1RM leg press and bench press were significant in all groups, but were significantly greater in the RT and CT compared to the ET group. Jump power improved significantly only in the RT group, and no group showed a significant change in vertical jump height. They concluded that concurrent training performed by young, healthy men does not interfere
with strength development, but may hinder development of maximal aerobic capacity.

McCarthy et al. (1995) examined the effects of combining conventional 3 d.wk\(^{-1}\) strength and endurance training on the compatibility of improving both VO\(_2\) peak and strength performance simultaneously. Sedentary adult males, randomly assigned to one of three groups (N = 10 each), completed 10 wk of training. A strength-only (S) group performed eight weight-training exercises (4 sets/exercise, 5-7 repetitions/set), an endurance-only (E) group performed continuous cycle exercise (50 min at 70% heart rate reserve), and a combined (C) group performed the same S and E exercise in a single session. S and C groups demonstrated similar increases (P < 0.0167) in 1RM squat (23% and 22%) and bench press (18% for both groups), in maximal isometric knee extension torque (12% and 7%), in maximal vertical jump (6% and 9%), and in fat-free mass (3% and 5%). E training did not induce changes in any of these variables. VO\(_2\) peak (ml.kg\(^{-1}\).min\(^{-1}\)) increased (P < 0.01) similarly in both E (18%) and C (16%) groups. Results indicated 3 d.wk\(^{-1}\) combined training can induce substantial concurrent and compatible increases in VO\(_2\) peak and strength performance.

Seo et al. (2010) examined the effects of combined exercise training on growth hormone (GH), insulin-like growth factor-1 (IGF-1), and metabolic-syndrome factors and determine whether the changes in GH and/or IGF-1 induced by exercise correlate to the metabolic-syndrome factors in healthy middle-aged women (50-65 years of age). The participants were randomly
assigned into an aerobic-exercise training (walking + aerobics) group (AEG; n = 7), a combined-exercise training (walking + resistance training) group (CEG; n = 8), or a control group (CG; n = 7). Exercise sessions were performed 3 times per wk for 12 wk. The aerobic-exercise training consisted of walking and aerobics at 60-80% of heart-rate reserve, and the combined-exercise training consisted of walking and resistance exercise at 50-70% of 1-repetition maximum. The result of their study showed that GH, percentage body fat, fasting glucose, systolic blood pressure, and waist circumference were significantly improved in CEG (p < .05). However, GH induced by exercise training showed no correlation with metabolic-syndrome factors. IGF-1 was not significantly increased in either AEG or CEG compared with CG. Their results indicated that the combined-exercise training produced more enhancement of GH, body composition, and metabolic-syndrome factors than did aerobic-exercise training.

Daray et al. (2011) determined whether endurance (E) or endurance + resistance (ER) training affects C-reactive protein (CRP) and if these changes are related to alterations in fitness and (or) body composition in young females. Thirty-eight females (aged 18-24 years) were assigned to 1 of 3 groups: (1) E, (2) ER or (3) active control (AC). The E and ER groups completed 15 weeks of marathon training. The ER group performed additional resistance training and the AC group maintained their usual exercise routine. Primary outcomes were measured pre- and post-training and included anthropometric indices, dual-energy x-ray absorptiometry, plasma
CRP, time to complete 1.5 miles (in minutes), and upper and lower body strength tests (i.e., 8 repetition max on bench and leg press (ER group only)). There were no differences in any variable among the groups at baseline. After training, the E group decreased time to complete 1.5 miles (p < 0.05). The AC group decreased percent and absolute body fat while the E group decreased percent body fat, absolute body fat, and android and gynoid body fat (p < 0.05). The ER group significantly improved strength (p < 0.001) and reduced plasma CRP from 2.0 ± 1.1 to 0.8 ± 0.3 mg·L\(^{-1}\) (p = 0.03). No significant associations were observed between CRP and measures of body composition or aerobic capacity. Combined endurance and resistance training may be an effective modality for reducing plasma CRP in young adult females independent of changes in aerobic capacity or body composition.

Davis et al. (2008) evaluated the effects of concurrent strength and aerobic endurance training on muscle strength and endurance, body composition, and flexibility in female college athletes and compared two concurrent exercise (CE) protocols. Twenty-eight women (mean age, 19.6 years) were divided into two matched groups and evaluated before and after a vigorous, 11-week, 3-days per week CE training program. One group did serial CE consisting of a warm-up, resistance exercises at low heart rate (HR), aerobics, and a range of motion cool down. The other group did integrated CE consisting of aerobics, the same resistance exercises at high HR achieved by cardioacceleration before each set, and the same range of motion cool down. The two protocols were balanced, differing only in the timing and sequence of
exercises. Serial CE produced discernible (p < 0.05) increases in lower- (17.2%) and upper- (19.0%) body muscle strength and fat-free mass (FFM) (1.8%) and trends toward greater lower-body muscle endurance (18.2%) and reduced upper-body flexibility (-160.4%). Integrated CE produced discernible increases in lower- (23.3%) and upper- (17.8%) body muscle strength, lower-body muscle endurance (27.8%), FFM (3.3%), and lower-body flexibility (8.4%) and a decline in fat mass (-4.5%) and percent body fat (-5.7%). Integrated CE produced discernibly larger gains than serial CE for six of nine training adaptations. Effect sizes were generally moderate (44.4% of discernible differences) to large (33.3%). They conclude that serial CE produces adaptations greater than those reported in the literature for single-mode (strength) training in athletes, whereas integrated CE produces discernibly greater gains than serial CE. Their results suggested synergy rather than interference between concurrent strength and aerobic endurance training, support prescription of CE under defined conditions, establish the importance of exercise timing and sequence for CE program outcomes, and document a highly effective athletic training protocol.

Sillanpää et al. (2009) examined the adaptation in body composition, physical fitness and metabolic health during 21 weeks of endurance and/or strength training in 39- to 64-year-old healthy women. Subjects (n = 62) were randomized into endurance training (E), strength training (S), combined strength and endurance training (SE), or control groups (C). S and E trained 2 and SE 2 + 2 times in a week. Muscle strength and maximal oxygen uptake
(VO$_2$max) were measured. Leg extension strength increased 9 +/- 8% in S (P < 0.001), 12 +/- 8% in SE (P < 0.001) and 3 +/- 4% in E (P = 0.036), and isometric bench press 20% only in both S and SE (P < 0.001). VO$_2$max increased 23 +/- 18% in E and 16 +/- 12% in SE (both P < 0.001). The changes in the total body fat (dual X-ray absorptiometry) did not differ between groups, but significant decreases were observed in E (-5.9%, P = 0.022) and SE (-4.8%, P = 0.005). Lean mass of the legs increased 2.2-2.9% (P = 0.004-0.010) in S, SE and E. There were no differences between the groups in the changes in blood lipids, blood pressure or serum glucose and insulin. Total cholesterol and low-density lipoprotein cholesterol decreased and high-density lipoprotein cholesterol increased in E. Both S and SE showed small decreases in serum fasting insulin. Both endurance and strength training and their combination led to expected training-specific improvements in physical fitness, without interference in fitness or muscle mass development. All training methods led to increases in lean body mass, but decreases in body fat and modest improvements in metabolic risk factors were more evident with aerobic training than strength training.

Lo et al. (2011) investigated the changes in the body composition, body size, muscle strength, and VO$_2$max after 24 weeks of resistance or endurance training and detraining in young men. Thirty healthy college-aged men (20.4 ± 1.36 years) participated in the study. Subjects were assigned to resistance training group (RTG, n = 10), endurance training group (ETG, n = 10), and control group (CG, n = 10). The training program consisted of
running or weight-resistance exercise for 3 sessions per week under supervision. VO\(_2\)max, upper and lower body strength (UBS, LBS), body fat, lean body mass, and body circumference were measured at baseline and after training and detraining. After the training period, the exercise groups demonstrated significant increases in VO\(_2\)max and LBS (p < 0.05). The UBS, lean mass (LM), and body size of arm and calf were significantly greater in the RTG than in the other 2 groups (p<0.05). In addition, the strength and LM of the RTG were still greater than the baseline values after 24 weeks of detraining (p < 0.05). The conclusions of their study was (a) that endurance or resistance training alone led to training-specific improvements in physical performance, body composition, and body size of the arms for the young men examined and (b) that the RTG maintained the gains in strength and LM for more prolonged periods after training ceased than the endurance training group.

Kraemer et al. (2001) investigated the comprehensive physiological alterations that take place during the combination of bench-step aerobics (BSA) and resistance exercise training. Thirty-five healthy, active women were randomly assigned to one of four groups that either a) performed 25 min of BSA only (SA25); b) performed a combination of 25 min of BSA and a multiple-set upper and lower body resistance exercise program (SAR); c) performed 40 min of BSA only (SA40); or d) served as a control group (C), only performing activities of daily living. Direct assessments for body composition, aerobic fitness, muscular strength, endurance, power, and cross-
sectional area were performed 1 wk before and after 12 wk of training. The result of their study showed that all training groups significantly improved peak VO$_2$ (3.7 to 5.3 mL O$_2$.kg$^{-1}$.min$^{-1}$), with the greatest improvement observed in the SAR group (P = 0.05). Significant reductions in preexercise heart rates (8-9 bpm) and body fat percent (5--6%) were observed in all training groups after training. Significant reductions in resting diastolic blood pressure were observed for the SAR and SA40 groups (6.7 and 5.8 mm Hg, respectively). Muscular strength and endurance only improved significantly in the SAR group (21 and 11% respectively). All groups demonstrated increased lower body power (11--14%), but only the SAR group significantly improved upper body power (32%). Thigh muscle cross-sectional areas measured via magnetic resonance imaging (MRI) increased primarily for the SAR group. They concluded that BSA is an exercise modality effective for improving physical fitness and body composition in healthy women. The addition of resistance exercise appears to enhance the total fitness profile by improving muscular performances, muscle morphology, and cardiovascular fitness greater than from performing BSA alone. Therefore, the inclusion of both modalities to an exercise program is most effective for improving total body fitness and a woman's health profile.

Mikkola et al. (2012) examined the effects of concurrent strength and endurance training on neuromuscular and endurance characteristics compared to strength or endurance training alone. Previously untrained men were divided into strength (S: n=16), endurance (E: n=11) or concurrent strength
and endurance (SE: n=11) training groups. S and E trained 2 times and SE 2 + 2 times a week for strength and endurance during the 21-week period. Maximal unilateral isometric and bilateral concentric forces of leg muscles increased similarly in S and SE by 20-28% (p<0.01) and improvements in isometric forces were accompanied by increases (p<0.05) of maximal muscle activation. Rate of force development of isometric action (p<0.05) improved only in S. The increase in muscle cross-sectional area of the quadriceps femoris in SE (11%, p<0.001) were greater than in S (6%, p<0.001) or in E (2%, p<0.05). SE and E increased maximal cycling power (SE: 17% and E: 11%, p<0.001) and VO\textsubscript{2} max (SE: 17%, p<0.001 and E: 5%, ns.). Their results suggested that the present moderate volume 21-week concurrent SE training in previously untrained men optimizes the magnitude of muscle hypertrophy, maximal strength and endurance development, but interferes explosive strength development, compared with strength or endurance training alone.

Holviala et al. (2010) examined the effects of twice weekly total body strength training (ST), endurance cycling (ET), and combined ST and ET (2+2 times a week) (SET) training on the load carrying walking test performance on the treadmill (TM) and changes in neuromuscular and endurance performance during a 21-week training period in aging men. Forty healthy men (54.8 +/- 8.0 years) were divided into 3 training groups (ET n=9, ST n=11, SET n=11) and a control group (C, n=9). Peak oxygen uptake (VO\textsubscript{2}peak), heart rate, and blood lactate concentration were measured before
and after a 21-week training program using a graded TM and maximal incremental bicycle ergometer (BE) tests. Isometric forces, vertical jump, and electromyographic activity of leg extensor and/or forearm flexor (F) muscles were measured before and after training and the TM tests. Increases of 20-21% in strength and of 7-12% in cycling BE VO₂peak occurred in the training groups, whereas the changes of C remained minor. VO₂peak was associated, both before and after training, with TM exercise time in all groups (from r=0.65, p=0.030 to r=0.93, p<0.001). Only SET showed a significant training-induced increase (p=0.011) in exercise time of the TM walking with no significant increase in TM VO₂peak. Their study suggest that in older men ET and SET induced specific increases in BE VO₂peak and ST and SET in strength. However, only SET increased walking exercise time indicating improved load carrying walking performance because of large individual differences in the magnitude of the development of either strength or endurance capacities.

Taipale et al. (2013) compared the effects of mixed maximal strength and explosive strength training with maximal strength training and explosive strength training combined with endurance training over an 8-week training intervention. Male subjects (age 21-45 years) were divided into three strength training groups, maximal (MAX, n = 11), explosive (EXP, 10) and mixed maximal and explosive (MIX, 9), and a circuit training control group, (CON, 7). Strength training one to two times a week was performed concurrently with endurance training three to four times a week. Significant increases in
maximal dynamic strength (1RM), countermovement jump (CMJ), maximal muscle activation during 1RM in MAX and during CMJ in EXP, peak running speed (S (peak)) and running speed at respiratory compensation threshold (RCT(speed)) were observed in MAX, EXP and MIX. Maximal isometric strength and muscle activation, rate of force development (RFD), maximal oxygen uptake and running economy (RE) at 10 and 12 km. hr\(^{-1}\) did not change significantly. No significant changes were observed in CON in maximal isometric strength, RFD, CMJ or muscle activation, and a significant decrease in 1RM was observed in the final 4 weeks of training. RE in CON did not change significantly, but significant increases were observed in S (peak), RCT(speed) and Low volume MAX, EXP and MIX strength training combined with higher volume endurance training over an 8-week intervention produced significant gains in strength, power and endurance performance measures of S (peak) and RCT(speed), but no significant changes were observed between groups.

Santos et al. (2011) compared the effects of an 8-week training period of strength training alone (GR), or combined strength and endurance training (GCOM), followed by 12-weeks of de-training (DT) on body composition, power strength and VO2max adaptations in a schooled group of adolescent girls. Sixty-seven healthy girls recruited from a Portuguese public high school (age: 13.5+1.03 years, from 7\(^{th}\) and 9\(^{th}\) grade) were divided into three experimental groups to train twice a week for 8 wks: GR (n=21), GCOM (n=25) and a control group (GC: n=21; no training program). Anthropometric
parameters variables as well as performance variables (strength and aerobic fitness) were assessed. No significant training-induced differences were observed in 1kg and 3kg medicine ball throw gains (2.7 to 10.8%) between GR and GCOM groups, whereas no significant changes were observed after a DT period in any of the experimental groups. Significant training-induced gains in CMVJ (8 to 12%) and CMSLJ (0.8 to 5.4%) were observed in the experimental groups. Time of 20m significantly decreased (GR: -11.5% and GCOM: -10%) after both treatment periods, whereas only the GR group kept the running speed after a DT period of 12 weeks. After training VO$_2$max increased only slightly for GCOM (4.0%). No significant changes were observed after the DT period in all groups, except to GCOM in CMVJ and CMSLJ. Performing simultaneous strength and endurance training in the same workout does not appear to negatively influence power strength and aerobic fitness development in adolescent girls. They viewed that concurrent strength and endurance training seemed to be an effective, well-rounded exercise program that can be prescribed as a means to improve initial or general strength in healthy school girls. De-training period was not sufficient to reduce the overall training effects.

Ferrete et al. (2013) examined the effects of a 26-week on-field combined strength and high-intensity training on physical performance capacity among prepubertal soccer players who were undetraking a competitive phase of training. Twenty-four prepubertal soccer players between the age of 8-9 years were randomly assigned to 2 groups: a control
(C) (n=13) and an experimental group (S) (n=11). Both groups performed an identical soccer training program, while the S group also performed combined strength and high-intensity training before the soccer specific training. The 15-m sprint time (sec), countermovement vertical jump (CMJ) displacement, Yo-Yo intermittent endurance test (Yo-Yo IE), and Sit & Reach flexibility were each measured before (baseline) and after 9 (T2), 18 (T3) and 26 weeks (post-test) of training. There were no significant differences between the groups in any of the variables tested at baseline. After 26 weeks significant improvements were found in CMJ (6.72%; ES = 0.37), Yo-Yo IE (49.57%, ES = 1.39), and Flexibility (7.26%; ES = 0.37) variables for the S group. Conversely, significant decreases were noted for the CMJ (-10.82%; ES = 0.61) and flexibility (-13.09%; ES = 0.94) variables in C group. A significant negative correlation was found between 15m sprint time and CMJ (r=-0.77) and Yo-Yo IE (r=-0.77) in S group. Specific combined strength and high-intensity training in prepubertal soccer players for 26 weeks produced a positive effect on performance qualities highly specific to soccer. Therefore, they proposed modifications to current training methodology for prepubertal soccer players to include strength and high-intensity training for athlete preparation in this sport.

The investigation of Wilson, et al. (2012) aimed at identifying which components of endurance training (e.g., modality, duration, frequency) are detrimental to resistance training outcomes. They performed meta-analysis of 21 studies was performed with a total of 422 effect sizes (ESs). Criteria for
the study included were (a) compare strength training alone to strength plus 
endurance training (concurrent) or to compare combinations of concurrent 
training; (b) the outcome measures include at least one measure of strength, 
power, or hypertrophy; and (c) the data necessary to calculate ESs must be 
included or available. The mean ES for hypertrophy for strength training was 
1.23; for endurance training, it was 0.27; and for concurrent training, it was 
0.85, with strength and concurrent training being significantly greater than 
endurance training only. The mean ES for strength development for strength 
training was 1.76; for endurance training, it was 0.78; and for concurrent 
training, it was 1.44. Strength and concurrent training was significantly 
greater than endurance training. The mean ES for power development for 
strength training only was 0.91; for endurance training, it was 0.11; and for 
concurrent training, it was 0.55. Significant differences were found between 
all the 3 groups. For moderator variables, resistance training concurrently 
with running, but not cycling, resulted in significant decrements in both 
hypertrophy and strength. Correlational analysis identified significant 
negative relationships between frequency (20.26 to 20.35) and duration (20.29 
to 20.75) of endurance training for hypertrophy, strength, and power. 
Significant relationships (p < 0.05) between ES for decreased body fat and % 
maximal heart rate (r = 20.60) were also found. Their results indicated that 
interference effects of endurance training are a factor of the modality, 
frequency, and duration of the endurance training selected.
Piacentini et al. (2013) evaluated the effects of two different strength training protocols on RE and strength parameters in a group of regularly training master marathon runners. Sixteen participants were randomly assigned to a maximal strength training program (MST; n = 6; 44.2 ± 3.9 years), a resistance training (n = 5; 44.8 ± 4.4 years), and a control group (n = 5; 43.2 ± 7.9 years). Before and after the experimental period, resting metabolic rate, body composition, 1 repetition maximum (1RM), squat jump, countermovement jump, and RE were evaluated. The MST group showed significant increases (p < 0.05) in 1RM (+16.34%) and RE (+6.17 %) at marathon pace. No differences emerged for the other groups (p > 0.05). Anthropometric data were unchanged after the training intervention (p > 0.05). Taken together, the results of their study indicated that master endurance athletes seemed to benefit from concurrent strength and endurance training because the rate of force development may be crucial for RE improvement, one of the major determinants of endurance performance.

Chtara et al. (2008) examined the influence of the sequence order of high-intensity endurance training and circuit training on changes in muscular strength and anaerobic power. Forty-eight physical education students (ages, 21.4 +/- 1.3 years) were assigned to 1 of 5 groups: no training controls (C, n = 9), endurance training (E, n = 10), circuit training (S, n = 9), endurance before circuit training in the same session, (E+S, n = 10), and circuit before endurance training in the same session (S+E, n = 10). Subjects performed 2 sessions per week for 12 weeks. Resistance-type circuit training targeted
strength endurance (weeks 1-6) and explosive strength and power (weeks 7-12). Endurance training sessions included 5 repetitions run at the velocity associated with VO₂ max (VO₂ max) for a duration equal to 50% of the time to exhaustion at VO₂ max; recovery was for an equal period at 60% VO₂ max. Maximal strength in the half squat, strength endurance in the 1-leg half squat and hip extension, and explosive strength and power in a 5-jump test and countermovement jump were measured pre- and post-testing. No significant differences were shown following training between the S+E and E+S groups for all exercise tests. However, both S+E and E+S groups improved less than the S group in 1 repetition maximum (p < 0.01), right and left 1-leg half squat (p < 0.02), 5-jump test (p < 0.01), peak jumping force (p < 0.05), peak jumping power (p < 0.02), and peak jumping height (p < 0.05). The intrasession sequence did not influence the adaptive response of muscular strength and explosive strength and power. Circuit training alone induced strength and power improvements that were significantly greater than when resistance and endurance training were combined, irrespective of the intrasession sequencing.

Taipale et al. (2010) examined effects of periodized maximal versus explosive strength training and reduced strength training, combined with endurance training, on neuromuscular and endurance performance in recreational endurance runners. Subjects first completed 6 weeks of preparatory strength training. Then, groups of maximal strength (MAX, n=11), explosive strength (EXP, n=10) and circuit training (C, n=7)
completed an 8-week strength training intervention, followed by 14 weeks of reduced strength training. Maximal strength (1RM) and muscle activation (EMG) of leg extensors, countermovement jump (CMJ), maximal oxygen uptake (VO_max), velocity at VO_max (v VO_max) running economy (RE) and basal serum hormones were measured. 1RM and CMJ improved (p<0.05) in all groups accompanied by increased EMG in MAX and EXP (p<0.05) during strength training. Minor changes occurred in VO_max, but v VO_max improved in all groups (p<0.05) and RE in EXP (p<0.05). During reduced strength training 1RM and EMG decreased in MAX (p<0.05) while v VO_max in MAX and EXP (p<0.05) and RE in MAX (p<0.01) improved. Serum testosterone and cortisol remained unaltered. Maximal or explosive strength training performed concurrently with endurance training was more effective in improving strength and neuromuscular performance and in enhancing v VO_max and RE in recreational endurance runners than concurrent circuit and endurance training.

Millet et al. (2002) examined the influence of a concurrent heavy weight training (HWT) plus endurance training on running economy (CR) and the VO_max kinetics in endurance athletes. They selected fifteen triathletes, they were assigned to endurance+strength (ES) or endurance-only (E) training for 14 wk. The training program was similar, except ES performed two HWT sessions a week. Before and after the training period, the subjects performed 1) an incremental field running test for determination of VO_max and the velocity associated (VVO2max), the second ventilatory threshold (VT2); 2) a
3000-m run at constant velocity, calculated to require 25% of the difference between VO\textsubscript{2}max and VT\textsubscript{2}, to determine CR and the characteristics of the VO\textsubscript{2} kinetics; 3) maximal hopping tests to determine maximal mechanical power and lower-limb stiffness; 4) maximal concentric lower-limb strength measurements. Their result showed that after the training period, maximal strength were increased (P < 0.01) in ES but remained unchanged in E. Hopping power decreased in E (P < 0.05). After training, economy (P < 0.05) and hopping power (P < 0.001) were greater in ES than in E. VO\textsubscript{2}max, leg hopping stiffness and the VO\textsubscript{2} kinetics were not significantly affected by training either in ES or E. Additional HWT led to improved maximal strength and running economy with no significant effects on the VO\textsubscript{2} kinetics pattern in heavy exercise.

Mikkola et al. (2007) studied the effects of concurrent explosive strength and endurance training on aerobic and anaerobic performance and neuromuscular characteristics, 13 experimental (E) and 12 control (C) young (16 - 18 years) distance runners trained for eight weeks with the same total training volume but 19% of the endurance training in E was replaced by explosive training. Maximal speed of maximal anaerobic running test and 30-m speed improved in E by 3.0 +/- 2.0% (p < 0.01) and by 1.1 +/- 1.3% (p < 0.05), respectively. Maximal speed of aerobic running test, maximal oxygen uptake and running economy remained unchanged in both groups. Concentric and isometric leg extension forces increased in E but not in C. E also improved (p < 0.05) force-time characteristics accompanied by increased (p <
0.05) rapid neural activation of the muscles. The thickness of quadriceps femoris increased in E by 3.9 +/- 4.7% (p < 0.01) and in C by 1.9 +/- 2.0% (p < 0.05). The concurrent explosive strength and endurance training improved anaerobic and selective neuromuscular performance characteristics in young distance runners without decreases in aerobic capacity, although almost 20% of the total training volume was replaced by explosive strength training for eight weeks. The neuromuscular improvements could be explained primarily by neural adaptations.

Jones et al. (2013) stated that interference effect attenuates strength and hypertrophic responses when strength and endurance training are conducted concurrently; however, the influence of training frequency upon these responses remain unclear when varying ratios of concurrent strength and endurance training are performed. Therefore the purpose of the study was to examine the strength, limb girth and neuromuscular adaptations to varying ratios of concurrent strength and endurance training. Twenty four men with >2 years resistance training experience completed 6 weeks of 3 d·wk of i) strength training (ST), ii) concurrent strength and endurance training ratio 3:1 (CT3), iii) concurrent strength and endurance training ratio 1:1 (CT1) or iv) no training (CON) in an isolated limb model. Assessments of maximal voluntary contraction via isokinetic dynamometry leg extensions (MVC), limb girth and neuromuscular responses via electromyography (EMG) were conducted at baseline, mid-intervention and post-intervention. Following training, ST and CT3 conditions elicited greater MVC increases than CT1 and
CON conditions (P ≤ 0.05). ST resulted in significantly greater increases in limb girth than both CT1 and CON conditions (P = 0.05 and 0.004 respectively). CT3 induced significantly greater limb girth adaptations than CON condition (P = 0.04). No effect of time or intervention was observed for EMG (P > 0.05). In conclusion greater frequencies of endurance training performed increased the magnitude of the interference response on strength and limb girth responses following 6 weeks of 3-d·of training. Therefore, the frequency of endurance training should remain low if the primary focus of the training intervention is strength and hypertrophy.

Martinmäki et al. (2008) evaluated the effects of low-dose endurance training on autonomic HR control. We assessed the heart rate variability (HRV) of 11 untrained male subjects (36.8 +/- 7.2 years) at rest and during an incremental maximal aerobic exercise test prior to a 7-week preparatory period and prior to and following a 14-week endurance training period, including a low to high intensity exercise session twice a week. Total (0.04-1.2 Hz), low (0.04-0.15 Hz) and high (0.15-1.2 Hz) frequency power of HRV were computed by short-time Fourier transform. The preparatory period induced no change in aerobic power or HRV. The endurance training period increased peak aerobic power by 12% (P < 0.001), decreased the HR (P < 0.01) and increased all HRV indices (P < 0.05-0.01) at absolute submaximal exercise intensities, but not at rest. They concluded that low-dose endurance training enhanced vagal control during exercise, but did not alter resting vagal HR control.
Karavirta et al. (2011) examined the possible interference of combined strength and endurance training on neuromuscular performance and skeletal muscle hypertrophy in previously untrained 40-67-year-old men. Maximal strength and muscle activation in the upper and lower extremities, maximal concentric power, aerobic capacity and muscle fiber size and distribution in the vastus lateralis muscle were measured before and after a 21-week training period. Ninety-six men [mean age 56 (SD 7) years] completed high-intensity strength training (S) twice a week, endurance training (E) twice a week, combined training (SE) four times per week or served as controls (C). SE and S led to similar gains in one repetition maximum strength of the lower extremities [22 (9)% and 21 (8)%, P<0.001], whereas E and C showed minor changes. Cross-sectional area of type II muscle fibers only increased in S [26 (22)%, P=0.002], while SE showed an inconsistent, non-significant change [8 (35)%, P=0.73]. Combined training may interfere with muscle hypertrophy in aging men, despite similar gains in maximal strength between the strength and the combined training groups.

Horne et al. (1997) determined the effect of concurrent resistance and endurance training on tumor necrosis factor alpha (TNF alpha), urinary free cortisol, strength [one-repetition maximum (1 RM)], and maximal oxygen consumption (VO_{2}max). They selected forty-five healthy female (n = 18) and male (n = 27) subjects who had not formally trained for at least 6 months prior to the study but were physically active. The mean +/- SD age, height, and body mass for all subjects were 22.3 +/- 3.3 years, 1.76 +/- 9.32 m, and
73.4 +/- 11.6 kg, respectively. The subjects were randomly assigned to four groups: strength training only (S), n = 10; endurance training only (E), n = 11; combined strength and endurance training (SE), n = 13; and a control group (C), n = 10. The S and E groups performed progressively overloaded training sessions three times per week for 12 weeks. The SE group completed the same strength and endurance training programs on different days (i.e., 6 days/week) for 12 weeks. Serum levels of TNF alpha, urinary free cortisol, 1 RM, and VO₂max were measured before and after 6 and 12 weeks of training.

Their result of their study showed that significant increases in leg press and knee extension 1 RM occurred after training in both S and SE groups, but the relative gains in knee extension 1 RM were greater in the S group. Similar increases in Vo2max were observed in groups E and SE (p < 0.05). Cortisol was significantly increased in the SE group for women and decreased in the E group for men after training. TNF alpha was significantly elevated in the women of group E after training. No correlation was observed between urinary free cortisol and TNF alpha with training. They concluded that their results indicate that a partial interference effect of compromised strength gains in unilateral knee extension of the men occurred after concurrent strength and endurance training that could not be attributed to an interaction between cortisol and TNF alpha in response to this type of exercise.

LeMura et al. (2000) evaluated the effects of various modes of training on the time-course of changes in lipoprotein-lipid profiles in the blood, cardiovascular fitness, and body composition after 16 weeks of training and 6
weeks of detraining in young women. A group of 48 sedentary but healthy women [mean age 20.4 (SD 1) years] were matched and randomly placed into a control group (CG, n = 12), an aerobic training group (ATG, n = 12), a resistance training group (RTG, n = 12), or a cross-training group that combined both aerobic and resistance training (XTG, n = 12). The ATG, RTG and XTG trained for 16 weeks and were monitored for changes in blood concentrations of lipoprotein-lipids, cardiovascular fitness, body composition, and dietary composition throughout a 16 week period of training and 6 weeks of detraining. The ATG significantly reduced blood concentrations of triglycerides (TRI) (P < 0.05) and significantly increased blood concentrations of high-density lipoprotein-cholesterol (HDL-C) after 16 weeks of training. The correlation between percentage fat and HDL-C was 0.63 (P < 0.05), which explained 40% of the variation in HDL-C, while the correlation between maximal oxygen uptake (VO\textsubscript{2max}) and HDL-C was 0.48 (P < 0.05), which explained 23% of the variation in HDL-C. The ATG increased VO\textsubscript{2max} by 25% (P < 0.001) and decreased percentage body fat by 13% (P < 0.05) after 16 weeks. Each of the alterations in the ATG had disappeared after the 6 week detraining period. The concentration of total cholesterol (TC), TRI, HDL-C and low density lipoprotein-cholesterol in the blood did not change during the study in RTG, XTG and CG. The RTG increased upper and lower body strength by 29% (P < 0.001) and 38%, respectively. The 6 week detraining strength values obtained in RTG were significantly greater than those obtained at baseline. The XTG increased upper and lower body strength
by 19% (P < 0.01) and 25% (P < 0.001), respectively. The 6 week detraining strength values obtained in XTG were significantly greater than those obtained at baseline. The RTG, XTG and CG did not demonstrate any significant changes in either VO$_2$max, or body composition during the training and detraining periods. The results of their study suggested that aerobic-type exercise improves lipoprotein-lipid profiles, cardiorespiratory fitness and body composition in healthy, young women, while resistance training significantly improved upper and lower body strength only.

Wong et al. (2008) studied the effects of a 12-week twice weekly additional exercise training, which comprised a combination of circuit-based resistance training and aerobic exercises, in additional to typical physical education sessions, on aerobic fitness, body composition and serum C-reactive protein (CRP) and lipids were analysed in 13- to 14-year-old obese boys contrasted with a control group. They selected exercise group (EG, n = 12) and control group (CG, n = 12) participated in the typical 2 sessions of 40-minute physical education (PE) per week in schools, but only EG participated in additional 2 sessions per week of 45 to 60 minutes per session of exercise training, which comprised a combination of circuit-based resistance training and aerobic exercises maintained at 65% to 85% maximum heart rate (HRmax = 220 - age). Body composition was measured using dual energy X-ray absorptiometry (DEXA). Fasting serum CRP and blood lipids were analysed pre- and postexercise programme. Aerobic fitness was measured by an objective laboratory submaximal exercise test, PWC170
(Predicted Work Capacity at HR 170 bpm). The result of their study showed that exercise training significantly improved lean muscle mass, body mass index, fitness, resting HR, systolic blood pressure and triglycerides in EG. Serum CRP concentrations were elevated at baseline in both groups, but training did not result in a change in CRP levels. In the CG, body weight increased significantly at the end of the 12-week period. They concluded that, their study supports the value of an additional exercise training programme, beyond the typical twice weekly physical education classes, to produce physiological benefits in the management of obesity in adolescents, including prevention of weight gain.

Cicioni-Kolsky et al. (2013) examined the effect of two different interval training programs-high-intensity interval training (HIT) and supramaximal interval training (SMIT)-on measures of sprint and endurance performance. Physically active individuals (Females: n=32; age 19.3, s=2.2 years; mass 67.6, s=9.1 kg; stature 172.7, s=6.6 cm. Males: n=23; age 20.0, s=2.7 years; mass 71.3, s=8.3 kg; stature 176.6, s=5.8 cm) completed pre-testing that comprised (1) 3000 m time-trial, (2) 40 m sprint, and (3) repeated sprint ability (RSA-6×40 m sprints, 24 s active recovery) performance. Participants were then matched for average 3000 m running velocity (AV) and randomly assigned to one of three groups: (i) HIT, n=19, 4 min at 100% AV, 4 min passive recovery, 4-6 bouts per session; (ii) SMIT, n=20, 30 s at 130% AV, 150 s passive recovery, 7-12 bouts per session; and (iii) control group, n=16, 30 min continuous running at 75% AV. Groups trained three
times per week for six weeks. When time to complete each test were
compared among groups: (i) improvements in 3000 m time trial performance
were greater following SMIT than continuous running, and (ii) improvements
in 40 m sprint and RSA performance were greater following SMIT than HIT
and continuous running. In addition, a gender effect was observed for the
3000 m time trial only, where females changed more following the training
intervention than males. They summarised that for concurrent improvements in
endurance, sprint and repeated sprint performance, SMIT provides the
greatest benefits for physically active individuals.

Chtara et al. (2005) examined the effects of the sequencing order of
individualised intermittent endurance training combined with muscular
strengthening on aerobic performance and capacity. They selected 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\(\text{VO}_2\)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\(\text{VO}_2\)max; (3) a time to exhaustion test
(t(lim)) at 100% v\(\text{VO}_2\)max; (4) a maximal cycling laboratory test to assess
\(\text{VO}_2\)max. Their result showed that 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 vVO₂ max (p < 0.01); 13.7%, 10.1%, 11.0%, and 6.4% for VO₂ max (ml/kg(0.75)/min) (p < 0.05) respectively. Similar significant results were observed for t(lim) and the second ventilatory threshold (%VO₂ max). They concluded that 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.

Wood et al. (2001) compared the fitness benefits of concurrent CVT and RT with those attained through an equivalent duration of CVT or RT alone. They selected thirty-six participants (ages 60-84) were assigned to a control group or to one of three exercise treatment groups. The treatment groups exercised three times per week for 12 wk using RT (N = 11), CVT (N = 10), or CVT and RT (BOTH, N = 9). Pre- and post-training, participants performed a submaximal exercise test (GXT), five repetition-maximum strength tests (5RM), and the AAHPERD functional fitness test for older adults. Their study showed that all exercise treatment groups revealed lower resting heart rate and rate-pressure product; lower exercise diastolic blood pressure and rating of perceived exertion; increased GXT duration; increased leg, back, and shoulder 5RM scores; and improved AAHPERD flexibility,
coordination, and cardiovascular endurance scores. The exercise treatment groups responded differently on the following: RT and BOTH enhanced arm and chest strength more than CVT; and BOTH enhanced AAHPERD strength and agility scores more than CVT or RT. They concluded that concurrent CVT and RT is as effective in eliciting improvements in cardiovascular fitness and 5RM performance as CVT or RT, respectively. Moreover, incorporating both CVT and RT in exercise programs for older adults may be more effective in optimizing aspects of functional fitness than programs that involve only one component.

Karavirta et al. (2013) studied the effects of combined strength and endurance training compared with those of endurance training or strength training alone on heart rate (HR) complexity and traditional HR variability indices were examined in middle-aged women. 90 previously untrained female volunteers between the age of 40 and 65 years completed a 21 week progressive training period of either strength training, endurance training or their combination, or served as controls. Continuous HR time series were obtained during supine rest and submaximal steady state exercise. The complexity of HR dynamics was assessed using multiscale entropy analysis. In addition, standard time and frequency domain measures were also computed. Endurance training led to increases in HR complexity and selected time and frequency domain measures of HR variability (P<0.01) when measured during exercise. Combined strength and endurance training or strength training alone did not produce significant changes in HR dynamics.
Inter-subject heterogeneity of responses was particularly noticeable in the combined training group. At supine rest, no training-induced changes in HR parameters were observed in any of the groups. Their findings emphasized the potential utility of endurance training in increasing the complex variability of HR in middle-aged women. They also stated that studies are needed to explore the combined endurance and strength training adaptations and possible gender and age related factors, as well as other mechanisms, that may mediate the effects of different training regimens on HR dynamics.

Karavirta et al. (2009) examined the effects of combining endurance and strength training compared with endurance or strength training alone on HR dynamics and physical fitness in older previously untrained men aged 40-67 yr. They selected subjects randomly and were randomized into endurance training (E, n = 23), strength training (S, n = 25), combined endurance and strength training (ES, n = 29), or control group (C, n = 16). Short-term fractal scaling exponent (alpha1) and spectral HRV were analyzed from maximal aerobic cycling tests and during supine rest, and leg extension one repetition maximum strength was measured. Their findings showed that aerobic capacity and maximal strength increased in the training groups performing endurance and/or strength training, respectively. Only ES showed a decrease after training in fractal HR behavior during exercise, and the difference was significant between groups (P = 0.019). During supine rest, alpha1 only decreased significantly (P = 0.039) in ES from 1.18 (SD = 0.20) to 1.11 (SD = 0.21). The decrease in alpha1 at rest from 1.21 (SD = 0.19) to 1.11 (SD =
0.22) also approached significance (P = 0.061) in E. Changes in spectral measures of HRV were minor during the study period and only occurred during exercise. They concluded that fractal HR dynamics were improved more by combining strength training with endurance training in our older men compared with endurance training alone, although strength training alone produced no changes in fractal HR behavior. The synergistic effect in fractal HR behavior occurred regardless of changes in aerobic capacity.

Izquierdo et al. (2005) studied the effects of a 16-week training period (2 days per week) of resistance training alone (upper- and lower-body extremity exercises) (S), endurance training alone (cycling exercise) (E), or combined resistance (once weekly) and endurance (once weekly) training (SE) on muscle mass, maximal strength (1RM) and power of the leg and arm extensor muscles, maximal workload (W(max)) and submaximal blood lactate accumulation by using an incremental cycling test were examined in middle-aged men [S, n = 11, 43 (2) years; E, n = 10, 42 (2) years; SE, n = 10, 41 (3) years]. During the early phase of training (from week 0 to week 8), the increase 1RM leg strength was similar in both S (22%) and SE (24%) groups, while the increase at week 16 in S (45%) was larger (P < 0.05) than that recorded in SE (37%). During the 16-week training period, the increases in power of the leg extensors at 30% and 45% of 1RM were similar in all groups tested. However, the increases in leg power at the loads of 60% and 70% of 1RM at week 16 in S and SE were larger (P < 0.05) than those recorded in E, and the increase in power of the arm extensors was larger (P < 0.05) in S than
in SE (P < 0.05) and E (n.s.). No significant differences were observed in the magnitude of the increases in W(max) between E (14%), SE (12%) and E (10%) during the 16-week training period. During the last 8 weeks of training, the increases in W(max) in E and SE were greater (P < 0.05-0.01) than that observed in S (n.s.). No significant differences between the groups were observed in the training-induced changes in submaximal blood lactate accumulation. Significant decreases (P < 0.05-0.01) in average heart rate were observed after 16 weeks of training in 150 W and 180 W in SE and E, whereas no changes were recorded in S. Their data indicated that low-frequency combined training of the leg extensors in previously untrained middle-aged men results in a lower maximal leg strength development only after prolonged training, but does not necessarily affect the development of leg muscle power and cardiovascular fitness recorded in the cycling test when compared with either mode of training alone.

Sedano et al. (2013) aimed at determining which mode of concurrent strength-endurance training might be the most effective at improving running performance in highly trained runners. Eighteen well-trained male runners (age 23.7 ± 1.2 years) with a maximal oxygen consumption (VO2max) more than 65 ml·kg⁻¹·min⁻¹ were randomly assigned into 1 of the 3 groups: Endurance-only Group (n = 6), who continued their usual training, which included general strength training with Thera-band latex-free exercise bands and endurance training; Strength Group (SG; n = 6) who performed combined resistance and plyometric exercises and endurance training; Endurance-SG
(ESG; n = 6) who performed endurance-strength training with loads of 40% and endurance training. The study comprised 12 weeks of training in which runners trained 8 times a week (6 endurance and 2 strength sessions) and 5 weeks of detraining. The subjects were tested on 3 different occasions (countermovement jump height, hopping test average height, 1 repetition maximum, running economy (RE), VO\textsubscript{2}\text{max}, maximal heart rate [HR\text{max}], peak velocity (PV), rating of perceived exertion, and 3-km time trial were measured). Findings revealed significant time × group interaction effects for almost all tests (p < 0.05). They concluded that concurrent training for both SG and ESG groups led to improved maximal strength, RE, and PV with no significant effects on the VO\textsubscript{2} kinetics pattern. The SG group also seems to show improvements in 3-km time trial tests.

Corrick \textit{et al.} (2013) studied whether combined (aerobic and anaerobic) training decreases blood pressure (BP) and improves vascular properties. Seventy-nine postmenopausal women were randomly assigned to 3 groups that trained at different frequencies. Maximum oxygen uptake, body composition, BP, and arterial elasticity were evaluated prior to training and after 16 weeks of training. There was a significant time effect (decrease) for resting systolic BP (SBP) and rate pressure product. Exercise SBP, diastolic BP (DBP), heart rate, and RPP also decreased. Changes in total vascular impedance were related to SBP and changes in systemic vascular resistance were related to changes in DBP independent of body composition changes. Their findings suggested that combined training reduces SBP and improves
vascular properties and that combined training 1 d/wk decreases BP similar to more frequent combined training. Training-induced changes in arterial resistance and impedance may be involved in inducing changes in BP.

Figueroa et al. (2011) tested the hypothesis that combined circuit RE and EE training would improve baPWV, blood pressure (BP), and muscle strength in postmenopausal women. Twenty-four postmenopausal women (age 47-68 y) were randomly assigned to a "no exercise" control (n = 12) or to combined exercise training (EX; n = 12) group. The EX group performed concurrent circuit RE training followed by EE training at 60% of the predicted maximal heart rate (HR) 3 days per week. Brachial systolic BP, diastolic BP, mean arterial pressure, baPWV, HR, and dynamic and isometric muscle strength were measured before and after the 12-week study. The result of their study mean ± SE baPWV (-0.8 ± 0.2 meters/s), systolic BP (-6.0 ± 1.9 mm Hg), diastolic BP (-4.8 ± 1.7 mm Hg), HR (-4.0 ± 1.0 beats/min), and mean arterial pressure (-5.1 ± 1.6 mm Hg) decreased (P < 0.05), whereas dynamic leg strength (5.1 ± 1.0 vs 0.6 ± 1.0 kg for the EX and control groups, respectively) and isometric handgrip strength (2.8 ± 0.7 vs -0.6 ± 1.2 kg) increased (P < 0.05) in the EX group but not in the control group. Their findings indicate that a 12-week moderate-intensity combined circuit RE and EE training improves arterial stiffness, hemodynamics, and muscle strength in previously sedentary postmenopausal women. Their study provided evidence that combined training may have important health implications for the prevention of hypertension and frailty in postmenopausal women.
Copeland et al. (1996) examined the hemodynamic effect of a 6-week training period of aerobic exercise or weight training. Twenty deconditioned healthy males ages 18-36, self-selected a training regimen. The aerobic group exercised 30 min/day, 4 times each week to achieve 60-80% maximal heart rate. The resistance group lifted weights at 65-80% maximal voluntary contraction; 3-4 sets of 8-12 repetitions; 3 day/week using large muscle groups. Hemodynamic measurements of heart rate, BP, venous capacitance, forearm blood flow, and vascular resistance were made at baseline and week 6 by plethysmography and analyzed by 2-way ANOVA. The groups showed no differences in baseline characteristics. A training effect was confirmed by a decrease in resting heart rate in the aerobic group (71.5 +/- 4.4 to 64.5 +/- 3.7, beats per minute, P = 0.004), and an increase in total work capacity in the weight lifting group (6231 vs 7508, P = 0.01). Forearm blood flow increased similarly in both groups, averaging 17% (3.5 +/- 0.2 vs 4.2 +/- 0.2 ml 100 g/min, P = 0.03), while forearm vascular resistance fell 19% (28.8 +/- 1.7 vs 24.3 +/- 1.7 mm Hg/ml/min 100 g, P = 0.08). The main differences between the groups after training was found in their response to isometric stress (1/3 maximal handgrip). The weight-lifting group had a greater increase of forearm blood flow and venous capacitance, less increase in systolic BP (SBP) and a greater fall of forearm vascular resistance, (P < 0.05) while the aerobic group had less increase in SBP and heart rate (P < 0.04) but no significant change of forearm hemodynamics. They concluded that both aerobic and repetitive weight programs have short term favorable effects on
resting forearm BP and resistance. The exercise programs differ in altering the individual's physiologic response to subsequent isometric stress. However, exercise training of longer duration or greater intensity or frequency could alter these results.

Murray, Delaney and Bell (2006) tested the hypothesis that the cardiovascular benefits of training would occur progressively over several weeks and would diminish over a similar time course on termination of training. In all, 17 young, healthy men undertook a 4-week programme of cycle ergometry (30 min at 60% VO2peak 3-4 times/week) and 13 subjects matched for age, body mass index and fitness acted as controls. Resting BP and rate-pressure product (RPP) had fallen significantly after only 1 week's training and reached a nadir after 2 weeks training. At this time, BP had fallen from 121+/−7/66+/−6 to 110+/−5/57+/−7 mmHg and resting RPP had fallen from 85+/−10 to 71+/−9 (mmHg (beats min−1))-2 (P<0.001 each). In parallel, resting forearm conductance had risen from 0.026+/−0.010 to 0.052+/−0.029 (ml min−1) 100 ml−1 mmHg−1 and peak reactive hyperaemia following 3 min brachial artery occlusion was increased from 0.105+/−0.031 to 0.209+/−0.041 (ml min−1) 100 ml-1 mmHg−1 (P<0.001 each). No significant further circulatory changes occurred over weeks 3-4 of training. On cessation of training, all values returned to pretraining levels within between 1 (SBP, RPP, vascular conductance) and 2 (DBP, MAP, heart rate, reactive hyperaemia) weeks. The results indicated that the optimal cardiovascular benefits of
moderate exercise occur rapidly. At least with short training programmes, the benefits regress once training stops just as quickly as they appeared.

Shing et al. (2012) aimed to determine the response of plasma adiponectin concentrations to acute exercise following two different training programs and to determine the influence of the training on body composition. Seven state level representative rowers [age: 19 ± 1.2 years (mean ± SD), height: 1.77 ± 0.10 m, body mass: 74.0 ± 10.7 kg, VO₂peak 62.1 ± 7.0 mL·kg·min] participated in the double-blind, randomized, cross-over investigation. Rowers performed an incremental graded exercise test before and after completing four weeks of high-intensity interval ergometer training and four weeks of traditional ergometer rowing training. Rowers' body composition was assessed at baseline and following each training program. Significant increases in plasma adiponectin concentration occurred in response to maximal exercise after completion of the high-intensity interval training (p = 0.016) but not following traditional ergometer rowing training (p = 0.69). The high-intensity interval training also resulted in significant increases in mean four-minute power output (p = 0.002) and peak (p = 0.05), as well as a decrease in body fat percentage (p = 0.022). Mean four-minute power output, peak and body fat percentage were not significantly different following four weeks of traditional ergometer rowing training (p > 0.05). Four weeks of high-intensity interval training is associated with an increase in adiponectin concentration in response to maximal exercise and a reduction in body fat percentage. The potential for changes in adiponectin concentration to
reflect positive training adaptations and athlete performance level should be further explored.

Song et al. (2012) tested the hypothesis that 12 weeks of air board exercise would enhance cardiorespiratory fitness and vascular compliance and reduce % body fat in obese Korean boys. Twenty-two obese boys (>30% body fat) were studied. They were divided into 2 groups- an aerobic exercise group (N.=12), which trained 3 days/week, 50 min/day for 12 weeks, and a control group (N.=10). Control subjects only performed activities involved in their physical education classes. Body composition, cardiovascular fitness (20 m multistage endurance test performance) and vascular compliance were assessed before and after the completion of exercise training. The result of their study showed % changes in body fat (-4.6±0.9 vs. -1.5±1.0%), fat mass (-5.4±1.5 vs. -0.1±1.6%) and performance on the cardiovascular fitness test (14.3±2.5 vs. 3.7±1.6%) were greater in the exercise group than in the controls. Compared to controls, % increases in vascular compliance were greater in the arms and legs of the exercise group (left arm: 2.8±0.5 vs. 2.0±2.9%; left leg: 2.6±1.2 vs. -0.5±2.0%; right arm: 2.9±0.9 vs. 0.3±2.9%; right leg: 4.8±1.8 vs. 1.5±2.0%). They concluded that exercise training can reduce % body fat and enhance vascular compliance in obese male adolescents; changes that may reduce the risk for later development of cardiovascular disease.

Kern and Robinson (2011) examined the effectiveness of β-alanine as an ergogenic aid in tests of anaerobic power output after 8 weeks of high-
intensity interval, repeated sprint, and resistance training in previously trained collegiate wrestlers (WR) and football (FB) players. Twenty-two college WRs (19.9 ± 1.9 years, age ± SD) and 15 college FB players (18.6 ± 1.5 years) participated in this double-blind, placebo-controlled study. Each subject ingested either 4 g·d⁻¹ β-alanine or placebo in powdered capsule form. Subjects were tested pre and posttreatment in timed 300-ya shuttle, 90° flexed-arm hang (FAH), body composition, and blood lactate after 300-ya shuttle. Although not statistically significant (p > 0.05) subjects taking β-alanine achieved more desirable results on all tests compared to those on placebo. Performance improvements were greatest in the FB supplement group, decreasing 300 shuttle time by 1.1 seconds (vs. 0.4-second placebo) and increasing FAH (3.0 vs. 0.39 seconds). The wrestlers, both placebo and supplement, lost weight (as was the goal, i.e., weight bracket allowance); however, the supplement group increased lean mass by 1.1 lb, whereas the placebo group lost lean mass (−0.98 lb). Both FB groups gained weight; however, the supplement group gained an average 2.1-lb lean mass compared to 1.1 lb for placebo. β-Alanine appears to have the ability to augment performance and stimulate lean mass accrual in a short amount of time (8 weeks) in previously trained athletes. Training regimen may have an effect on the degree of benefit from β-alanine supplementation.

Sandbakk et al. (2012) tested whether a long duration of aerobic high-intensity interval training is more effective than shorter intervals at a higher intensity in highly trained endurance athletes. The sample comprised of 12
male and 9 female, national level junior cross-country skiers (age: 17.5±0.4 yr, maximal oxygen uptake (VO$_2$max): 67.4±7.7 ml/min/kg), who performed 8-week baseline and 8-week intervention training periods on dry land. During the intervention period, a short-interval group (n=7) added two weekly sessions with short duration intervals (2- to 4-min bouts, total duration of 15-20 min), a long-interval group (n=7) added two weekly sessions with long duration intervals (5- to 10-min bouts, total duration of 40-45 min). The interval sessions were performed with the athletes' maximal sustainable intensity. A control group (n=7) added two weekly sessions with low-intensity endurance training at 65-74% of maximal heart rate. Before and after the intervention period, the skiers were tested for time-trial performance on 12 km roller-ski skating and 7 km hill run. VO$_2$max and oxygen uptake at the ventilatory threshold (VO$_2$VT) were measured during treadmill running. After the intervention training period, the long-interval group improved 12 km roller-ski, 7 km hill run, VO$_2$max and VO$_2$VT by 6.8±4.0%, 4.8±2.6%, 3.7±1.6% and 5.8±3.3%, respectively, from pre to post-testing, and improved both performance tests and VO$_2$VT when compared to the short-interval group and the control group (all p<0.05). The short-interval group improved VO$_2$max by 3.5±3.2% from pre to post-testing (p<0.05), whereas the control group remained unchanged. As hypothesized, a long duration of aerobic high-intensity interval training improved endurance performance and oxygen uptake at the ventilatory threshold more than shorter intervals at a higher intensity.
Laursen & Jenkins (2002) stated that the physiological adaptations that occur following endurance training in previously sedentary and recreationally active individuals are relatively well understood, the adaptations to training in already highly trained endurance athletes remain unclear. While significant improvements in endurance performance and corresponding physiological markers are evident following submaximal endurance training in sedentary and recreationally active groups, an additional increase in submaximal training (i.e. volume) in highly trained individuals does not appear to further enhance either endurance performance or associated physiological variables [e.g. peak oxygen uptake (VO$_2$peak), oxidative enzyme activity]. It seems that, for athletes who are already trained, improvements in endurance performance can be achieved only through high-intensity interval training (HIT). The limited research which has examined changes in muscle enzyme activity in highly trained athletes, following HIT, has revealed no change in oxidative or glycolytic enzyme activity, despite significant improvements in endurance performance (p < 0.05). Instead, an increase in skeletal muscle buffering capacity may be one mechanism responsible for an improvement in endurance performance. Changes in plasma volume, stroke volume, as well as muscle cation pumps, myoglobin, capillary density and fibre type characteristics have yet to be investigated in response to HIT with the highly trained athlete. Information relating to HIT programme optimisation in endurance athletes is also very sparse. Preliminary work using the velocity at which VO$_2$max is achieved (Vmax) as the interval intensity, and fractions (50
to 75%) of the time to exhaustion at V(max) (T(max)) as the interval duration has been successful in eliciting improvements in performance in long-distance runners. However, V(max) and T(max) have not been used with cyclists. Instead, HIT programme optimisation research in cyclists has revealed that repeated supramaximal sprinting may be equally effective as more traditional HIT programmes for eliciting improvements in endurance performance. Further examination of the biochemical and physiological adaptations which accompany different HIT programmes, as well as investigation into the optimal HIT programme for eliciting performance enhancements in highly trained athletes is required.

Støren et al. (2012) investigated to what extent more high aerobic intensity interval training (HAIT) and reduced training volume would influence maximal oxygen uptake (VO$_2$max) and time trial (TT) performance in an elite national cyclist in the preseason period. The cyclist was tested for VO$_2$max, cycling economy (C(c)), and TT performance on an ergometer cycle during 1 year. Training was continuously logged using heart rate monitor during the entire period. Total monthly training volume was reduced in the 2011 preseason compared with the 2010 preseason, and 2 HAIT blocks (14 sessions in 9 days and 15 sessions in 10 days) were performed as running. Between the HAIT blocks, 3 HAIT sessions per week were performed as cycling. From November 2010 to February 2011, the cyclist reduced total average monthly training volume by 18% and cycling training volume by 60%. The amount of training at 90-95% HRpeak increased by 41%. VO2max
increased by 10.3% on ergometer cycle. TT performance improved by 14.9%. C(c) did not change. In conclusion, preseason reduced total training volume but increased amount of HAIT improved VO2max and TT performance without any changes in C(c). These improvements on cycling appeared despite that the HAIT blocks were performed as running. Reduced training time, and training transfer from running into improved cycling form, may be beneficial for cyclists living in cold climate areas.

Zuniga et al. (2011) compared 4 interval training (IT) sessions with different intensities and durations of exercise to determine the effect on mean VO₂, total VO₂, and duration of exertion ≥95% maximum power output (MPO), and the effects on biomarkers of fatigue such as blood-lactate concentration (BLC) and rating of perceived exertion. The subjects were 12 recreationally competitive male (n = 7, mean ± SD age = 26.2 ± 3.9 years) and female (n = 5, mean ± SD age = 27.6 ± 4.3 years) triathletes. The selected subjects performed 4 IT sessions on a cycle ergometer varying in intensity (90 and 100% MPO) and duration of exercise (30 seconds and 3 minutes). This study revealed that IT using 30-second duration intervals (30-30 seconds) allows the athlete to perform a longer session, with a higher total and mean VO₂ HR and lower BLC than 3-minute durations. Similarly, submaximal exertion at 90% of MPO also allows performing longer sessions with a higher total VO₂ than 100% intensity. Thus, the results of their study suggested that to increase the total time at high intensity of exercise and total VO₂ of a single exercise session performed by the athlete, IT protocols of short durations (i.e.,
30 seconds) and submaximal intensities (i.e., 90% MPO) should be selected. Furthermore, performing short-duration intervals may allow the athlete to complete a longer IT session with greater metabolic demands (VO₂) and lower BLC than longer (i.e., 3 minutes) intervals.

Seiler (2010) stated that successful endurance training involves the manipulation of training intensity, duration, and frequency, with the implicit goals of maximizing performance, minimizing risk of negative training outcomes, and timing peak fitness and performances to be achieved when they matter most. Numerous descriptive studies of the training characteristics of nationally or internationally competitive endurance athletes training 10 to 13 times per week seem to converge on a typical intensity distribution in which about 80% of training sessions are performed at low intensity (2 mM blood lactate), with about 20% dominated by periods of high-intensity work, such as interval training at approx. 90% VO₂max. Endurance athletes appear to self-organize toward a high-volume training approach with careful application of high-intensity training incorporated throughout the training cycle. Training intensification studies performed on already well-trained athletes do not provide any convincing evidence that a greater emphasis on high-intensity interval training in this highly trained athlete population gives long-term performance gains. The predominance of low-intensity, long-duration training, in combination with fewer, highly intensive bouts may be complementary in terms of optimizing adaptive signaling and technical mastery at an acceptable level of stress.
Sperlich et al. (2010) stated that training volume in swimming is usually very high when compared to the relatively short competition time. High-intensity interval training (HIIT) has been demonstrated to improve performance in a relatively short training period. The main purpose of the present study was to examine the effects of a 5-week HIIT versus high-volume training (HVT) in 9-11-year-old swimmers on competition performance, 100 and 2,000 m time (T(100 m) and T(2,000 m)), VO$_2$peak and rate of maximal lactate accumulation (Lac(max)). In a 5-week crossover study, 26 competitive swimmers with a mean (SD) age of 11.5 ± 1.4 years performed a training period of HIIT and HVT. Competition (P < 0.01; effect size = 0.48) and T (2,000 m) (P = 0.04; effect size = 0.21) performance increased following HIIT. No changes were found in T(100 m) (P = 0.20). Lac(max) increased following HIIT (P < 0.01; effect size = 0.43) and decreased after HVT (P < 0.01; effect size = 0.51). VO$_2$peak increased following both interventions (P < 0.05; effect sizes = 0.46-0.57). The increases in competition performance, T(2,000 m), Lac(max) and VO$_2$peak following HIIT were achieved in significantly less training time (~2 h/week).

Farsani & Rezaeimanesh (2011) examined the effect of six-week aerobic interval training on some Blood lipids and VO$_2$max in female athlete students. Thus, 15 players of university's teams with an average age of 19.4–25.7, height of 158.8–172.6 centimetres, and weight of 45.3–63.8 kg were chosen. The effect of six- week aerobic interval training on body weight, waist circumference, body mass index, triglycerides, total cholesterol, HDL-
cholesterol, LDL-cholesterol and VO$_2$max was evaluated on pre and post test. The subjects participated in four weekly 60–75 minute training sessions in a 6 week period. Descriptive statistic and t-Test at ($\alpha = 0.05$) were used to analyze data. The results their study showed that there was a significant difference in body weight, waist circumference, body mass index, triglycerides, total cholesterol, HDL-cholesterol and VO$_2$max. According to their study the training programs produced significant benefits on some blood lipids and VO$_2$max in athletes.

Clark (2010) examined the improvements in cardiorespiratory fitness (VO$_2$) after the use of a mixed-intensity interval endurance-training (MI-ET) program in female soccer players, to validate the MI-ET program as an appropriate training regimen to improve cardiorespiratory fitness (VO$_2$) in soccer players. 32 female soccer players (average 18.66 +/- 0.31 years) were recruited from a group of currently conditioning local U-19 and college soccer teams and randomly assigned to participate in an 8-week periodized training program that involved either the MI-ET program or the continuation of a current endurance-training (ET) program. Analysis of variance indicates no differences in VO$_2$ values within the group of athletes before participating in the exercise program. After the 8 weeks of training, the MI-ET group of athletes had significantly greater average VO$_2$ values (62.13 +/- 0.96 ml O$_2$.kg.min vs. 57.27 +/- 1.59 ml O$_2$.kg.min), $p = 0.015$, along with a greater group average of change in VO$_2$ (12.44 +/- 0.92 ml O$_2$.kg.min vs. 7.72 +/- 0.99 ml O$_2$.kg.min), $p < 0.001$. The MI-ET program has shown to be a valid
means to improve aerobic fitness as indicated by the MI-ET group exhibiting significantly greater VO$_2$ measures after training.

Astorino et al. (2012) examined the effects of short-term high-intensity interval training (HIIT) on cardiovascular function, cardiopulmonary fitness, and muscular force. Active, young (age and body fat = 25.3 ± 4.5 years and 14.3 ± 6.4%) men and women (N = 20) of a similar age, physical activity, and maximal oxygen uptake (VO$_2$max) completed 6 sessions of HIIT consisting of repeated Wingate tests over a 2- to 3-week period. Subjects completed 4 Wingate tests on days 1 and 2, 5 on days 3 and 4, and 6 on days 5 and 6. A control group of 9 men and women (age and body fat = 22.8 ± 2.8 years and 15.2 ± 6.9%) completed all testing but did not perform HIIT. Changes in resting blood pressure (BP) and heart rate (HR), VO$_2$max, body composition, oxygen (O$_2$) pulse, peak, mean, and minimum power output, fatigue index, and voluntary force production of the knee flexors and extensors were examined pretraining and posttraining. Results showed significant (p < 0.05) improvements in VO$_2$max, O$_2$ pulse, and Wingate-derived power output with HIIT. The magnitude of improvement in VO$_2$max was related to baseline VO$_2$max (r = -0.44, p = 0.05) and fatigue index (r = 0.50, p < 0.05). No change (p > 0.05) in resting BP, HR, or force production was revealed. Data show that HIIT significantly enhanced VO$_2$max and O$_2$ pulse and power output in active men and women.

Tabata et al. (1996) in their study which consists of two training experiments using a mechanically braked cycle ergometer. First, the effect of
6 wk of moderate-intensity endurance training (intensity: 70% of maximal oxygen uptake (VO$_2$max), 60 min.d-1, 5 d.wk-1) on the anaerobic capacity (the maximal accumulated oxygen deficit) and VO$_2$max was evaluated. After the training, the anaerobic capacity did not increase significantly (P > 0.10), while VO$_2$max increased from 53 +/- 5 ml.kg-1 min-1 to 58 +/- 3 ml.kg-1.min-1 (P < 0.01) (mean +/- SD). Second, to quantify the effect of high-intensity intermittent training on energy release, seven subjects performed an intermittent training exercise 5 d.wk-1 for 6 wk. The exhaustive intermittent training consisted of seven to eight sets of 20-s exercise at an intensity of about 170% of VO$_2$max with a 10-s rest between each bout. After the training period, VO$_2$max increased by 7 ml.kg-1.min-1, while the anaerobic capacity increased by 28%. They concluded that their study showed that moderate-intensity aerobic training that improves the maximal aerobic power does not change anaerobic capacity and that adequate high-intensity intermittent training may improve both anaerobic and aerobic energy supplying systems significantly, probably through imposing intensive stimuli on both systems.

Tanisho and Hirakawa (2009) examined the effects of 2 different training regimens, continuous (CT) and interval (IT), on endurance capacity in maximal intermittent exercise. Eighteen lacrosse players were divided into CT (n = 6), IT (n = 6), and nontraining (n = 6) groups. Both training groups trained for 3 days per week for 15 weeks using bicycle ergometers. Continuous training performed continuous aerobic training for 20-25 minutes, and IT performed high-intensity pedaling comprising 10 sets of 10-second
maximal pedaling with 20-second recovery periods. Maximal anaerobic power, maximal oxygen uptake (V(O2max)), and intermittent power output were measured before and after the training period. The intermittent exercise test consisted of a set of ten 10-second maximal sprints with 40-second intervals. Maximal anaerobic power significantly increased in IT (p <0.05), whereas VO2max increased in both training groups (p <0.05). In the intermittent exercise test, the average of the total mean power output (1-10 sets) increased in both training groups (p <0.05); however, the mean power output in the last stage (8-10 sets) and fatigability improved only in IT. Consequently, continuous aerobic training reduced lactate production and increased the mean power output, but there was little effect on high-power endurance capacity in maximal intermittent exercise. In contrast, although lactate production did not decrease, IT improved fatigability and mean power output in the last stage. These results indicated that the endurance capacities for maximal intermittent and continuous exercises were not identical. Ball game players should therefore improve their endurance capacity with high-intensity intermittent exercise, and it is insufficient to assess their capacity with only VO2max or continuous exercise tests.

Heydari, Boutcher and Boutcher (2013a) examined the effect of a 12-week exercise intervention on the cardiovascular and autonomic response of males to mental and physical challenge. Thirty four young overweight males were randomly assigned to either an exercise or control group. The exercise group completed a high-intensity intermittent exercise (HIIE) program three
times per week for 12 weeks. Cardiovascular response to the Stroop task was determined before and after the intervention by assessing heart rate (HR), stroke volume (SV), arterial stiffness, baroreflex sensitivity (BRS), and skeletal muscle blood flow. The exercise group improved their aerobic fitness levels by 17% and reduced their body weight by 1.6 kg. Exercisers compared to controls experienced a significant reduction in HR (p<0.001) and a significant increase in SV (p<0.001) at rest and during Stroop and exercise. For exercisers, arterial stiffness significantly decreased at rest and during Stroop (p<0.01), whereas BRS was increased at rest and during Stroop (p<0.01). Forearm blood flow was significantly increased during the first two minutes of Stroop (p<0.05). HIIE induced significant cardiovascular and autonomic changes at rest and during mental and physical challenge after 12 weeks of training.

Heydari, Boutcher and Boutcher (2013b) studied the 12 weeks effect of high-intensity intermittent exercise (HIIE) on cardiac, vascular, and autonomic function of young males was examined. Thirty-eight young men with a BMI of 28.7 ± 3.1 kg m(-2) and age 24.9 ± 4.3 years were randomly assigned to either an HIIE or control group. The exercise group underwent HIIE three times per week, 20 min per session, for 12 weeks. Aerobic power and a range of cardiac, vascular, and autonomic measures were recorded before and after the exercise intervention. The result of their study showed that the exercise, compared to the control group, recorded a significant reduction in heart rate accompanied by an increase in stroke volume. For the
exercise group forearm vasodilatory capacity was significantly enhanced, $P < 0.05$. Arterial stiffness, determined by pulse wave velocity and augmentation index, was also significantly improved, after the 12-week intervention. For the exercise group, heart period variability (low- and high-frequency power) and baroreceptor sensitivity were significantly increased. They concluded that high-intensity intermittent exercise induced significant cardiac, vascular, and autonomic improvements after 12 weeks of training.

Helgerud et al., (2007) compared the effects of aerobic endurance training at different intensities and with different methods matched for total work and frequency. Responses in maximal oxygen uptake ($VO_{2\text{max}}$), stroke volume of the heart (SV), blood volume, lactate threshold (LT), and running economy ($CR$) were examined. Forty healthy, nonsmoking, moderately trained male subjects were randomly assigned to one of four groups:1) long slow distance (70% maximal heart rate; $HR_{\text{max}}$); 2) lactate threshold (85% $HR_{\text{max}}$); 3) 15/15 interval running (15 s of running at 90-95% $HR_{\text{max}}$ followed by 15 s of active resting at 70% $HR_{\text{max}}$); and 4) 4 × 4 min of interval running (4 min of running at 90-95% $HR_{\text{max}}$ followed by 3 min of active resting at 70%$HR_{\text{max}}$). All four training protocols resulted in similar total oxygen consumption and were performed 3 d·wk$^{-1}$ for 8 wk. The result of the study showed that high-intensity aerobic interval training resulted in significantly increased $VO_{2\text{max}}$ compared with long slow distance and lactate-threshold training intensities ($P < 0.01$). The percentage increases for the 15/15 and 4 × 4 min groups were 5.5 and 7.2%, respectively, reflecting increases in $VO_{2\text{max}}$.
from 60.5 to 64.4 mL·kg\(^{-1}\)·min\(^{-1}\) and 55.5 to 60.4 mL·kg\(^{-1}\)·min\(^{-1}\). SV increased significantly by approximately 10% after interval training \((P < 0.05)\). They concluded that high-aerobic intensity endurance interval training is significantly more effective than performing the same total work at either lactate threshold or at 70% HR\(_{\text{max}}\), in improving VO\(_{2\text{max}}\). The changes in VO\(_{2\text{max}}\) correspond with changes in SV, indicating a close link between the two.

Obembe & Oyeyipo (2011) studied the effect of exercise-training on heart rate and blood pressure both at rest and after an all out effort on a bicycle ergometer was studied in 87 healthy Nigerian males. The age groups of the subjects are 15-19, 20-24, 25-29 and 30-34 years. Results showed that exercise-trained individuals have a significantly lower resting rate \((p<0.05)\) and a significantly lower maximum heart rate \((p<0.05)\) than sedentary individuals in all the age groups. However, no significant difference was recorded in the blood pressure (both systole and diastole) between exercise-trained and sedentary individuals in all the age groups. Endurance training, through improvement of heart efficiency may improve cardiac autonomic balance; increasing parasympathetic while decreasing sympathetic stimulation of the heart. Exercise training results in markedly lower heart rate readings in exercise-trained individuals compared with sedentary individuals.

Maltsev et al., (2010) assessed central hemodynamic and heart rate variability (HRV) parameters in highly qualified athletes differing in the types of their training programs at relative rest. During endurance (the endurance
group, \( n = 27 \) and strength (the strength group, \( n = 17 \)) trainings, the total peripheral resistance (TPR) was decreased by 15\% \( (p = 0.003) \) in the endurance group and by 16\% \( (p = 0.011) \) in the strength group, and the stroke volume increased by 31\% \( (p < 0.0001) \) in the endurance group and by 19\% \( (p = 0.024) \) in the strength group. In the strength group, the cardiac output (Q) was higher \( (p = 0.012) \) and the temporal and spectral parameters of HRV (RMSSD, \( pNN_{50} \), and HF) were lower \( (p < 0.05) \) than those in the control group \( (n = 56) \). Some of these differences can be explained by an increased body mass index \( (p = 0.005) \) in the strength group. In the endurance group, the HRV parameters (RMSSD, \( pNN_{50} \), HF, VLF, and TP) were higher \( (p \leq 0.02) \), and the mean blood pressure was lower \( (p < 0.003) \) than those in the control group, with no significant differences in the Q from the control group. Their findings suggest that, in the strength-training athletes, resting hemodynamics were characterized by a greater Q level and a greater tension of mechanisms regulating cardiac activity. In the endurance-training athletes, a low Q level was associated with a lower tension of the mechanisms regulating cardiac activity (an increased vagal tone).

Currie, Thomas & Goodman (2009) investigated effects of 6 days of endurance exercise training [cycling at 65\% of peak oxygen consumption \( (VO_{2peak}) \) for 2 h a day on six consecutive days] on vascular function in young males. Measures of \( VO_{2peak} \), arterial stiffness, calf vascular conductance and heart rate variability were obtained pre- and post-training. Indices of arterial stiffness were obtained by applanation tonometry to determine aortic
augmentation index normalized to a heart rate of 75 bpm (AI_x @75 bpm), and central and peripheral pulse wave velocity (CPWV, PPWV). Resting and maximal calf vascular conductances were calculated from concurrent measures of blood pressure and calf blood flow using venous occlusion strain-gauge plethysmography. Time and frequency domain measures of heart rate variability were obtained from recording R–R intervals during supine and standing conditions. Both CPWV (5.9 ± 0.8 vs. 5.4 ± 0.8 m/s) and PPWV (9.7 ± 0.8 vs. 8.9 ± 1.3 m/s) were reduced following the training program. No significant changes were observed in AI_x @75 bpm, vascular conductance, heart rate variability or VO_{2peak}. Their data indicate that changes in arterial stiffness independent of changes in heart rate variability or vascular conductance can be achieved in healthy young males following only 6 days of intense endurance exercise.

Ackland, et al., (2012) stated that quantifying human body composition has played an important role in monitoring all athlete performance and training regimens, but especially so in gravitational, weight class and aesthetic sports wherein the tissue composition of the body profoundly affects performance or adjudication. Over the past century, a myriad of techniques and equations have been proposed, but all have some inherent problems, whether in measurement methodology or in the assumptions they make. To date, there is no universally applicable criterion or ‘gold standard’ methodology for body composition assessment. Having considered issues of accuracy, repeatability and utility, the multi-component
model might be employed as a performance or selection criterion, provided the selected model accounts for variability in the density of fat-free mass in its computation. However, when profiling change in interventions, single methods whose raw data are surrogates for body composition (with the notable exception of the body mass index) remain useful.

Högström, et al., (2012) stated that body composition is well known to be associated with endurance performance among adult skiers; however, the association among adolescent crosscountry and alpine skiers is inadequately explored. The study sample comprised 145 male and female adolescent subjects (aged 15-17 years), including 48 crosscountry skiers, 33 alpine skiers, and 68 control subjects. Body composition (%body fat [BF], %lean mass [LM], bone mineral density [grams per centimeter squared]) was measured with a dual-emission x-ray absorptiometer, and pulse and oxygen uptake was measured at 3 break points during incremental performance tests to determine physical fitness levels. Female crosscountry and alpine skiers were found to have significantly higher %LM (mean difference = 7.7%, p < 0.001) and lower %BF (mean difference = 8.1%, p < 0.001) than did female control subjects. Male crosscountry skiers were found to have lower %BF (mean difference = 3.2%, p < 0.05) and higher %LM (mean difference = 3.3%, p < 0.01) than did male alpine skiers and higher %LM (mean difference = 3.7%, p < 0.05) and %BF (mean difference = 3.2%, p < 0.05) than did controls. They found strong associations between %LM and the onset of blood lactate accumulation and VO$_{2\text{max}}$ weight adjusted thresholds among
both genders of the cross-country skiing cohort ($r = 0.47-0.67$, $p < 0.05$) and the female alpine-skiing cohort ($r = 0.77-0.79$, $p < 0.001$ for all). They suggested that body composition is associated with physical performance amongst adolescents.

Gibala, et al., (2006) viewed that intense exercise training may induce metabolic and performance adaptations comparable to traditional endurance training. However, no study has directly compared these diverse training strategies in a standardized manner. They therefore examined changes in exercise capacity and molecular and cellular adaptations in skeletal muscle after low volume sprint-interval training (SIT) and high volume endurance training (ET). Sixteen active men (21 +/- 1 years) were assigned to a SIT or ET group ($n = 8$ each) and performed six training sessions over 14 days. Each session consisted of either four to six repeats of 30 s 'all out' cycling at approximately 250% with 4 min recovery (SIT) or 90-120 min continuous cycling at approximately 65% (ET). Training time commitment over 2 weeks was approximately 2.5 h for SIT and approximately 10.5 h for ET, and total training volume was approximately 90% lower for SIT versus ET (approximately 630 versus approximately 6500 kJ). Training decreased the time required to complete 50 and 750 kJ cycling time trials, with no difference between groups (main effects, $P \leq 0.05$). Biopsy samples obtained before and after training revealed similar increases in muscle oxidative capacity, as reflected by the maximal activity of cytochrome c oxidase (COX) and COX subunits II and IV protein content (main effects, $P$
but COX II and IV mRNAs were unchanged. Training-induced increases in muscle buffering capacity and glycogen content were also similar between groups (main effects, P <= 0.05). Given the large difference in training volume, their data demonstrated that SIT is a time-efficient strategy to induce rapid adaptations in skeletal muscle and exercise performance that are comparable to ET in young active men.

Iaia, et al., (2009) studied the effect of an alteration from regular endurance to speed endurance training on muscle oxidative capacity, capillarization, as well as energy expenditure during submaximal exercise and its relationship to mitochondrial uncoupling protein 3 (UCP3) in humans. Seventeen endurance-trained runners were assigned to either a speed endurance training (SET; n = 9) or a control (Con; n = 8) group. For a 4-wk intervention (IT) period, SET replaced the ordinary training (approximately 45 km/wk) with frequent high-intensity sessions each consisting of 8-12 30-s sprint runs separated by 3 min of rest (5.7 +/- 0.1 km/wk) with additional 9.9 +/- 0.3 km/wk at low running speed, whereas Con continued the endurance training. After the IT period, oxygen uptake was 6.6, 7.6, 5.7, and 6.4% lower (P < 0.05) at running speeds of 11, 13, 14.5, and 16 km/h, respectively, in SET, whereas remained the same in Con. No changes in blood lactate during submaximal running were observed. After the IT period, the protein expression of skeletal muscle UCP3 tended to be higher in SET (34 +/- 6 vs. 47 +/- 7 arbitrary units; P = 0.06). Activity of muscle citrate synthase and 3-hydroxyacyl-CoA dehydrogenase, as well as maximal oxygen uptake and 10-
km performance time, remained unaltered in both groups. In SET, the capillary-to-fiber ratio was the same before and after the IT period. Their study showed that speed endurance training reduces energy expenditure during submaximal exercise, which is not mediated by lowered mitochondrial UCP3 expression. Furthermore, speed endurance training can maintain muscle oxidative capacity, capillarization, and endurance performance in already trained individuals despite significant reduction in the amount of training.

Schmidt, Biwer and Kalscheuer (2001) examined whether three 10 minute bouts of exercise per day (3 x 10) and two 15 minute bouts per day (2 x 15) were as effective as one 30 minute bout per day (1 x 30) for improving VO$_{2\text{max}}$ and weight loss. To achieve this purpose overweight, female college students (body mass index > or = 28 kg/m$^2$) were recruited and assessed at baseline and post-treatment for aerobic fitness (Astrand maximal cycle test), weight, skinfold thickness (7-site), and circumference measures (4-site). Following measurement of resting energy expenditure (REE), subjects were asked to follow a self-monitored calorie restricted diet (80% of REE) for the twelve week duration of the study and were assigned (non-random) to one of four treatment groups: 1) a non exercising control group (control, n = 8), 2) a 30 minutes continuous exercise group (1 x 30, n = 12), 3) a 30 minutes accumulated exercise group (2 x 15, n = 10) and 4) a second 30 minutes accumulated exercise group (3 x 10, n = 8). The exercising subjects participated in aerobic exercise training at 75% of heart rate reserve three to
five days per week with all exercise monitored. The result of the study showed that VO$_{2\text{max}}$ increased significantly while weight, body mass index, sum of skinfolds, and sum of circumferences decreased significantly from baseline to post-treatment in the 1 x 30, 2 x 15 and the 3 x 10 groups, but not in the control group. A tertiary finding was that exercise participation did not differ among the exercising groups with regard to the average number of days per week. They concluded that results of the study supported the hypothesis that exercise accumulated in several short bouts has similar effects as one continuous bout with regard to aerobic fitness and weight loss during caloric restriction in overweight young women.

Tjønna, et al., (2008) stated that individuals with the metabolic syndrome are 3 times more likely to die of heart disease than healthy counterparts. Exercise training reduces several of the symptoms of the syndrome, but the exercise intensity that yields the maximal beneficial adaptations is in dispute. They compared moderate and high exercise intensity with regard to variables associated with cardiovascular function and prognosis in patients with the metabolic syndrome. Thirty-two metabolic syndrome patients (age, 52.3+/−3.7 years; maximal oxygen uptake VO$_{2\text{max}}$, 34 ml/kg/min) were randomized to equal volumes of either moderate continuous moderate exercise (CME; 70% of highest measured heart rate [Hfmax]) or aerobic interval training (AIT; 90% of Hfmax) 3 times a week for 16 weeks or to a control group. VO$_{2\text{max}}$ increased more after AIT than CME (35% versus 16%; P<0.01) and was associated with removal of more risk factors that
constitute the metabolic syndrome (number of factors: AIT, 5.9 before versus 4.0 after; P<0.01; CME, 5.7 before versus 5.0 after; group difference, P<0.05). AIT was superior to CME in enhancing endothelial function (9% versus 5%; P<0.001), insulin signaling in fat and skeletal muscle, skeletal muscle biogenesis, and excitation-contraction coupling and in reducing blood glucose and lipogenesis in adipose tissue. Both the exercise programs were equally effective at lowering mean arterial blood pressure and reducing body weight (-2.3 and -3.6 kg in AIT and CME, respectively) and fat. They concluded that exercise intensity was an important factor for improving aerobic capacity and reversing the risk factors of the metabolic syndrome. Their findings may have important implications for exercise training in rehabilitation programs and future studies.

Trembley, Simaneau and Bouchard (1994) studied the impact of two different modes of training on body fatness and skeletal muscle metabolism was investigated in young adults who were subjected to either a 20-week endurance-training (ET) program (eight men and nine women) or a 15-week high-intensity intermittent-training (HIIT) program (five men and five women). The mean estimated total energy cost of the ET program was 120.4 MJ, whereas the corresponding value for the HIIT program was 57.9 MJ. Despite its lower energy cost, the HIIT program induced a more pronounced reduction in subcutaneous adiposity compared with the ET program. When corrected for the energy cost of training, the decrease in the sum of six subcutaneous skinfolds induced by the HIIT program was ninefold greater
than by the ET program. Muscle biopsies obtained in the vastus lateralis before and after training showed that both training programs increased similarly the level of the citric acid cycle enzymatic marker. On the other hand, the activity of muscle glycolytic enzymes was increased by the HIIT program, whereas a decrease was observed following the ET program. The enhancing effect of training on muscle 3-hydroxyacyl coenzyme A dehydrogenase (HADH) enzyme activity, a marker of the activity of beta-oxidation, was significantly greater after the HIIT program. Their results reinforce the notion that for a given level of energy expenditure, vigorous exercise favors negative energy and lipid balance to a greater extent than exercise of low to moderate intensity. Moreover, the metabolic adaptations taking place in the skeletal muscle in response to the HIIT program appear to favor the process of lipid oxidation.

Jakicic, et al., (1995) investigated whether prescribing exercise in several short-bouts versus one long-bout per day would enhance exercise adherence, cardiorespiratory fitness, and weight loss in overweight adult females in a behavioral weight control program. Randomized controlled trial with subjects randomized to either a short-bout exercise group (SB, n = 28, age = 40.4 +/- 5.9 yrs) or a long-bout exercise group (LB, n = 28, age = 40.9 +/- 7.3 yrs), with subjects followed for a period of 20 weeks. Both groups were instructed to exercise 5 days per week with exercise duration progressing from 20 to 40 min per day. The LB group performed one exercise bout per day, whereas the SB group performed multiple 10 min bouts of
exercise per day. The recommended caloric intake for all subjects was 5022-
6277 kJ/day (1200-1500 kcal/day), with fat reduced to 20% of caloric intake.
Fifty-six obese, sedentary females (BMI = 33.9 +/- 4.1 kg/m²). Exercise
participation was assessed from self-reported diaries and Tri-Trac
Accelerometers. Cardiorespiratory fitness was assessed using a submaximal
cycle ergometer test. The result of the study showed that exercising in
multiple short-bouts per day improved adherence to exercise: the SB group
reported exercising on a greater number of days (mean +/- s.d. = 87.3 +/- 29.5
days vs 69.1 +/- 28.9 days; P < 0.05) and for a greater total duration (223.8
+/- 69.5 min/week vs 188.2 +/- 58.4 min/week; P = 0.08) than the LB group.
Predicted VO₂Peak increased by 5.6% and 5.0% for the LB and SB groups,
respectively (P < 0.05). There was a trend for the weight loss to be greater in
the SB group (-8.9 +/- 5.3 kg) compared to the LB group (-6.4 +/- 4.5 kg; P <
0.07). They concluded that short-bouts of exercise may enhance exercise
adherence. Short-bouts of exercise may also enhance weight loss and produce
similar changes in cardiorespiratory fitness when compared to long-bouts of
exercise. Thus, short-bouts of exercise may be preferred when prescribing
exercise to obese adults.

Christou, et al., (2006) examined the effects of a progressive resistance
training program in addition to soccer training on the physical capacities of
male adolescents. Eighteen soccer players (age: 12-15 years) were separated
in a soccer (SOC; n = 9) and a strength-soccer (STR; n = 9) training group
and 8 subjects of similar age constituted a control group. All players followed
a soccer training program 5 times a week for the development of technical and tactical skills. In addition, the STR group followed a strength training program twice a week for 16 weeks. The program included 10 exercises, and at each exercise, 2-3 sets of 8-15 repetitions with a load 55-80% of 1 repetition maximum (1RM). Maximum strength ([1RM] leg press, bench-press), jumping ability (squat jump [SJ], countermovement jump [CMJ], repeated jumps for 30 seconds) running speed (30 m, 10 x 5-m shuttle run), flexibility (seat and reach), and soccer technique were measured at the beginning, after 8 weeks, and at the end of the training period. After 16 weeks of training, 1RM leg press, 10 x 5-m shuttle run speed, and performance in soccer technique were higher (p < 0.05) for the STR and the SOC groups than for the control group. One repetition maximum bench press and leg press, SJ and CMJ height, and 30-m speed were higher (p < 0.05) for the STR group compared with SOC and control groups. The data showed that soccer training alone improves more than normal growth maximum strength of the lower limbs and agility. The addition of resistance training, however, improves more maximal strength of the upper and the lower body, vertical jump height, and 30-m speed. Thus, the combination of soccer and resistance training could be used for an overall development of the physical capacities of young boys.

Coutts, Murphy and Dascombe (2004) examined the influence of direct supervision on muscular strength, power, and running speed during 12 weeks of resistance training in young rugby league players. Two matched groups of
young (16.7 +/- 1.1 years [mean +/- SD]), talented rugby league players completed the same periodized resistance-training program in either a supervised (SUP) (N = 21) or an unsupervised (UNSUP) (N = 21) environment. Measures of 3 repetition maximum (3RM) bench press, 3RM squat, maximal chin-ups, vertical jump, 10- and 20-m sprints, and body mass were completed pretest (week 0), midtest (week 6), and posttest (week 12) training program. Results showed that 12 weeks of periodized resistance training resulted in an increased body mass, 3RM bench press, 3RM squat, maximum number of chin-ups, vertical jump height, and 10- and 20-m sprint performance in both groups (p < 0.05). The SUP group completed significantly more training sessions, which were significantly correlated to strength increases for 3RM bench press and squat (p < 0.05). Furthermore, the SUP group significantly increased 3RM squat strength (at 6 and 12 weeks) and 3RM bench press strength (12 weeks) when compared to the UNSUP group (p < 0.05). Finally, the percent increase in the 3RM bench press, 3RM squat, and chin-up (max) was also significantly greater in the SUP group than in the UNSUP group (p < 0.05). They concluded that the direct supervision of resistance training in young athletes results in greater training adherence and increased strength gains than does unsupervised training.

Gorostiaga, et al., (1999) determined the effects of 6-weeks of heavy-resistance training on physical fitness and serum hormone status in adolescents (range 14–16 years old). 19 male handball players were divided into two different groups: a handball training group (NST, n = 10), and a
handball and heavy-resistance strength training group (ST, n = 9). A third group of 4 handball goalkeepers of similar age served as a control group (C, n = 4). After the 6-week training period, the ST group showed an improvement in maximal dynamic strength of the leg extensors (12.2%; P < 0.01) and the upper extremity muscles (23%; P < 0.01), while no changes were observed in the NST and C groups. Similar differences were observed in the maximal isometric unilateral leg extension forces. The height of the vertical jump increased in the NST group from 29.5 (SD 4) cm to 31.4 (SD 5) cm (P < 0.05) while no changes were observed in the ST and C groups. A significant increase was observed in the ST group in the velocity of the throwing test [from 71.7 (SD 7) km ⋅ h\(^{-1}\) to 74.0 (SD 7) km ⋅ h\(^{-1}\); P < 0.001] during the 6-week period while no changes were observed in the NST and C groups. During a submaximal endurance test running at 11 km ⋅ h\(^{-1}\), a significant decrease in blood lactate concentration occurred in the NST group [from 3.3 (SD 0.9) mmol ⋅ l\(^{-1}\) to 2.4 (SD 0.8) mmol ⋅ l\(^{-1}\); P < 0.01] during the experiment, while no change was observed in the ST or C groups. Finally, a significant increase (P < 0.01) was noted in the testosterone:cortisol ratio in the C group, while the increase in the NST group approached statistical significance (P < 0.08) and no changes in this ratio occurred in the ST group. The findings suggested that the addition of 6-weeks of heavy resistance training to the handball training resulted in gains in maximal strength and throwing velocity but it compromised gains in leg explosive force production and endurance running. The tendency for a compromised testosterone:cortisol
ratio observed in the ST group could have been associated with a state of overreaching or overtraining.

Reilly (1997) stated that soccer entails intermittent exercise with bouts of short, intense activity punctuating longer periods of low-level, moderate-intensity exercise. High levels of blood lactate may sometimes be observed during a match but the active recovery periods at submaximal exercise levels allow for its removal on a continual basis. While anaerobic efforts are evident in activity with the ball and shadowing fast-moving opponents, the largest strain is placed on aerobic metabolism. On average, competitive soccer corresponds to an energy expenditure of about 75% maximal aerobic power. The energy expenditure varies with playing position, being highest among midfield players. Muscle glycogen levels can be reduced towards the end of a game, the level of reduction being reflected in a decrease in work rate. Blood glucose levels are generally well-maintained, although body temperature may rise by 2°C even in temperate conditions. The distance covered by players tends to under-reflect the energy expended. Unorthodox modes of motion-running backwards and sideways, accelerating, decelerating and changing direction-accentuate the metabolic loading. These are compounded by the extra requirements for energy associated with dribbling the ball and contesting possession. The overall energy expended is extreme when players are required to play extra-time in tournaments. Training, nutritional and tactical strategies may be used to reduce the effects of fatigue that may occur late in the game.
Wisløff, Helgerud and Hoff (1998) examined whether there exists a relationship between preseasonal physiological tests and performance results in the soccer league. Further, they investigated maximal oxygen uptake and maximal strength in proportion to body mass for soccer players. A secondary aim was to establish some normative data of Norwegian elite soccer players. To fulfill the purpose two teams selected from Norwegian elite soccer league who participated in the study. The result of the study supports previous investigations indicating a positive relationship between maximal aerobic capacity, physical strength, and performance results in the elite soccer league. They concluded that for soccer players, maximal oxygen uptake should be expressed in relation to body mass raised to the power of 0.75 and maximal strength in relation to body mass raised to the power of 0.67, when the aim is to evaluate maximal aerobic capacity when running and strength capacity among players with different body mass. Midfield players had significantly higher maximal oxygen uptake compared with defense players using the traditional expression, ml/kg/min, while no significant differences were found expressing maximal oxygen uptake either absolutely (L/min) or in relation to body mass raised to the power of 0.75 (ml/kg/min) among players grouped by position. There was a significant correlation ($r = 0.61, P < 0.01$) between squat IRM and vertical jump height. Vertical jump heights for defense and forward players were significantly higher compared with midfield players. Mean results from the laboratory test were 63.7 ml/kg/min or 188.6 ml/kg/min for maximal oxygen uptake, 150 kg or 8.0 kg x mb(-0.67) for 90
degrees squats, 79.9 kg or 4.4 kg x mb(-0.67) for bench press. Mean values of vertical jump height were 54.9 cm.

Helgerud, et al., (2001) studied the effects of aerobic training on performance during soccer match and soccer specific tests. Nineteen male elite junior soccer players, age 18.1 +/- 0.8 yr, randomly assigned to the training group (N = 9) and the control group (N = 10) participated in the study. The specific aerobic training consisted of interval training, four times 4 min at 90-95% of maximal heart rate, with a 3-min jog in between, twice per week for 8 wk. Players were monitored by video during two matches, one before and one after training. The result of the study showed that in the training group: a) maximal oxygen uptake (VO2max) increased from 58.1 +/- 4.5 mL x kg(-1) x min(-1) to 64.3 +/- 3.9 mL x kg(-1) x min(-1) (P < 0.01); b) lactate threshold improved from 47.8 +/- 5.3 mL x kg(-1) x min(-1) to 55.4 +/- 4.1 mL x kg(-1) x min(-1) (P < 0.01); c) running economy was also improved by 6.7% (P < 0.05); d) distance covered during a match increased by 20% in the training group (P < 0.01); e) number of sprints increased by 100% (P < 0.01); f) number of involvements with the ball increased by 24% (P < 0.05); g) the average work intensity during a soccer match, measured as percent of maximal heart rate, was enhanced from 82.7 +/- 3.4% to 85.6 +/- 3.1% (P < 0.05); and h) no changes were found in maximal vertical jumping height, strength, speed, kicking velocity, kicking precision, or quality of passes after the training period. The control group showed no changes in any of the tested parameters. They concluded that enhanced aerobic endurance in
soccer players improved soccer performance by increasing the distance covered, enhancing work intensity, and increasing the number of sprints and involvements with the ball during a match.

Conley and Gary (1980) examined the relationship between running economy and distance running performance in highly trained and experienced distance runners of comparable ability. Oxygen uptake (VO$_2$) during steady-state and maximal aerobic power (VO$_2$max) were measured during treadmill running using the open-circuit method. Distance running performance was determined in a nationally prominent 10 km race; all subjects (12 males) placed among the top 19 finishers. The subjects averaged 32.1 min on the 10 km run, 71.7 ml.kg$^{-1}$min$^{-1}$ for VO$_2$max, and 44.7, 50.3, and 55.9 ml.kg$^{-1}$min$^{-1}$ for steady-state VO$_2$ at three running paces (241, 268, and 295 m.min$^{-1}$). The relationship between VO$_2$max and distance running performance was $r = -0.12$ ($p = 0.35$). The relationships between steady-state VO$_2$ at 241, 268, and 295 m*min$^{-1}$ and 10 km time were $r = 0.83$, 0.82, and 0.79 ($p<0.01$), respectively. Within this elite cluster of finishers, 65.4% of the variation observed in race performance time on the 10 km run could be explained by variation in running economy. They concluded that among highly trained and experienced runners of comparable ability and similar Vo2max, running economy accounts for a large and significant amount of the variation observed in performance on a 10 km race.

Daniels, Yarborough and Foster (1978) evaluated the response of VO$_2$ max and of running performance to the onset of training in untrained
individuals and to an increase in the volume and intensity of training in well trained individuals. In series A, VO$_2$ max and performances of 12 previously untrained individuals were determined before and after 4 and 8 weeks of training. In series B, performances, VO$_2$ max and VO$_2$ submax of 15 previously well trained runners were determined before and after 4 and 8 weeks of controlled training. In series A, VO$_2$ max increased during the first 4 weeks of training but failed to increase further even in the presence of an increased training load (80 total km for the first 4 weeks, 130 total km for the second 4 weeks). Running performances improved throughout the training period. In series B, neither VO$_2$ max nor VO$_2$ submax changed but running performance improved throughout the experimental period. The results indicated that not all of the improvement in running performance subsequent to training is attributable to changes in VO$_2$ max. Further the results indicated that changes in running economy are not a likely explanation for performance improvement among previously well trained runners. They suggested that physiological adaptations not integrated in the test of VO$_2$ max, or improvement in pacing contribute to training induced improvements in running performance.

Bransford and Howley (1977) compared the oxygen cost of running as it relates to speed of running among the following four groups: trained male distance runners, trained female distance runners, untrained but active men and women. Each subject was given a series of treadmill tests during which VO$_2$ was measured at submaximal work loads. The linear regression equation
was utilized to compute the relationship between VO$_2$ and running speed for each group. The results indicated that the rate of increase in VO$_2$ for a given increase in running speed could be represented as a straight line and was the same for all groups ($P > .05$). The trained male runners had a significantly lower VO$_2$ ($P < .05$) than those of the other three groups at any measured speed. The trained females and untrained males had significantly lower VO$_2$ than the untrained females ($P < .05$) at any of the given range of speeds. No significant differences were observed between the untrained men and trained women ($P > .05$). They concluded that there were differences in the oxygen cost of running not only between the trained and untrained groups but also between males and females.

**Summary of Literature**

In order to improve the qualities of aerobic fitness and muscle strength simultaneously, specific attention must be paid to create the optimal combination of endurance and strength training. Handball is fast body contact sports which require both aerobic fitness and muscle strength. Endurance and strength training are often performed concurrently in an attempt to acquire gains in more than one physiological system. However, it has been proposed that by simultaneously performing these two modes of exercise training, the strength gains achieved by resistance training alone may be impaired. In the present investigation, the collected literatures showed that both factors are
improved and some studies showed that aerobic capacity improved and strength parameters are impaired or remained unchanged. Therefore, the aim of this study was to examine the alterations on selected motor fitness and physiological variables of male handball players due to combined high intensity intermittent training and weight training for eight weeks.