Chapter I

REVIEW OF LITERATURE
Chapter II

REVIEW OF RELATED LITERATURE

The known facts build up the edifice of the new theories and principles. Review of research studies serve as buckle between the old and new, between the known and unknown. It is a milestone leading the research on the high road of future. Review of literature develops researcher insight and establishes his intellectual superiority over others. A study of relevant literature is an essential step to get a good comprehension of what has been done with regard to the problem under study. “The literature in any field forms the function upon which all future work will be built”. The literatures relevant to the present study that have been collected from different sources of reference are described in this chapter.

Studies related to body composition

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 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 cross-country and alpine skiers is inadequately explored. The study sample comprised 145 male and female adolescent subjects (aged 15-17 years), including 48 cross-country 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 cross-country 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 cross-country 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, $P </=$ 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, $P \leq 0.05$), 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, $P \leq 0.05$). 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 sub maximal 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 $\geq$ 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 \( \text{VO}_2\text{max} \) 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 \( \text{VO}_2\text{max} \), 34 ml/kg/min) were randomized to equal volumes of either moderate continuous moderate exercise (CME; 70% of
highest measured heart rate \([Hf_{\text{max}}]\) or aerobic interval training (AIT; 90% of
Hf_{\text{max}}) 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, cardio respiratory 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 exercisebout 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.
Polman et al., (2004) compared the efficacy of three physical conditioning programmes provided over a 12 week period (24 h in total) on selected anthropometric and physical fitness parameters in female soccer players. Two of the groups received physical conditioning training in accordance with speed, agility and quickness (SAQ); one group used specialized resistance and speed development SAQ equipment (equipment group; n = 12), while the other group used traditional soccer coaching equipment (non-equipment group; n = 12). A third group received their regular fitness sessions (active control group; n = 12). All three interventions decreased (P < 0.001) the participants' body mass index (-3.7%) and fat percentage (-1.7%), and increased their flexibility (+14.7%) and maximal aerobic capacity (VO₂max) (+18.4%). The participants in the equipment and non-equipment conditioning groups showed significantly (P < 0.005) greater benefits from their training programme than those in the active control group by performing significantly better on the sprint to fatigue (-11.6% for both the equipment and non-equipment groups versus -6.2% for the active control group), 25 m sprint (-4.4% vs -0.7%), left (-4.5% vs -1.0%) and right (-4.0% vs -1.4%) side agility, and vertical (+18.5% vs +4.8%) and horizontal (+7.7% vs +1.6%) power tests. Some of these differences in improvements in physical fitness between the equipment and non-equipment conditioning groups on the one hand and the active control group on the other hand were probably due to the specificity of the training programmes. They concluded that SAQ training principles appear to be effective in the physical conditioning of female soccer players. Moreover,
the principles can be implemented during whole team training sessions without
the need for specialized SAQ equipment. Finally, more research is required to
establish the relationship between physical fitness and soccer performance as
well as the principles underlying the improvements seen through the
implementation of SAQ training programmes.

MacDonald, Lamont and Garner (2012) stated that complex training
(CT; alternating between heavy and lighter load resistance exercises with
similar movement patterns within an exercise session) is a form of training that
may potentially bring about a state of postactivation potentiation, resulting in
increased dynamic power (Pmax) and rate of force development during the
lighter load exercise. Such a method may be more effective than either
modality, independently for developing strength. The purpose of the research
was to compare the effects of resistance training (RT), plyometric training
(PT), and CT on lower body strength and anthropometrics. Thirty
recreationally trained college-aged men were trained using 1 of 3 methods:
resistance, plyometric, or complex twice weekly for 6 weeks. The participants
were tested pre, mid, and post to assess back squat strength, Romanian dead lift
(RDL) strength, standing calf raise (SCR) strength, quadriceps girth, triceps
surae girth, body mass, and body fat percentage. Diet was not controlled during
this study. Statistical measures revealed a significant increase for squat strength
(p = 0.000), RDL strength (p = 0.000), and SCR strength (p = 0.000) for all
groups pre to post, with no differences between groups. There was also a main
effect for time for girth measures of the quadriceps muscle group (p = 0.001),
the triceps surae muscle group (p = 0.001), and body mass (p = 0.001; post hoc
revealed no significant difference). There were main effects for time and group ×
time interactions for fat-free mass % (RT: p = 0.031; PT: p = 0.000). They
suggested that CT mirrors benefits seen with traditional RT or PT. Moreover,
CT revealed no decrement in strength and anthropometric values and appears
to be a viable training modality.

Sedano et al., (2009) examined whether explosive strength, kicking
speed, and body composition are affected by a 12-week plyometric training
program in elite female soccer players. The hypothesis was that their program
would increase the jumping ability and kicking speed and that these gains could
be maintained by means of regular soccer training only. Twenty adult female
players were divided into 2 groups: control group (CG, n = 10, age 23.0 +/- 3.2
yr) and plyometric group (PG, n = 10; age 22.8 +/- 2.1 yr). The intervention
was carried out during the second part of the competitive season. Both groups
performed technical and tactical training exercises and matches together.
However, the CG followed the regular soccer physical conditioning program,
which was replaced by a plyometric program for PG. Neither CG nor PG
performed weight training. Plyometric training took place 3 days a week for 12
weeks including jumps over hurdles, drop jumps (DJ) in stands, or horizontal
jumps. Body mass, body composition, countermovement jump height, DJ
height, and kicking speed were measured on 4 separate occasions. The PG
demonstrated significant increases (p < 0.05) in jumping ability after 6 weeks of training and in kicking speed after 12 weeks. There was no significant time x group interaction effects for body composition. They concluded that a 12-week plyometric program can improve explosive strength in female soccer players and that these improvements can be transferred to soccer kick performance in terms of ball speed. However, players need time to transfer these improvements in strength to the specific task. Regular soccer training can maintain the improvements from a plyometric training program for several weeks.

Marković et al., (2005) compared the effects of sprint and plyometric training on morphological Characteristics of physically active men. One hundred and fifty one physical education students (18-24 years of age) were allocated into one of three groups: the plyometric group (PG; n = 50), the sprint group (SG; N = 50), and the control group (CG; n = 51). Both experimental groups participated in a training programme 3 times a week for 10 weeks. SG performed maximal sprints for distances between 10 and 50 meters, while The training programme in PG consisted of hurdle jumps and drop jumps. Anthropometric measurement was performed in the week before and the week after the experiment. There were no significant differences (P > 0.05) in magnitude of changes in any of the analysed anthropometric variables between the groups. However, a significant decrease (P < 0.0167) in the percentage of body fat (6.1%) was found in SG. They also found a significant decrease (P < 0.0167) in body mass (1%), fat-free mass (0.4%) and body mass index (0.9%)
for the SG, but the magnitude of these changes was rather low. They conclude that the short-term explosive-type training programmes in which muscles operate in the fast stretch-shortening cycle conditions (i.e., sprinting, jumping) have a limited potential to induce morphological changes in physically active men.

Hakkinen, Komi and Alen (1985) investigated the influence of explosive type strength training on isometric force- and relaxation-time and on electromyographic and muscle fibre characteristics of human skeletal muscle, 10 male subjects went through progressive training which included primarily jumping exercises without extra load and with light extra weights three times a week for 24 weeks. Specific training-induced changes in force-time curve were observed and demonstrated by great ($p < 0.05-0.01$) improvements in parameters of fast force production and by a minor ($p < 0.05$) increase in maximal force. The continuous increases in fast force production during the entire training were accompanied by and correlated with the increases ($p < 0.05$) in average IEMG-time curve and with the increase ($p < 0.05$) in the FT:ST muscle fibre area ratio. The percentage of FT fibres of the muscle correlated ($p < 0.05$) with the improvement of average force-time curve during the training. The increase in maximal force was accompanied by significant ($p < 0.05$) increases in maximum IEMGs of the trained muscles. However, the hypertrophic changes, as judged from the anthropometric and muscle fibre area data, were only slight during the training. They concluded that in training for
fast force production considerable neural and selective muscular adaptations may occur to explain the improvement in performance, but that genetic factors may determine the ultimate potential of the trainability of this aspect of the neuromuscular performance.

Potteiger et al., (1999) examined the changes in muscle power output and fiber characteristics following a 3 days/week, 8-week plyometric and aerobic exercise program. Male subjects (n = 19) were randomly assigned to either group 1 (plyometric training) or group 2 (plyometric training and aerobic exercise). The plyometric training consisted of vertical jumping, bounding, and depth jumping. Aerobic exercise (at 70% maximum heart rate) was performed for 20 minutes immediately following the plyometric workouts. Muscle biopsy specimens were collected from the musculus vastus lateralis before and after training. Type I and type II fibers were identified and cross-sectional areas calculated. Peak muscle power output, measured using a countermovement vertical jump, significantly increased from pretraining to posttraining for group 1 (2.8%) and group 2 (2.5%). Each group demonstrated a significant increase in fiber area from pretraining to posttraining for type I (group 1, 4.4%; group 2, 6.1%) and type II (group 1, 7.8%; group 2, 6.8%) fibers, but there were no differences between the groups. Following plyometric training, there is an increased power output that may in part be related to muscle fiber size.

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 limps 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), mid test (week 6), and post test (week 12) training program. Results showed that 12 weeks of periodized resistance training resulted in an increased body mass, 3RM bench press, 3RM squat, and maximum number of chin-ups, vertical jump height, and 10-m 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.
Diallo et al., (2001) stated that in adult population, stretch-shortening cycle exercise (plyometric exercise) is often used to improve leg muscle power and vertical jump performance. In children, limited information regarding this type of exercise is available. The purpose of their study was to examine the effectiveness of plyometric training and maintenance training on physical performances in prepubescent soccer players. They selected twenty boys aged 12-13 years was divided in two groups (10 in each): jump group (JG) and control group (CG). JG trained 3 days/week during 10 weeks, and performed various plyometric exercises including jumping, hurdling and skipping. The subsequent reduced training period lasted 8 weeks. However, all subjects continued their soccer training. Maximal cycling power (Pmax) was calculated using a force-velocity cycling test. Jumping power was assessed by using the following tests: countermovement jump (CMJ), squat jump (SJ), drop jump (DJ), multiple 5 bounds (MB5) and repeated rebound jump for 15 seconds (RRJ15). Running velocities included: 20m, 30m and 40m (V20, V30, V40m). Body fat percentage (BF percent) and lean leg volume were estimated by anthropometry. The result showed that before training, except for BF percent, all baseline anthropometric characteristics were similar between JG and CG. After the training programme, Pmax (p<0.01), CMJ (p<0.01), SJ (p<0.05), MB5 (p<0.01), RRJ15 (p<0.01) and V20 m (p<0.05), performances increased in the JG. During training period no significant performance increase was obtained in the CG. After the 8-week of reduced training, except Pmax (p<0.05) for CG, any increase was observed in both groups. They concluded
that short-term plyometric training programmes increase athletic performances in prepubescent boys. These improvements were maintained after a period of reduced training.

Gabbett, Johns and Riemann (2008) investigated the time course of adaptations to training in young (i.e., <15 years) and older (i.e., <18 years) junior rugby league players. Fourteen young (14.1 +/- 0.2 years) and 21 older (16.9 +/- 0.3 years) junior rugby league players participated in a 10-week preseason strength, conditioning, and skills program that included 3 sessions each week. Subjects performed measurements of standard anthropometry (i.e., height, body mass, and sum of 7 skinfolds), muscular power (i.e., vertical jump), speed (i.e., 10-m, 20-m, and 40-m sprint), agility (505 test), and estimated maximal aerobic power (i.e., multistage fitness test) before and after training. In addition, players underwent a smaller battery of fitness tests every 3 weeks to assess the time course of adaptation to the prescribed training stimulus. During the triweekly testing sessions, players completed assessments of upper-body (i.e., 60-second push-up, sit-up, and chin-up test) and lower-body (i.e., multiple-effort vertical jump test) muscular endurance. Improvements in maximal aerobic power and muscular endurance were observed in both the young and the older junior players following training. The improvements in speed, muscular power, maximal aerobic power, and upper-body muscular endurance were greatest in the young junior players, while improvements in lower-body muscular endurance were greatest in the older
junior players. Their findings demonstrate that young (i.e., <15 years) and older (i.e., <18 years) junior rugby league players adapt differently to a given training stimulus and that training programs should be modified to accommodate differences in maturational and training age. In addition, the results of their study provided conditioning coaches with realistic performance improvements following a 10-week preseason strength and conditioning program in junior rugby league players.

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 11km·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.

**Studies related to anaerobic capacity and fatigue index**

Walklate et al., (2009) stated that repeated-agility sprint ability is an important performance characteristic of badminton players. However, it is unclear whether regular badminton training is sufficient to improve repeated-agility sprint ability or whether supplementary training is required. Therefore, their aim was to investigate whether supplementing regular group training with short sessions of badminton-specific agility-sprint training conferred any greater changes in performance than regular training alone. Twelve national level badminton players completed a set of performance tests in the week
before and after a 4-week training period. Performance tests consisted of 10-meter and 20-meter sprints, a multistage fitness test, a 300-meter shuttle run, and a novel badminton sprint protocol. After pretesting, pair-matched participants were randomly assigned into regular or supplementary training groups. Both groups undertook regular national squad training consisting of 4 2-hour sessions per week. In addition, the supplementary group completed a high-intensity sprint-training regime consisting of 7 to 15 repeats of badminton-specific sprints twice per week. Relative to control, the supplementary training group reported improvements (mean ± 90% confidence limits) in the 300-meter shuttle run (2.4% ± 2.7%) and badminton sprint protocol (3.6% ± 2.6%). However, there were no substantial difference in either the 10-meter (-0.3% ± 2.1%) or 20-meter (-0.6% ± 1.8%) sprint or the multistage fitness test (0.0% ± 2.7%). Supplementing regular training with sessions of short-duration sprint training appears to lead to worthwhile increases in repeated-agility sprint performance with national level badminton players.

Buchheit et al., (2010) compared the effects of explosive strength (ExpS) vs. repeated shuttle sprint (RS) training on repeated sprint ability (RSA) in young elite soccer players, 15 elite male adolescents (14.5 ± 0.5 years) performed, in addition to their soccer training program, RS (n = 7) or ExpS (n = 8) training once a week for a total of 10 weeks. RS training consisted of 2-3 sets of 5-6 × 15-m to 20-m repeated shuttle sprints interspersed with 14
seconds of passive or 23 seconds of active recovery (≈2 m·s⁻¹); ExpS training consisted of 4-6 series of 4-6 exercises (e.g., maximal unilateral countermovement jumps (CMJs), calf and squat plyometric jumps, and short sprints). Before and after training, performance was assessed by 10m and 30m (10m and 30m) sprint times, best (RSAbest) and mean (RSAmean) times on a repeated shuttle sprint ability test, a CMJ, and a hopping (Hop) test. After training, except for 10 m (p = 0.22), all performances were significantly improved in both groups (all p's < 0.05). Relative changes in 30 m (-2.1 ± 2.0%) were similar for both groups (p = 0.45). RS training induced greater improvement in RSAbest (-2.90 ± 2.1 vs. -0.08 ± 3.3%, p = 0.04) and tended to enhance RSAmean more (-2.61 ± 2.8 vs. -0.75 ± 2.5%, p = 0.10, effect size [ES] = 0.70) than ExpS. In contrast, ExpS tended to induce greater improvements in CMJ (14.8 ± 7.7 vs. 6.8 ± 3.7%, p = 0.02) and Hop height (27.5 ± 19.2 vs. 13.5 ± 13.2%, p = 0.08, ES = 0.9) compared with RS. Improvements in the repeated shuttle sprint test were only observed after RS training, whereas CMJ height was only increased after ExpS. Because RS and ExpS were equally efficient at enhancing maximal sprinting speed, RS training-induced improvements in RSA were likely more related to progresses in the ability to change direction.

Balciunas et al., (2006) identified the effect of 4 months of different training modalities on power, speed, skill and anaerobic capacity in 15-16 year old male basketball players. Thirty five Lithuanian basketball players were
randomly assigned into three groups: power endurance group (intermittent exercise, PE, n = 12), general endurance group (continuous exercise, GE, n = 11) and control group (regular basketball training, CG, n = 12). The power endurance model was based in basketball game external structure whereas the general endurance model was based in continuous actions that frequently occur during the basketball game. The training models were used for 16 weeks in sessions conducted 3 times a week during 90 minutes each in the competition period. The following tests were performed: 20 m speed run, Squat jump, Countermovement jump, Running-based Anaerobic Sprint Test (RAST), 2 min. shooting test and the Shuttle ball-dribbling test. A 3×2 repeated measures ANOVA revealed no statistically significant differences in the 20 m speed run, Squat jump and Countermovement jump (p > 0.05). On the other hand, RAST showed significant increases in PE, with greater increases during the 5th and 6th runs. The PE training model also produced a significant improvement in the shuttle ball-dribbling test (48.7 ± 1.5 in the pretest, 45.5 ± 1.3 in the posttest, p ≤ 0.05). Globally, their results suggest that both training modalities were able to maintain initial values of speed and power, however, the anaerobic capacity and skill increased only in the players from the power endurance group. Therefore, the power endurance training (intermittent high intensity exercise) may be more beneficial to prepare junior players according to the game cardiovascular and metabolic specific determinants.
Zagatto, Beck and Gobatto (2009) investigated the reliability and validity of the running anaerobic sprint test (RAST) in anaerobic assessment and predicting short-distance performance. Forty members of the armed forces were recruited for this study (age 19.78 +/- 1.18 years; body mass 70.34 +/- 8.10 kg; height 1.76 +/- 0.53 m; body fat 15.30 +/- 5.65 %). The RAST test was applied to six 35-meter maximal running performances with a 10-second recovery between each run; the peak power, mean power, and the fatigue index were measured. The study was divided in two stages. The first stage investigated the reliability of the RAST using a test-retest method; the second stage aimed to evaluate the validity of the RAST comparing the results with the Wingate test and running performances of 35, 50, 100, 200, and 400 m. There were not significant differences between test-retest scores in the first stage of the study (p > 0.05) and were found significant correlations between these variables (intraclass correlation coefficient [approximately equal to]0.88). The RAST had significant correlations with the Wingate test (peak power r = 0.46; mean power r = 0.53; fatigue index r = 0.63) and 35, 50, 100, 200, and 400 m performances scores (p < 0.05). The advantage of using the RAST for measuring anaerobic power is that it allows for the execution of movements more specific to sporting events that use running as the principal style of locomotion, is easily applied and low cost, and due to its simplicity can easily be incorporated into routine training. They concluded that this procedure is reliable and valid, and can be used to measure running anaerobic power and predict short-distance performances.
Keir, Thériault and Serresse (2012) referred repeated sprint ability (RSA) as an individual's ability to perform maximal sprints of short duration in succession with little recovery between sprints. The running-based anaerobic sprint test (RAST) has been adapted from the Wingate anaerobic test (WAnT) protocol as a tool to assess RSA and anaerobic power. The purpose of their study was to evaluate the relationship between performance variables and physiological responses obtained during the RAST and the WAnT using eight collegiate level soccer players. Participants performed a single trial of both the WAnT and the RAST. Breath-by-breath gas exchange was monitored throughout each trial, and blood lactate (BL) measures were recorded post-exercise. The oxygen uptake (VO₂) profile suggested that the RAST required greater contributions from aerobic metabolism although there was no difference in VO₂ (p < 0.05). Peak BL values were also similar between the RAST and the WAnT (p < 0.05). Neither peak physiological values nor performance variables (peak and mean power) were significantly correlated between protocols. The weak association in physiological responses indicates that different combinations of metabolic contributions exist between protocols suggesting that individual performances on each test are not related in collegiate soccer players. Further studies on these relationships with players of other competitive levels and team sport athletes are warranted.

Shiran et al., (2008) compared the effects of a five week APT and LPT intervention on physical performance and muscular enzymes in 21-male, club
wrestlers (age: 20.3 ± 3.6 years). Effects of the APT and LPT intervention upon anaerobic power was assessed by means of a running anaerobic sprint test (RAST). Results indicated the APT and LPT experimental groups provided similar yet no significant improvements in peak and mean power, without any meaningful difference between the training environments. Both groups increased the fatigue indices from pre-and post-test.

Hoffman et al., (2000) in their study compared 2 types of sport-specific field tests common in the training programs of basketball players to a laboratory measure of anaerobic power. Nine 17-year-old members of the Israel National Youth Basketball Team participated in this investigation. Field tests included a countermovement jump (CMJ), a 15-second anaerobic jump test (APJT), and a sprint test to assess anaerobic power (line drill). The line drill was performed 3 times (T1, T2, and T3) with a 2-minute passive rest between each sprint. In addition, all subjects performed a 30-second Wingate anaerobic power test (WaNT) to determine peak power (PP), mean power (MP), and fatigue index (FIWaNT). Kendall tau ([middle dot]) rank correlation analysis revealed moderate positive rank correlations between MP and both T1 and T2 ([middle dot] = 0.61 and 0.54, respectively). No significant rank correlations were observed between PP and the line drill. Significant (p <0.05) positive rank correlations were noted between CMJ and both PP and MP ([tau] = 0.59 and 0.76, respectively). However, only a poor relationship (p > 0.05) was observed between APJT and both PP and MP ([tau] = 0.20 and 0.28,
respectively). Their results suggested that the line drill and jump tests may be acceptable field measures of anaerobic power specific for basketball players.

Roberts, Billeter and Howald (1982) stated that in contrast to endurance training, little evidence is available concerning the effects of sprint-type training programs on the anaerobic metabolism of skeletal muscle. Four male subjects completed a mean of 16 training sessions consisting of eight 200-m runs at 90% of maximal speed, which were separated by 2-min rest periods. Before and after the 5-week training period, muscle biopsies were taken out of the lateral head of m. gastrocnemius and analyzed for the activities of phosphorylase, phosphofructokinase (PFK), glyceraldehyde phosphate dehydrogenase (GAPDH), lactate dehydrogenase (LDH), succinate dehydrogenase (SDH), and malate dehydrogenase (MDH). Following training there was a significant increase in the subjects' performance time in a treadmill test at a speed of 16 km/h speed and 15% grade. Significant increases were observed in the activities of phosphorylase, PFK, GAPDH, LDH, and MDH, whereas the 17.5% increase in SDH was not statistically significant. They concluded that interval training with high intensity and a 1:4 work-rest ratio leads to increased activities of key enzymes involved in glycogenolysis and anaerobic glycolysis of skeletal muscle.

Sporis, Ruzic and Leko (2008) evaluated changes in anaerobic endurance in elite First-league soccer players throughout 2 consecutive seasons, in 2 phases, with and without high-intensity situational drills. Eighteen
soccer players were tested before and after the 8-week summer conditioning and again in the next season. The measured variables included 300-yard shuttle run test, maximal heart rate, and maximal blood lactate at the end of the test. During the first phase of the study, the traditional sprint training was performed only 2 x weeks and consisted of 15 bouts of straight-line sprinting. In the second year the 4 x 4 min drills at an intensity of 90-95% of HRmax, separated by periods of 3-minute technical drills at 55-65% of HRmax were introduced. Statistical significance was set at P <= 0.05. The traditional conditioning program conducted during the first year of the study did not elicit an improvement in anaerobic endurance as recorded in the 300-yard shuttle run test. After the intervention, the overall test running time improved significantly (55.74 +/- 1.63 s vs. 56.99 +/- 1.64 s; P < 0.05) with the maximal blood lactate at the end of the test significantly greater (15.4 +/- 1.23 mmol.L vs. 13.5 +/- 1.12 mmol.L. P < 0.01). Their findings showed some indication that situational high-intensity task training was more efficient than straight-line sprinting in improving anaerobic endurance measured by the 300-yard shuttle run test.

Sirotic and Coutts (2007) stated that a large number of team sports require athletes to repeatedly produce maximal or near maximal sprint efforts of short duration interspersed with longer recovery periods of submaximal intensity. This type of team sport activity can be characterized as prolonged, high-intensity, intermittent running (PHIIR). The primary purpose of their study was to determine the physiological factors that best relate to a generic
PHIIR simulation that reflects team sport running activity. The second purpose of their study was to determine the relationship between common performance tests and the generic PHIIR simulation. Following a familiarization session, 16 moderately trained ($\text{VO}_{2\text{max}} = 40.0 \pm 4.3 \text{ ml/kg/min}$) women team sport athletes performed various physiological, anthropometrical, and performance tests and a 30-minute PHIIR sport simulation on a nonmotorized treadmill. The mean heart rate and blood lactate concentration during the PHIIR sport simulation were $164 \pm 6 \text{ b x min}^{-1}$ and $8.2 \pm 3.3 \text{ mmol x L}^{-1}$, respectively. Linear regression demonstrated significant relationships between the PHIIR sport simulation distance and running velocity attained at a blood lactate concentration of 4 mmol/L (LT) ($r = 0.77$, $p < 0.05$), 5 x 6-second repeated cycle sprint work ($r = 0.56$, $p < 0.05$), 30-second Wingate test ($r = 0.61$, $p < 0.05$), peak aerobic running velocity ($\text{Vmax}$) ($r = 0.69$, $p < 0.05$), and Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) distance ($r = 0.50$, $p < 0.05$), respectively. Their results indicated that an increased LT is associated with improved PHIIR performance and that PHIIR performance may be monitored by determining Yo-Yo IR1 performance, 5 x 6-second repeated sprint cycle test work, 30-second Wingate test performance, Vmax, or LT. They suggested that training programs should focus on improving both LT and Vmax for increasing PHIIR performance in moderately trained women. Future studies should examine optimal training methods for improving these capacities in team sport athletes.
Thébault, Léger and Passelergue (2011) reinvestigated the relationship between aerobic fitness and fatigue indices of repeated-sprint ability (RSA), with special attention to methodological normalization. Soldiers were divided into low \((n = 10)\) and high \((n = 9)\) fitness groups according to a preset maximal aerobic speed (MAS) of 17 km·h\(^{-1}\) (~60 ml O\(_2\)·kg\(^{-1}\)·min\(^{-1}\)) measured with the University of Montreal Track Test (UMTT). Subjects' assessment included the RSA test (3 sets of 5 40-m sprints with 1-minute rest between sprints and 1.5 minutes between sets), a 40-m sprint (criterion test used in the computation of fatigue indices for the RSA test), strength and power measurement of the lower limbs, and the 20-m shuttle run test (20-m SRT) and the UMTT, which are measures of maximal aerobic power. The highest correlation with the RSA fatigue indices was obtained with the 20-m SRT \((r = 0.90, p = 0.0001, n = 19)\), a test with 180° direction changes and accelerations and decelerations. The lower correlation \((r = 0.66, p < 0.01, n = 19)\) with the UMTT (continuous forward running) suggests that some aerobic tests better disclose the importance of aerobic fitness for RSA and that aerobic power is not the sole determinant of RSA. However, neither strength nor vertical jumping power was correlated to the RSA fatigue indices. Subjects with greater MAS were able to maintain almost constant level of speed throughout series of repeated sprints and achieved better recovery between series. A MAS of at least 17 km·h\(^{-1}\) favors constant and high speed level during repeated sprints. From a practical point of view, a high aerobic fitness is a precious asset in counteracting fatigue in sports with numerous sprint repetitions.
da Silva, Guglielmo and Bishop (2010) investigated the relationship between physiological variables related to aerobic fitness (maximal oxygen uptake: $\dot{V}$O$_2$max; the minimum velocity needed to reach $\dot{V}$O$_2$max: $v$VO$_2$max; velocity at the onset of blood-lactate accumulation: $v$OBLA) and repeated-sprint ability (RSA) in elite soccer players. Twenty-nine Brazilian soccer players (17.9 ± 1.0 years; 178.7 ± 5.2 cm; 73.6 ± 6.7 kg; 11.1 ± 1.3% body fat) from 2 national level teams (A, B) took part in the study. Subjects first performed an incremental test on a treadmill to determine their $\dot{V}$O$_2$max, $v$VO$_2$max and $v$OBLA. After at least 48 hours, subjects performed an RSA test consisting of 7 34.2-m sprints interspersed with 25 seconds of active recovery, to determine the mean time (MT), the fastest time (FT) and the Sprint decrement ($S_{\text{dec}}$). Pearson product moment correlations and multiple regressions were used to assess the relationship between aerobic fitness and RSA variables (FT, MT, $S_{\text{dec}}$, [La] Peak). An analysis of variance, followed by a post hoc test (Tukey), was used to compare the 7 sprints of the RSA test. The level of significance was set at $p < 0.05$. A significant negative correlation was found between both $v$OBLA and $v$VO$_2$max and MT during the RSA test ($r = -0.49$, $p < 0.01$; $r = -0.38$, $p < 0.05$, respectively). There were also negative correlations between $S_{\text{dec}}$ and $v$OBLA ($r = -0.54$), $v$VO$_2$max ($r = -0.49$) and $V$O$_2$max ($r = -0.39$). The multiple regression revealed that the aerobic ($v$OBLA) and anaerobic (FT) components explained approximately 89% of the variance of MT. The results of their study demonstrated that RSA is
more strongly correlated with vOBLA and vVO_{2}max than the more commonly measured VO_{2}max.

Chelly et al., (2010) framed hypothesis that the addition of an 8-week lower limb plyometric training program (hurdle and depth jumping) to normal in-season conditioning would enhance measures of competitive potential (peak power output [PP], jump force, jump height, and lower limb muscle volume) in junior soccer players. The subjects (23 men, age 19 ± 0.7 years, body mass 70.5 ± 4.7 kg, height 1.75 ± 0.06 m, body fat 14.7 ± 2.6%) were randomly assigned to a control (normal training) group (Gc; n = 11) and an experimental group (Gex, n = 12) that also performed biweekly plyometric training. A force-velocity ergometer test determined PP. Characteristics of the squat jump (SJ) and the countermovement jump (CMJ) (jump height, maximal force and velocity before take-off, and average power) were determined by force platform. Video-camera kinematic analyses over a 40-m sprint yielded running velocities for the first step (V_{S}), the first 5 m (V_{5m}) and between 35 and 40 m (V_{max}). Leg muscle volume was estimated using a standard anthropometric kit. Gex showed gains relative to controls in PP (p < 0.01); SJ (height p < 0.01; velocity p < 0.001), CMJ (height p < 0.001; velocity p < 0.001, average power p < 0.01) and all sprint velocities (p < 0.001 for V_{5m} and V_{max}, p < 0.01 for V_{S}). There was also a significant increase (p < 0.05) in thigh muscle volume, but leg muscle volume and mean thigh cross-sectional area remain unchanged. They concluded that biweekly plyometric training of junior soccer players (including
adapted hurdle and depth jumps) improved important components of athletic performance relative to standard in-season training. Accordingly, such exercises are highly recommended as part of an annual soccer training program.

Urtado et al., (2012) stated that plyometric training is an essential tool for improving the explosive force. The objective of their study was to analyze the responses of a plyometric training program on fatigue index in young women athletes. 14 young female basketball players aged 13.28±0.63 years; body mass 51.71±9.11 kg; height 1.61±6.77 m; and body fat percentage 22.71±4.93 % were selected. The training was developed with the preparatory phase of periodization, during 8 weeks with 3 sessions/week, divided into 3 separate programs: jump training (swedish bench height of 30 cm; barriers with height of 40 cm and stands of timber); depth jumps (with wooden boxes of 40 and 70 cm) and jumps with additional loads on the shoulders (bags of sand with 5 kg and 40 cm wood boxes). The jump training sessions were performed in a circuit fashion. An anaerobic endurance test was done by the forward-backward protocol, before and after the plyometric training. Student's t-test was applied ($p \leq 0.05$). The percentage of fatigue index (%FI) declined by 2% (from 7.4% to 5.4%), showing a significant improvement ($p = 0.022$) in the forward-backward protocol test (Table 1). The structure of the proposed plyometric program proved to be effective in improving the rate of fatigue in
basketball athletes in an anaerobic test, which may directly affect specific sport performance.

Table 1 – Fatigue Index percentage (%FI) pre and post-training

<table>
<thead>
<tr>
<th></th>
<th>%FI pre</th>
<th>%FI post</th>
<th>P value</th>
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<tbody>
<tr>
<td>Means</td>
<td>7.4%</td>
<td>5.4%*</td>
<td>0.022</td>
</tr>
<tr>
<td>SEM</td>
<td>3.8%</td>
<td>3.0%</td>
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</table>

*Statistically significant difference as compared with pre-training value.

Ranjbar, Kordi and Gaeini (2009) determined the effects of endurance, plyometric and concurrent training (combination of plyometric and endurance training) on the bio-energetic and skill characteristics of male soccer players. To this study 29 male soccer players with average age of 25.42 ± 4.72 yr, height of 177.60 ± 7.10 cm and body mass of 73.20 ± 6.59 kg were randomly assigned and divided into three groups of endurance (n=10), plyometric (n=10) and concurrent (n=9). The endurance training consisted of 4×4 min interval running at 90-95% of maximal heart rate, with a 3 min jogging in between. The plyometric training consisted of 9 explosive jumping and throwing exercises in 3 sets with 10 repetitions which subjects done with low to maximal intensity. The concurrent training consisted of both plyometric and endurance training at one session that plyometric training performed at first. All training program performed for 8 week and 3 times a week. The subjects performed 1600m run
test for VO$_2$max, RAST and vertical jump height for anaerobic power and Mor-Cherestian test for skill characteristics before and after training period. The analysis of data before and after training programs using T-test, ANOVA and LSD showed that: In all of the three groups VO$_2$max increased significantly. In plyometric and concurrent training groups, peak and average anaerobic power increased and the fatigue index decreased, significantly. No changes were found in this variable in endurance group. Also, no changes were found in dribbling and shooting skills in all of the groups after the training program. They concluded that utilizing concurrent plyometric and endurance training not only had no negative influence on bio-energetic and skills characteristics, but this can also improves their VO$_2$max, average anaerobic power and fatigue index more than along of plyometric and endurance training (p<0.05).

**Studies pertaining to aerobic capacity**

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.

Léger et al., (1988) designed a maximal multistage 20 m shuttle run test to determine the maximal aerobic power of schoolchildren, healthy adults attending fitness class and athletes performing in sports with frequent stops and starts (e.g. basketball, fencing and so on). Subjects run back and forth on a 20 m course and must touch the 20 m line; at the same time a sound signal is emitted from a prerecorded tape. Frequency of the sound signals is increased
0.5 km h-1 each minute from a starting speed of 8.5 km h-1. When the subject can no longer follow the pace, the last stage number announced is used to predict maximal oxygen uptake (VO2max) (Y, ml kg\(^{-1}\) min\(^{-1}\)) from the speed (X, km h\(^{-1}\)) corresponding to that stage (speed = 8 + 0.5 stage no.) and age (A, year): 
\[
Y = 31.025 + 3.238X - 3.248A + 0.1536AX,
\]
\[r = 0.71\] with 188 boys and girls aged 8-19 years. To obtain this regression, the test was performed individually. Right upon termination VO2 was measured with four 20 s samples and VO2max was estimated by retroextrapolating the O2 recovery curve at time zero of recovery. For adults, similar measurements indicated that the same equation could be used keeping age constant at 18 (r = 0.90, n = 77 men and women 18-50 years old). Test-retest reliability coefficients were 0.89 for children (139 boys and girls 6-16 years old) and 0.95 for adults (81 men and women, 20-45 years old).

Gehri et al., (1998) conducted a study to determine which plyometric training technique is best for improving vertical jumping ability, positive energy production, and elastic energy utilization. Data were collected before and after 12 weeks of jump training and were analyzed by ANOVA. Subjects (N = 28) performed jumps under 3 testing conditions-squat jump, countermovement jump, and depth jump-and were randomly assigned to 1 of 3 groups: control, depth jump training, or countermovement jump training. The 12-week program resulted in significant increases in vertical jump height for both training groups. The depth jump group significantly improved their
vertical jump height in all 3 jumps. None of the training methods improved utilization of elastic energy. In activities involving dynamic stretch-shorten cycles, drop jump training was superior to countermovement jump training due to neuromuscular specificity. Their study provided support for the strength and conditioning professional to include plyometric depth jump training as part of the athlete’s overall program for improving vertical jumping ability and concentric contractile performance.

Bal et al., (2012) investigated the effects of 6 week plyometric training on biochemical and physical fitness parameters of inter collegiate jumpers. A group of 30 jumpers (mean ± SD: age 22.02 ± 1.64 years, height 1.78 ± 0.04 m, body mass 75.5 ± 5.2 kg), who participated in inter-college athletic competition volunteered to participate in this study. The study was approved by the Ethics Committee of Directorate of Sport in Guru Nanak Dev University, Amritsar, India. All participants were informed about the study aim and methodology. All the subjects agreed to the above conditions in writing. They were randomly assigned into plyometric training (P) and control (C) groups, n=15 each. Plyometric group (P) was subjected to 6 week plyometric training program of 30 min a day and the control group did not perform any plyometric training techniques. The following biochemical and physical fitness parameters were determined: haemoglobin (g.dl⁻¹), urea (mg.dl⁻¹), uric acid (mg.dl⁻¹), total cholesterol (mg.dl⁻¹), triglyceride (mg.dl⁻¹), aerobic capacity, body composition and trunk strength and endurance. A paired (samples) t-test was used in data
analysis. The level of p<0.05 was considered significant. Significant between-group differences were found in aerobic capacity (t=2.40*), body composition (t=2.43*) and abdominal strength and endurance (t=2.96*) whereas no significant between-group differences were noted in haemoglobin (t=1.25), urea (t=1.14), uric acid (t=1.10), total cholesterol (t=1.61) and triglyceride (t=1.56). The plyometric training may be recommended to improve and maintain physical fitness parameters of Jumpers.

Spurrs, Murphy and Watsford (2003) examined whether changes in running performance resulting from plyometric training were related to alterations in lower leg musculotendinous stiffness (MTS). Seventeen male runners were pre- and post-tested for lower leg MTS, maximum isometric force, rate of force development, 5-bound distance test (5BT), counter movement jump (CMJ) height, RE, VO\textsubscript{2}max, lactate threshold (Th(la)), and 3-km time. Subjects were randomly split into an experimental (E) group which completed 6 weeks of plyometric training in conjunction with their normal running training, and a control (C) group which trained as normal. Following the training period, the E group significantly improved 3-km performance (2.7%) and RE at each of the tested velocities, while no changes in VO\textsubscript{2}max or Th(la) were recorded. CMJ height, 5BT, and MTS also increased significantly. No significant changes were observed in any measures for the C group. The results clearly demonstrated that a 6-week plyometric programme led to improvements in 3-km running performance. It was postulated that the increase
in MTS resulted in improved RE. They speculated that the improved RE led to changes in 3-km running performance, as there were no corresponding alterations in VO₂max or Th(la).

Turner, Owimngs and Schwane (2003) determined whether a 6-week regimen of plyometric training would improve running economy (i.e., the oxygen cost of submaximal running). Eighteen regular but not highly trained distance runners (age = 29 ± 7 [mean ± SD] years) were randomly assigned to experimental and control groups. All subjects continued regular running training for 6 weeks; experimental subjects also did plyometric training. Dependent variables measured before and after the 6-week period were economy of running on a level treadmill at 3 velocities (women: 2.23, 2.68, and 3.13 m·s⁻¹; men: 2.68, 3.13, and 3.58 m·s⁻¹), VO₂max, and indirect indicators of ability of muscles of lower limbs to store and return elastic energy. The last were measurements during jumping tests on an inclined (20°) sled: maximal jump height with and without countermovement and efficiencies of series of 40 submaximal countermovement and static jumps. The plyometric training improved economy (p < 0.05). Averaged values (m·ml⁻¹·kg⁻¹) for the 3 running speeds were: (a) experimental subjects—5.14 ± 0.39 pre training, 5.26 ± 0.39 post training; and (b) control subjects—5.10 ± 0.36 pre training, 5.06 ± 0.36 post training. The VO₂max did not change with training. Plyometric training did not result in changes in jump height or efficiency variables that would have indicated improved ability to store and return elastic energy. They concluded
that 6 weeks of plyometric training improves running economy in regular but not highly trained distance runners; the mechanism must still be determined.

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 (VO₂) during steady-state and maximal aerobic power (VO₂max) 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 VO₂max, and 44.7, 50.3, and 55.9 ml.kg⁻¹.min⁻¹ for steady-state VO₂ at three running paces (241, 268, and 295 m.min⁻¹). The relationship between VO₂max and distance running performance was r = -0.12 (p = 0.35). The relationships between steady-state VO₂ 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 VO₂ 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, VO₂ max and performances of 12 previously untrained individuals were determined before and after 4 and 8 weeks of training. In series B, performances, VO₂ max and VO₂ submax of 15 previously well trained runners were determined before and after 4 and 8 weeks of controlled training. In series A, VO₂ 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 VO₂ max nor VO₂ 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 VO₂ 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 VO₂ 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 VO₂ 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.

**Studies related to speed**

Delecluse (1997) viewed that today, it is generally accepted that sprint performance, like endurance performance, can improve considerably with training. Strength training, especially, plays a key role in this process. Sprint performance will be viewed multidimensionally as an initial acceleration phase (0 to 10m), a phase of maximum running speed (36 to 100m) and a transition phase in between. Immediately following the start action, the powerful extensions of the hip, knee and ankle joints are the main accelerators of body mass. However, the hamstrings, the musculus adductor magnus and the musculus gluteus maximus are considered to make the most important contribution in producing the highest levels of speed. Different training methods are proposed to improve the power output of these muscles. Some of
them aim for hypertrophy and others for specific adaptations of the nervous system. This includes general (hypertrophy and neuronal activation), velocity specific (speedstrength) and movement specific (sprint associated exercises) strength training. In developing training strategies, the coach has to keep in mind that strength, power and speed are inherently related to one another, because they are all the output of the same functional systems. As heavy resistance training results in a fibre type IIb into fibre type IIa conversion, the coach has to aim for an optimal balance between sprint specific and nonspecific training components. To achieve this they must take into consideration the specific strength training demands of each individual, based on performance capacity in each specific phase of the sprint.

Young, McLean and Ardagna (1995) investigated the relationship between strength measures and sprinting performance, and to determine if these relationships varied for different phases of sprint running. Twenty (11 males and 9 females) elite junior track and field athletes served as subjects. Athletes performed maximum sprints to 50 m from a block start and time to 2.5, 5, 10, 20, 30, 40 and 50 m were recorded by electronic timing gates. The resultant forces applied to the blocks were obtained from two force platforms. Twenty-seven measures of strength and speed-strength (absolute and relative to bodyweight) were collected from the height jumped and the force-time curve recorded from the takeoff phase of vertical jumping movements utilizing pure concentric, stretch shortening cycle (SSC) and isometric muscular contractions.
Pearson correlation analysis revealed that the single best predictor of starting performance (2.5 m time) was the peak force (relative to bodyweight) generated during a jump from a 120 degree knee angle (concentric contraction) \( (r = 0.86, p = 0.0001) \). The single best correlate of maximum sprinting speed was the force applied at 100 ms (relative to bodyweight) from the start of a loaded jumping action (concentric contraction) \( (r = 0.80, p = 0.0001) \). SSC measures and maximum absolute strength were more related to maximum sprinting speed than starting ability. They concluded that strength qualities were related to sprinting performance and these relationships differed for starting and maximum speed sprinting.

Rimmer and Sleivert (2000) studied the effects of a plyometric programme on sprinting performance in a group of 26 male participants (age: 24 ± 4 years), consisting of 22-rugby players and four touch-rugby players, playing at elite or under-21 level of competition. Participants were divided into a plyometric-group (n=10) performing sprint-specific plyometric exercises, a sprint-group (n=7), performing sprints and a control-group (n=9). All three groups performed sprint tests before and after the eight week intervention (15-sessions), consisting of three to six maximal sprint test efforts between 10- and 40-metres (m). During the 40-metre sprint, time was also recorded, at the 10-, 20-, 30-, and 40-m marks. The stride frequency was determined with a video camera in the 10- and 40-m sprints. Ground reaction time was measured with a force plate platform between the seven and 10-m marks, and also between the
37- and 40-m marks. The plyometric-group showed a significant decrease in time over the 0–10-m (2.6%; p=0.001) and 0–40-m (2.2%; p=0.001) distances, with the greatest improvement within the first 10-m of the sprint. These improvements were not significantly different from those observed in the sprint-group. However, there were no significant improvements in the sprint-group. The control group also showed no improvements in sprint times. There were no significant changes in stride length or frequency for any of the groups during the study. PT-group was the only group to show a significant decrease (4.4%) in ground contact time, and this only occurred between the 37-m and 40-m mark. The results showed that sprint specific plyometric exercises can improve sprint performance to the same extent as regular sprint training, especially over the first 10-m (acceleration phase) of the sprint, possibly due to shorter ground reaction times. In sports where speed up to 40-m are important, benefits would be derived by adding sprint-specific exercises to a regular sprint training programme, especially when acceleration adds to enhanced performance.

Lehnert, Lamrova and Elfmark (2009) studied the plyometric training effects on speed and explosive power predispositions during and after the end of the training program. The program was applied to a group of female youth volleyball players (n = 11) twice a week during an eight week period. Their actual level of explosive power and locomotor speed was evaluated before, during and after the intervention was completed. The levels were determined
with the following tests: the standing vertical jump, the vertical jump with an 
approach and the shuttle run for $6 \times 6$ m. There were positive changes in the 
average values of test scores during the period of testing, but the dynamics of 
the changes in the explosive power and the speed were different. Other 
increases in all the characteristics were noticeable when the final measurements 
were made six weeks after the completion of the training program. 
Examination of the differences in the test scores by the follow up group, before 
the beginning and six weeks after finishing the intervention, was centred on 
objectively and statistically important changes in the volleyball players’ motor 
predispositions ($p < .05$). The results of the program supported the opinion that 
plyometric exercises are effective tools in the development of explosive power 
and speed in young athletes.

Benito-Martínez et al., (2011) determined the performance evolution of 
a group of athletes after 8 weeks of training that combined electrostimulation 
(NM ES) and plyometrics (PT). 78 medium level sprinter athletes participated, 
40 women and 38 men (age, 15.9±1.4 years old, body mass index, 20.5±1.68 
kg/m²; weight 58.53±8.05 kg; height, 1.68±0.07 m). The sample was 
randomized into four groups [Control (PT only), NM ES + PT, PT + NM ES, 
and Simultaneous (plyometric jumps were performed through the passage of 
current)]. Improvements were obtained in the Abalakov jump of 3.57% 
($p<0.01$), 13.51% ($p<0.001$), 1.23% ($p<0.01$), and 0.77%, and in the sprint of 
0.45%, 3.87% ($p<0.05$), 4.56% ($p<0.01$) and 7.26% $p<0.001$ for the control
group, NM ES + PT group, PT + NM ES group, and Simultaneous group, respectively. They concluded that a) improvement in vertical jump requires the application of the NM ES prior to PT; b) the sprinter athlete must combine the workout simultaneously or apply the ES after the PT training; and c) in sportspeople that require improvement in both the vertical jump and speed tests (e.g. basketball) the simultaneous method is not recommended, the order of application of NM ES and PT being non-determinant. Finally, the time needed to obtain significant improvement in strength training through a combination of NM ES and PT is substantially lower (15 days) than the time needed to improve speed (30 days).

Studies related to vertical and horizontal explosive Power

Kubo et al., (2007) investigated the effects of plyometric and weight training protocols on the mechanical properties of muscle-tendon complex and muscle activities and performances during jumping. To fulfill the purpose ten subjects were selected and completed 12 wk (4 d·wk⁻¹) of a unilateral training program for plantar flexors. They performed plyometric training on one side (PT; hopping and drop jump using 40% of 1RM) and weight training on the other side (WT; 80% of 1RM). Tendon stiffness was measured using ultrasonography during isometric plantar flexion. Three kinds of unilateral jump heights using only ankle joint (squat jump: SJ; countermovement jump: CMJ; drop jump: DJ) on sledge apparatus were measured. During jumping, electromyographic activities were recorded from plantar flexors and tibial
anterior muscle. Joint stiffness was calculated as the change in joint torque divided by the change in ankle angle during eccentric phase of DJ. The result showed that tendon stiffness increased significantly for WT, but not for PT. Conversely, joint stiffness increased significantly for PT, but not for WT. Whereas PT increased significantly jump heights of SJ, CMJ, and DJ, WT increased SJ only. The relative increases in jump heights were significantly greater for PT than for WT. However, there were no significant differences between PT and WT in the changes in the electromyographic activities of measured muscles during jumping. Their results indicated that the jump performance gains after plyometric training are attributed to changes in the mechanical properties of muscle-tendon complex, rather than to the muscle activation strategies.

Markovic et al., (2007) evaluated the effects of sprint training on muscle function and dynamic athletic performance and to compare them with the training effects induced by standard plyometric training. Male physical education students were assigned randomly to 1 of 3 groups: sprint group (SG; n = 30), plyometric group (PG; n = 30), or control group (CG; n = 33). Maximal isometric squat strength, squat-and counter-movement jump (SJ and CMJ) height and power, drop jump performance from 30-cm height, and 3 athletic performance tests (standing long jump, 20-m sprint, and 20-yard shuttle run) were measured prior to and after 10 weeks of training. Both experimental groups trained 3 days a week; SG performed maximal sprints over distances of
10-50 m, whereas PG performed bounce-type hurdle jumps and drop jumps. Participants in the CG group maintained their daily physical activities for the duration of the study. Both SG and PG significantly improved drop jump performance (15.6 and 14.2%), SJ and CMJ height (~10 and 6%), and standing long jump distance (3.2 and 2.8%), whereas the respective effect sizes (ES) were moderate to high and ranged between 0.4 and 1.1. In addition, SG also improved isometric squat strength (10%; ES = 0.4) and SJ and CMJ power (4%; ES = 0.4, and 7%; ES = 0.4), as well as sprint (3.1%; ES = 0.9) and agility (4.3%; ES = 1.1) performance. They concluded that short-term sprint training produces similar or even greater training effects in muscle function and athletic performance than does conventional plyometric training. Their study provided support for the use of sprint training as an applicable training method of improving explosive performance of athletes in general.

Thomas, French and Hayes (2009) compared the effects of two plyometric training techniques on power and agility in youth soccer players. Twelve males from a semiprofessional football club's academy (age = 17.3 ± 0.4 years, stature = 177.9 ± 5.1 cm, mass = 68.7 ± 5.6 kg) were randomly assigned to 6 weeks of depth jump (DJ) or countermovement jump (CMJ) training twice weekly. Participants in the DJ group performed drop jumps with instructions to minimize ground-contact time while maximizing height. Participants in the CMJ group performed jumps from a standing start position with instructions to gain maximum jump height. Post training, both groups
experienced improvements in vertical jump height \( (p < 0.05) \) and agility time \( (p < 0.05) \) and no change in sprint performance \( (p > 0.05) \). There were no differences between the treatment groups \( (p > 0.05) \). Their study concluded that both DJ and CMJ plyometrics are worthwhile training activities for improving power and agility in youth soccer players.

Saez Saez de Villarreal et al., (2009) stated that plyometric training improves vertical jump height (VJH). However, the effectiveness of plyometric training depends on various factors. A meta-analysis of 56 studies with a total of 225 effect sizes (ESs) was carried out to analyze the role of various factors on the effects of plyometrics on VJH performance. The inclusion criteria for the analysis were a) studies using plyometric programs for lower-limb muscles, b) studies employing true experimental designs and valid and reliable measurements, and c) studies including enough data to calculate ESs. Subjects with more experience in sport obtained greater enhancements in VJH performance \( (p < 0.01) \). Subjects in either good or bad physical condition benefit equally from plyometric work \( (p < 0.05) \), although men tend to obtain better power results than women after plyometric training \( (p < 0.05) \). With relation to the variables of performance, training volumes of more than 10 weeks and more than 20 sessions, using high-intensity programs (with more than 50 jumps per session), were the strategies that seemed to maximize the probability of obtaining significantly greater improvements in performance \( (p < 0.05) \). To optimize jumping enhancement, the combination of different types
of plyometrics (squat jump + countermovement jump + drop jump) is recommended rather than using only 1 form ($p < 0.05$). However, no extra benefits were found to be gained from doing plyometrics with added weight. The responses identified in this analysis are essential and should be considered by strength and conditioning professionals with regard to the most appropriate dose-response trends for optimizing plyometric-induced gains.

Markovic (2007) examined the precise effect of plyometric training (PT) on vertical jump height in healthy individuals. Meta-analyses of randomised and non-randomised controlled trials that evaluated the effect of PT on four typical vertical jump height tests were carried out: squat jump (SJ); countermovement jump (CMJ); countermovement jump with the arm swing (CMJA); and drop jump (DJ). Studies were identified by computerised and manual searches of the literature. Data on changes in jump height for the plyometric and control groups were extracted and statistically pooled in a meta-analysis, separately for each type of jump. A total of 26 studies yielding 13 data points for SJ, 19 data points for CMJ, 14 data points for CMJA and 7 data points for DJ met the initial inclusion criteria. The pooled estimate of the effect of PT on vertical jump height was 4.7% (95% CI 1.8 to 7.6%), 8.7% (95% CI 7.0 to 10.4%), 7.5% (95% CI 4.2 to 10.8%) and 4.7% (95% CI 0.8 to 8.6%) for the SJ, CMJ, CMJA and DJ, respectively. When expressed in standardised units (ie, effect sizes), the effect of PT on vertical jump height was 0.44 (95% CI 0.15 to 0.72), 0.88 (95% CI 0.64 to 1.11), 0.74 (95% CI 0.47 to 1.02) and
0.62 (95% CI 0.18 to 1.05) for the SJ, CMJ, CMJA and DJ, respectively. PT provides a statistically significant and practically relevant improvement in vertical jump height with the mean effect ranging from 4.7% (SJ and DJ), over 7.5% (CMJA) to 8.7% (CMJ). These results justified the application of PT for the purpose of development of vertical jump performance in healthy individuals.

Wilson et al., (1993) carried out a study to determine which of three theoretically optimal resistance training modalities resulted in the greatest enhancement in the performance of a series of dynamic athletic activities. The three training modalities included 1) traditional weight training, 2) plyometric training, and 3) explosive weight training at the load that maximized mechanical power output. Sixty-four previously trained subjects were randomly allocated to four groups that included the above three training modalities and a control group. The experimental groups trained for 10 wk performing either heavy squat lifts, depth jumps, or weighted squat jumps. All subjects were tested prior to training, after 5 wk of training and at the completion of the training period. The test items included 1) 30-m sprint, 2) vertical jumps performed with and without a countermovement, 3) maximal cycle test, 4) isokinetic leg extension test, and 5) a maximal isometric test. The experimental group which trained with the load that maximized mechanical power achieved the best overall results in enhancing dynamic athletic
performance recording statistically significant (\(P < 0.05\)) improvements on most test items and producing statistically superior results to the two other training modalities on the jumping and isokinetic tests.

Sáez-Sáez De Villarreal et al., (2010) identified and stated that majority of the research suggests plyometric training (PT) improves maximal strength performance as measured by 1RM, isometric MVC or slow velocity isokinetic testing. However, the effectiveness of PT depends upon various factors. A meta-analysis of 15 studies with a total of 31 effect sizes (ES) was carried out to analyse the role of various factors on the effects of PT on strength performance. The inclusion criteria for the analysis were: (a) studies using PT programs for lower limb muscles; (b) studies employing true experimental design and valid and reliable measurements; (c) studies including sufficient data to calculate ES. When subjects can adequately follow plyometric exercises, the training gains are independent of fitness level. Subjects in either good or poor physical condition, benefit equally from plyometric work, also men obtain similar strength results to women following PT. In relation to the variables of program design, training volume of less than 10 weeks and with more than 15 sessions, as well as the implementation of high-intensity programs, with more than 40 jumps per session, were the strategies that seem to maximize the probability to obtain significantly greater improvements in performance \((p < 0.05)\). In order to optimise strength enhancement, the combination of different types of plyometrics with weight-training would be
recommended, rather than utilizing only one form \((p < 0.05)\). The responses identified in the analysis are essential and should be considered by the strength and conditioning professional with regard to the most appropriate dose–response trends for PT to optimise strength gains.

Adams et al., (1992) stated that explosive leg power is a key ingredient to maximizing vertical jump performance. In training, the athlete must use the most effective program to optimize leg power development. The purpose of their study was to compare the effectiveness of three training programs squat (S), plyometric (P) and squat-plyometric (SP) in increasing hip and thigh power production as measured by vertical jump. Forty-eight subjects were divided equally into four groups: S, P, SP or control (C). The subjects trained two days a week for a total of seven weeks, which consisted of a one-week technique learning period followed by a six-week periodized S, P or SP training program. Hip and thigh power were tested before and after training using the vertical jump test, and the alpha level was set at 0.05. Statistical analysis of the data revealed a significant increase in hip and thigh power production, as measured by vertical jump, within all three treatment groups. The SP group achieved a statistically greater improvement \((p < 0.0001)\) than the S or P groups alone. Examination of the mean scores shows that the S group increased 3.30 centimeters in vertical jump, the P group increased 3.81 centimeters and the SP group increased 10.67 centimeters. They found that both S and P training are
necessary for improving hip and thigh power production as measured by vertical jumping ability.

Faigenbaum et al., (2007) compared the effects of a six week training period of combined plyometric and resistance training (PRT, n = 13) or resistance training alone (RT, n = 14) on fitness performance in boys (12-15 yr). The RT group performed static stretching exercises followed by resistance training whereas the PRT group performed plyometric exercises followed by the same resistance training program. The training duration per session for both groups was 90 min. At baseline and after training all participants were tested on the vertical jump, long jump, medicine ball toss, 9.1 m sprint, pro agility shuttle run and flexibility. The PRT group made significantly (p < 0.05) greater improvements than RT in long jump (10.8 cm vs. 2.2 cm), medicine ball toss (39.1 cm vs. 17.7 cm) and pro agility shuttle run time (-0.23 sec vs. -0.02 sec) following training. They suggested that the addition of plyometric training to a resistance training program may be more beneficial than resistance training and static stretching for enhancing selected measures of upper and lower body power in boys.

Dodd and Alvar (2007) carried out a study to test the effects of complex training vs. heavy resistance or plyometric interventions alone on various power-specific performance measures. Forty-five male division II junior college baseball players participated in 3 separate 4-week resistance training interventions. Subjects were randomly assigned to one of three groups. In a
counterbalanced rotation design, each group participated in complex, heavy resistance, and plyometric training interventions. Each individual was tested in 20-yd (SP20), 40-yd (SP40), 60-yd (SP60), vertical jump, standing broad jump, and T-agility measures pre- and post-4-week training interventions. There was no statistical significant difference (p = 0.11) between groups across all performance measures. Review of each distinct training intervention revealed greater percent improvements in SP20 (0.55; -0.49; -0.12), SP40 (0.26; -0.72; -1.33), SP60 (0.27; 0.15; -0.27), standing broad jump (1.80; 0.67; 1.1), and T-agility (2.33; 1.23; -0.04) with complex training interventions than with the heavy resistance or plyometric training interventions, respectively. Plyometric-only training showed greater percent changes in vertical jump (1.90) than with complex (0.97) or heavy resistance training (0.36). They concluded that complex training can provide strength and conditioning professionals equal, if not slightly greater, improvements in muscular power than traditional heavy resistance- and plyometric-only interventions in moderately trained athletes. Complex training can be another valuable method for short-term power and speed improvements in athletes in isolation or in conjunction with other power development methods.

Randell et al., (2011) investigated the effect of instantaneous performance feedback (peak velocity) provided after each repetition of squat jump exercises over a 6-week training block on sport-specific performance tests. Thirteen professional rugby players were randomly assigned to 1 of 2
groups, feedback \((n = 7)\) and non-feedback \((n = 6)\). Both groups completed a 6-week training program (3 sessions per week) comprising exercises typical of their normal preseason conditioning program. Squat jumps were performed in 2 of the 3 sessions each week during which both groups performed 3 sets of 3 concentric squat jumps using a barbell with an absolute load of 40 kg. Participants in group 1 were given real-time feedback on peak velocity of the squat jump at the completion of each repetition using a linear position transducer and customized software, whereas those in group 2 did not receive any feedback. Pre and posttesting consisted of vertical jump, horizontal jump, and 10-/20-/30-m timed sprints. The relative magnitude (effect size) of the training effects for all performance tests was found to be small (0.18-0.28), except for the 30-m sprint performance, which was moderate (0.46). The probabilities that the use of feedback during squat jump training for 6 weeks was beneficial to increasing performance of sport-specific tests was 45% for vertical jump, 65% for 10-m sprints, 49% for 20-m sprints, 83% for horizontal jump, and 99% for 30-m sprints. In addition to improvements in the performance of sport-specific tests, suggesting the potential for greater adaptation and larger training effects, the provision of feedback may also be used in applications around performance targets and thresholds during training.

Remco et al., (2004) compared the efficacy of three physical conditioning programmes provided over a 12 week period (24 h in total) on selected anthropometric and physical fitness parameters in female soccer
players. Two of the groups received physical conditioning training in accordance with speed, agility and quickness (SAQ); one group used specialized resistance and speed development SAQ equipment (equipment group; n=12), while the other group used traditional soccer coaching equipment (non-equipment group; n=12). A third group received their regular fitness sessions (active control group; n=12). All three interventions decreased (P<0.001) the participants’ body mass index (73.7%) and fat percentage (71.7%), and increased their flexibility (+14.7%) and maximal aerobic capacity (VO2max) (+18.4%). The participants in the equipment and non-equipment conditioning groups showed significantly (P<0.005) greater benefits from their training programme than those in the active control group by performing significantly better on the sprint to fatigue (711.6% for both the equipment and non-equipment groups versus 76.2% for the active control group), 25 m sprint (74.4% vs 70.7%), left (74.5% vs 71.0%) and right (74.0% vs 71.4%) side agility, and vertical (+18.5% vs +4.8%) and horizontal (+7.7% vs +1.6%) power tests. Some of these differences in improvements in physical fitness between the equipment and non-equipment conditioning groups on the one hand and the active control group on the other hand were probably due to the specificity of the training programmes. They concluded that SAQ training principles appear to be effective in the physical conditioning of female soccer players. Moreover, these principles can be implemented during whole team training sessions without the need for specialized SAQ equipment. Finally, more research is required to establish the relationship between physical fitness
and soccer performance as well as the principles underlying the improvements seen through the implementation of SAQ training programmes.

Jovanovic et al., (2011) evaluated the effects of the speed, agility, quickness (SAQ) training method on power performance in soccer players. Soccer players were assigned randomly to 2 groups: experimental group (EG; n = 50) and control group (n = 50). Power performance was assessed by a test of quickness—the 5-m sprint, a test of acceleration—the 10-m sprint, tests of maximal speed—the 20- and the 30-m sprint along with Bosco jump tests—squat jump, countermovement jump (CMJ), maximal CMJ, and continuous jumps performed with legs extended. The initial testing procedure took place at the beginning of the in-season period. The 8-week specific SAQ training program was implemented after which final testing took place. The results of the 2-way analysis of variance indicated that the EG improved significantly (p < 0.05) in 5-m (1.43 vs. 1.39 seconds) and in 10-m (2.15 vs. 2.07 seconds) sprints, and they also improved their jumping performance in countermovement (44.04 vs. 4.48 cm) and continuous jumps (41.08 vs. 41.39 cm) performed with legs extended (p < 0.05). They concluded that the SAQ training program appears to be an effective way of improving some segments of power performance in young soccer players during the in-season period.

Studies associated to Agility

Miller et al., (2006) studied the impact of plyometric training for six weeks on agility. Subjects were divided into two groups, a plyometric training
and a control group. The plyometric training group performed in a six week plyometric training program and the control group did not perform any plyometric training techniques. All subjects participated in two agility tests: T-test and Illinois Agility Test, and a force plate test for ground reaction times both pre and post testing. Univariate ANCOVAs were conducted to analyze the change scores (post – pre) in the independent variables by group (training or control) with pre scores as covariates. The Univariate ANCOVA revealed a significant group effect $F_{2,26} = 25.42$, $p=0.0000$ for the T-test agility measure. For the Illinois Agility test, a significant group effect $F_{2,26} = 27.24$, $p = 0.000$ was also found. The plyometric training group had quicker posttest times compared to the control group for the agility tests. A significant group effect $F_{2,26} = 7.81$, $p = 0.002$ was found for the Force Plate test. The plyometric training group reduced time on the ground on the posttest compared to the control group. They found that plyometric training can be an effective training technique to improve an athlete’s agility.

Robinson and Owens (2004) conducted a study to evaluate the increase in agility during preparatory phase for which their program targets fundamental techniques and skills required for straight ahead speed, directional changes, and lower body power development to be used during a collegiate athlete's non-traditional season. The goal of their program is to teach generalized movement patterns and build a solid foundation that can be used by individual sport coaches during their traditional season.
Young, McDowell and Scarlett (2001) tried to identify whether straight sprint training transferred to agility performance tests that involved various change-of-direction complexities and if agility training transferred to straight sprinting speed. Thirty-six males were tested on a 30-m straight sprint and 6 agility tests with 2-5 changes of direction at various angles. The subjects participated in 2 training sessions per week for 6 weeks using 20-40-m straight sprints (speed) or 20-40-m change-of-direction sprints (3-5 changes of 100[degrees]) (agility). After the training period, the subjects were retested, and the speed training resulted in significant improvements (p < 0.05) in straight sprinting speed but limited gains in the agility tests. Generally the more complex the agility task, the less the transfer from the speed training to the agility task. Conversely, the agility training resulted in significant improvements in the change-of-direction tests (p < 0.05) but no significant improvement (p > 0.05) in straight sprint performance. They concluded that straight speed and agility training methods are specific and produce limited transfer to the other. Their findings have implications for the design of speed and agility training and testing protocols.

Alricsson, Harms-Ringdahl and Werner (2001) investigated the reliability of two sports related functional tests, a speed test (slalom-test) and an agility test (hurdle-test). Eleven athletes aged 11 years (8 boys, 3 girls) participated voluntarily in the study. All subjects completed four different test sessions for both the slalom-test and the hurdle-test using six standard track
hurdles placed at 2-m intervals along a 12-m length of track. There were no significant differences between testing sessions for either the slalom-test ($P=0.99$) or the hurdle-test ($P=0.96$), showing no systematic variation between test times. The intraclass correlation coefficients were 0.96 and 0.90 respectively, indicating a good reliability. They concluded that the slalom-test and the hurdle-test are reliable sports related functional tests for measuring speed and agility in groups of young athletic individuals.

Complex training has gained popularity as a training strategy combining weight training and plyometric training. Anecdotal reports recommend training in this fashion in order to improve muscular power and athletic performance. Recently, several studies have examined complex training. Despite the fact that questions remain about the potential effectiveness and implementation of this type of training, results of recent studies are useful in guiding practitioners in the development and implementation of complex training programs. In some cases, research suggests that complex training has an acute ergogenic effect on upper body power and the results of acute and chronic complex training include improved jumping performance. Improved performance may require three to four minutes rest between the weight training and plyometrics sets and the use of heavy weight training loads (Ebben, 2002).

Bal, Kaur and Singh (2011) assessed the effects of a short term plyometric training program on agility in young basketball players. A group of Thirty (N=30) male basketball players aged 18 – 24 years, who participated in
intercollege basketball competitions organized by the Department of Sports, Guru Nanak Dev University, volunteered to participate in this study. Their mean height, weight, and age were 1.87±0.06m, 75.5±5.2kg, 22.5±0.4 years. All subjects, after having been informed about the objective and protocol of the study, gave their written consents and the study was approved by the local Committee of Ethics. The subjects were randomly assigned into two groups: experimental (E; n = 15) and control (C; n = 15). Group E was subjected to a 6-week training, 25 min a day. Student’s t-test for independent data was used to assess the between-group differences and for dependent data to assess the Post-Pre differences. Level of $p \leq 0.05$ was considered significant. The results of their study are very encouraging and demonstrate the benefits of short term plyometric training program on agility in young basketball players. They concluded that the use of plyometrics training program is not only useful to break the monotony of training, but it can also improve the strength of basketball players.

Asadi and Arazi (2012) evaluated the effects of high-intensity plyometric training program on dynamic balance, agility, vertical jump, and sprint performance in young male basketball players. To fulfill the purpose sixteen semi-professional basketball players participated in this study. Subjects were divided into two groups: plyometric training (PL; n = 8) and control group (CG; n = 8). Plyometric training took place 2 days a week for 6 weeks including depth jump, squat depth jump, and depth jump to standing long jump.
Star Excursion Balance Test (SEBT), vertical jump (VJ), standing long jump (SLJ), 4 × 9- m shuttle run, T-test, Illinois Agility Test, and 20-m sprint were measured at pre- and post-training. The result of the study showed that PL demonstrated significant improvement (P < 0.05) in VJ (~23%), SLJ (~10%), 4 × 9-m shuttle run (~7%), T-test (~9%), Illinois Agility test (~7%), and 20-m sprint (~9%) after a 6- week of training and compared to CG. There were not significant changes (P > 0.05) in SEBT, but PL showed ~4% improvement. They concluded that a 6-week high-intensity plyometric program can improve power, agility, sprint and balance in young male basketball players. Also, their study provided support for coaches and basketball players who use plyometric training method at the preparation (conditioning) phase.

Shallaby (2010) studied the effectiveness of plyometric exercises on the special physical abilities and skillful performance of basketball players. It was applied to a sample of 20 players of 16 years old from El- Shoban El-Muslmeen club in Port Said. The participants were divided into two equivalent groups (experimental and control) of 10 players each. The experimental group applied the plyometric exercises and the control group applied the usual program. The program was applied for 12 weeks with 3 training units at 120 minutes for each unit. Through the training unit, the exercises were united between the two groups except for the part of the special physical preparation. The experimental group performed the plyometric exercises while the control group performed the physical exercise. Then, the scientific coefficients were
applied to tests using a sample outside the study sample. The scientific coefficients of constancy were between 0.764 and 0.970 and the reliability was between 0.903 and 984. The results pointed to a significant progress in the improvement percentages for the experimental group in all study tests compared to the improvement percentages of the control group, which were respectively: tests of vertical jump at 27.01%, medicine ball push (3 kg) at 20.14%, running 30m x 5n at 1.62% and shuttle running at 7.53%, which led to an improvement in the skillful performance (passing at 13.62%, dribbling at 13.46%, under-basket shooting 18.58% and lay-up at 57.97%).

Lim et al., (2012) examined the effects of 6-week plyometric training on the agility of college badminton players. A total of 42 college co-curriculum badminton students, aged 18-20 years participated in their study. Cluster sampling was used to select the two groups of students and subsequently the groups were randomly assigned to the control (n=23, male=7, female=16) and experimental (n=19, male=8, female=11) groups. Both groups were trained according to the compulsory co-curriculum programme once a week for six weeks. Additional plyometric training was provided to the experimental group. Illinois Agility Test (IAT) was used to determine the effect of plyometric training during pre and post intervention on agility. Control and experimental groups showed significant improvement in the mean agility scores during the post test as compared with the pre test (t=-2.48; p=0.001; and t=-2.89; p<0.001 respectively). The experimental group exhibited greater improvement
(7%) as compared to the control group (2.5%) (p=0.012) based on their pre test mean scores. They summarized that plyometric training improved the agility of college co-curriculum badminton players and plyometric training is recommended for training in improving agility in other sports as well. Young, James and Montgomery (2002) indentified the relationships -

between leg muscle power and sprinting speed with changes of direction. The study was designed to describe relationships between physical qualities and a component of sports performance. All testing was conducted in an indoor sports hall and a biomechanics laboratory. To achieve the purpose 15 male participants were required to be free of injury and have recent experience competing in sports involving sprints with changes of direction. The subjects were -
timed in 8 m sprints in a straight line and with various changes of direction. They were also tested for bilateral and unilateral leg extensor muscle concentric power output by an isokinetic squat and reactive strength by a drop jump. The result of the study showed the correlations between concentric power and -
straight sprinting speed were non-significant whereas the relationships between reactive strength and straight speed were statistically significant. Correlations -
between muscle power and speed while changing direction were generally low and non significant for concentric leg power with some moderate and signifi-cant (p<0.05) coefficients found for reactive strength. The participants who -
turned faster to one side tended to have reactive strength dominance in the leg responsible for the push off action. They concluded that the relationships -
between leg muscle power and change-of-direction speed were not consistent. Reactive strength as measured by the drop jump appears to have some importance for lateral change-of-direction speed, possibly because of similar push-off actions. They also concluded that reactive strength of the leg extensor muscles has some importance in change-of-direction performance but the other technical and perceptual factors that influence agility performance should also be considered.

**Studies related to flexibility**

Chaudhary and Jhajharia (2010) reported that there is not a single sport in the world at the competitive level for which resistance training in some or the other form is not used as conditioning exercises. Plyometric training is an excellent method of developing body power and it is proved as a very effective method for improving explosive strength. The purpose of their study was to find out the effects of plyometric exercises on selected motor abilities of university level female basketball players. The subjects, 20 female basketball players of Lakshmibai National Institute of Physical Education, Gwalior, were randomly divided in two groups, that is, experimental and control group. The age of subjects varied between 18 and 22 years. The criterion measures vertical jump, 20-m dash, movement speed, flexibility and agility in the beginning and at the end of the experimental period of 6 weeks for both the groups. The analysis of co-variance was used as a statistical technique and it was tested at 0.05 level of significance. They concluded that the plyometric training is an
effective means for improving agility, flexibility, vertical jump and movement speed. On the other hand, plyometric training is not an effective means for improving speed of movement (20-m dash).

Faigenbaum et al., (2000) compared the effects of a six week training period of combined plyometric and resistance training (PRT, n = 13) or resistance training alone (RT, n = 14) on fitness performance in boys (12-15 yr). At baseline and after training all participants were tested on the vertical jump, long jump, medicine ball toss, 9.1 m sprint, pro agility shuttle run and flexibility. The result suggested that the addition of plyometric training to a resistance training program may be more beneficial than resistance training and static stretching for enhancing selected measures on vertical jump, long jump, pro agility shuttle run, medicine ball toss and flexibility. Post-hoc analysis revealed that PRT made significant improvements on the vertical jump, long jump, pro agility shuttle run, medicine ball toss and flexibility, whereas RT made significant improvements on the medicine ball toss and flexibility only.

Messner et al., (1999) studied the effect of plyometric training on strength, vertical jump, flexibility and range of motion in volleyball players. To fulfill the purpose nine female I Division volleyball players were selected and plyometric training was administered during post season. The protocol followed twice a week for eight weeks. The result showed that no changes were found in a number of strength factors for the quadriceps or hamstring muscle groups. No improvements in vertical jump were recorded. The only feature of
improvement was an increase in range of motion for dorsiflexion in both legs. They concluded that plyometrics training was not beneficial for female volleyball players, possibly because they already engage in many maximal vertical jumps as part of the sport.

Bloomfield et al., (2007) compared the effectiveness of two methodologies for flexibility and agility conditioning for random, intermittent, and dynamic activity sports (e.g., soccer, tennis, hockey, basketball, rugby, and netball) and the necessity for specialized coaching equipment. Result suggested that both conditioning groups showed a significant decrease in body mass and body mass index, although programmed method (PC) achieved significantly greater improvements on acceleration, deceleration, leg power, dynamic balance, and the overall summation of percentage (%) increases when compared to random method (RC) and no conditioning NC (p < 0.05). PC in the form of flexibility, agility, quickness (SAQ) exercises appears to be a superior method for improving flexibility and agility parameters.

**Studies associated with abdominal muscular endurance**

Polman, Bloomfield and Edwards (2009) investigated the efficacy of both programmed (speed, agility, and quickness; SAQ) and random (small-sided games; SSG) conditioning methods on selected neuromuscular and physical performance variables. Twenty volunteers (21.1±4.0 y, 1.71±0.09 m, 66.7±9.9 kg; mean±SD) completed the study. The study design used two physically challenging periodized experimental conditions (SAQ and SSG
conditions) and a nonexercise control condition (CON). Participants engaged in 12.2±2.1 h of directed physical conditioning. All participants had at least 24 h of recovery between conditioning sessions, and each 1-h session included 15 min of general warm-up and a 45-min exercise session. Participants completed a battery of tests (15-m sprint, isokinetic flexion/extension, depth jump) before and following the training program. The result of the study showed that there was a 6.9% (95% CI: −4.4 to 18.3) greater improvement in 5-m acceleration time and 4.3% (95% CI: −0.9 to 9.5) in 15-m mean running velocity time for the SAQ group compared with the SSG group. In addition, increases in maximal isokinetic concentric strength for both the flexor and extensor muscles, with the exception of 180 °/s flexion, were greater in the SAQ than SSG condition. The SAQ group also showed 19.5% (95% CI: −11.2 to 50.2) greater gain in reactive strength (contact time depth jump) and 53.8% (95% CI: 11.2 to 98.6) in mean gastrocnemius medialis activity in comparison with SSG. They concluded that SAQ training should benefit the physical conditioning programs of novice players performing invasion games.

Behm et al., (2010) reviewed the effectiveness of instability resistance training for athletic, nonathletic, and rehabilitation conditioning. The anatomical core is defined as the axial skeleton and all soft tissues with a proximal attachment on the axial skeleton. Spinal stability is an interaction of passive and active muscle and neural subsystems. Training programs must prepare athletes for a wide variety of postures and external forces, and should
include exercises with a destabilizing component. While unstable devices have been shown to be effective in decreasing the incidence of low back pain and increasing the sensory efficiency of soft tissues, they are not recommended as the primary exercises for hypertrophy, absolute strength, or power, especially in trained athletes. For athletes, ground-based free-weight exercises with moderate levels of instability should form the foundation of exercises to train the core musculature. Instability resistance exercises can play an important role in periodization and rehabilitation, and as alternative exercises for the recreationally active individual with less interest or access to ground-based free-weight exercises. Based on the relatively high proportion of type I fibers, the core musculature might respond well to multiple sets with high repetitions (e.g., >15 per set); however, a particular sport may necessitate fewer repetitions.

Bliss and Teeple (2005) stated that core strengthening and stability exercises have become key components of training programs for athletes of all levels. The core muscles act as a bridge between upper and lower limbs, and force is transferred from the core, often called the powerhouse, to the limbs. Stability initially requires maintenance of a neutral spine but must progress beyond the neutral zone in a controlled manner. Some studies have demonstrated a relationship between core stability and increased incidence of injury. A training program should start with exercises that isolate specific core
muscles but must progress to include complex movements and incorporate other training principles.

Hibbs et al., (2008) have highlighted the benefits of core training for elite athletes and how this training should be carried out to optimize sporting performance. Many elite athletes undertake core stability and core strength training as part of their training programme, despite contradictory findings and conclusions as to their efficacy. This is mainly due to the lack of a gold standard method for measuring core stability and strength when performing everyday tasks and sporting movements. A further confounding factor is that because of the differing demands on the core musculature during everyday activities (low load, slow movements) and sporting activities (high load, resisted, dynamic movements), research performed in the rehabilitation sector cannot be applied to the sporting environment and, subsequently, data regarding core training programmes and their effectiveness on sporting performance are lacking. There are many articles in the literature that promote core training programmes and exercises for performance enhancement without providing a strong scientific rationale of their effectiveness, especially in the sporting sector. In the rehabilitation sector, improvements in lower back injuries have been reported by improving core stability. Few studies have observed any performance enhancement in sporting activities despite observing improvements in core stability and core strength following a core training programme. A clearer understanding of the roles that specific muscles have
during core stability and core strength exercises would enable more functional training programmes to be implemented, which may result in a more effective transfer of these skills to actual sporting activities.

Hill and Leiszler (2011) identified core stability and plyometric training have become common elements of training programs in competitive athletes. Core stability allows stabilization of the spine and trunk of the body in order to allow maximal translation of force to the extremities. Plyometric training is more dynamic and involves explosive-strength training. Integration of these exercises theoretically begins with core stabilization using more static exercises, allowing safe and effective transition to plyometric exercises. Both core strengthening and plyometric training have demonstrated mixed but generally positive results on injury prevention rehabilitation of certain types of injuries. Improvement in performance compared to other types of exercise is unclear at these times. Their article discussed the theory and strategy behind core stability and plyometric training; reviews the literature on injury prevention, rehabilitation of injury, and performance enhancement with these modalities; and discussed the evaluation and rehabilitation of core stability.

In recent years, fitness practitioners have increasingly recommended core stability exercises in sports conditioning programs. Willardson (2007) stated that greater core stability may benefit sports performance by providing a foundation for greater force production in the upper and lower extremities. Traditional resistance exercises have been modified to emphasize core stability.
Such modifications have included performing exercises on unstable rather than stable surfaces, performing exercises while standing rather than seated, performing exercises with free weights rather than machines, and performing exercises unilaterally rather than bilaterally. Despite the popularity of core stability training, relatively little scientific research has been conducted to demonstrate the benefits for healthy athletes. Therefore, the investigator examined core stability training and other issues to determine useful applications for sports conditioning programs. Based on the current literature, prescription of core stability exercises should vary based on the phase of training and the health status of the athlete. During preseason and in-season mesocycles, free weight exercises performed while standing on a stable surface are recommended for increases in core strength and power. Free weight exercises performed in this manner are specific to the core stability requirements of sports-related skills due to moderate levels of instability and high levels of force production. Conversely, during postseason and off-season mesocycles, Swiss ball exercises involving isometric muscle actions, small loads, and long tension times are recommended for increases in core endurance. Furthermore, balance board and stability disc exercises, performed in conjunction with plyometric exercises, are recommended to improve proprioceptive and reactive capabilities, which may reduce the likelihood of lower extremity injuries.
Cowley and Swensen (2008) identified and recognized the link between core stability and back and lower extremity injury in sport, however additional field tests that assess the strength and power component of core stability are needed to identify athletes at risk of such injury. For which they developed and tested the reliability of the front and side abdominal power tests (FAPT and SAPT), which were adapted from plyometric medicine ball exercises. The FAPT and SAPT were performed by explosively contracting the core musculature using the arms as a lever to project a medicine ball. Twenty-four untrained young women (aged 20.9 +/- 1.1 year) completed three trials each of the FAPT and SAPT on separate nonconsecutive days. The average distance the medicine ball was projected on each day was recorded; power was inferred from this measure. There was an approximately 3% increase in the mean distance between the testing sessions for the FAPT and SAPT; this was not significant and indicates there was no learning effect in the measurement protocol. Heteroscedasticity was present in the SAPT data but not the FAPT data. For the FAPT, the intraclass correlation coefficient was 0.95, standard error of measurement was 24 cm, and random error using the limits of agreement method was 67.5 cm. For the SAPT, the intraclass correlation coefficient was 0.93, mean coefficient of variation was 9.8%, and the limits of agreement ratio were 36.8%. The FAPT and SAPT displayed excellent test-retest reliability, as well as acceptable measurement error. Their findings suggested that the FAPT and SAPT are reliable tests and may be used to assess the power component of core stability in young women.
Barber-Westin, Hermeto and Noyes (2010) evaluated the effectiveness of a tennis-specific training program on improving neuromuscular indices in competitive junior players. Tennis is a demanding sport because it requires speed, agility, explosive power, and aerobic conditioning along with the ability to react and anticipate quickly, and there are limited studies that evaluate these indices in young players after a multiweek training program. The program designed for their study implemented the essential components of a previously published neuromuscular training program and also included exercises designed to improve dynamic balance, agility, speed, and strength. Fifteen junior tennis players (10 girls, 5 boys; mean age, 13.0 +/- 1.5 years) who routinely participated in local tournaments and high-school teams participated in the 6 week supervised program. Training was conducted 3 times a week, with sessions lasting 1.5 hours that included a dynamic warm-up, plyometric and jump training, strength training (lower extremity, upper extremity, core), tennis-specific drills, and flexibility. After training, statistically significant improvements and large-to-moderate effect sizes were found in the single-leg triple crossover hop for both legs (p < 0.05), the baseline forehand (p = 0.006) and backhand (p = 0.0008) tests, the service line (p = 0.0009) test, the 1-court suicide (p < 0.0001), the 2-court suicide (p = 0.02), and the abdominal endurance test (p = 0.01). Mean improvements between pretrain and posttrain test sessions were 15% for the single-leg triple crossover hop, 10-11% for the baseline tests, 18% for the service line test, 21% for the 1-court suicide, 10% for the 2-court suicide, and 76% for the abdominal endurance test. No athlete
sustained an injury or developed an overuse syndrome as a result of the training program. The results demonstrated that their program is feasible, low in cost, and appears to be effective in improving the majority of neuromuscular indices tested. They accomplished their goal of developing training and testing procedures that could all be performed on the tennis court.
Summary of Literature

Handball is a strenuous body contact Olympic team sport that places emphasis on strong physique and fitness to excel. To prepare handball players, coaches around the world practice numerous training methods to enhance performance of the players. PLYO training is one of the oldest form of training method utilized by coaches to prepare players. Plyometric training for six weeks significantly decreased percent body fat and increased lean body mass (MacDonald, Lamont & Garner 2012; Marković, et al., 2005). However, Sedano and others (2009) found that no changes were elicited in body composition. Previous studies reported that high intensity PLYO training methods influenced the improvement of anaerobic power based on vertical jump in female team sport players (Gora, Lana & Goran 2008; Sirotic & Coutts 2007). In the present study repeated sprint interspersed with short recovery, from which anaerobic capacity and fatigue index are calculated and this was the pioneer attempt made to study the impact of PLYO training on it.

Plyometric training is strictly anaerobic in nature. When sufficient recovery is not allowed, the activity moves toward being aerobic, but quality of movement and explosiveness is sure to suffer (Gehri, et al., 1998). The six weeks of plyometric training resulted in improvement of jumper’s aerobic capacity (Bal, et al., 2012) but several studies show no improvement in aerobic capacity.
Sprint, power and agility could be improved through plyometric training (Rimmer & Sleivert 2000; Markovic & Mikulic 2010; Lehnert, Lamrova & Elfmark 2009; Benito-Martínez, et al., 2011; Kubo et al., 2007; Markovic, et al., 2007; Thomas, French & Hayes 2009; Gehri, et al., 1998; Markovic & Mikulic, 2010; Markovic, 2007; Sáez-Sáez De Villarreal, et al., 2009; Sáez-Sáez De Villarreal, et al., 2010; Miller, et al., 2006; Robinson & Owens 2004; Young, McDowell & Scarlett 2001; Alricsson, Harms-Ringdahl & Werner 2001; Ebben 2002; Bal, Kaur & Singh 2011; Asadi & Arazi 2012; Shallaby 2010; Lim, et al., 2012).

Plyometric training improves hamstring flexibility measured by sit and reach test (Chaudhary & Jhajharia, 2010). According to Messner, et al., (1999) eight weeks of PLYO training showed no significant difference on flexibility of women volleyball players. Similarly, abdominal muscular endurance show an increase in the amount of sit-ups in athletes (Bal, et al., 2012; Hill & Leiszler 2011; Willardson 2007; Barber-Westin, Hermeto & Noyes, 2010).

Leg strength is the primary source of power in many sports. According to Gambetta (2003) the legs can be seen as a functional unit of a closed kinetic chain without which an athlete cannot have speed, strength, power or suppleness to perform.

SAQ training shows greater impact on soccer players but no research has been carried out on handball players. In women soccer player’s, administration of SAQ training resulted in decrease in percent body fat, fatigue

The effectiveness of PLYO and SAQ training is well supported by research. In India, however, there is a lack of research and related literature pertaining to PLYO and SAQ and their effect on handball. Even at international level, the lack of research into PLYO and SAQ, specifically applicable to promoting or developing specific functional capacities needed in the game of handball, is evident. The underlying physiology would contribute to the better understanding and more effective application of PLYO and SAQ training in handball. It is therefore important to find out the changes elicited in selected physiological and motor performance variables induced by PLYO and SAQ trainings in handball players.