CHAPTER – II

REVIEW OF RELATED LITERATURE

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LITERATURE SURVEY

Literature survey comprises locating, reading and evaluating reports of research as well as reports of casual observation and opinion that are related to the individual's planned research report. A study of relevant literature is an essential step to get a full picture of what has been done with regard to the problem under study. The investigator has made an attempt to bring a brief review of research related to the present study to form the background for the present study and has presented the same with appropriate headings.

2.1 STUDIES ON RESISTANCE TRAINING

Resistance training has been shown to improve not only the force production of a muscle, but also muscular power (Adams et. al., 1992; Baker, 1996; Holcomb et. al, 1996; Newton & Kraemer, 1994). However power production gained from high load, slow speed lifting is thought to be restricted mainly to the initial stages of training (Stone, 1993). As resistance increases, the effect of maximum strength has on power production increases, with its greatest benefit seen in situations where an athlete must overcome high levels of inertia, as in early stages of movements when implements or equipment are moved or thrown (Stone, 1993). Knowing this, coaches should plan for more power lifting (heavy load low speed lifting) type practices early in the off season training programme and work toward more powerful lifting cycles which would incorporate more high speed lifting exercises. Coaches and trainers should also keep in mind that power athletes, especially throwers and athletes who must come over large initial inertia, need to maintain their maximum strength during the season for best performances. As far as resistance training and increased movement speed is concerned, some research support the hypothesis that heavy resistance training will increase movement speed, while others feel prolonged heavy workloads might actually decrease speed (Ebben & Blackard, 1997 and Yessis, 1994).

Two other forms of resistance training used in strength and power development in athletic programmes are maximum power training, and Olympic lifting (clean and jerk, and the snatch) and Olympic assistance lifts (e.g. power clean, high pull, jerks, power snatches etc.). Maximum power training is a technique where the lift is accelerated through the full range of motion using a weight approximately 30% of maximum force (Lyttle, 1996). This training technique has been shown to improve athletic performance more than traditional heavy resistance training or plyometric training (Lyttle, 1996). Olympic lifting has become popular as a power training technique and as a method to improve an athlete's vertical jump performance (Canavan et. al., 1996, Garhammer, 1993, Garhammer & Gregor, 1992, and Hedrick, 1996). Competitive style lifting has also been shown to increase muscular power in athletes (Baker, 1996, Garhammer, 1993; Headrick, 1994; Headrick & Anderson, 1996; Newton & Kraemer, 1994, Pearson, 1998, Canavan et. al., 1996). This is in contrast to power lifting (high load slow movement speed), which has a marked decrease in power output as performance in the sport improves (Garhammer, 1993). The bench press, back squat and dead lift are the three power lifting competitive lifts, and are popular in strength and conditioning programmes. As the loads in these lifts increase or improve the speed of movement drastically decreases, which actually results in a decreased power output in contrast to Olympic style lifts (Garhammer, 1993).

Another reason for the use of investigation into maximum power and Olympics style lifting is the specificity of training speed seen in strength training. Earlier it was stated that power in athletics deal with speed of muscular contraction and strength (Yessis, 1994). Additionally studies have shown that the strength gains in resistance training are specific to the speed at which the training occurred (Canavcan et. al., 1996, Garhammer, 1992, Hedrick, 1996, Hedrick s& Anderson, 1996, Newton & Kraemer, 1994, Stone 1993, Yessis, 1994, Yessis, 1995). Therefore heavy resistance training at slow speeds will optimize force production in the slow portion of the force velocity curve while training at fast speeds will increase the force capacity of a muscle at the faster portion of the force velocity curve. In sport, this would lend support for both training technique being utilized in conditioning.

Kraemer et al., (2001) conducted a study on effect of resistance training on women's strength/power and occupational performances for which they examined the strength, power, and military occupational task performances in women. Untrained women aged (mean +/- SD) 23 +/- 4 yr were matched and randomly placed in total (TP, N = 17 and TH, N = 18) or upper-body resistance training (UP, N = 18 and UH, N = 15), field (FLD, N = 14), or aerobic training groups (AER, N = 11). Two periodized resistance training programmes (with supplemental aerobic training) emphasized explosive exercise movements using 3- to 8-RM training loads (TP, UP), whereas the other two emphasized slower exercise movements using 8- to 12-RM loads (TH, UH). The FLD group performed plyometric and partner exercises. Specific training programmes resulted in significant increases in body mass (TP), 1-RM squat (TP, TH, FLD), bench press (all except AER), high pull (TP), squat jump (TP, TH, FLD), bench throw (all except AER), squat endurance (all except AER), 1-RM box lift (all except aerobic), repetitive box lift (all), push-ups (all except AER), sit-ups (all except AER), and 2-mile run (all). Strength training improved physical performances of women over 6 months and adaptations in strength, power, and endurance were specific to the subtle differences (e.g., exercise choice and speeds of exercise movement) in the resistance training programmes (strength/power vs strength/hypertrophy). Upper and total body resistance training resulted in similar improvements in occupational task performances, especially in tasks that involved upper-body musculature. Finally, gender differences in physical performance measures were reduced after resistance training in women, which underscores the importance of such training for physically demanding occupations

Wilson et. al., (1993) compared the effects of 10 wk of training with traditional back squats or one of two forms of plyometric training loaded jump squats or drop jumps on vertical jump performance. Two types of vertical jump tests were performed: 1) a counter-movement jump in which the subjects started from a standing position, performed a rapid crouch, and then jumped for maximal height, and 2) a jump from a static crouching position, i.e., with no counter movement. All training groups except the drop-jump group produced significant increases in vertical jump performance. For the counter-movement jump, the group that trained with loaded jump squats produced the greatest improvement (18%), which was significantly greater than that for the drop-jump group (10%) or for the weight-trained group (5%). For the static crouch jump, the group trained with loaded jump squats increased jump height by 15%, which was significantly greater than the increase for the drop-jump group (7.2%) and for the weight training group (6.8%). These results were similar to those obtained by Berger (1963), who also found that training with jump squats loaded at 30% of maximum resulted in greater increases in vertical jump than did training programmes consisting of traditional weight training, drop-jump training, or isometric training.

Kraemer et. al., (2004) examined the adaptations of arm and thigh muscle hypertrophy to different long-term periodized resistance training programmes and the influence of upper body resistance training. Eighty-five untrained women (mean age = 23.1 +/- 3.5 yr) started in one of the following groups: total-body training [TP, N = 18 (3-8 RM training range) and TH, N = 21 (8-12 RM training range)], upper-body training [UP, N = 21 (3-8 RM training range) and UH, N = 19, (8-12 RM training range)], or a control group (CON, N = 6). Training took place on three alternating days per week for 24 weeks. Assessments of body composition, muscular performance, and muscle cross-sectional area (CSA) via magnetic resonance imaging (MRI) were determined pre-training (T1), and after 12 (T2) and 24 weeks (T3) of training. Results of the study were: arm cross-sectional area increased at T2 (approximately 11%) and T3 (approximately 6%) in all training groups and thigh CSA increased at T2 (approximately 3%) and T3 (approximately 4.5%) only in TP and TH. Squat one-repetition maximum (1 RM) increased at T2 (approximately 24%) and T3 (approximately 11.5%) only in TP and TH and all training groups increased 1 RM bench press at T2 (approximately 16.5%) and T3 (approximately 12.4%). Peak power produced during loaded jump squats increased from T1 to T3 only in TP (12%) and TH (7%). Peak power during the ballistic bench press increased at T2 only in TP and increased from T1 to T3 in all training groups. Finally he concluded that training specificity was supported (as sole upper-body training did not influence lower-body musculature) along with the inclusion of heavier loading ranges in a periodized resistance-training programme. This may be advantageous in a total conditioning programme directed at development of muscle tissue mass in young women.

Elliott et al., (1989) studied on the effect of weight training and plyometric on vertical jump ability. From the results he has concluded that the traditional weight training increases vertical jump performance, but not to the same extent as plyometric training with loaded jump squats. He gave explanation for the less effect of weight training is that the weight being lifted is decelerating for a considerable proportion of the movement. On the other hand plyometric training by drop jumping or by performing weighted jump squats allows athletes to use "compensatory acceleration" whereby they can complete the entire movement at high velocity (Hatfield, 1989). In comparing heavy weight training with the use of lighter weight and explosive jumps, most studies have found the latter to be more effective (Hakkinen & Komi, 1985b; Komi et. al., 1982; Wilson et. al., 1993).

Newton et. al., (1999) conducted a study on the effects of ballistic training on pre-season preparation of elite volleyball players. The purpose of this study was to determine whether ballistic resistance training would increase the vertical jump (VJ) performance of already highly trained jump athletes (sixteen male volleyball players from a NCAA division I team participated in the study). A Vertex was used to measure standing vertical jump and reach (SJR) and jump and reach from a three-step approach (AJR). Several types of vertical jump tests were also performed on a plyometric power system and a force plate to measure force, velocity, and power production during vertical jumping. The subjects completed the tests and were then randomly divided into two groups, control and treatment. All subjects completed the usual preseason volleyball on-court training combined with a resistance training programme. In addition, the treatment group completed 8 wk of squat jump training while the control group completed squat and leg press exercises at a 6RM load. Both groups were retested at the completion of the training period. The treatment group produced a significant increase in both SJR and AJR of 5.9+/-3.1% and 6.3+/-5.1%, respectively. These increases were significantly greater than the pre-test to post-test changes produced by the control group, which were not significant for either jump. Analysis of the data from the various other jump tests suggested increased overall force output during jumping, and in particular increased rate of force development were the main contributors to the increased jump height. These results lend support to the effectiveness of ballistic resistance training for improving vertical jump performance in elite jump athletes.

Campos et al., (2002) studied on muscular adaptations in response to three resistance training regimens: specificity of repetition maximum training zones. Thirty two untrained men [mean (SD) age 22.5 (5.8) years, height 178.3 (7.2) cm, body mass 77.8 (11.9) kg] participated in an 8-week progressive resistance-training programme to investigate the "strength endurance continuum". Subjects were divided into four groups: a low repetition group (low rep, n = 9) performing 3-5 repetitions maximum (RM) for four sets of each exercise with 3 min rest between sets and exercises, an intermediate repetition group (int rep, n = 11) performing 9-11 RM for three sets with 2 min rest, a high repetition group (high rep, n = 7) performing 20-28 RM for two sets with 1 min rest, and a non-exercising control group (con, n = 5). Three exercises (leg press, squat, and knee extension) were performed 2 days/week for the first 4 weeks and 3 days/week for the final 4 weeks. Maximal strength [one repetition maximum, 1RM), local muscular endurance (maximal number of repetitions performed with 60% of 1RM), and various cardio respiratory parameters (e.g., maximum oxygen consumption, pulmonary ventilation, maximal aerobic power, time to exhaustion) were assessed at the beginning and end of the study. In addition, pre-training and post-training muscle biopsy samples were analyzed for fiber type composition, cross-sectional area, myosin heavy chain (MHC) content, and capillarization. Maximal strength improved significantly more for the low rep group compared to the other training groups, and the maximal number of repetitions at 60% 1RM improved the most for the high rep group. In addition, maximal aerobic power and time to exhaustion significantly increased at the end of the study for only the high rep group. All three major fiber types (types I, IIA, and IIB) hypertrophied for the low repetitions and intermediate repetitions groups, whereas no significant increases were demonstrated for either the high repetitions or control groups. However, the percentage of type IIB fibers decreased, with a concomitant increase in IIAB fibers for all three resistance-trained groups. These fiber-type conversions were supported by a significant decrease in MHC II accompanied by a significant increase in MHC II. No significant changes in fiber-type composition were found in the control samples. Although all three training regimens resulted in similar fiber-type transformations (IIB to IIA), the low to intermediate repetition resistance-training programmes induced a greater hypertrophic effect compared to the high repetition regimen. The high repetitions group, however, appeared better adapted for sub maximal, prolonged contractions, with significant increases after training in aerobic power and time to exhaustion. Thus, low and intermediate RM training appears to induce similar muscular adaptations, at least after short-term training in previously untrained subjects. Overall, however, these data demonstrate that both physical performance and the associated physiological adaptations are linked to the intensity and number of repetitions performed, and thus lend support to the "strength-endurance continuum."

Toumi et al., (2004) studied the effects of jump training as a complement to weight training on jump performance and muscle strategy during the squat and countermovement jump. Twenty-two male handball players, between the ages of 17 and 24, and in good health, were randomly divided into three groups. Two were trained groups, weight training (WTG) and jump training combined with weight training (CTG), and one was a control group (CG). Maximal isometric force and maximal concentric power were assessed by a supine leg press, squat jump (SJ), counter movement jump (CMJ), and surface EMG was used to determine changes in muscle adaptation before and after the training period. After 6-week training programmes, the two training groups increased maximal isometric force, maximal concentric power, and squat jump performance. However, only combined training presented a significant increase in height jump performance during the countermovement jump ($P < 0.05$). EMG analysis (as interpreted through the root mean square values) showed that the SJ was performed similarly before and after the training period for the two training groups. However, during the CMJ, only the CTG group adopted a new technique manifested by a short transition phase together with an increase in knee joint stiffness and knee extensor muscle activation and rectus femoris ratio. It was suggested that the central activities in knee joint during the transition phase, in conjunction with intrinsic muscle contractile properties, play a major role in the regulation of performance during a CMJ. Furthermore, our study suggests that a change in maximal strength and/or explosive strength does not necessarily cause changes in combined movement such as the stretch shortening cycle.

Hoff et. al., (2000) conducted a study on resistance training loads and the literature proposes that light loads (30% 1 RM) and heavy loads (85% 1 RM) are the appropriate loads to improve dynamic athletic performance, usually the vertical jump. In these formulations, body weight is seldom considered. It could be an important factor. This investigation used male soccer players performing half-squats under different treatments. A control group (N = 10), a body-weight alone group doing simulated training without external loads (N = 11), a group using an external load of 30% of 1 RM squats (N = 10), and group using an external load of 85% of 1 RM squats (N = 10) When performing the exercises in the treatment groups, emphasis was placed on the maximal mobilization of force in the concentric portion of the half-squat. Training was 4 x 5 repetitions, three times per week for seven weeks. After each squat training, 3 x 5 vertical counter-movement jumps were performed. In both externally loaded groups, 1 RM increased. Vertical jump improved only in the highest training load group but only when the vertical jump was performed with a 50-kg weight. Vertical jump measures did not improve in outweighed or light-loaded jumping protocols. The highest power production occurred when jumping without any external load. Sprinting tests of 10 and 40 m improved only in the highest-load training group. It was concluded that improving vertical jumping height involved more than just the training load in resistance training. The specificity of the training effects of resistance exercises is again demonstrated in this investigation. There is little to no carry-over of training benefits to actual dynamic performance. However, why Sprint times improved and the specifically targeted vertical jump did not is not addressed. One could propose that sprinting is improved by strength training, but since the training employed only the half-squat, which is more related to vertical jumping and less so to sprinting, the effects are puzzling. The Effects of strength training activities on the performance of a dynamic vertical jump are minimal at best.

Robertson et. al., (2001) studied on the effects of in-season strength and power training on squat jump performance in NCAA women volleyball players. The effects of four weeks of in-season strength and power training on the ability to rapidly develop force during jumping were evaluated in 12 division I female volleyball players. Testing occurred before and after a traditional strength and power training experience. The dependent variable was force created by the concentric portion of a squat jump. Normal training and competitions occurred during the training period. Time to peak force decreased, peak force increased, and average concentric force increased. There was no change in the rate of force development, a component of improved speed. Athletes were stronger as a result of the experience while "speed" of force development did not change. Since no control group was used in this study, one is set to ponder whether the strength gains were "retraining gains", because the study implies that no strength training had occurred in-season. If pre-season strength training was experienced and then stopped, resulting in strength-detraining, it is possible that the observed changes in this investigation were re-adaptations and possibly unrelated to performance. If strength gains from pre-season training were appropriate for volleyball, their use in training and competitions should have stimulated them to be maintained and additional strength training would have resulted in little to no further gains. Additional in-season strength training improves existing strength in females if they are not undergoing concurrent strength training. The question as to whether the strength gains transfer to improved performance was not answered.

Rutherford et. al., (1986) studied on the strength training and power output of transference effects in the human quadriceps muscle. “The effect of the training programmes was to produce a large increase in the ability to perform leg extension exercises (160-200%). As the majority of subjects did not take part in regular physical exercise prior to the study, the initial load lifted in training was low. The increase in this load after 12 weeks of training was not accounted for by an increase in isometric strength of the quadriceps (3-20%) and it has been argued that this is most likely due to improved coordination of recruitment of fixated muscles which stabilize the body and allow maximum force to be exerted. If the improvement in performance is due to the establishment of neural pathways it is questionable whether these pathways will be of any use in tasks requiring different patterns of muscular coordination [they will not]. Our measurements of power output substantiate this view. The very considerable improvement in ability to perform leg extension exercises was not reflected in an improvement in power output measured on the cycle ergo meter. The Ss in this investigation were non-athletes, so some transfer might have been expected, certainly more than that which would have been hypothesized for highly-trained athletes. An increase in strength in a particular quadriceps exercise did not affect power output in cycling, an activity that used those same muscles both before and after they were strengthened. Neural reorganization is specific and such movement patterns do not transfer to other activities even those which use the same muscles (but in a different manner).

Kraemer et. al., (1994) conducted a study on the factors of training for development of vertical jump. The explosive strength is a characteristic of performance that is common in many sporting endeavors. However, training very frequently includes reduced velocity "strength" training which develops capacities which are only appropriate for a very few activities (e.g., power lifting).Weight or strength training is often required because it is believed to improve explosive strength. Research has shown that it does increase explosive power in individuals who begin training with average strength. However, it has little benefit for explosive strength performances for individuals with previously trained or above average levels of strength. Training with heavy loads (70-120% of 1 RM) improves maximal isometric strength but not the maximal rate of force development. In some cases it might even reduce the ability of the muscles to develop force rapidly. On the other hand, light load training with an accent on speed of movement increases an athlete's ability to rapidly develop force. A typical total-body explosive movement (e.g., vertical jump) requires force to be developed in a time period between 200 and 350 mts. Most of the heavy-strength training-induced increases in force-producing potential cannot be realized over such a short time. Heavy strength training is of little benefit to already strong individuals who wish to perform explosive Movements.

Hisacda et al., (1996) conducted a study to assess the influence of two different modes of resistance training in female's subject. This study consists of two groups. One group underwent resistance training with low intensity and high volume training and other participated in high intensity and low volume training. The former consisted of sets of 1 – 20 RM with sufficient rest between sets. While the latter consists of 8-9 sets of 4 – 6 RM with no seconds rest in between sets. In both the groups the percentage changes of Isokinetic strength were significantly higher. The result suggests that during the early phase of resistance training two different modes of resistance training may have similar effects on untrained females.

Hetzler et. al., (1997) conducted a study on strength and power training in young male Baseball players who did not improve functional performance. Two groups of 10 pre-pubescent and pubescent male baseball players trained three times per week for 12 weeks using a variety of general free weight and machine exercises designed for both strength and power acquisition. For the experienced, notice and control groups respectively the following gains were recorded; leg press – 41%, 40 % and 14% and bench press 23%, 18% and 0 %. Both training groups were significantly better than the control group. Similarly the two training groups improved in vertical jump.

Marques et. al., (2006) investigated the changes in physical parameters produced during an in-season resistance training (RT) and detraining (DT, or RT cessation) in 16 high level team handball players (THPs). Apart from normal practice sessions, THPs underwent 12 weeks of RT. Subjects performed 3 sets of 3-6 reps with a load of 70-85% concentric 1 repetition maximum bench press (1RMBP), 3 sets of 3-6 reps with a load of 70-95% of 4 repetition maximum parallel squats (4RMPS), plus vertical jumps and sprints. The 1RMBP, 4RMPS, speed over 30 m (S30), jump (countermovement jump height [CMJ]; CMJ with additional weights [20kg and 40kg], and ball throw velocity (BTv) were tested before the experimental period (T1), after 6 weeks (T2), and after the 12-week experimental period (T3). Immediately after these 12 weeks, THPs started a 7-week DT period, maintained normal practices. The CMJ and the BTv were the only parameters evaluated during DT. The most important gains ($p < 0.001$) in S30 were obtained between T1-T2 and T1-T3. The BTv improved significantly ($p < 0.001$) only between T1-T2 and T1-T3. The most relevant increases ($p < 0.001$) in jumping performance took place between T1-T2 and T1-T3. The 1RMBP showed significant increases ($p < 0.001$) only between T1-T2 and T1-T3. The 4RMPS increased significantly between all testing trials. After the DT, THPs showed no significant losses in CMJ performance. However, they declined significantly in BTv ($p = 0.023$). The results suggest that elite THPs can optimize important physical parameters over 12 weeks in-season and that 7 weeks of DT, although insufficient to produce significant decreases in CMJ, are sufficient to induce significant decreases in BTv. It is concluded that after RT cessation THPs reduced BTv performance.

Berger (1963) conducted a study on three groups totaling 48 college students who were trained with progressive resistance exercise for a period of nine weeks three times a week. Each group trained with a different programme using the bench press lift. Groups I trained with the 2 – RM for six sets, group – II with the 6-RM for three sets and group – III with the 10 RM for three sets each training session. The 1 – RM for the bench press lift was determined before and after the nine week training period. A comparison was made between groups – II (39-6R and II (3g – 10RI) after nine week of training. In both the studies, group – II had a higher mean than group – III, but the mean differences were not significant. In both the studies, group – II had a higher mean than group – III but the mean difference were not significant. In Berger’s study, training continued up to 12 week and at that time the mean of group – II was significant higher than the group – III mean. It is probable that the continuation of the present study to 12 weeks would have resulted in significant differences between groups II and III. The results of this study is that training for nine weeks, three times a weekly with heavy for few repetitions per set and numerous sets is not more effective for improving strength then training with lighter loads for more repetitions per set and fewer sets.

Anderson and Kearney (1982) conducted a study on resistance training. Three sets of a) high –resistance-low repetition (HL) group (N=15) performed three sets of 6-8 Rm per session: b) medium-resistance-medium-repetition (MM) group (N=16) performed two sets of 30-40Rm per session: and c) low resistance – high repetition (LH) group (N=12) performed one set of 100-150 Rm, trained three times per week for nine weeks. Strength (1 Rm) absolute and relative endurance were assessed before and after the training period. Low repetitions and high resistances favour strength, whereas moderate to high repetitions using a moderate weight that can be accommodated produce endurance and minor strength changes. It is anticipated that the specificity of these effects will be more evident at the higher levels and training states of athletes who engage in this type of exercise.

Tan (1999) has found that resistance training programme variables can be manipulated to specifically optimize maximum strength. After deciding on the exercises appropriate are training intensity (load) and volume. The other factors that are related to intensity are loading form, training to failure, speed of contraction, psychological factors, interest recovery, order of exercise, and number of sessions per day. Repetitions per set, sets per session, and training frequency together constitute training volume. In general, maximum strength is best developed with 1–6 repetition maximum loads, a combination of concentric and eccentric muscle actions, 3–6 maximal sets per session, training to failure for limited periods, long interest recovery time, 3–5 days of training per week and dividing the day’s training into 2 sessions. Variations of the volume and intensity in the course of a training cycle will further enhance strength gains. The increase in maximum strength is affected by neural, hormonal, and muscular adaptations.

Nakao et. al., (1995) investigated the effects of a long term weight lifting programme characterized by high intensity, low repetition and long rest period between sets on maximal oxygen consumption (VO_2 max) and to determine the advantage of this programme combined with jogging. Male untrained students were involved in weight training for a period of 3 years. The VO_2 max and body composition of the subjects were examined at beginning and 1 year, 2 years (T2) and 3 years after (T3 the training of the group 19 subjects performed the weight lifting programme 5 days each week for 3 years (W – group), 4 subjects performed the same weight lifting programme for 3 year with an additional running programme consisting of 2 miles jogging once a week during the 3rd year (R1 – group) and 3 subject performed the weight lifting, programme during the 1st year and the same combined jogging and weight lifting, programme as the RI group during the 2nd and 3rd years (R2 – group). The average VO_2 max relative to their body mass of the W – group decrease significantly during the 1st year followed by an insignificant decrease in the 2nd year and a leveling off in the 3rd year. The average VO_2 max of the W – group at T2 and T3 was 44.2 and 44.11 ml kg – 1 min-1, respectively. The tendency of VO_2 max changes in the R, and R2 group was similar to the W – group until they started the jogging programme, after which they recovered significantly to the initial level within a year of including that programme and they then leveled off during the next year. Lean body mass estimated from skin fold thickness has increase by about 8% after 3 years of weight lifting. The maximal muscles strength, defined by total Olympic lifts (snatch and clean jerk) of these three groups increased significantly and there was no significant difference among the amounts of the increase in the three groups.

Go to et. al., (2004) studied the acute and long-term effects of resistance-training regimens with varied combinations of high and low-intensity exercises. Acute changes in the serum growth hormone (GH) concentration were initially measured after 3 types of regimens for knee extension exercise. They were: a medium intensity (approximately 10 repetition maximum [RM]) short interest rest period (30s) with progressively decreasing load ("hypertrophy type"); 5 sets of a high-intensity (90% of 1RM) and low-repetition exercise ("strength type"); and a single set of low-intensity and high-repetition exercise added immediately after the strength-type regimen ("combi-type"). Post-exercise increase in serum GH concentration showed significant regimen dependence: hypertrophy-type > combi-type > strength-type ($p < 0.05$, $n = 8$). Next, the long term effects of periodized training protocols with the above regimens on muscular function were investigated. Male subjects ($n = 16$) were assigned to hypertrophy/combi (HC) or hypertrophy/ strength (HS) groups performed leg press and extension exercises twice a week for 10 weeks. During the first 6 weeks, both groups used the hypertrophy-type regimen to gain muscular size. During the subsequent 4 weeks, HC and HS groups performed combination type and strength type regimens, respectively. Muscular strength, endurance, and cross sectional area CSA) were examined after 2, 6, and 10 weeks. After the initial 6 weeks, no significant difference was seen in the percentage changes of all variables between the groups. After the subsequent 4 weeks, however, 1RM of leg press, maximal isokinetic strength, and muscular endurance of leg extension showed significantly ($p < 0.05$) larger increases in the HC group than in the HS group. In addition, increases in CSA after this period also tended to be larger in the HC group than in the HS group ($p = 0.08$). It was finalized that a combination of high and low-intensity regimens is effective for optimizing the strength adaptation of muscle in a periodized training programme.

2.2 STUDIES ON PLYOMETRIC TRAINING

The studies related to effect of plyometric training on criterion measures used in the present study are as follows.

Along with Olympic lifting, traditional strength training and maximum power training, plyometric are another form of resistance training used to promote muscular power improvements in athletes. Examples of plyometric exercises are squat jumps, single and double leg hops, bounds, and single and double leg jumps. Plyometric training has been proposed by many as the link between power, strength and speed (Adams et. al., 1992, Chu & Plummer, 1984; Hedrick & Andreson, 1996, Thomas, 1983). Plyometric include any exercise that utilizes the stretch reflex to produce an explosive movement (Chu, 1984). The stretch shortening cycle is essentially an eccentric contraction followed immediately by a concentric contraction (Chu, 1984, Henson, 1996). During the eccentric phase of a drill/exercise, kinetic energy is generated and stored in the muscle and connective tissue, and muscle activation increases. This stored energy and increased muscle stimulation is used in the following concentric contraction for increased speed and force of the contraction (Adams, 1992, Chu, 1984, Gambetta, 1998, Newton, 1994). Plyometric exercises have been shown to be effective at increasing muscular power (Adams et. al., 1992, Hedrick, 1994, Hedrick 1996, Lyttle, 1996, Wathen, 1993, Yessis, 1995). It appears that weight training and plyometric training modify different capacities of the neuromuscular system, plyometric increase the muscles rate of eccentric force development, and resistance training increases concentric performance (Wilson, 1996)

Toplica et. al., (2004) has proved experimentally that an eight week training model using the plyometric method can have an effect on the statistically relevant increase in the explosive type strength of the leg muscles, which in turn leads to an increase in the vertical jump of a block, spike and the long jump.

Luebbers et. al., (2003) conducted a study on the effects of plyometric training and recovery on vertical jump performance and anaerobic power. They examined the effects of two plyometric training programmes, equalized for training volume, followed by a 4-week recovery period of no plyometric training on anaerobic power and vertical jump performance. Physically active, college aged men were randomly assigned to either a 4-week (n = 19, weight = 73.4 +/- 7.5 kg) or a 7-week (n = 19, weight = 80.1 +/- 12.5 kg) program. Vertical jump height, vertical jump power, and anaerobic power via the Margaria staircase test were measured pre training, immediately post training, and 4 weeks post training (POST-4). Vertical jump height decreased in the 4-week group pre (67.8 +/- 7.9 cm) to post (65.4 +/- 7.8 cm). Vertical jump height increased from pre to post in 4-week (67.8 +/- 7.9 to 69.7 +/- 7.6 cm) and 7-week (64.6 +/- 6.2 to 67.2 +/- 7.6 cm) training programmes. Vertical jump power decreased in the 4-week group from pre (8,660.0 +/- 546.5 W) to post (8,541.6 +/- 557.4 W) with no change in the 7-week group. Vertical jump power increased pre to post-4 in 4-week (8,660.0 +/- 546.5 W to 8,793.6 +/- 541.4 W) and 7-week (8,702.8

+/- 527.4 W to 8,931.5 +/- 537.6 W) training programmes. Anaerobic power improved in the 7-week group from pre (1,121.9 +/- 174.7 W) to post (1,192.2 +/- 189.1 W) but not the 4-week group. Anaerobic power significantly improved pre to post-4 in both groups. There were no significant differences between the 2 training groups. Four-week and 7-week plyometric programmes are equally effective for improving vertical jump height, vertical jump power, and anaerobic power when followed by a 4-week recovery period. However, a 4-week programme may not be as effective as a 7-week programme if the recovery period is not employed.

Brown et. al., (1986) has shown that plyometric training can improve the vertical jump of high school male basketball players. The vertical jumping ability of 26 freshman and sophomore high school male players (average age = 15 years) was tested after 3 weeks (18 sessions) of practice. Two jump types were measured: a vertical jump in which the arms were free to be used in a double-arm swing (VJA) and one in which the arms were clasped behind the back (VJNA). The group was divided into two sub-groups: the "plyometric" group performed 3 sets of 10 repetitions (with 1 minute rest between sets) of depth jumping from a 45 cm bench. A total of 34 training sessions were undertaken over a 12 week period. The "control" group performed normal basketball training only. From the results, it was observed that there was no difference between the 2 groups at the pre-training stage. After training, there was again no difference between the groups for the 'no arms' condition, and both groups had improved their vertical jumping ability. Both groups made significant improvements in their vertical jump when using the arms (21.3% and 17.7% for the plyometric and control groups respectively), but the improvement made by the plyometric group was significantly greater than that made by the control group. The findings support the use of plyometric-style training, in which the muscles are shortened immediately after being loaded eccentrically (i.e. lengthened). The results of this study suggest that 57% of the increase in jump ability is due to improvements in technique, while the remaining 43% is due to the plyometric training. Thus, while basketball practice alone is sufficient to improve vertical jump performance in high school boys, greater improvements may be generated by employing plyometric training techniques.

Kubachka et. al., (1966) studied the effects of plyometric training and strength training on the muscular capacities of the trunk. The effects of plyometric, strength training, and body weight exercises on the power, strength, and endurance capacities of the trunk muscles were examined. Training sessions occurred twice per week for five weeks (a total of 10 training sessions). Plyometrics use two physiological properties of muscle, the stretch reflex and storage of elastic energy. When a rapid lengthening of a muscle occurs just prior to rapid shortening, a more powerful contraction results. Plyometrics significantly increased power (8.6%) and strength (45.9%). Strength training increased power (7.3%) and strength (82.5%). Body weight increased strength only (21.9%). Both plyometrics and strength training were as effective as each other. This study showed the rapid and substantial gains that can be made when plyometric or strength training is confined to a restricted set of muscles. No inference should be made that these improvements will be transferred to any other activity.

Hewett et. al., (1966) conducted a study on the effects of plyometric jump training in females, decreased impact forces and increased hamstrings torques in female athletes with plyometric training. The effect of a jump-training programme on landing mechanics and lower extremity strength was assessed in females involved in jumping sports. Responses to a six-week training programme were compared to untrained males. The programme was designed to decrease landing forces by teaching neuromuscular control of the lower limb during landing and to increase vertical jump height. Training produced a 9.2% increase in vertical jump. Landing training decreased impact forces by reducing medial and lateral torque at the knee, increased power, and decreased hamstrings strength imbalances. Performance can be increased and injury potential decreased if plyometric training is performed along with landing technique instruction with females.

Matavulj et. al., (2001) conducted a study on the effects of plyometric training on jumping performance in junior basketball players. This study attempted to assess the effects of plyometric training when it is added to the training of adolescent males (N = 33; 15-16 years) who can already jump very well. Three groups of elite junior basketball players were established: a) a control group that only performed regular basketball training, b) a group that performed plyometrics (drop-jumps) from 50 cm, and c) a group that performed plyometrics from 100 cm. The added training was performed three times per week for six weeks. Both experimental groups improved significantly in the maximal vertical jump (4.8 cm for the 50-cm group and 5.6 cm for the 100-com group) and rate of force development in the knee extensors. There were no significant differences between the experimental groups in any measure. Drop-jump plyometric training could improve jumping height in adolescent basketball players. [Eventually published as Diallo, O., Dore, E., Duche, P., & Van Praagh, E. (2001). Effects of plyometric training followed by a reduced training programme on physical performance in prepubescent soccer players.

Maffiuletti et. al., (2002) examined the effect of combined electro stimulation and plyometric training on vertical jump height. The study investigated the influence of a 4 week combined electromyo stimulation (EMS) and Plyometric training programme on the vertical jump performance of 10 volleyball players. Training sessions were carried out three times weekly. Each session consisted of three main parts: EMS of the knee extensor muscles (48 contractions), EMS of the plantar flexor muscles (30 contractions), and 50 plyometric jumps. Subjects were tested before (week 0), during (week 2), and after the training programme (week 4), as well as once more after 2 wk of normal volleyball training (week 6). Different vertical jumps were carried out, as well as maximal voluntary contraction (MVC) of the knee extensor and plantar flexor muscles. At week 2, MVC significantly increased (+20% knee extensors, +13% plantar flexors) as compared to baseline (< 0.05). After the 4 week training program, different vertical jumps considered were also significantly higher compared to pre-training (< 0.001), and relative gains were comprised between 8-10% (spike-counter movement jump) and 21% (squat jump). The significant increases in maximal strength and explosive strength produced by the present training program were subsequently maintained after an additional 2 wk of volleyball training. EMS combined with plyometric training has proven useful for the improvement of vertical jump ability in volleyball players. This combined training modality produced rapid increases (approximately 2 wk) of the knee extensors and plantar flexors maximal strength. These adaptations were then followed by an improvement in general and specific jumping ability, which were to likely affect performance on the court. In conclusion, when EMS resistance training is proposed for vertical jump development, specific work out (e.g., plyometric) must complement EMS sessions to obtain beneficial effects.

Olasupo's (2009) study determined the comparative effect of three modes of Plyometrics training [depth jumping, rebound jumping and horizontal jumping] on leg muscle strength of untrained University male students. Participants were forty untrained male University students within the age range of 18-27 years. The randomized pre-test and post-test control group design was adopted. Subjects were randomly assigned to control group, and three experimental groups based on the types of plyometrics training adopted for the study. The training programme consisted of twelve weeks of interval training administered three times a week. Data collected were analyzed using the mean score, standard deviation and range. Analysis of Covariance [ANCOVA] was used to test for significant differences in the post-test measures among the treatment and control groups using the pre-test score variation as covariates. Scheffe's post hoc analysis was used to determine which of the means were significantly different. All hypotheses for the study were tested at 0.05 critical level. Findings revealed that only the depth jumping and rebound jumping training significantly altered leg muscle strength of subjects ($P<0.05$). Based on the findings, it was concluded that plyometrics exercises with depth jumping and rebound jumping characteristics are best used in developing muscle strength of the lower extremities.

Robert and Kerry (1994) examined the effect of upper body plyometric training, using medicine balls, and upper body conventional weight training on baseball throwing velocity and strength levels as assessed by a 6-RM bench press. Twenty-four junior development baseball players took part in an 8 week training study in conjunction with their baseball training. They were randomly allocated to one of three groups: a medicine ball training group, a weight training group, and a control group. The first group performed explosive upper body medicine ball throws, the weight training group performed conventional upper body weight training, and the control group only performed their normal baseball training. Pre-training and post- training measurements of throwing velocity and 6-RM bench press were recorded. The weight training group produced the greatest increase in throwing velocity and 6-RM strength. The medicine ball group showed no significant increase in throwing velocity but did show a significant increase in strength. For this group of non-strength-trained baseball players, it was found more effective to implement a weight training programme rather than medicine ball training to increase throwing velocity.

Michael et.al (2006) study was aimed to determine if six weeks of plyometric training can improve an athlete's 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 programme 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 F2, 26 = 25.42, p=0.0000 for the T-test agility measure. For the Illinois Agility test, a significant group effect F2, 26 = 27.24, p = 0.000 was also found. The plyometric training group had quicker post test times compared to the control group for the agility tests. A significant group effect F2, 26 7.81, p = 0.002 was found for the Force Plate test. The Plyometric training group reduced time on the ground on the post test compared to the control group. The results of this study show that plyometric training can be an effective training technique to improve an athlete's agility

Rahman and Nasar (2005) compared the effects of 3 different training protocols -- plyometric training, weight training, and their combination on the vertical jump performance, anaerobic power and muscular strength. Based on their training, forty-eight male college students were divided into 4 groups: a plyometric training group (n=13), a weight training group (n=11), a plyometric plus weight training group (n=14), and a control group (n=10). The vertical jump, the fifty-yard run and maximal leg strength were measured before and after a six-week training period. Subjects in each of the training groups trained 2 days per week, where as control subjects did not participate in any training activity. The data was analyzed by a 1-way analysis of variance (repeated-measures design). The results showed that all the training treatments elicited significant ($P < 0.05$) improvement in all of the tested variables. However, the combination training group showed signs of improvement in the vertical jump performance, the 50 yard dash, and leg strength that was significantly greater than the improvement in the other 2 training groups (plyometric training and weight training). This study provides support for the use of a combination of traditional weight training and plyometric drills to improve the vertical jumping ability, explosive performance in general and leg strength.

Kin (2006) examined the effects of plyometric training following a four week training programme on vertical jump height, 40 yard dash, 10 yard dash, and anaerobic power. The subjects included 17, healthy, male Division 3 hockey players, between the ages of 18-24. All subjects were tested in the vertical jump, 40 yard dash time, 10 yard dash time, and anaerobic power using the Wingate Bike test prior to starting the plyometric programme. The subjects then completed a four week plyometric training programme and were retested. There were significant differences ($p < .05$) in the mean anaerobic power drop percentage $p = .020$, peak relative power $p = .046$, peak power $p = .005$, right foot vertical jump height ($p = .046$), left foot vertical jump height ($p = .000$). The findings suggested that two days of plyometric training a week for four weeks is sufficient enough to show improvements in single leg vertical jump height and overall power endurance. In contrast, plyometric training two days a week for four weeks was not sufficient enough to show improvements in 40 yd dash times, 10 yd dash times, two foot vertical jump height, minimum power (W) values, and relative minimum power (W/kg) values.

2.3 STUDIES ON COMBINED RESISTANCE AND PLYOMETRIC TRAINING

Adaptations by the neuromuscular system are very specific, therefore training programmes should include movements which mimic those used in sport. Slow contractions train the muscular system, while fast contractions stimulate the nervous system (Canavan, 1996). Also Wilson et. al. (1996) proposed that plyometric and strength training train different components of the neuromuscular system. It is logical then, to train optimally for competition in power sports, both fast and slow contractions, as well as plyometrics, should be included in the training programme. This will ensure that all aspects of the neuromuscular system are addressed. This concept is being put to use today in combined resistance training and plyometric-type programmes, and have been shown in many studies to be more effective at improving muscular strength and power than either plyometric or resistance training alone (Adams et. al., 1992, Baker, 1996, Canavan et. al., 1996, Garhammer & Gregaor, 1992, Hedrick, 1996, Hedrick & Anderson, 1996, Newton & Kraemer, 1994, Stone 1993, Yessis, 1994, Yessis, 1995). So it appears that training contractile and neural/elastic components of the musculature from combined training does in fact offer an improved training stimulus (Baker, 1996). It is this concept that complex training is built from.

The effectiveness of plyometric training is well supported by research. 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 programmes. 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. The combination of plyometric training and weight training are thought to be useful for developing athletic power. More specifically, complex training alternates biomechanically similar high load weight training exercises with plyometric exercises, set for set, in the same workout. An example of complex training would include performing a set of squats followed by a set of jump squats. Anecdotal sources have described the application of complex training

Jeffery et.al., (2000) compared dynamic push-up (DPU) and plyometric push-up (PPU) training programmes on 2 criterion measures: (a) the distance achieved on a sit-ting, 2-handed medicine ball put, and (b) the maximum weight for 1 repetition of a sitting, 2-handed chest press. Thirty-five healthy women completed 18 training sessions over a 6-week period, with training time and repetitions matched for the DPU (n = 17) and PPU (n = 18) groups. Dynamic push-ups were completed from the knees, using a 2-second-up–2-second-down cadence. Plyometric push-ups were also completed from the knees, with the subjects allowing themselves to fall forward onto their hands and then propelling themselves upward and back to the starting position, with 1 push-up completed every 4 seconds. The PPU group experienced significantly greater improvements than the DPU group on the medicine ball put ($p = 0.03$). There was no significant difference between groups for the chest press, although the PPU group experienced greater increases.

Rahman Rahimi et. al., (2005) conducted a study on the effect of plyometric, weight and plyometric-weight training on anaerobic power and muscular strength. The effect of three different training protocols-plyometric training, weight training, and their combination on the vertical jump performance, anaerobic power and muscular strength. Based on their training, 48 male college students were divided into four groups. Plyometric training group(n=13),a Weight training group (n=11), Plyometric plus weight training group(n=14) and a control group (n=10) The vertical jump,50 yard run and maximal leg strength were measured before and after a six-week training period. The subjects of the each training group were trained for 2 days per week, whereas control subjects did not participate in any training activity. The data were analyzed by a one-way analysis of variance (repeated measure design). The results showed that all the training treatments elicited significant ($p<0.5$) improvement in the entire tested variable. However the combination training group showed signs of improvement in the vertical jump performance, the 50 yard run, and leg strength that was significantly greater than the improvement in the other 2 training groups (plyometric, weight training groups). This study provides support for the use of combination of traditional weight training and plyometric drills to improve the vertical jump ability, explosive performance in general and leg strength.

Studies (Adams et. al., 1992; Clutch et. al., 1983; Delecluse et. al., 1995; Duke and BenEliyahu,1992; Fatourous et. al., 2000; Ford et. al., 1983; Lyttle et. al., 1996; McLaughlin, 2001; Polhemus and Burkherdt, 1980; Potteiger et. al., 1999; and Vossen et. al., 2000) demonstrated an enhancement of motor performance associated with plyometric training combined with weight training or the superiority of plyometrics, compared to other methods of training. The evidence indicates that the combination weight training and plyometrics are effective. One way to combine the two forms of training is complex training or the contrast method. Recent studies have evaluated this type of training with mixed results.

Ebben et. al., (2000) quantified differences between complex and non-complex plyometric exercises: one acute study compared electromyographic (EMG) and kinetic variables, such as ground reaction forces, associated with the medicine ball power drop performed before and following a set of 3-5 RM bench press. More specifically, subjects performed the power drop exercise lying supine on a bench press bench that was mounted to a force platform. Subjects caught and forcefully threw the ball upward with horizontal flexion/adduction of the shoulders and extension of the elbow in a movement that is similar to the bench press with the exception that the medicine ball is projected into free space. Results from this study revealed no significant difference for mean or maximum ground reaction force and integrated EMG for the muscles evaluated in each power drop condition. In other words, the medicine ball power drop performed in the complex training condition was equally effective, but not superior, in eliciting motor unit activation or force output compared to the same exercise performed before the 3-5RM bench press set in the non-complex condition

Jensen et. al., (1999) examined the use of complex training as a method of combining weight and plyometric exercises during the same training session is growing in popularity, despite limited scientific support for its efficacy. The purpose of this study was to examine the effect of a set of high-load bench press exercises (BP) on a subsequent set of medicine ball power drop exercises (MBPD) via mean ground reaction force, maximum ground reaction force, and mean electromyography (EMG_{int}). Ten male (19 ± 1.4 years) NCAA Division 1 basketball players with experience in weight and plyometric training performed plyometric exercises under 2 randomly determined conditions. One condition included a BP followed immediately by a MBPD. The other condition included only the MBPD. Mean ground reaction force, maximum ground reaction force, and EMG_{int} were recorded during the MBPD for both conditions. Results indicated that no significant differences exist for mean ground reaction force, maximum ground reaction force, and EMG_{int} for the pectoralis major and triceps muscles between the MBPD and the BP plus MBPD conditions. These results indicate that there is no heightened excitability of the central nervous system. However, there also appears to be no disadvantage of performing high-load weight training and plyometric exercises in complex pairs. Therefore, complex training may be a useful training strategy because of the organizational advantages of performing weight and plyometric exercises in the same training session

Evans et. al., (2000) examined the complex training effect of combined bench press and medicine ball throws demonstrating improved plyometric performance in the complex condition. More specifically, one study sought to determine whether or not upper body power could be enhanced by performing a heavy bench press set prior to an explosive medicine ball put. Subjects included 10 college age males with experience performing the bench press. Subjects performed a seated medicine ball put before and four minutes after performing the bench press with a 5RM load. Results indicate a significant increase medicine ball put distance of 31.4 cm (no standard deviation available) following the 5RM bench press compared to the medicine ball put before the bench press. Researchers also report a strong correlation between improvement in medicine ball put distance and 5RM bench press strength

Young et. al., (1998) in his study demonstrated a potential acute complex training effect. He evaluated the counter movement jumps (LCMJ) could be enhanced if proceeded by a set of five repetition maximum (5 RM) half squats. Subjects performed two sets of five LCMJ, one set of 5 RM half squats, and one set of five LCMJ with four minutes rest between all sets. The jump height for the LCMJ after the squat was 40.0 cm ± 3.5cm compared to a pre-squat jump height of 39.0 ± 3.3 cm, resulting in a 2.8% improvement in jump performance. The authors indicate that there was a significant correlation between the 5 RM load and jump performances. Results suggest that for complex training, a high load weight training exercise performed four minutes before a power exercise increased the performance of the power exercise, especially for stronger individuals

Faigenbaum et. al., (1999) conducted a study to examine the effectiveness of complex training. For example, one study compared the effects of strength training and complex training in boys and girls (8.1 ± 1.6 years). Results demonstrate that children attain similar gains in upper-body strength and endurance using either strength or complex training programmes.

Gonzalez et. al., (2000), studied children as subjects, using other training studies examined the effects of a three-week complex training programme with seven divisions I college female basketball players. Pre and post test results reveal improvement in the 300 m shuttle, 1 mile run, VO2 max, 20 yd dash, pro agility run and the t-test, reverse leg press and back squat. The data show that the complex training programme was effective in eliciting statistically significant improvement in the 300-meter shuttle. However, the research design does not appear to have evaluated the effectiveness of non-complex training combinations of plyometrics and weight training or used a control group.

Zepeda et. al., (2000) examined the effectiveness of a complex training group compared to a group who performed all of the weight training exercises after the plyometric exercises. Each group performed the same 7 week routine except the complex training group performed the plyometric exercises in a superset with biomechanically similar resistance training exercises, whereas the other group performed the plyometric exercises separately, following the resistance training exercises. Subjects included seventy eight division I college football players. Subjects were pre and post-tested with a variety of tests including percentage of body fat, bench press, squat, power clean, medicine ball throw, broad jump, and vertical jump. Both groups demonstrated improvement in all eight of the tests. However, the complex training group demonstrated significant between group vertical jumps improvements (2.8 cm) compared to the non-complex training group (0.1cm).

Ebben and Watts (1998) reviewed the research on various combinations of weight training and plyometric training as well as complex training. At that time, despite numerous brief references to complex training in the literature, only one training study specifically examined complex training. The results from that study were difficult to interpret, however, due to the absence of published numerical data (Verkhoshansky and Tetyan, 1973). According to Ebben and Watts (1998), complex training programme design must consider important variables such as exercise selection, load, and rest between sets. Recent research offers additional guidelines regarding these variables and raises the question about age and gender specific effects as well.

Jensen et. al., (2003) studied on the kinetic analysis of complex training, rest interval on vertical jump performance. Complex training has been recommended as a method of incorporating plyometrics with strength training. Some research suggests that plyometric performance is enhanced when performed 3-4 minutes after the strength training set, whereas other studies have failed to find any complex training advantage when plyometrics are performed immediately after the strength training portion of the complex. The purpose of this study was to determine if there is an ergogenic advantage associated with complex training and if there is an optimal time for performing plyometrics after the strength training set. Subjects were 21 NCAA Division I athletes who performed a countermovement vertical jump, a set of 5 repetitions maximum (5 RM) squats, and 5 trials of countermovement vertical jump at intervals of 10 seconds and 1, 2, 3, and 4 minutes after the squat. Jump height and peak ground reaction forces were acquired via a force platform. The pre-squat jump performance was compared with the post-squat jumps. Repeated measures ANOVA determined a difference ($p \le 0.05$) between genders and that jump performance immediately following the squat exercise was hindered (0.66 m), but no effect ($p > 0.05$) was found comparing subsequent jumps (0.72-0.76 m) to the pre-squat condition (0.74 m). When comparing high to low strength individuals, there was no effect on jump performance following the squat ($p > 0.05$). In conclusion, complex training does not appear to enhance jumping performance significantly and actually decreases it when the jump is performed immediately following the strength training set; however, a non significant trend toward improvement seemed to be present. Therefore to optimize jump performance it appears that athletes should not perform jumps immediately following resistance training. It may be possible that beyond 4 minutes of recovery performance could be enhanced. However, that is not within the scope of the current study.

2.4 STUDIES ON COMPLEX TRAINING

Volume and intensity of a training programme influence the increase performance gained more than the order and selection of exercises (Robinson et. al., 1995). This principle and the concept that trained individual require more advanced, intense and faster training to continue to make improvements in strength and power compared to less or untrained people (Baker, 1996, Newton & Kraemer, 1994) may have led to the development of the complex training strategy. This would suggest that complex training would be a great addition to strength and conditioning for training highly trained strength and power athletes.

Complex training is defined as the use of heavy resistance training followed immediately by a plyometric activity with a biomechanically similar movement pattern (Ebben, 1997, Hedrick 1994, Hedrick, 1996). Other researchers and coaches have used complex training with a much different meaning. For example, Verkhoshansky & Tatyan (1973) explained that a complex training programme used heavy loads followed by light loads in the same workout, but he did not use these exercises in a super-set (Flex, & Kontor, 1986). In Verkhoshansky's complex training programme, the individuals would perform x sets and x repetitions of a squat exercise, and when those sets and repetitions were completed, then they would perform x sets and x reps of the light load exercise (Fleck & Kontor, 1986). In a super-set, two exercises are performed immediately after one another with no rest until both exercises have been completed once. An example would be performing a set of squats for eight repetitions, then immediately performing five to fifteen repetitions of squat jumps. The individual would then rest after the squat jumps for a designated time before performing both exercises again for the prescribed number of sets.

Complex training has also been associated with training principles that do not use heavy load followed by lighter loads. Armstrong (1994) used the term complex to explain his training programme that uses combinations of similar lifting motions with increasing resistance. And Torcolacci (1994) used the term complex to identify the cycles used within a larger training programme. To date, there has been little research performed on complex training (Ebben, 1998), and this may be the reason for the flexible use of definition. For this study the definition for complex training given by Ebben (1997) and Hedrick (1994 & 1996) will be used. Hedrick's definition of complex training is the use of heavy load resistance training followed immediately by a plyometric exercise. Ebben defines complex training similarly as, alternating biomechanically similar high load weight training and plyometric exercises, set for set, with in the same workout.

Complex training will result in an increased training intensity (through increased work per minute of workout with the super-set), which should benefit experience lifters, but it may also provide a few other benefits. Integrating the plyometric with the resistance training requires the athletes to perform the plyometric exercise in a fatigued state, resulting potentially in increased power production (Hedrick, 1994, Hedrick 1996). This also makes the activity more specific to what might be encountered in sport situations. Another benefit of complex training is that the muscle may "remember" the heavy weight performed prior to the plyometric or light load set, and will allow the lighter load to be moved quicker than without the heavy set prior to the light set. This should help develop power (Fleck & Kontor, 1986, Torcolacci, 1994). This speed of movement results in high speed training specificity, and some researchers believe this perception of speed can be transferred to sport competition (Yessis, 1995).

Ebben (2002) conducted a studied on the effectiveness of plyometric training is well supported by research. Complex training has gained popularity as a training strategy combining weight training and Plyometric training. Anecdotal reports recommend training in his fashion in order to improve muscular power and athletic performance. Recently, several studies have examined complex training. Despite the fact that question remain about the potential effectiveness and implementation of this type of training, results of recent studies are useful in guiding practioneres 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 to four minutes rest between the weight training and plyometric sets and the use of heavy weight training loads.

The proposed reason for the benefit of complex training is the adaptation to the neuromuscular system. Some researchers (Ebben & Watts, 1998) believe that the high-load resistance training increases motor neuron excitability and reflex potentiation. This potentiating may create an optimal training condition for the plyometric exercise to follow. Another potential benefit is the fatigue which follows high-load resistance training may result in more motor units being recruited during the plyometric exercise, which may increase the training effect (Ebben & Watts, 1998). In reality however, there has been little research done on complex training, and the results can only be speculated. Comparing complex training to other methods of combined training offers some insight and promise to the effectiveness of complex training (Ebben & Watts, 1998), and further research may in fact find complex training to a viable resource.

2.5 STUDIES ON SKILL PERFORMENCE

Gabbett et. al., (2006) investigated the effect of a skill-based training programme on measurements of skill and physical fitness in talent-identified volleyball players. Twenty-six talented junior volleyball players (mean +/- SE age, 15.5 +/- 0.2 years) participated in an 8-week skill based training programme that included 3 skill-based court sessions per week. Skills sessions were designed to develop passing, setting, serving, spiking, and blocking technique and accuracy as well as game tactics and positioning skills. Coaches used a combination of technical and instructional coaching, coupled with skill based games to facilitate learning. Subjects performed measurements of skill (passing, setting, serving, and spiking technique and accuracy), standard anthropometry (height, standing reach height, body mass, and sum of 7 skin folds), lower-body muscular power (vertical jump, spike jump), upper-body muscular power (overhead medicine-ball throw), speed (5- and 10-m sprint), agility (T-test), and maximal aerobic power (multistage fitness test) before and after training. Training induced significant ($p < 0.05$) improvements in spiking, setting, and passing accuracy and spiking and passing technique. Compared with pre-training, there were significant ($p < 0.05$) improvements in 5- and 10-m speed and agility. There were no significant differences between pre-training and post-training for body mass, skin fold thickness, lower-body muscular power, upper-body muscular power, and maximal aerobic power. These findings demonstrate that skill-based volleyball training improves spiking, setting, and passing accuracy and spiking and passing technique, but has little effect on the physiological and anthropometric characteristics of players.

Bénédicte Forthomme et. al., (2005) studied on the factors correlated with volleyball spike velocity. Spike effectiveness represents a determining element in volleyball. To compete at a high level, the player must, in particular, produce a spike characterized by a high ball velocity. Some muscular and physical features could influence ball velocity during the volleyball spike. A total of 19 male volleyball players from the 2 highest Belgian national divisions underwent an isokinetic assessment of the dominant shoulder and elbow. Ball velocity performance (radar gun) during a spike test, morphological feature, and jump capacity (ergo jump) of the player were measured. We tested the relationship between the isokinetic parameters or physical features and field performances represented by spike velocity. He also compared first-division and second-division player data. Spike velocity correlated significantly with strength performance of the dominant shoulder (internal rotators) and of the dominant elbow (flexors and extensors) in the concentric mode. Negative correlations were established with the concentric external rotator on internal rotator ratio at 400 deg/s and with the mixed ratio (external rotator at 60 deg/s in the eccentric mode on internal rotator at 240 deg/s in the concentric mode). Positive correlations appeared with both the volleyball players' jump capacity and body mass index. First-division players differed from second-division players by higher ball velocity and increased jump capacity. Some specific strength and physical characteristics correlated significantly with spike performance in high-level volleyball practice

Sawyer et. al., (2002) examined the relationships between football playing ability (FPA) and selected anthropometric and performance measures were determined among NCAA Division I-A football players (N = 40). Football playing ability (determined by the average of coaches' rankings) was significantly correlated with vertical jump (VJ) in all groups (offense, defense, and position groups of wide receiver-defensive back, offensive linemen-defensive linemen, and running back-tight end-linebacker). Eleven of 50 correlations (groups by variables), or 22%, were important for FPA. Five of the 11 relationships were related to VJ. Forward stepwise regression equations for each group explained over half of the criterion variable, FPA, as indicated by the R(2) values for each model. Vertical jump was the prime predictor variable in the equations for all groups. The findings of this study are discussed in relation to the specificity hypothesis. Strength and conditioning programmes that facilitate the capacity for football players to develop forceful and rapid concentric action through plantar flexion of the ankle, as well as extension of the knee and hip, may be highly profitable.

Hakkinen (1993) conducted a study on the changes in physical fitness profile in female volleyball players during the competitive season. Nine members of a female volleyball team served as experimental subjects in order to examine changes in a physical fitness profile during the competitive season consisting of a first season (I) for 10 weeks followed by season II for 11 weeks. The entire season was characterized by 4-5 weekly sessions for playing drills and competitive games and by 2-3 weekly sessions for physical conditioning mostly for strength and explosive strength training. The control group consisted of eight other female volleyball players who trained for physical conditioning during the competitive season 1-2 times per week. The present findings showed that the entire competitive season in experimental subjects led to no changes (from 47.3 +/- 1.7 to 48.1 +/- 3.4 ml x kg-1 x min-1) in VO2max but a significant ($p < 0.05$) decrease took place in average power in a 30 s anaerobic jumping test. Significant increases took place in the maximal vertical jumping heights in the squat (from 30.3 +/- 1.7 to 31.6 +/- 1.3 cm) ($p < 0.05$) and in the counter movement jump (from 32.8 +/- 1.6 to 34.3 +/- 1.3 cm) ($p < 0.05$) as well as in the spike and block jumps ($p < 0.05$) during competitive season.

Eom et. al., (1992) studied on the transition play in team performance of volleyball. The purpose of this study was to develop and test a method to analyze and evaluate sequential skill performances in a team sport. An on-line computerized system was developed to record and summarize the sequential skill performances in volleyball. Seventy-two sample games from the third Federation of International Volleyball Cup men's competition were videotaped and grouped into two categories according to the final team standing and game outcome. Log-linear procedures were used to investigate the nature and degree of the relationship in the first-order (pass-to-set, set-to-spike) and second-order (pass-to-spike) transition plays. Results showed that there was a significant dependency in both the first-order and second-order transition plays, indicating that the outcome of a skill performance is highly influenced by the quality of a preceding skill performance. In addition, the pattern of the transition plays was stable and consistent, regardless of the classification status: Game Outcome, Team Standing, or Transition Process. The methodology and subsequent results provide valuable aids for a thorough understanding of the characteristics of transition plays in volleyball. In addition, the concept of sequential performance analysis may serve as an example for sport scientists in investigating probabilistic patterns of motor performance.

Smith et. al., (1992) conducted a study on the physical, physiological and performance differences between Canadian national team and Universidad volleyball players. This investigation compared teams at the two uppermost levels of men's volleyball in Canada for differences in physical, physiological and performance characteristics. The subjects were members of the national (n = 15) and Universidad teams (n = 24). The parameters examined included percent body fat, maximal oxygen uptake (VO_2 max), anaerobic power, bench press, 20-m sprint time and vertical jumping ability. The only significant difference in physical characteristics between the two teams was in age. Despite similarities in standing and reach height, the national team players had significantly higher block (3.27 vs 3.21 m) and spike (3.43 vs 3.39 m) jumps. An evaluation of anaerobic power measures produced similar power outputs during a modified Wingate test, yet the national team members had higher scores (P less than 0.05) for spike and block jump differences as well as 20-m sprint time. The large aerobic component of elite volleyball play was supported by the high VO2 max value recorded for the national team players (56.7 vs 50.3 ml kg-1 min-1). The results suggest that either years of specific physical conditioning and playing or the selection of individuals for the national team who possess more desirable characteristics as a consequence of genetic endowment, plays a significant role in the preparation of international caliber volleyball players.

Sawyer et. al., (2002) studied on the relationship between football playing ability and performance measures. The relationships between football playing ability (FPA) and selected anthropometric and performance measures were determined among NCAA Division I-A football players (N = 40). Football playing ability (determined by the average of coaches' rankings) was significantly correlated with vertical jump (VJ) in all groups (offense, defense, and position groups of wide receiver-defensive back, offensive linemen defensive linemen, and running back-tight end-linebacker). Eleven of 50 correlations (groups by variables), or 22%, were important for FPA. Five of the 11 relationships were related to VJ. Forward stepwise regression equations for each group explained over half of the criterion variable, FPA, as indicated by the R(2) values for each model. Vertical jump was the prime predictor variable in the equations for all groups. Strength and conditioning programmes that facilitate the capacity for football players to develop forceful and rapid concentric action through plantar flexion of the ankle, as well as extension of the knee and hip, may be highly profitable.

Tsunawake et. al., (2003) conducted a study on the body composition and physical fitness of female volleyball and basketball players of the Japan inter-high school championship teams. This study evaluated the body composition (underwater weighing) and cardio respiratory function (VO(2)max and O(2)debt max measured by the treadmill exercise test) in 12 members of the women's volleyball team (mean age 17.4 years) and 11 members of the women's basketball team (mean age 17.6 years) that won the championship in the Japan Inter-high School Meeting. He also examined the differences in the physical abilities between the members of the top teams of different events. From the results of this study, it was observed that the female volleyball players and basketball players evaluated in this study had the physical abilities needed to win the championship in the Japan Inter-high School Meets, i.e. a large FFM and excellent aerobic and anaerobic work capacities. Also, basketball appears to require higher aerobic and anaerobic work capacities than volleyball.

Stamm et. al., (2003) conducted a study on the dependence of young female volleyballers performance on their body build, physical abilities, and psycho-physiological properties. The study was designed to determine the success of adolescent female volleyball players either anthropometric characteristics, physical abilities or psycho-physiological properties at competitions. For this purpose he studied 32 female volleyballers aged 13-16 years. The anthropometric examination included 43 measurements, 7 tests of physical fitness, and 4 series of computerized psycho-physiological tests (n=21). The performance of game elements was measured empirically during championship games using the original computer programme "Game". The proficiency of performing volleyball elements serve, reception, feint, block and spike - was calculated by regression models from the 14 anthropometric measurements, 4 physical fitness and 7 psycho physiological test results, which showed significant correlation with proficiency in the game. The predictive power of the models was at least 32% and in average 56%. The anthropometric factor was significant in the performance of all the elements of the game, being most essential (71-83%) for attack, block and feint. Good results in physical ability tests granted success in serve, attack and reception. It was possible to predict the efficiency of reception (44%) by endurance, flexibility and speed measuring tests. Medicine ball throwing test was essential for attack (22%). Psycho-physiological tests were significant for the performance of block (98%), attack (80%), feint (60%) and reception (39%).

Gorostiaga et. al., (2005) studied the differences in physical fitness and throwing velocity among elite and amateur male handball players. This study compared physical characteristics (body height, body mass [BM], body fat [BF], and free fatty mass [FFM]), one repetition maximum bench-press (1RM (BP)), jumping explosive strength (VJ), handball throwing velocity, power-load relationship of the leg and arm extensor muscles, 5- and 15-m sprint running time, and running endurance in two handball male teams: elite team, one of the world's leading teams (EM, n = 15) and amateur team, playing in the Spanish National Second Division (AM, n = 15). EM had similar values in body height, BF, VJ, 5- and 15-m sprint running time and running endurance than AM. However, the EM group gave higher values in BM (95.2 +/- 13 kg vs. 82.4 +/- 10 kg, $p < 0.05$), FFM (81.7 +/- 9 kg vs. 72.4 +/- 7 kg, $p < 0.05$), 1RM (BP) (107 +/- 12 kg vs. 83 +/- 10 kg, $p < 0.001$), muscle power during bench-press (18 - 21 %, $p < 0.05$) and half squat (13 - 17 %), and throwing velocities at standing (23.8 +/- 1.9 m . s (-1) vs. 21.8 +/- 1.6 m . s (-1), $p < 0.05$) and 3-step running (25.3 +/- 2.2 m . s (-1) vs. 22.9 +/- 1.4 m . s (-1), $p < 0.05$) actions than the AM group. Significant correlations (r = 0.67 - 0.71, p < 0.05 - 0.01) were observed in

EM and AM between individual values of velocity at 30 % of 1RM (BP) and individual values of ball velocity during a standing throw. Significant correlations were observed in EM, but not in AM, between the individual values of velocity during 3-step running throw and the individual values of velocity at 30 % of 1RM (BP) ($r = 0.72$, $p < 0.05$), as well as the individual values of power at 100 % of body mass during half-squat actions ($r = 0.62$, $p < 0.05$). The present results suggest that more muscular and powerful players are at an advantage in handball. The differences observed in free fatty mass could partly explain the differences observed between groups in absolute maximal strength and muscle power. In EM, higher efficiency in handball throwing velocity may be associated with both upper and lower extremity power output capabilities, whereas in AM this relationship may be different. Endurance capacity does not seem to represent a limitation for elite performance in handball.