CHAPTER II

REVIEW OF THE RELATED LITERATURE

2.0. INTRODUCTION

In general literature survey has served as guideline to identify the general trends of the present study. Since effective research is based upon past knowledge this review helps to do much better. The salient aspects related to study are briefly discussed under this chapter.

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 and 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 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 overcome 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 actually may decreased speed (Ebben and Blackard, 1997, 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,
lifting has also been shown to increase muscular power in athletes (Baker, 1996,
Garhammer, 1993; Headrick, 1994; Headrick and Anderson, 1996; Newton and
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 of 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 and 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
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 wk. 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 wk (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 per-forming 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 and Komi, 1985b; Komi et al., 1982; Wilson et al., 1993).

**Newton et al. (1999)** conducted a study on the effects of ballistic training on preseason 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.

**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.

**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 program 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- 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 rep and int rep groups, whereas no significant increases were demonstrated for either the high rep or con 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 b accompanied by a significant increase in MHC II a. 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 programs induced a greater hypertrophic effect compared to the high repetition regimen.

The high rep 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."

**Marcinik et al. (1991)** showed that strength training had positive effects of endurance cycling capacity. Eighteen males performed 12 weeks of strength training three times a week. The strength training consisted of 8-12 repetitions of upper body
exercise (bench press, push-ups, lat pull-downs, arm curls) and 15-20 repetitions on lower body exercises (knee extensions, hip flexion's, parallel squats) with a 30-second rest between exercises. The strength training program had no effect on the subjects VO2max. However, 1 RM for knee extension and hip flexion improved by 30% and 52% respectively. More important, cycle time to exhaustion at 75% of VO2max improved a massive 33% from 26.3 minutes before strength training to 35.1 minutes after training. He concluded that the "Strength training improves cycle endurance performance independently of changes in VO2max... and that this improvement appears to be related to increase in leg strength."

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 a 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.

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. 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).
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-wk training programs, 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.

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Additionally studies have shown that the strength gains in resistance training are specific to the speed at which the training occurred (Canavan et al., 1996, Garhammer, 1992, Hedrick, 1996, Hedricks and Anderson, 1996, Newton and 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.

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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.

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Newton et al. (1999) conducted a study on the effects of ballistic training on preseason 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.

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2.2. STUDIES ON PLYOMETRIC TRAINING

The studies related to effect of plyometric training on criterion measures used in the present study were 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
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).

Robert and Kerry et al. (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 $F_{2, 26} = 25.42$, $p=0.0000$ 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 post test 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 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.

**Karin Vassil and Boris Bazanovk et al. (2012)** conducted a study on “The effect of Plyometric training program on young volleyball players” in their usual training period. For the purpose of this study plyometric training program was applied during 16 week period. It was attended by twenty-one 12-19 years old youth volleyball players. Twelve of them were female and nine male volleyball players. There were three control testings. All subjects participated in following tests: standing long jump, depth leap long jump, medicine ball throws up in 10 seconds, medicine ball overhead throws forward against the wall in 10 seconds, maximal vertical jumps to the maximal height in 10 seconds, maximal vertical jump height. Testing results statistical analysis has shown athletes legs and arms speed force reliable improvement. Standing long jump, depth leap long jump and maximal vertical jump height test results, what has shown legs explosive power, has not shown remarkable reliable difference ($P>0.05$). Medicine ball throws and maximal vertical jumps to the maximal height in 10 seconds, what show speed force improvement, showed reliable difference ($P<0.01$).
Thomas, K, French, D and Hayes, Philip R et al. (2009) conducted a study on “The effect of two plyometric training techniques on muscular power and agility in youth soccer players”. The aim of this study was to compare 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 ($p > 0.05$). The study concludes that both DJ and CMJ plyometrics are worthwhile training activities for improving power and agility in youth soccer players.

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 programs consisting of traditional weight training, drop-jump training, or isometric training.
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 programs, 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 (pre), immediately post training (post) 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 programs. 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 programs. 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 programs 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 program may not be as effective as a 7-week program 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 2 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.

**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 already can 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-cm 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., and Van Praagh, E. (2001). Effects of plyometric training followed by a reduced training programme on physical performance in prepubescent soccer players.

**Martel et al., (2005)** studied on aquatic plyometric training increases vertical jump in female volleyball players numerous studies have reported that land-based plyometrics can improve muscular strength, joint stability and vertical jump (VJ) in athletes; however, due to the intense nature of plyometric training, the potential for acute muscle soreness or even musculoskeletal injury exists. Performance of aquatic plyometric training (APT) could lead to similar benefits, but with reduced risks due to the buoyancy of water. Unfortunately, there is little information regarding the efficacy of APT. Nineteen female volleyball players (aged 15 ± 1 yr) were randomly assigned to perform 6 wk of APT or flexibility exercises (con) twice weekly, both in addition to traditional preseason volleyball training.
Testing of leg strength was performed at baseline and after 6 wk and VJ was measured at baseline and after 2, 4 and 6 wk. Similar increases in VJ were observed in both groups after 4 wk (APT = 3.1%, con = 4.9%; both P < 0.05); however, the APT group improved by an additional 8% (P < 0.05) from week 4 to week 6, whereas there was no further improvement in the con group (-0.9%; P = NS). After 6 wk, both groups displayed significant improvements in concentric peak torque during knee extension and flexion at 60 and 180 degrees x s(-1) (all P < 0.05). The combination of APT and volleyball training resulted in larger improvements in VJ than in the con group. Thus, given the likely reduction in muscle soreness with APT versus land-based plyometrics, APT appears to be a promising training option.

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basketball practice alone is sufficient to improve vertical jump performance in high school boys, greater improvements may be generated by employing plyometric training techniques.

**Diallo et al. (2000)** studied on the 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 this study was to examine the effectiveness of plyometric training and maintenance training on physical performances in prepubescent soccer players. 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: 20, 30 and 40 m (V20, V30, V40 m). Body fat percentage (BF percent) and lean leg volume were estimated by anthropometry. As results, 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 this 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. These results demonstrate that short-term plyometric training programmes increase athletic performances in prepubescent boys. These improvements were maintained after a period of reduced training.

### 2.3. STUDIES ON COMPLEX TRAINING

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 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. 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

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 and Gregaor, 1992, Hedrick, 1996, Hedrick and Anderson, 1996, Newton and 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.

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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.

**Baker et al. (2005)** studied on the acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training. The efficient coordination of agonist and antagonist muscles is one of the important early adaptations in resistance training responsible for large increases in strength. Weak antagonist muscles may limit speed of movement; consequently, strengthening them leads to an increase in agonist muscle movement speed. However, the effect of combining agonist and antagonist muscle exercises into a power training session has been largely unexplored. The purpose of this study was to determine if a training complex consisting of contrasting agonist and antagonist muscle exercises would result in an acute increase in power output in the agonist power exercise. Twenty-four college-aged rugby league players who were experienced in combined strength and power training served as subjects for this study.

They were equally assigned to an experimental (Antag) or control (Con) group and were no different in age, height, body mass, strength, or maximal power. Power output was assessed during bench press throws with a 40-kg resistance (BT P40) with the Plyometric Power System training device. After warming up, the Con group performed the BT P40 tests 3 minutes apart to determine if any acute augmentation to power output could occur without intervention. The Antag group also performed the BT P40 tests; however, an intervention strategy of a set of bench pulls, which is an antagonistic action to the bench throw, was performed between tests to determine if this would acutely affect power output during the second BT P40 test. Although the power output for the Con group remained unaltered between test occasions, the significant 4.7% increase for the Antag group indicates that a strategy of alternating
agonist and antagonist muscle exercises may acutely increase power output during complex power training. This result may affect power training and specific warm-up strategies used in ballistic sports activities, with increased emphasis placed upon the antagonist muscle groups.

**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 4 groups. Plyometric training group (n=13), 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 subject of the each training groups trained for 2 days per week, whereas control subjects did not participate in any training activity. The data were analysed by a 1-way analysis of variance (repeated measure design). The results showed that all the training elicited significant (p<0.5) improvement in all of the tested variable. However the combination training group showed sings 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.

**Evans et al. (2000)** examined the complex training effect of combined bench press and medicine ball throws demonstrating improve 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.

Gonzalez et al. (2000) studied using children as subjects, other training studies examined the effects of a three-week complex training program 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 program 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).

Zepeda and Gonzalez et al. (2000) recently studies on complex training and examined the effect of complex training for children and female athletes suggests that complex training was equally as effective, but not superior to other strength training
programs. This finding may be consistent with the idea that prerequisite strength is necessary for complex training to be most effective and that this type of training may be best suited for those who are highly trained (Faigenbaum et al. 1999).

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 </= 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 was not within the scope of the current study.
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 smaller 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 per-forming 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 and Komi, 1985b; Komi et al. 1982; Wilson et al. 1993).

Burger et al. (2000) These researchers has evaluated the effect of high load weight training and weightlifting exercises and their effect on explosive motor performance referring to this phenomenon as the contrast method (Young et al. 1998). The purpose of this article is to review the recent research related to complex training and the contrast method and its potential practical application

Ebben and Watts et al. (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 program 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.

Radcliffe et al. (1999) in their study suggested that the recent acute complex training may be effective for upper body and lower body training it may be more effective for males. Additionally, prerequisite strength and the intensity of the load (RM) used in the weight training portion of the complex may be important in eliciting a complex training effect during the plyometric condition (Young et al. 1998).
Evans et al. (2000) In their recent research also suggests that three to four minutes of rest between the weight training and plyometric training portions of the complex may be optimal Ultimately, even the study that demonstrated no advantage associated with performing power drops after the bench press showed that performing plyometrics in complex training is at least as effective as performing them in a non-complex fashion.

Burger et al. (2000) concluded in his study which is contrast to the effectiveness of complex training was demonstrated in part, with male division I college football players. In this case, researchers found that the complex training group demonstrated significant between group vertical jump improvements the vertical jump performance improvement associated with complex training is consistent with the purported role of complex training as an effective training strategy for improving power. Evidence suggests that jumping ability seems to demonstrate an acute improvement in response to complex training stimulus according to the findings of Young et al. (1998) as well as improving as a result of a chronic complex training stimulus.