STELLENBOSCH UNIVERSITY

THE EFFECT OF A PLYOMETRIC TRAINING PROGRAMME ON SELECTED PHYSICAL CAPACITIES OF RUGBY PLAYERS

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Thesis presented in fulfillment of the requirements for the degree of
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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree.

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Signature Date

ABSTRACT

The purpose of this study was to investigate the influence of a six-week plyometric training programme on the explosive power, speed and agility as well as certain physiological characteristics and the physical fitness of rugby players. Thirty subjects, that include the first and second rugby teams of the Paul Roos Gymnasium participated in the study. After a thorough evaluation of their medical history, their health status was confirmed as being “apparently healthy” and fit for participation in the project.

The subjects were divided into two groups. The experimental group followed a specially designed plyometric training programme in addition to their conventional rugby training, while the control group persisted with the conventional rugby training for the season.

Body fat percentage was measured and specific girth measurements were taken to assess physiological changes. Cardiovascular fitness was evaluated by means of the three-minute step test and muscle endurance by means of the push-up and sit-up tests in order to assess the physical fitness of the subjects. The explosive power, speed and agility of the subjects were assessed by means of the agility test [T-drill], ten-meter speed test, Sargent vertical jump test, depth jump test, standing triple jump and the medicine ball chest pass. All measurements and tests were taken before and after the six-week intervention programme of plyometric training.

With regards to physiological changes the results showed that the plyometric training programme had a positive effect on the experimental group. The body fat percentage of the experimental group showed a significant decrease and the circumference of their thighs, calves, arms and waist increased. Their chest circumferences did, however, not increase, which might be due to the fact that the plyometric exercises were more specifically aimed at the lower body muscle groups.

The results pertaining to physical fitness were mixed. There was a significant improvement ($p<0,01$) in the cardiovascular fitness of the experimental group while that of the control group stayed relatively constant (p=1,0). With regards to muscle endurance, the control group fared significantly better in the push-up test than the experimental group, while the experimental group fared significantly better in the sit-up test than the control group.

The six-week plyometric intervention programme had a statistically significant effect on the performance of the experimental group as compared to the control group, when biomotor skills were assessed.

It was concluded that the addition of the specific plyometric exercises to a conventional rugby-training programme would improve the speed, explosive power and agility of rugby players significantly. Beneficial anthropometric changes as well as improved cardiovascular fitness would be additional benefits of a plyometric training programme.

The findings of this research suggest that the value of plyometric exercises to motor skills, specific physiological characteristics and physical fitness should not be underestimated and that the trainers and coaches should be informed in this regard. To establish the positive effects of plyometrics as a functional cross training regime for rugby players, more comprehensive research is, however, recommended.

Key words: rugby**,** plyometric exercises, agility, power and explosive power, speed and anhtropometry.

OPSOMMING

Die doel van die navorsing was om die effek van ‘n ses-weeklange pliometriese oefenprogram op die eksplosiewe krag, spoed, ratsheid asook sekere fisiologiese karaktereienskappe en die fisieke fiksheid van rugbyspelers te ondersoek.
Dertig spelers, wat lede van die eerste en tweede rugbyspan van Paul Roos Gimnasium hoërskool ingesluit het, het aan die studie deelgeneem. Na deeglike evaluering van hulle mediese geskiedenis, is hulle gesondheidsvlakke goedgekeur vir deelname in die studie.

Die spelers is in twee groepe verdeel. Die eksperimentele groep het ‘n spesiale pliometriese oefenprogram gevolg, saam met die konvensionele rugby-oefensessies. Die kontrole groep het slegs aan die konvensionele rugby-oefensessies vir die seisoen deelgeneem.

Persentasie liggaamsvet en spesifieke omtrekmates is genoteer om die fisiologiese veranderinge te evalueer. Kardiovaskulêre fiksheid is deur middel van ‘n drie-minute opstaptoets geëvalueer en spieruithouvermoë deur middel van opstoot-en opsittoetse om sodoende die speler se fisieke fiksheid te evalueer. Die ratsheid, spoed en eksplosiewe krag van die spelers is deur die ratsheidstoets (T-drill), tien-meter spoedtoets, Sargent vertikale sprongtoets, diepte sprongtoets, staande driesprong en die medisynebal-gooi-toets bepaal. Al die bogenoemde toetse en assessering is voor en na die ses-weke intervensie program van pliometriese oefening gedoen.

Met betrekking tot die fisiologiese veranderinge, dui die resultate aan dat die pliometriese oefenprogram ‘n positiewe effek op die eksperimentele groep gehad het. Die eksperimentele groep se persentasie liggaamsvet het beduidend verlaag en daar was ‘n neiging tot toename in omtrekmates van die bobeen, kuite, arms en middel. Die bors-omtrekmate het egter nie vergroot nie, en kan toegeskryf word aan die feit dat die pliometriese oefenprogram op die ontwikkeling van die spiere in die onderlyf gefokus het. Die resultate ten opsigte van die fisieke fiksheid was eenders vir die twee groepe.

Daar was ‘n neiging tot verbetering in die kardiovaskulêre fiksheid van die eksperimentele groep, terwyl die kontrole groep konstant gebly het. Met betrekking tot spieruithouvermoë het die kontrole groep in die opstoottoets verbeter in vergelyking met die eksperimentele groep. Die eksperimentele groep het egter weer verbeter ($p<0,01$) in die opsittoets, terwyl die kontrole groep konstant ($p=1,0$) gebly het.

Die eksperimentele groep het statisties betekenisvol in die biomotoriese vaardigheidtoetse verbeter na die ses-weeklange pliometriese oefenprogram. Die kontrole groep het geen verbetering getoon nie.

Die gevolgtrekking is dat ‘n kombinasie van ‘n pliometriese oefenprogram en konvensionele rugby-oefening kan lei tot die verbetering van spoed, eksplosiewe krag en ratsheid van spelers. Positiewe antropometriese veranderinge sal addisionele voordele van die pliometriese oefenprogram wees.

Die bevinding van die navorsing is dat die waarde van pliometriese oefening vir biomotoriese vaardighede, spesifieke fisiologiese eienskappe en fisieke fiksheid nie onderskat moet word nie en dat afrigters in hierdie opsig ingelig word. Om die positiewe effek van pliometrie as ‘n funksionele alternatiewe oefenmetode vir rugbyspelers te bewys, word meer intense navorsing oor die effek van die spesifieke oefenmetode aanbeveel.

Sleutelwoorde: rugby, pliometriese oefeninge, ratsheid, krag en eksplosiewe krag oefeninge, spoed en antropometrie.

DEDICATION

To my mother, Sulene and father, Rian and friends

for their undenying love,

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CHAPTER ONE

INTRODUCTION

Rugby employs both speed and powerful movements, and players are increasingly expected to perform both with speed and power (Blazevich, 2003). Conventional rugby training often extends and develops each player's specific abilities (Pearson, 2001). The challenge is to develop speed, agility and power simultaneously. In modern rugby one often finds forwards that sprint like backs and backs that tackle with the power of forwards (Biscombe & Drewett, 1998: 35-51).

With its concentration on speed and power, the inclusion of plyometric training into running training programmes seems inevitable (Chu, 1992). Throughout the history (almost 50 years) of development in plyometric training, (or "stretch-shortening" training, as it was initially known) it was kept on the leading edge for explosive power athletes (Young, 1991). Sprinters, jumpers and throwers (the initial target for plyometrics) have gained enormously by exploiting the technique (Siff & Verkhoshansky, 1993: 290-306). The application of plyometrics to other sports is well advanced and has outgrown its initial field and other sports seem destined to reap the benefits.

1.1 MOTIVATION FOR THE STUDY

Strength is the basis of high-level performance in most sports. Improvement of speed strength, referred to as explosive strength or explosive power, is an important objective of plyometric training that could benefit rugby players greatly. Lloyd (2001) focused on the prevention of injuries in Australian football, a game similar to rugby. He examined the effects of different types of training methods on the control of joint stability in order to present a rationale for training programmes to reduce anterior cruciate ligament (ACL) injuries. A combination of stability and balance training, combined with plyometric training, is recommended to reduce the occurrence of ACL injuries.

Leg strength is the primary source of power in many sports. According to Gambetta (2003) the legs can be seen as a functional unit of a closed kinetic chain without which an athlete cannot have speed, strength, power or suppleness to perform. According to Ebben (2002) the effectiveness of plyometric training is well supported by research. In South Africa, however, there is a lack of research and related literature pertaining to plyometrics and the effect of plyometric training on specific sports. Even at international level, the lack of research into plyometrics, specifically applicable to promoting or developing specific skills needed in the game of rugby, is evident. Grantham (2004) wrote that substantial research of plyometrics or stretch-shortening cycle movements and the underlying physiology would contribute to the better understanding and more effective application of plyometric training to specific sports. It is therefore important to find out to what extent a plyometric intervention programme, aimed at the development of speed, explosive power and agility, could benefit rugby players.

In view hereof, the following research question arises:
Would the addition of a plyometric training programme to conventional rugby training improve selected physical capacities of rugby players?

The following sub-questions were set to address the research question:
Would a plyometric intervention programme:

- affect biomotor abilities that manifest as explosive power, speed and agility in rugby players?
- bring about certain anthropometric changes in rugby players?
- affect the general fitness of rugby players?

1.2 AIM OF THIS STUDY

The aim of this study was to examine the effects of a specific plyometric training programme, when combined with the conventional rugby training, on selected physical capacities of rugby players.

Pursuing this aim, the following directional hypothesis is presented:
The addition of a plyometric intervention programme to traditional rugby training would bring about positive changes in selected physical capacities of rugby players.

The selected physical capacities include biomotor skills considered to be valuable to rugby players, namely, explosive power, speed and agility; the concomitant anthropometric advantages, namely, a decrease in body fat percentage and certain changes in specific girth measurements as well as an improvement in general fitness, including cardiovascular fitness and muscle endurance.

1.3 RESEARCH METHOD

A convenience sample of established rugby players, were divided into two test groups of 15 each. One group, the experimental group (n=15), undertook both conventional and plyometric training, whilst the second group, the control group (n=15), only did conventional rugby training. The assumption was that, by means of careful measurement and control, the benefits incurred to those employing plyometrics, could be demonstrated.

1.4 LIMITATIONS

The researcher experienced the following limitations:

1. The small sample size of each group had a limiting effect on the statistical power that restricted the ability to detect small differences, as well as non-significant changes.

2. The subjects were not always able to exercise at the same time of the day, due to preparation for mid-year examinations. Sometimes the exercise sessions took place in the early mornings and at other times in the late afternoons, which had an effect on their motivation for exercise.

3. The subjects' physical activity levels outside the plyometric training programme could not be controlled. They had to participate in the normal rugby training sessions, which not only included the basic functional training sessions, but also fitness training, gym training and other sporting activities offered by the school. A number of subjects were also selected for regional teams, which meant that they participated in school training sessions, as well as the regional training sessions. The inability to control the activity of the subjects also made it impossible for the researcher to control the physical state of the subjects regarding injuries. During the six-week training period, two subjects could not continue the plyometric training sessions due to ankle and knee injuries, respectively. Both these subjects were members of the first team. They were replaced by two players from the third team. Both subjects were injured while playing touch rugby as a warm-up prior to their rugby training session.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Plyometric training is a specific exercise regime that is needed to develop muscles that contract maximally in the shortest possible time (Chu, 1992; Siff & Verkhoshansky, 1993). Plyometric training is also defined as quick, powerful movements, which lead to the activation of the stretch-shortening cycle (Voight, Draovitch & Tippett, 1995). This training method was initiated about 30 years ago. The system of plyometric training, as a discrete training approach, can be applied effectively in most sports today (Grantham, 2004). Plyometrics is a valid and viable training method to develop muscular strength, speed and explosive power. One principle factor in plyometric training is that the nervous system is trained to respond to stimuli and to improve neuromuscular skills and muscular strength coordination (Blazevich, 2003; Brown, Mayhew & Boleach, 1986).

Plyometric training may be used to develop an athlete's power, increase response time from stationary, promote agility, and increase acceleration and therewith, ultimate speed (Blazevich, 2003). Sport-specific exercises, when combined with plyometric training, have been shown to effectively correspond with power training (Jacoby & Gambetta, 1989; Siff & Verkhoshansky, 1993). Recently, plyometric research has focused on the positive effects of this training method on a variety of sports and the prevention of injury (Diallo, Dore, Duche, & Van Praagh, 2001; Granata, Wilson & Padua, 2001; Matavulji, Kukolj, Ugarkovic, Tihanyi & Jaric, 2001).

With the emphasis in rugby being on strength, explosive power and agility would be a key aspect in a player's overall performance (Turnbull, Coetzee & McDonald, 1995: 60). There are numerous phases in rugby where speed, stamina, power and agility are required and in many cases fairly simultaneously (Anon, 2003; Pearson, 2001). Plyometric requirements in rugby are not conformed solely to forward play, because the modern game emphasises the need for all team members to be powerful, fast and agile. Such modern requirements emphasise the potential for the application of plyometric exercises in rugby training (Noakes & Du Plessis, 1996). There is, however, no information available on systematic investigation of plyometrics as applied to rugby. This may be due to "team secrecy", a problem that had previously occurred in plyometric research (Siff & Verkhoshansky, 1993).

The relative importance of stamina, speed, power and agility will vary according to playing position (Turnbull, *et al*, 1995: 1-23). Physical conditioning for rugby players, therefore, has to account for at least these four aspects of physical fitness, which in turn must be integrated into factors such as skill development and physiological preparation during training and playing phases. Whether a player is training for speed, strength endurance or power, there are elements, which are common to all training programmes for these fitness components (Pearson, 2001; Jenkins, 1988: 5-23).

Rugby players have different body types and positional requirements (Biscombe & Drewett, 1998). The nature of this sport is physical, therefore, players have to be physically strong and sturdy (Bloomfield, Ackland & Elliott, 1994). Running, as a training modality, is a very successful way of achieving an effective aerobic and anaerobic capacities. The major problem with running is that it is a potentially stressful and injurious activity due to the impact loading which occurs every time the feet make contact with the ground (Collier, 1988: 13-24).

Speed is the essence of the excitement in rugby. It is the essential ingredient, which lifts a player or team's performance to a higher level. In rugby, the term 'speed' is more complex than simply getting from point A to point B in the shortest possible time (Pearson, 2001). It manifests, *inter alia*, in 'speed to the breakdown', 'accelerating through space', 'getting across in cover defense' (Misson, 1988: 55).

Many of the specific movements in a rugby game are plyometric (explosive) in nature (Pearson, 2001). Whether players are jumping in the lineout, going for a high ball or simply launching themselves into a tackle, the muscle's stretch reflex is continually being relied upon (Turnbull, *et al.*, 1995:7). It is, therefore, important to include plyometric training in a speed-conditioning programme. Many jumping and agility movements on the field are dictated by a player's ability to move his body weight rapidly and efficiently (Biscombe & Drewett, 1998). Players should vary their starting positions to facilitate a plyometric training effect in sprint sessions, for example, ten times ten meter sprint from an off-ground start or three times squat jumps (replicating a line-out), followed by a shuttle run. Combining plyometric movements and sprint running will assist in the replication of many match-specific movements (Misson, 1988: 55-64). According to Hawley and Burke (1998) previous research highlighted the sustained high-intensity pattern of team sports and the stochastic (stop-start) nature of rugby.

Explosive events, that include jumping, throwing or speed movements, benefit from the use of plyometric exercises. These observations have been extensively confirmed by Gambetta (1993), Matavulji *et al.* (2001), Robberds (2002) and Yessis, (1991), although Gambetta (1993) commented that plyometrics must be accompanied by power training to maximize the power to explosive power ratio. He further stated that a basis of power training is necessary to maximize plyometric-training effects, and such a mixture should provide a recipe for success (Gambetta, 1993). A combination of weight training and plyometric exercises has gained popularity as a strategy to improve muscle power and athletic performance (Ebben, 2002).

Rugby, as an amateur game, with long-standing traditions, tended to lag behind other sports in systematically adopting sport science. One of the outstanding features of the modern sport has been the application of science to assist participants in achieving imshowed performances. The acceptance of rugby into the Australian Institute of sports programmes in 1988 served as a catalyst for the change in Australia. Essentially, this facilitated exposure to sports science and permitted experimentation to ascertain the most practical services to adopt for rugby (Harry, 1988).

It seems that plyometric exercises could have a positive effect on sport performance (Yessis, 1991). The extent to which performance in rugby could be enhanced through the addition of plyometric training is still to be scientifically established, which is the main objective of this research project. In view thereof, a review of the relevant research pertaining to plyometrics and plyometric training will be given in this chapter after a brief account of the historical development of plyometrics and a comprehensive description of the fundamental theory of plyometrics. In conclusion, a detailed account of all the relevant concepts, pertaining to plyometrics as a discrete training system, will be discussed.

2.2 HISTORICAL DEVELOPMENT

Plyometrics, when first developed in success-hungry Eastern European countries, was initially termed "jump training" (Chu, 1998). As Eastern Block successes in track and field events, gymnastics and weightlifting began to accrue, the training methods employed were scrutinized. In the West, plyometrics was referred to as the "Russian Training Secret", a term that did not demystify the training system (Siff & Verkhoshansky, 1993).

Initiated in Russia, since its scientific formulation as a discrete training system in the 1960's, it was well established in the Eastern Block when the demand came for explosive power training. Verkhoshansky, the originator of the system, always favoured the term "shock" training to distinguish between naturally occurring plyometric action in sport and the effects of his discrete training methods (Chu, 1998). Much earlier sport physiological work used different terms to describe what is now termed " plyometric", the most popular being "stretch-shortening". "Plyometrics", as a training term, was wined in America, deriving from the Latin term meaning "measurable increases". Plyometrics was responsible for the increasing competitiveness and growing superiority of Eastern Block athletes in track and field events (Chu, 1998).

Driven by the success of the Eastern Block athletes, plyometric training became essential for all power athletes (Siff & Verkhoshansky, 1993). As a conditioning method, plyometrics became widely employed for the development of leg power (Young, 1991). Plyometrics is valuable due to the different ways in which muscle groups contract and are manipulated to maximize the "load up" before explosive movements (Blazevich, 2003; Kessel, 2002).

As plyometric training became more valuable, other, less explosive, sports began employing plyometric concepts linked to their specific movements and activities. This gradual acceptance began in the late 1970's, but only became widespread at the end of the 1980's. This successful progress was retarded by the lack of plyometric expertise in American coaches, who believed that there must be a "better alternative". Once the quality of the plyometric exercises were accepted, the quality rather than the quantity, was emphasised (Chu, 1998).

During the 1980's much effort has been expended in reproving the efficacy and safety of plyometric training. Some mixed results have been reported, although many of the problems might have been generated by comparing trained national and untrained athletes under variable conditions. Most poor results can be attributed to the fact that athletic development follows its own time curve, which cannot easily be reflected in short-term programmes, when development may occur throughout a whole athletic career. For some, this time span may be as short as a single season, for others it may be thirty years of competitive activities. Bearing this in mind, the athlete's skill, injury history and many other variables can compromise long-term athletic development. Realistic expectations for plyometric training can, thus, only be learned as a result of applied research (Chu, 1998).

2.3 FUNDAMENTAL PLYOMETRICS THEORY

Plyometrics are designed to enable muscles to contract to the maximum extent in the shortest possible time (Chu, 1992). This training involves quick, powerful movements that require stretching or counter movements to activate the stretch-shortening cycle (Siff & Verkhoshansky, 1993). During this training, the athlete's neuromuscular system shows imshowed reactions to stimuli by the training of their nervous system (Voight *et al*., 1995). Normal daily and sport requirements of stretch-shortening exercises produce the need for functional exercises undertaken before sport-specific plyometrics. Theoretically, plyometrics can close the gap between speed and power (Voight *et al*., 1995).

Although speed and power are the most common products of a plyometric training programme, the promotion of agility cannot be totally ignored (Pearson, 2001). In this regard, plyometric exercises reduce the amortisation phase, where the eccentric phase transforms to the concentric. Generally, this conversion from eccentric (negative) energy to concentric (positive) energy is termed the "amortisation" which occurs within a few one hundredths of a second (Siff & Verkhoshansky, 1993). A formula has been proposed which links the efficiency of contraction time to the relationship between "time spent on the ground" and the height achieved during jumping (Voight *et al.,* 1995). This approach was further validated by work illustrating that sprinters and jumpers (i.e. athletes that rely on the speed and strength capability of leg muscles) actually spend very little time in contact with the ground (Duda, 1988). These athletes store energy (from the eccentric and concentric phases) in their leg muscles, then partially release this energy during the concentric contraction. Energy from the eccentric phase cannot be stored indefinitely in the leg muscles, as it disperses in the form of heat, unless the concentric phase immediately follows the eccentric phase. Typically, elite high jumpers amortise in about 0,12 seconds (Duda, 1988). Plyometric exercises have been developed to minimise the amortisation phase, although the duration of their phases have been demonstrated to also depend on learning. Therefore athletes may shorten their personal amortisation phase by learning from skills training within strength development (Chu, 1998).

It is well recognised that whilst many coaches realise the importance of explosive power as an ingredient of sport performance, very few of them are familiar with the functioning of the mechanism that develops and improves this essential power (Brown *et al.*, 1986). Plyometric exercises that enable muscles to reach maximum strength within the shortest time possible, develop speed-strength, which manifests as explosive power in athletes (Diallo *et al.*, 2001).

Diallo *et al*. (2001) stress the fact that physiological considerations were increasingly essential to optimal performance, not only in adults, but also in young children. In this regard a clear understanding of the way in which muscles function physiologically, would demonstrate the straightforward, yet complex, way in which plyometric training relates to imshowed performance in sport, which, according to Gambetta (1993) is indispensable for a thorough understanding of plyometrics.

Relevant muscle physiology will next be described, followed by a brief description of the different types of muscle contractions. Thereafter, two concepts that both have an effect on an athlete's plyometric ability, namely energy storing and energy repair will be discussed.

2.4 RELEVANT MUSCLE PHYSIOLOGY

Muscles, along with bones, are essential for posture and movement of the human body and work concentrically or eccentrically, depending on the movement performed. The position and the type of muscle fibre will determine whether the fibre will have a movement or stabilisation role in the body. Muscles always cross a joint in order to support or stabilise the joint and they play a part in the dynamic stability of joints throughout the complete range of movement (Baechle & Earle, 2000). They possess a unique ability to impart dynamic activity, unlike the other supporting structures, namely ligaments and tendons (Chu, 1992). The two types of muscles are skeletal muscles (contractile) and connective tissue (non-contractile). Muscle tissue is described as being viscoelastic.

Ligaments are strong non-contractile collagen fibres, that stop movement and prevent the joint from moving in certain directions. Ligaments are tough, dense, fibrous tissues that attach bone to bone for support and mobility. Tendons are the fibrous structures that attach muscles to bones, but have less elasticity and contractile potential than muscles and consist of more connective tissue fibres (Chu, 1992; Baechle & Earle, 2000).

2.4.1 Muscle structure

Muscles comprise' two types of muscle fibre, namely, extrafusal and intrafusal. Extrafusal fibres contain myofibrils, that contract, relax, and elongate muscles. Extrafusal fibres receive nerve impulses from the brain, which cause chemical reactions. Intrafusal fibres, also called muscle spindles, are parallel to the extrafusal fibres. Muscle spindles are the main stretch receptors in muscles (Chu, 1992; McArdle, Katch & Katch, 1997).

Muscle fibres are grouped together in bundles called fasciculi and an individual muscle contains many fasciculi. Like other body cells, the muscle is composed of cytoplasm, (which in muscle is called sarcoplasm) which consists of structures called myofibrils, comprising the contractile proteins, glycogen, and mitochondria, required for cell metabolism.

The myofibril comprises tiny filaments, myofilaments, some of which are composed of the protein actin, while others are made up of the protein myosin when bound together. These two filaments cause muscle contractions (Marieb, 2000; McArdle *et al.*, 1997). The thin actin myofilaments take on the form of chainlike actin strings and wound around each other. Molecules of the globular protein, troponin, are found in notches between the two actin strings and tropomyosin molecules which control the binding of actin and myosin myofilaments.

When examined as a contractile unit, the portion of the myofibril located between two Z lines is called the sarcomere. At rest, the sarcomere is about 2.5 µm long. Z lines, located at regular intervals throughout the myofibril, not only serve as boundaries to the sarcomere but also link actin filaments together (Baechle & Earle, 2000). Voluntary activation of a muscle is initiated when a nerve impulse arrives at the motor end plate, which produces an electric impulse, or action potential, that travels along the muscle fibre (Seeley, Stephens & Tate, 2003). This action potential initiates the release of calcium ions, which cause troponin to reposition the tropomyosin molecules to enable actin binding sites to free, whilst the head groups of the myosin bind with this actin. Such filament bonding is called a cross-bridge and is thought to be the basic unit of active muscle tension (Marieb, 2000). The sarcomere is shortened when there is a complete overlap of the filaments. This action may be summarized as follows:

- Tension is generated whenever cross-bridges are formed.
- No cross-bridges can be formed and no generation of active tension can occur unless there is some overlapping of the actin and myosin myofilaments.
- The maximum number of cross-bridges can be formed when there is maximum overlap of myofilaments (Baechle & Earle, 2000).

2.4.1.1 The functional unit

Muscle tissue possesses the properties of contractility and irritability. Contractility refers to the muscle's ability to develop tension, whilst irritability refers to the ability to respond to chemical, electrical or mechanical stimuli. Stimuli causing the muscle fibre to begin the contractile process are transmitted to the alpha motor neuron. This neuron is located in the anterior horn of the grey matter of the spinal cord (Baechle & Earle, 2000). A long fibre called the axon, extends from the cell body to the muscle, where it may divide into thousands of small branches. Each small branch terminates in a motor end plate lying in close proximity of the sarcolemma of any single muscle fibre. All muscle fibres, upon which a branch of the axon terminates, are part of one motor unit, along with the cell body and the axon. Nerve impulses transmitted from the cell body along the axon to the motor end plate cause depolarization of each individual muscle fibre sarcolemma. This effect generates an action potential, which spreads along both the external surface of the sarcolemma and the interior of the fibre by means of the transverse tubules (T tubules); two transverse tubules supply each sarcomere.

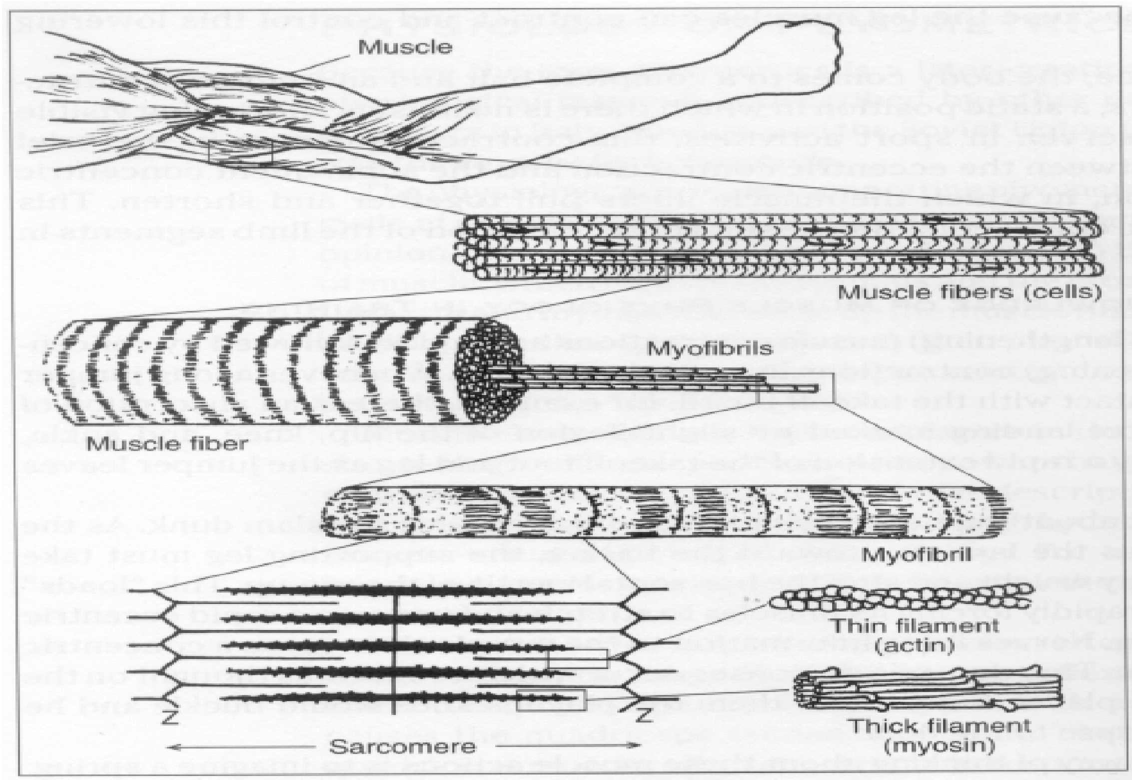

Figure: 2.1: The structure of the muscle cell (Chu, 1998: 3).

The sarcoplasmic reticulum has a large calcium storage capacity. When the action potential sweeps through the T tubules, free calcium ions are released into the myofibrils. These calcium ions initiate the actin-myosin cross-bridge activity and cause muscle tension. Once the sarcolemma becomes electrically stable after depolarisation, calcium ions return to the sarcoplasmic reticulum and the muscle fibre relaxes. Motor units go through a latency or refractory period soon after firing, and require time to recover before the depolarisation or tension generation cycle can be repeated. Therefore, motor units firing frequent off-motor units are limited by the requirement for recovery time prior to subsequent reactivation (Seeley *et al*., 2003).

2.4.1.2 Muscle fibres

Muscle fibre length, fibre arrangement and the number of fibres per muscle vary throughout the body. These structural variations affect both the overall shape and size of muscles and their functions. Each fibre is capable of shortening to approximately one-half of its free length, thus, a long muscle fibre can shorten over a greater linear distance than a short muscle fibre (Baechle & Earle, 2000).

2.4.1.2.1 Muscle fibre types

There are three muscle fibre types in skeletal muscles, but individuals differ regarding the number of motor units allocated to each fibre type in similar muscles.
In fast–twitch fibres the fibres are capable of performing quick powerful action. The electrochemical transmission of action potentials, a high activity level of myosin ATP-ase, a rapid rate of calcium release and uptake by a highly developed sarcoplasmic reticulum and a high rate of cross-bridge turnover, all of which are related to the ability to generate energy rapidly for quick, powerful actions. The fast-twitch fibre's intrinsic shortening speed and tension development is three to five times faster than fibres classified as slow twitch. The fast-twitch fibres often rely on their well-developed, short-term glycolytic system for energy transfer. This explains how these fibres can be activated in short term, sprinting activities as well as in other forceful muscle actions that depend almost entirely on anaerobic metabolism for energy. Activation of the fast-twitch fibres is also important in soccer or field hockey, that, at times, require rapid energy release that is only supplied by the anaerobic metabolic pathways (Baechle & Earle, 2000).

Slow-twitch fibres generate energy from ATP resynthesis, predominantly through the aerobic system of energy transfer. They are distinguished by a relatively low activity level of myosin ATP-ase, slower calcium-handling ability and shortening speed, and a glycolytic capacity that is more developed than their fast-twitch counterparts. Slow-twitch fibres also contain relatively large and numerous mitochondria. This concentration of mitochondria, combined with high myoglobin levels, gives the slow-twitch fibre its characteristic red pigmentation (Dick, 1995).

Accompanying this enhanced metabolic machinery, is a high concentration of mitochondrial enzymes that is required to sustain aerobic metabolism. Thus, slow-twitch fibres are fatigue-resistant and well suited for prolonged aerobic exercises. These fibres have been labeled slow oxidative (SO) fibres to describe their slow shortening speed and their great reliance on oxidative metabolism. Many researchers classify slow-twitch fibres as type I fibres, whereas the fast twitch-fibres are known as type II fibres (McArdle *et al*., 1997).

Fast-twitch subdivisions, the type IIa fibre is considered intermediate, because its fast shortening speed is combined with a moderately well-developed capacity for both aerobic and anaerobic energy transfer. These are the fast-oxidative-glycolytic (FOG) fibres. Another subdivision, the type II (b) fibre, possesses the greatest anaerobic potential and is the “true” fast glycolytic (FG) fibre. The type II (c) fibre is normally a rare and undifferentiated fibre that may be involved in reinnervation or motor unit transformation (Marieb, 2000).

2.4.1.3 Muscular connective tissue

Muscles and muscle fibres, similarly to other soft body tissues, are surrounded and supported by connective tissue. The sarcolemma of individual muscle fibres is surrounded by connective tissue, called the endomysium, whilst groups of muscle fibres (fasciculi) are covered by connective tissue, called the perimysium. Both endomysium and perimysium are continuous with the outer connective tissue sheath, termed the epimysium, which envelops the entire muscle. These continuations of the outer sheath form the tendons that attach each end of the muscle to the bony components. Tendons are attached to bones, which become continuous with the periosteum (Baechle &Earle, 2000).

Other connective tissue associated with muscles are fasciae, aponeuroses and sheaths. Fasciae may be divided into the following two zones: superficial and deep. The superficial fasciae zone comprises loose tissue, located directly under the dermis and contributes to the mobility of the skin, acting as an insulator and containing skin muscles (e.g. platysma in the neck). The deep fasciae zone comprises compact and regularly-arranged collaginous fibres, which are attached to muscles and bones and may form tracts or bands and retinacula (Baechle & Earle, 2000).

All of the connective tissue in a muscle is interconnected and constitutes the passive elastic component of a muscle. These connective tissues, surrounding muscle fibres, run parallel to the muscle fibres. These tissues, as well as the sarcolemma, intracellular elastic filaments, made of the protein titin, and other structures (i.e. nerves and blood vessels) form the parallel elastic component of a muscle. When a muscle lengthens or shortens, these tissues must also lengthen or shorten, (i.e. act in parallel with the muscle fibres). Increased resistance of the perimysium to elongation may prevent muscle fibre bundles from overstretching. When sarcomeres shorten from their resting position, the slack collagen fibres within the parallel elastic component, buckle. Any existing tension, in the collagen at rest, is diminished by the shortening of the sarcomere. Given the many parallel elastic components of a muscle, the increase or decrease in passive tension can substantially affect the total tension output of a muscle (McArdle *et al*., 1997).

2.4.1.4 Muscle function

a) Muscle tension

The most important characteristic of a muscle is its ability to develop tension and to exert a force on the bony lever. Tension can be either active or passive and the total tension that a muscle may develop comprises both active and passive components (McArdle *et al*., 1997).

b) Active tension

Active tension refers to tension developed by the contractile elements of the muscle, which is initiated by cross-bridge formation and movement of the actin and myosin. The amount of active tension that a muscle can generate depends on the frequency of stimulation, number and size of motor units firing simultaneously. At sarcomere level, it depends on the number of cross-bridges that are formed.

- Tension may be increased by increasing the frequency of firing of a motor unit or by increasing the number of motor units that are firing.
- Tension may be increased by recruiting motor units with larger numbers of fibres.
- The greater the number of cross-bridges formed, the greater the tension (Marieb, 2000).

c) Passive tension

Passive tension refers to tension developed in the passive non-contractile components of the muscle. Passive tension in the connective tissue elements can be created by active and passive shortening and lengthening of muscles. The connective tissue structures associated with the muscles may either add to the active tension produced by the muscle or may become slack, contributing nothing to the total tension. The total tension that developed during an active muscle contraction is a combination of the contractile (active) tension plus the non-contractile (passive) tension.

To produce motion, active tension must be sufficient to take up the slack in the tendon and must also be sufficient to exert a force capable of overcoming any external resistance and inertia of the bony lever. Other factors that determine the exerted muscle tension are, speed and the type of contraction. Total muscle tension and biomechanical variables, such as the length of the lever, determine the muscle's ability to produce torque.

d) Length-tension

A direct relationship exists between tension development in a muscle and the length of that muscle. The optimal length at which a muscle develops maximal tension is close to the resting length of the muscle. Experimentally, the actual resting length is measured as the assumed muscle length, once detached from the bone. Optimal length is approximately 1.2 times longer than the resting length (Dick, 2002).

Muscles can develop maximal tension at optimal length because the actin and myosin filaments are positioned in such a way that the maximum number of cross-bridges can be formed. If a muscle is lengthened or shortened beyond optimal length, the amount of tension that a muscle is able to generate, diminishes. When a muscle is lengthened beyond optimal length, there is less overlapping between the actin and the myosin filaments, thus, causing fewer possibilities for cross-bridge formation. Should the muscle, however, be elongated, the passive elastic tension in the parallel component may be increased (Baechle & Earle, 2000).

A similar loss of active tension or a diminished development of tension capacity occurs when a muscle is shortened from its optimal length. The distance between the Z bands is decreased at sarcomere level leading to an overlap of the filaments, leading to the formation of the maximum number of cross-bridges. Beyond a critical shortened length, there are no additional opportunities for cross-bridge formation with further shortening and consequently, no further tension can be generated. The reason for the decline in tension is not totally clear, although the optimal range in which a muscle fibre may develop maximum tension is very small. Whilst muscle length is not the sole factor affecting muscle tension, the body unconsciously and/or consciously learns to place muscles at their optimal length for maximum tension development. Muscles are able to generate moderate tension in the lengthened range, maximum tension in the middle of the contractile range, and minimal tension in the shortened range during a concentric or active shortening contraction (McArdle *et al*., 1997).

Duda (1988) pointed out that many authors reviewed the physiological research that support plyometrics, or the stretch-shortening cycle of muscle tissue. The consensus of opinion cites the importance of two factors: the serial elastic components of muscle, which include the tendons and the cross-bridging characteristics of the actin and myosin that make up the muscle fibres; and the sensors in the muscle spindles (proprioceptors) that pre-set muscle tension and relay sensory input related to rapid muscle stretching for the activation of the "stretch reflex". To stretch, the muscle spindles receive a message from the brain that initiates a stretch reflex, and the muscle stretches to its full potential. (Gambetta, 1993).

Muscles derive information from the central nervous system, via the spinal cord, out into the peripheral nervous system, which extends from the spinal cord, and ultimately to every muscle in the body. Among the messages reaching the muscles are those governing the length of each muscle at any point, the expected tension necessary for maintaining posture and initiating or ending movement. A great amount of information is processed in this way every second (Gambetta, 1993). The different types of muscle contractions that take place during each movement will be briefly discussed below.

2.4.2 Muscle contractions

Motor function is focused on the muscle contraction where the muscle shortens. The muscle system tries to overcome the external force. When the external force overcomes the resistance of the muscle, the muscle lengthens (Baechle & Earle, 2000).

This lengthening of the muscle only takes place after the additional force was produced. When a concentric contraction immediately follows an eccentric contraction, the force created can increase drastically (Dick, 2002). With the stretching of the muscle a lot of energy is lost as heat, but some of this energy can be stored in the muscle through the elastic component. This stored energy is only accessible once there is an increase in the number of muscle contractions (Bosco, 1985).

It is very important to note that the above-mentioned "energy boost" will be lost if the eccentric contraction is not immediately followed by a concentric contraction. The muscle must contract in the shortest possible time to use this energy. This process is called the stretch-shortening cycle, and is one of the important characteristics of plyometric exercises (Hennesy, 1990). The activity of the muscle is normally presented in the three-component model. (Figure 2.2) (Voight *et al*., 1995).

It is important to know that there are three types of contractions. This model demonstrates the three-mechanism characteristics of muscles (Voight *et al.*, 1995).

The three types of contractions showed in Figure 2.2 illustrate that the contraction component (CC), series elastic component (SEC) and a parallel elastic component (PEC) play an important roles in the creation of force. Although the CC is easily understandable, the SEC and PEC is symbolised as different structures. They can react like a wind-up spring, meaning that they can shorten or lengthen. The CC and SEC present the nature of the muscle that contracts actively.

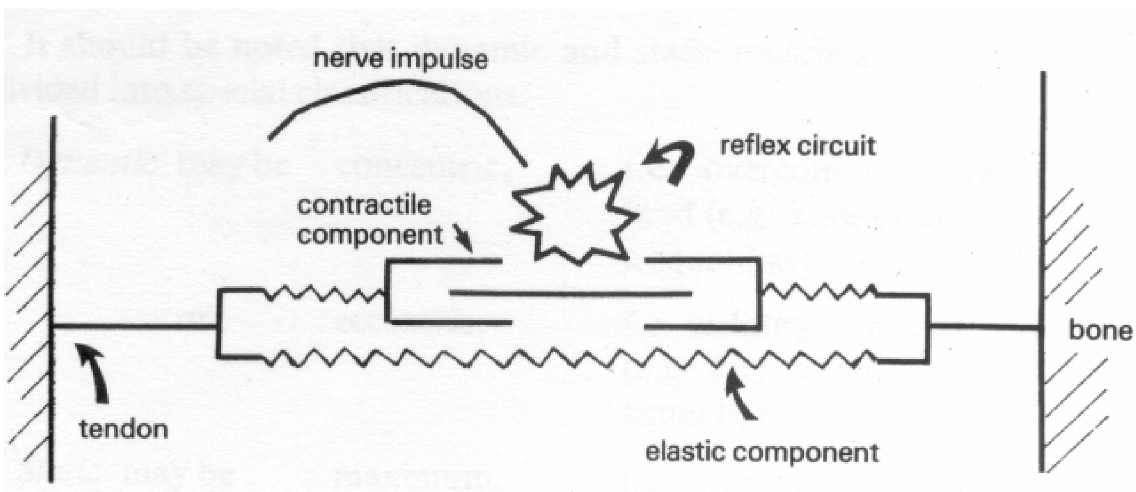

Figure 2.2: Schematic representation of the contractile and elastic components plus reflex mechanisms in muscles (Dick, 2002: 93).

Eccentric contraction that occurs when the muscle lengthens under tension, is used to slow down the body. This will occur when a muscle is loaded enough to lengthen, even if the muscle tries to shorten (Wilt, 1976).

Chu (1998) gives an excellent report on muscle contractions and their functioning as applied to plyometrics. In this report the athlete has to concentrate on three modes of muscle contraction in sport: eccentric, isometric, and concentric (Chu, 1998). Eccentric contractions, which occur when the muscle lengthens under tension, are used to decelerate the body. When an athlete, for example, runs there is ground impact that causes the body’s centre of gravity to move downwards. The leg muscles contract and prevent the athlete from collapsing and also control the downward movement. To a certain extent some form of stretching is found at the series elastic component (SEC), although most of the power is produced through the movement of the muscle filaments. The CC creates power that is carried by the SEC to register externally. Maximal tension develops when active muscles are stretched quickly. When a muscle gets stretched even more before the contraction, the tension will be greater than the muscle resistance. A muscle applies twice as much tension during an eccentric contraction as during a concentric contraction that followed an eccentric contraction (Dick, 2002).

In the middle of an athlete's running stride, the body "stops" and an isometric contraction takes place. This is a static position where the observer will not see any muscle shortening. In sport activities this contraction period between the eccentric and concentric contraction, is the period where the muscles contract and shorten. The concentric contraction causes the acceleration of the body segment during the running action. When the eccentric contraction takes place, the muscle lengthens like a relaxed spring. With the lengthening of the SEC, the muscle also gets stretched which allows the addition of the power. The total power produced is the sum of contraction component and the stretching of the SEC that has been produced (Marieb, 2000; McArdle *et al*., 1997).

Wilt (1976), Hennesy (1990), Voight *et al*. (1995) Chu (1998) and Young (1991) all agree that with an eccentric contraction, followed shortly after the concentric contraction there is an increase in power of the concentric contraction, because of the elastic energy. The mechanism responsible for the increase in the concentric contraction, is the ability to use power that has been produced by the SEC. During the eccentric contraction the load gets transferred to the SEC and is stored as elastic energy. When the muscles execute the concentric contraction, the elastic energy recuperates in the SEC and is used for the shortening contraction. The ability to use the stored energy is influenced by the time, size/extent of the power and the stretching speed.

Changes in the concentric contraction are most effective when the initial eccentric contraction occurs quickly and without any delay. When the elastic component of the muscle is used, one of the most important advantages is the ability to change direction. During the stretch-shortening cycle, the proprioreceptive stretch reflex (another positive power producing mechanism) is connected to the muscle behavior. Musculoskeletal motor control is regulated by the central nervous system (Blazevich, 2003).

Proprioreceptors situated in the muscles, supply afferent information about the muscular distraction level. This information influences the muscle tension, motor execution programme and kinetic sensation. The most important propriocepters are the Golgi-tendon organ (GTO) and the muscle spindles (McArdle *et al*., 1997).

The muscle spindles are small complex organs that are situated in the muscle fibres. They contain both afferent and efferent nerve supply and function mainly as a stretch receptor. Sensory information is carried over to the central nervous system through the afferent axon, which informs the other nerves in the spinal column and brain about the muscle spindle length and the stretching rate. The muscle spindle comprises contractible fibres that are controlled through a small y-efferent of the spinal cord. When the length of the surrounding muscle fibres is smaller than that of the muscle spindle the frequency of the nerve impulse, downloaded from the receptors, decreases. When a muscle spindle is activated through stretching, the afferent sensory response created, gets carried over to the spinal cord. From there the impulse is sent back to the muscles and a motor reaction is caused. The short swing of the muscle decreases the stretching of the muscle spindle and eliminates thereby the stimulus of the stretch receptors. This process is called the stretch or myotic reflex. This is the only mono sinaptic reflex in the body (Baechle & Earle, 2000).

The GTO's that are situated in the muscle tendons, close to the attachment between the muscle fibre and the tendon is working closely together with the limited tension reflex. The GTO's are different from the muscle spindle due to their inhibiting effect. The GTO's are activated during stretching because of the series setup in the contractible muscle fibres (Marieb, 2000; McArdle *et al*., 1997).

When tension is produced, the sensory impulse quickly gets carried over to the spinal cord and cerebellum. The arrival of the impulse at the spinal cord leads to the inhibition of the alpha motor neuron of the contractible muscle and its synergists, whereby the developed power is limited (Marieb, 2000; McArdle *et al*., 1997).

The activity of the muscle spindle during a muscle contraction decreases due to the shortening or the attempted shortening of muscle fibres. During the eccentric contraction the stretch reflex tries to create more tension in the lengthening of the muscle. The GTO's react when the muscle tension increases, leading to a high level of potential damage. They generate a neural pattern that decreases the activation of the muscle. As soon as the GTO's respond to high muscular tension or stretching, the inhibiting effect during the spontaneous muscular activation of the muscle can start. When the muscular tension gets too much, the potential for injuries increases. As the two systems are in contrast with each other they produce an increase in muscular power. The downward direction of the brain needs to balance the two powers and have absolute power over the dominant reflex (Baechle & Earle, 2000).

2.4.3 Muscle physiology during exercise

The transfer of negative (eccentric) to positive (concentric) contraction is, as previously mentioned in European literature, the amortisation phase. According to Voight *et al.* (1995) the amortisation phase is defined as the electromechanical delay between the eccentric and concentric contraction, in which the muscles have to change from overcoming the workload, to supplying acceleration. This phase is important in changing direction in which the movement is taking place. Komi (1984) claimed that the biggest tension develops during the stretch-shortening cycle during muscle lengthening, just before the concentric contraction. He also claimed that the increase in the amortisation phase leads to a decrease in muscle tension.

A whole system of exercises and plyometric exercises had been used to develop a shorter amortisation phase. Research showed that the length of this phase could be changed.

Where power and natural speed is important, the athlete can decrease the amortisation phase through the development of a power base and by executing the plyometric skills correctly (Voight *et al*., 1995).

2.5 PLYOMETRIC EXERCISES

Plyometric exercises enable the athlete to overload and train his/her body in a specific position required for a specific competition situation. Today the high level of professional sport focuses on specific training and plyometric training is a form of overload exercise. Plyometric exercises, in conjunction with a weight-training programme, can lead to the execution of specific aspects of exercises (Siff & Verkhoshansky, 1993).

Wilson, Murphy and Giorgi (1996) as well as Bosco (1985) state that plyometric exercises can increase participants' ability to use elastic energy. Researchers state that plyometric exercises can change the elasticity of muscles and tendons, to enable them to store bigger quantities of elastic energy during a given stretch-shortening movement. The faster the execution of the plyometric activity, the more elastic energy gets stored when the muscles and tendons are stretched to produce more power. In this way the delay between the stretch-shortening cycle is minimal causing maximum energy storage. Another advantage of plyometric exercises is that it includes movements, which cause elastic energy to maximize the stretch-shortening cycle (Blazevich, 2003).

2.6. PHYSIOLOGY OF PLYOMETRIC EXERCISES

Plyometric exercises involve the quick pre-stretching of a muscle (eccentric contraction), immediately followed by the shortening of that same muscle. This eccentric-concentric muscle contraction is often described as the stretch-shortening cycle and occurs naturally in running and jumping activities (Blazevich, 2003).

Chu (1992), Wilt (1976), Wilson *et al.* (1996), Voight *et al.* (1995) and Maarten (1990) support the principle of plyometric exercises and the stretch-shortening cycle. If muscles are stretched before the concentric contraction, the result is a more powerful contraction, due to:

- the series elastic component of the muscle, that includes the tendon and crossbridge-crossover characteristic of the actin-myosin.
- the sensors in the muscle spindle (proprioreceptors) that play a big role in preparing the right muscle tension.
- the variation of sensory information that relates to the quick stretching of the muscle for the activation of the stretch reflex.

Muscle elasticity is an important characteristic of muscle tissue that explains how the stretch-shortening cycle can produce more power than a simple concentric contraction (Blazevich, 2003). As previously illustrated the muscles can develop the tension through quick stretching that is only stored for a short while so that it contains a sort of elastic energy. For example, if one would take an elastic and stretch it out, the elastic has potential energy to return quickly to its original length (Wilt, 1976). The quick stretching of the muscles and tendons causes energy storage, which can lead to the recuperation during the concentric contraction which makes the execution easier (Wilson *et al.*, 1996). Plyometric exercises can develop elastic characteristics of muscles and tendons, so that greater amounts of energy can be stored and used during the stretch-shortening cycle (Young, 1991).

The stretch reflex is another mechanism of the stretch-shortening cycle. This indicates that the particular muscles in any specific action have much stronger contraction values than when following a gathering phase, which contains the stretching of the muscles (Wilt, 1976). The muscles resist overstretching. Through stimulation of the stretch receptors of the muscle spindle, which causes the proprioreceptive nerve impulses to move to the spinal cord and back to the same muscle, strong contractions take place to prevent the overstretching of the muscle (Duda, 1988). This is called the stretch/miotic reflex (Wilt, 1976). A general example of the stretch reflex is the knee’s shock reaction when the doctor taps on the patella tendon with a rubber-hammer. The tap on the patella tendon causes the quadriceps tendon to stretch. The stretching is observed by the quadriceps muscle, which in turn contracts to stimuli. The stretch reflex gets activated when the muscle spindle activates stretching and leads to a powerful concentric contraction (Lundin, 1989). Fast stretching or high stretch loads can lead to the activation of the Golgi-tendon organs (GTO's). They are stimulated in the tendons and have an inhibiting effect on the power of the next concentric contraction. The reflex acts as a protective mechanism for the musculoskeletal system through the prevention of contractions, which can lead to injury. Plyometric exercises can lead to the increase of the functioning of the stretch reflex, and this will lead to a decrease in the activation of the Golgi-tendon mechanism resulting in a more powerful stretch-shortening cycle (Young, 1991).

The stretch or miotic reflex responds to the rate of the muscle stretch and this reflex is of the fastest in the human body, due to the direct connection between the sensory receptors in the muscle and the cells in the spinal cord, responsible for the contraction (Baechle & Earle, 2000). Other reflexes are slower than the stretch reflex because they have to be carried over through different canals (interneuron) to the central nervous system (brain) before the reaction (Chu, 1998).

The importance of the small delays in the stretch reflex is that the muscles contract faster during the stretch-shortening cycle than during any other contraction method (Blazevich, 2003). Any action that has to be thought through before the muscle can be stretched will cause a delay if an athlete wants to jump or throw. Apart from the reaction time, one also has to consider the intensity of the response when determining the relationship between plyometric exercises and sport performance. Although the reaction time of the stretch reflex remains the same after exercise, the power of the response in terms of the muscle contraction changes during exercise (Chu, 1992). The faster a muscle stretches or lengthens, the bigger the concentric power of the stretch. This results in a more powerful movement to overcome the power of the object, if the power is the body weight of the individual, or an external object, for example, in shot put or a blocking bag (Chu, 1998).

According to Jacoby and Gambetta (1989) the base of plyometric exercises can be summarized as follows. A muscle concentric contraction (shortening action) is more powerful if immediately followed by an eccentric contraction (lengthening) of the muscle. Body weight movements that occur at a high speed, like throwing and jumping, is best executed when the movement is started in the opposite direction. When this opposite movement is stopped, a positive acceleration power is created for the opposite movement. An example of that is illustrated in the golf or baseball back swing. This change in movement in the opposite direction activates the stretch or miotic reflex. The muscle then offers resistance against overstretching. The stretch receptors in the muscles create a powerful contraction to prevent over-stretching (Blazevich, 2003).

The power produced during a concentric contraction, after a series of small eccentric movements, is more than twice as much as what is taken up after the execution of a big eccentric movement (1004 Newton versus 421 Newton) (Hennesy, 1990). The bigger the eccentric contraction, the bigger the elastic tension that is lost. Therefore, while executing plyometric exercises, for example, the single leg hop, the subject has to limit the amount of knee flexion.

Many athletes have a lot of power, but cannot apply this power to their jumps or throws. They do not have the ability to convert their power into an explosive reaction. The answer to this is not to increase the muscle or explosive power, but to combine them. Plyometric exercises stress the eccentric aspect of the muscle contraction, to improve the relation between maximal and explosive power. Suppose a rubber ball represents a dead body that is dropped from a certain height. When the ball makes contact with the ground the shape is changed to store energy. As the rubber ball returns to its normal shape the stored energy is released and the rubber ball is sent back to more or less the same height than where it was dropped from (Jacoby & Gambetta., 1989).

Hennessy (1990) supports the research done by Brown *et al*. (1986) on basketball players. He showed that the players that did three sets of ten repetitions of depth jumps (45cm), three times per week for twelve weeks, showed a statistical improvement in the vertical jump with the assistance of their arms, compared to the control group. It appears that this improvement in the vertical jump was caused by a combination of imshowed jumping skills and an increase in power.

According to Voight *et al.* (1995) there is not a lot of research being done on exercises that can improve the speed of the stretch reflex, but it is speculated that the intensity of the next muscle contraction can be imshowed through more efficient strengthening of the motor unit. There is proof in the literature that the faster a muscle is loaded or lengthened eccentrically, the bigger the concentric power being produced (Chu, 1992; Maarten 1990; Voight *et al.*, 1995; Wilt, 1976). Eccentric lengthening also overloads the elastic component of the muscle system and the tension of the resulting reaction spring power. The stretch reflex can increase the tension of the muscle spring by recruiting additional muscle fibres. This is not possible with the concentric contraction (Voight *et al*., 1995). The additional stiffness allows the muscular system to use more of the external tension in the form of elastic reaction (Voight *et al.*, 1995). The question whether one can improve the stretch/ miotic reflex, is still not answered.

Another possible mechanism for an increase in power production with plyometric exercises, is the inhibiting effect of the GTO's on the power production. GTO's have a protective mechanism that limits the amount of power produced in a muscle as well as the stimulation request. Voight *et al*. (1995), Bosco (1985) and Komi (1984) suggested that GTO's could become insensitive due to the stressful explosive exercises. The level of inhibition is increased and a larger power load is allowed in the muskuloskeletal system.

Plyometric exercises could help to improve muscular performance, centred around the neuromuscular coordination. The speed of the strain can be limited through the neuromuscular coordination. This means that the body will only move in the speed range determined by the nervous system, notwithstanding the power of the muscle. Exercise with an explosive pre-stretch, improves neural effectiveness which increases the neuromuscular execution. Plyometric exercises can cause changes in the nervous system that enables the individual to better coordinate the activity of the muscle groups. More power is generated, even in absence of morphological adaptation in the muscle itself. The positive changes in the nervous system that increase the power and strength of the execution is called the neural adaptation. The nervous system can be enlarged to become more automatic (Voight *et al*., 1995).

2.6.1 Application of muscle physiology in plyometric training

In many sport skills eccentric (lengthening) muscle contractions are rapidly followed by concentric (shortening) contractions. Duda (1988) explains the application of knowledge of these concepts in muscle physiology in training with clear examples.

Whenever a long jumper makes contact with the take-off board, contact stresses are absorbed by the slight flexion of the hip, knee, and ankle, followed by a rapid extension of the take-off foot and legs as the jumper leaves the board. In similar fashion, the supporting leg of a basketball player, driving in for the slam-dunk, takes the last step toward the basket carrying the body's full weight on one leg, absorbing all the horizontal inertia of the run-up. This "loads" the leg rapidly by forcing the muscles to stretch, to undergo rapid eccentric contraction. Nerves firing information to the muscle then cause a concentric contraction. It is important to note that the muscle response occurs with no conscious thought on the part of the player, but without this response the player's knee would buckle and he would collapse (Duda, 1988).

Duda (1988) compared these muscle contractions to the functioning of a spring. In basketball, the run-up puts pressure on the take-off leg, equivalent to compressing the coils of the spring. The stored energy is released as the athlete leaves the floor. Kessel (2002) stated that the further and the quicker the "spring can be compressed", the more force potential energy it stores and the greater the power it produces upon uncoiling. Kessel (2002), however, points out that this process places a great deal of stress on both joints and connective tissue, and that plyometric training, therefore, requires the athlete to possess adequate strength to absorb these forces in order to prevent injury.

A voluntary response to muscle stretch would always be meaningless to an athlete during jump, run, or throw movements (Chu, 1998). Apart from the response time, the strength of response should also be considered when determining the relationship between plyometrics and sport performance. Although the stretch reflex response time remains much the same, even after training, training modifies the response strength in muscle contraction terms.

2.6.2 Elastic energy storing

The basic principle of elastic energy storing in muscles is also applicable to the training process. Elastic energy is stored in tendons and muscles, but is independent of the level of muscle activity during the stretch phase. The greater the tension in the stretching muscles, the greater the amount of elastic energy that is stored. The muscle has to avoid the stretch phase to try and save elastic energy to the maximum (Wilson *et al.,* 1996). Research shows that if the speed of the stretch phase increases from slow to relatively high speed, the storage of elastic energy will increase. This occurs when speed increases or stretch power increases the muscle's and tendon's ability to store more energy (Wilson *et al.,* 1996).

2.6.3 Energy repair

The recovery of elastic energy depends to a great extent on the time between the stretch-shortening phase. Research showed that the use of elastic energy decreases, when there is a delay during the stretch-shortening cycle, because elastic energy gets released as heat during the delay. The longer the delay, the greater the loss of elastic energy (Wilson *et al.,* 1996). Therefore, the stretch-shortening cycle of movements has to be executed with minimal delay between the stretch-shortening phase. The recovery of the stored energy seems to occur relatively quickly during the shortening phase.

Adams (1985), Brown *et al*. (1986), Chu (1992) and Gambetta (1993) showed that a highly professional athlete only has a few seconds of ground contact. The athlete knows that energy gets stored during the eccentric phase of muscle contraction, and that this stored energy is partly responsible for the recovery during the concentric contraction. The eccentric concentric contractions follow each other rapidly. Good jumpers have only 0,125 seconds of ground contact.

2.7 PLYOMETRICS AND SPORT PERFORMANCE

A considerable amount of research has been undertaken to show the positive effects of plyometrics on sports performance. Brown *et al.* (1986) examined the effect of plyometric training on the vertical jump capability of male high school basketball players (N=26). These players were randomly assigned to an experimental training group (the plyometric group) and a control group. The experimental training group performed three sets of ten depth jumps, three days per week for twelve weeks, whilst the control group only performed regular basketball training. Results showed that the plyometric group imshowed significantly ($p<0.05$) in the vertical jump with arm assistance compared to the control group. Neither group differed significantly ($p>0.05$) in the vertical jump without arm assistance. In the plyometric group, 57% of the vertical jump gain was due to jumping skill improvement, and 43% was due to strength gain. Plyometric training appeared to enhance arm coordination in addition to leg strength development and could, therefore, be regarded as a suitable in-season training method (Brown *et al.*, 1986).

In a recent South African study by Kemp (1998) three different training programmes, including a gymnasium programme, a plyometric and a combined gymnasium and plyometric programme, was implemented in order to see which of these programmes would have a positive effect on certain elements, relevant to netball players. These elements include speed, agility, suppleness, explosive power and strength. The results of this study showed that the combined programme would have a positive effect on the biomotor abilities of the netball players.

Matavulji *et al.* (2001) looked into the effect of plyometric training on the jumping performance of junior basketball players. Although the plyometric training has showed its efficiency, it remains generally unknown whether a limited amount of plyometric training could improve movements in subjects who already demonstrate a high level of performance. While the control group participated only in regular midseason training activity, the other two groups performed a limited amount of plyometric training, employing drop jumps from the height of either 50 cm, or 100 cm.

The heights of the maximal vertical jump, as well as the maximal voluntary force and the rate of force development of the hip and knee extensors were tested prior to as well as after the training. An increase in the maximal vertical jump, as well as maximal voluntary force of the hip extensors and rate of force development of the knee extensors was observed in both experimental groups, while no significant changes were recorded in the control group. Matavulji *et al*. (2001) concluded that a limited amount of plyometric training could improve jumping performance in elite junior basketball players and that the improvement could be partly related to an increase in the force of the hip extensors and rate of force development of the knee extensors. The results obtained generally support the concept that plyometric training, employing drop jumps, could be a powerful tool to improve jumping performance even in high level athletes (Matavulji *et al*., 2001).

Diallo *et al*. (2001) investigated the effectiveness of plyometric training and maintenance training regarding physical performance of prepubescent soccer players. They maintained that stretch-shortening cycle exercises (plyometric exercises) were often used to improve leg muscle power and vertical jump performance in adults but limited information is available regarding the effect of such exercises on children.

The study group consisted of 20 boys, aged 12-13 years, in the control group and 10 in the experimental group. The experimental group trained three days a week for 10 weeks. They performed various plyometric exercises, including jumping, hurdling and skipping. Their later, reduced training period lasted for eight weeks, during which all the subjects continued to undertake “normal” soccer training. At the end of this period maximal power was calculated, using a force-velocity cycling test. Jumping power was assessed, using the following tests: counter movement jump, squat jump, drop jump, multiple five bounds, then a repeated rebound jump for 15 seconds. Running distances covered 20, 30 and 40m runs. Body fat percentage and lean leg volume were estimated by means of anthropometric tests. All baseline anthropometric characteristics were similar in both groups prior to the commencement of training, except for body fat percentage.

After the training programme, maximal cycling power ($p<0.01$), counter movement jump ($p<0.01$), squat jump ($p<0.01$), multiple five bounds ($p<0.01$), repeated rebound jump ($p<0.01$) and running velocities 20m ($p<0.05$) performances had increased in the experimental group. After the eight weeks of reduced training, with the exception of maximal cycling power ($p<0.05$) for the control group, no changes were observed in either of the two groups. It was thus concluded that short-term plyometric training programmes increase athletic performance in prepubescent boys. Furthermore, it was demonstrated that these improvements were maintained even after a period of reduced training (Diallo *et al*., 2001).

A study by Schultz, Perrin, Gansneder, Granata, Adams and Arnold (2001), determined whether static measures influence muscular response times and activation patterns following lower extremity perturbation in a functional, single leg weight-bearing stance.These findings suggest that limb alignment may influence neuromuscular timing and activation patterns, although this work was done on a limited number of subjects. No attempt to allow for gender balance between the test groups or any influences of other lower extremity malalignments may confound their results obtained.

In a study by Granata *et al*., (2001), active muscle stiffness of both quadriceps and hamstrings were examined in male and female subjects. They found that gender differences exist in active muscle stiffness, as yet, but mechanisms to explain these differences remain unknown. During functional tasks, it was shown that stiffness recruitment strategies may be utilised to influence neuromuscular and biomechanical factors to compensate for reduced effective muscle stiffness (Granata *et al*., 2001).

Lephart, Ferris, Riemann, Myers and Fu (2001) evaluated impact forces, joint kinematics and muscle strength variables in female basketball, soccer, and volleyball players when compared to matched male athletes. Their conclusions were that there was a difference between the two genders pertaining to both biomechanical and neuromuscular variables during landing activities. Male athletes had a greater amount of knee flexion when subjected to impact. The larger flexion displacement served to attenuate impact forces and reduce imposed loads on the knee joint. Absence of this controlled knee flexion in females may relate to weaker quadriceps and hamstrings, leading to stiffening of the knee joint. They also believe that these factors influence anterior cruciate ligament injuries in the female athlete.

According to Heiderscheit, McLean and Davies (1996) numerous studies have been performed to establish the effectiveness of plyometric training for increasing lower extremities power, but that the efficacy of plyometric training for the upper extremity had not been documented. They compared the effects of plyometric and isokinetic concentric/eccentric training on the shoulder internal rotators. In this particular study 78 female subjects were randomly assigned to three groups: control, isokinetic training and plyometric training. Pre-testing and post-testing measurements included concentric/eccentric isokinetic power measurements of the shoulder internal rotators at 60º/second, 180º/second, and 240º/second, kinesthetic measurements of shoulder internal rotation, external rotation <45º and external rotation >45º, and a softball distance test. Both groups trained twice a week for eight weeks.

It was found that isokinetic training of the shoulder internal rotators increased isokinetic power, but plyometric training was not as effective in increasing power output. Neither isokinetic nor plyometric training resulted in a functional improvement with the softball throw. This study demonstrated that the isolated increase of shoulder internal rotation power did not produce an increase in functional throwing performance (Heiderscheit *et al.*, 1996).

Research has also been undertaken to compare different types of training to enhance performance. Wilson *et al.* (1996) conducted a study to gain greater insight into the adaptations invoked by plyometric and weight training. Forty-one (41) previously-trained males were randomly allocated to either a control, plyometric or weight-training group. The experimental groups trained for eight weeks, performing either heavy lifts or dynamic plyometric exercises. Vertical jump, a series of iso-inertial concentric and eccentric tests, push-up tests and maximal bench press and squats lifts were performed prior to and after the completion of the training period. Plyometric training, which included depth jumps, significantly enhanced rapid eccentric force production. The weight training dominantly facilitated concentric muscular function. These specific training adaptations would appear to be a direct result of the nature of stresses imposed during the training, with plyometric training involving the rapid development of eccentric force and weight training being limited by the concentric force potential of the musculature (Wilson *et al*., 1996).

In a rather unique study, McLaughlin (2001) investigated the effects of a plyometric training programme and a traditional weight-training programme on the onset rate of fatigue in the vertical jump in women. It was claimed that fatigue rates had never been isolated for the purpose of study. Twenty-five (25) untrained college women, ranging in the age group from 18 to 35, were randomly divided into three groups: a plyometric group, a traditional weight-training group, and the untrained control group. For the purpose of the study, the traditional weight-training group had to perform three sets of ten repetitions at 70% of the subject's one repetition maximum (1RM). Training took place over a 10-week period for both the plyometric and weight-training groups, after which the plyometric group prolonged their fatigue onset by 3.85 seconds, compared to their pre-test data. The traditional weight-trained group fatigued 0,55 seconds faster after training, compared to their pre-test data. These results showed significant differences between the groups in their fatigue onset rates ($p < 0,05$), producing the conclusion that a plyometric training programme prolongs the fatigue onset rate in vertical jump in women, when compared to the effects of a traditional weight-training approach.

In the research of Hunter and Marshall (2002) different training methods were used to improve jumping techniques. The power training was designed to increase vertical jump height, with maximum height as the only goal. With power training the following changes were found in the drop jump: a decrease in eccentric lower limb stiffness, and an increase in the magnitude of counter movements and ground contact time. Flexibility training appeared to hold no benefits for drop jump height and had no significant effect on drop jump technique. Power training was associated with the following changes in the counter-movement technique: an increase in eccentric lower limb stiffness and the magnitude of counter movement.

Cossor, Blanksby and Elliot (1999) examined the effects of a plyometric training programme on freestyle tumble turns. Thirty-eight (38) age-group swimmers were assigned to a control group, which swam 1,5 hours, three times per week for twenty weeks, or an experimental group, which supplemented 1,25 hours of swimming with 15 minutes of plyometrics for the same time frame. The same coach conducted all swimming and plyometric sessions to ensure uniformity. Swimming performance was assessed from 50m time. Freestyle turning performance was measured by 2,5 m round trip time (RTT), 5 m RTT, wall contact time and selected kinematic and kinetic variables associated with the turn. A plypower system was also used to test jump height and velocity. No significant differences between the groups (pre-, mid- and post-intervention) were found over the period of the study, for any swimming, kinetic or plypower measures. It is concluded that equal benefits were derived from normal practice time in water or land-based plyometric exercises.

Some research is aimed at gender differences in the biomechanics of the human body to explain injuries or to enhance performance in certain plyometric exercises or movements. In a study by Shapiro, Yates, McClay and Ireland (2001) it was found that differences do exist between male and female knee deceleration, although these differences did not appear sufficient to explain the different rate of injury. Using the two-leg landing, females exhibited significantly greater hip flexion while males tended towards greater dorsiflexion and eversion. This suggested that, at landing, the males were executing different strategies for stability on landing. It was suggested that the actions of the two joint muscles, which act on the knee and hip, might have an important impact on what ultimate stresses that occur at the knee (Shapiro *et al.*, 2001).

Byrne and Eston (2002) assessed the effect of exercise-induced muscle damage on the knee extensor muscle strength during isometric, concentric and eccentric actions and vertical jump performance while subjects were doing the squat-jump, counter-movement jump and drop jump. Eight subjects participated in this study; five males and three females. Strength loss of the exercise-induced muscle damage was independent of the muscle action being performed. However, the impairment of muscle function was attenuated when the stretch-shortening cycle was used in the vertical jump performance. The stretch-shortening cycle possibly attenuates the detrimental performance associated with exercise induced muscle damage.

In the research of Hunter and Marshall (2002) different training methods were used to improve jumping techniques. The power training was designed to increase vertical jump height, with maximum height as the only goal. With power training the following changes in drop jump was found: a decrease in eccentric lower limb stiffness, and an increase in the magnitude of counter movement and ground contact time. Flexibility training appeared to offer no benefits to drop jump height and had no significant effect on the drop jump technique. Power training was associated with the following changes in counter-movement jump technique: an increase in eccentric lower limb stiffness and the magnitude of counter movement.

Lloyd (2001) as well as Hewett and Stroupe (1996) are of the opinion that plyometric training may affect knee stabilisation in order to prevent serious knee injuries. The study by Lloyd (2001) is of considerable importance, presenting the rationale for specific training programmes to reduce the incidence of knee injuries in football players. It was revealed that the external knee loading patterns during sidestep cutting, put the anterior cruciate ligament at greatest risk for injury. Lloyd examined the effects of different types of training on the control of joint stability. It is proposed that resistance training may not be appropriate because it enhances muscle stretch reflexes, which may reduce co-contraction, and produce no reductions in voluntary activation times and times to peak torque. Stability and balance training as well as plyometric training produce reductions in voluntary activation times and times to peak torque, which may decrease muscle response times for players to perform rapid and unexpected sports manoeuvres.

Hewett and Stroupe (1996) tested the effect of a plyometric training programme on landing mechanics and lower extremity strength in female athletes involved in jumping sports. The parameters were also compared with those of male athletes before and after training. The programme was designed to decrease landing forces by teaching neuromuscular control of lower limb during landing and to increase vertical jump height. After training, peak landing forces from a volleyball block jump decreased by 22% and knee adduction and abduction movements (medially and laterally directed torques) decreased by approximately 50%. Female athletes demonstrated lower landing forces than male athletes and lower adduction and abduction movements after training. External knee extension movements (hamstring muscle dominant) of male athletes were three times higher than those of female athletes. Hamstring-to-quadriceps muscle peak torque ratios increased by 26% on the non-dominant side and by 13% on the dominant side, correcting side-to-side imbalances. Hamstring muscle power increased by 44% on the dominant side and by 21% on the non-dominant side with training. Peak torque ratios of male athletes were significantly greater than those of untrained female athletes, but similar to those of trained females. Mean vertical jump height increased by approximately 10%. Hewett and Stroupe (1996) conclude that plyometric training may have a significant effect on knee stabilisation and prevention of serious knee injury among female athletes.

Other research focused on methods of analysing techniques to measure performance in popular plyometric training exercises or to improve the types of plyometric exercises in order to make them safer. Baca (1999) looked into the different techniques applied to determine parameter values quantifying drop jumps, such as jump height or the duration phase of downward and upward movements of the centre of mass during foot contact after dropping. Baca's study was focussed on determining which technique yielded the lowest errors compared to the results obtained by the reference method, double force plate technique. In the investigation, two force plates were employed with one located under the drop platform. Flight-time methods were used to calculate the jump height, this being the time between leaving the ground to landing. In video-based methods, markers were placed on the subjects' skin to define the positions of individual body segments. Twenty-five (25) drop jumps were analysed, by means of eight different methods. Large differences between the reference method and other methods were found. Using the height of the drop platform (0,39 m) to calculate the terminal velocity of the free fall, plus data from one force plate, resulted in a mean difference of 4,2% (SD: 9,6%) in calculated jump heights. Using video information to measure the time taken for the mass-centre velocity to reach zero after the drop phase, when combined with data from one force plate, resulted in calculated differences in the jump height from as high as 17%. Differences between the reference method and video-based methods were comparatively small, although not negligible. It was concluded that video-based methods were the most promising alternative for the reference method to determine accurate variables in the drop jump performance.

Fowler and Lees (1990) conducted a study to compare the kinematic characteristics of drop jump and pendulum exercises. One of the most commonly used methods of plyometric training is the drop jump, in which a subject drops from a raised platform and immediately upon landing, initiates a rebounded vertical jump. Plyometric exercises are effective for improving strength and vertical jump performance. However, drop jumps also carry a high risk of injury due to the large ground reaction force. One training device that has been widely used in Eastern Europe as an alternative to the drop jump is the pendulum swing.

It was found that pendulum exercises involved a greater range of motion at the ankle and knee, but less motion at the hip joint than drop jumps. Although different in absolute terms, pendulum exercises used a stimulus similar to that of drop jumps. The similarity between the movement patterns for the two modes of exercise led to the conclusion that the pendulum exercises offer a training stimulus similar to that of drop jumps.

The development of effective methods to develop explosive strength and reactive ability logically begins with an analysis of the speed-strength methods traditionally used for this purpose. Athletes used to do heavy barbell squats to develop explosive strength in the legs, and found that they only place a large and generally unnecessary load on the spine with the heavy weights. Athletes started training with lighter weights to improve their speed-strength. They found that fast exercises with light weights improved speed. The most common exercise used to improve speed-strength, was squat thrusts. Explosive strength is a motor quality requiring specific movements and training means. It has been found that barbell squats, as a strength-training exercise, did not adequately enhance specific components of explosive movements such as the rapid excitation of the muscles and the rapid changing from eccentric to concentric work (Siff & Verkhoshansky, 1993).

In a study by Humphries, Newton and Wilson (1995) 20 subjects performed a series of loaded jumps for maximal height, with and without a breaking mechanism designed to reduce impact force during landing, called the Plyometric Power System (PPS). Plyometric training involves the union between strength and speed, using muscular contractions that are characterized by explosive stretch-shortening cycle (SSC) movements. This type of training, involving dynamic SSC movements, has become a popular training modality for many athletes, as it enables the development of high force production over a short period of time. This is achieved by utilising exercises such as depth jumps, exaggerated hops, bounds and box drills. This training regime offers several advantages over the more traditional forms of resistance training such as weightlifting. Plyometric movements are more explosively performed, enabling the athlete to rapidly develop force and mimic the actual athletic performance by means of dynamic SSC movements. Despite the advantages of plyometric training, over other recognised training modalities, a problem did arise regarding repetitive impact loading or excessively high eccentric impact forces. As a consequence of performing plyometric exercises, such as depth jumps, impact forces placed on the musculoskeletal system during landings can lead to potential injury.

Humphries *et al.*, (1995) found that the PPS significantly reduced ground impact forces without impeding concentric force production. The reduction of eccentric loading, using the breaking mechanism, may reduce the incidence of injury associated with landings from high intensity plyometric exercises.

With regards to the research described above, it is clear that plyometric training, when combined with other methods of training, mostly enhances performance, especially in sports types where strength in the lower extremities play an important role. Many sports types, such as basketball, netball and soccer seem to have benefited from this research. It is, however, important to note that no research pertaining to the effect of plyometrics on rugby performance could be found, though it seems such an obvious sport to benefit from plyometric exercises.

2.8 THE BASICS OF PLYOMETRIC TRAINING

According to Heiderscheit *et al.* (1996), plyometrics have become a popular training method. It is extremely important to distinguish clearly between plyometric actions, occurring as part of many elements in sport and plyometric training, which applies plyometric actions as a distinct goal-directed training modality according to a definite methodology. There is an argument as to whether plyometric training is a specific training system in its own right (Siff & Verkhoshansky, 1993). It is argued that resistance to movement is encountered in all sports, which also questions resistance training as a specific training entity. The critics of plyometrics as a definite training method should agree that it could therefore be logical to conclude that resistance training should not be regarded as a distinct training system. Basic biomechanical analysis of the forces and tensions involved, clearly show that high levels of resistance and muscle tension are involved in many sports (such as gymnastics, swimming, rowing, and wrestling). Running or cycling over distances are examples of resistance training methods, as the athlete overcomes resistance and produces high levels of muscular tension in both sports. It is therefore easy to justify objections regarding resistance training as a separate training method. In a similar manner, specific training for stretch-shortening actions – the development of a shortened amortisation phase - which results in shortened response time, coupled with powerful movement, is a very specific training system in its own right. Siff and Verkhoshansky (1993) clearly and comprehensively explained the plyometric method of training. It is stated that prolonged research in the direction of special strength training led to the development of the so-called 'shock' (plyometric) method of developing explosive strength and reactive ability.

The plyometric training method stimulates the muscles by means of a sudden stretch preceding any voluntary effort (Blazevich, 2003). Kinetic energy, and not heavy weights, accumulated by means of the body, or a load falling from a certain height, should be employed. Depth jumps and medicine ball rebounding are two of the exercise regimens commonly used in plyometrics. Plyometrics or the shock method requires the use of mechanical shock to stimulate the muscles to produce the highest possible tension. This training method is characterized by minimal duration impulsive action between the end of the eccentric (breaking) phase and initiation of the concentric (acceleration) phase. It relies on the production of a very brief explosive-isometric and eccentric-isometric phase preceding the release of the elastic energy stored in the tendons and other muscle components of the series of the eccentric (deceleration) phase. With a prolonged transition phase, also called "coupling phase", of more than 0,15 second, the action may be considered to constitute ordinary jumping and not plyometric training. This may be visualized as if the surface, being touched by the hands or feet during the plyometric contract phase, is red hot, so that prolonged contact would be dangerous (Siff & Verkhoshansky, 1993). They further stated that it was important to note that true plyometric training usually involves ballistic rather than concentric processes. Their contention was that the activity was not purely plyometric if the athlete relies on feedback processes to control the isometric and concentric actions, instead of on feed forward programmes established before any movement begins.

A key factor in plyometric training is the development of explosive strength and reactive ability in the athlete. Explosive movements are required in many sports and are typically performed at high speeds against resistance (Robberds, 2002). The flexibility, strength and aerobic training of the athlete, are also important considerations in plyometric training. The development of explosive strength and reactive ability will be discussed later, with brief reference to flexibility, strength and aerobic training. Thereafter submaximal plyometric drills and specific movements and means that could be identified and organised into a discreet training programme for reactive ability development and explosive strength as well as important training considerations will be discussed.

2.8.1 The development of explosive strength and reactive ability

Siff and Verkhoshansky (1993) stressed the fact that for an athlete to successfully develop a high level of explosive strength - a motor quality - certain specific movements and means need to be identified in and organised into a discreet training programme. They explained that effective methods for the development of explosive strength and reactive ability logically begin with an analysis of traditional speed-strength methods. As an example, athletes frequently attempt to develop explosive leg strength by using heavy barbell squats and dumbbell step-ups, but the muscles work very slowly (quasi-isometrically) with a relative constant load of tension being produced. Even though this causes the leg muscles primarily to develop isometric strength, it does not mean that speed strength, or explosive strength cannot be developed in this way. Fast and dynamic contractions are required (Bosco, 1985). The weight should not be increased, as is often done to improve strength fitness, because this places large, unnecessary loads on the spine. It has been demonstrated that exercises with heavy weights, for example, squat thrusts carrying a 60 kg barbell on the athlete’s shoulders, tend to increase the muscle’s strength potential combined with a large dynamic maximum force, whilst fast exercises with light weights improve speed.

Siff & Verkhoshansky (1993) contended that the force-mentioned strength training means do not suitably enhance specific components of explosive movements, such as the rapid excitation of muscles and thus the rapid changing from eccentric to concentric work. These and related skills require that a more specific training regime be implemented which is impossible to imitate using only one resistance exercise. Stimulation of muscular activity slows resistance movements, and lifting a barbell in preparation for squatting or jumping with it, removes the possibility of controlling the mechanisms which are crucial to the rapid switching of muscles to the active state (Dick, 2002). At the same time, a decrease in the resistance diminishes the dynamic effort required and creates a vicious cycle from which there is no apparent escape.

2.8.2 Plyometric training and flexibility

Maarten (1990) held the view that anyone undertaking a plyometric-training programme should be reasonably flexible. Static stretching, which increases flexibility, uses passive techniques to change the structures of ligaments, tendons, and muscles. The muscle is put into a stretched position and held for 6 to 15 seconds (sometimes longer) and then repeated three times. Ballistic stretching involves elongating a muscle to its normal length, bouncing gently against the end of the range of muscle length (six to 12 times) then repeating this action three times. Research has shown static stretching techniques to be as effective as, and possibly safer than, ballistic stretching. Ballistic stretching is, however, still a valuable means of increasing the range of motion (Chu, 1998). Both methods of stretching are beneficial, but in view of the principles of eliciting the stretch reflex and the serial elastic components of muscles to perform jumping activities, it might behoove the athlete to “prime” the mechanism by undertaking controlled ballistic stretching (Chu, 1998).

2.8.3 Plyometric training and strength

Eccentric strength, or the ability of a muscle to lengthen while under tension, is a precursor to success in plyometrics. Plyometric training requires the athlete to possess an adequate strength base to absorb the forces which the explosive movements place upon joints and connective tissues (Kessel, 2002). These contractions are often full-force muscular efforts, therefore Kessel urged the necessity of regular strength training to be incorporated into the athlete's training programme. Being an important consideration for all athletes, it is crucial to rehabilitate the injured athletes (Hewett; Lindenfeld, Riccobene, & Noyes, 1999). Given that healthy limbs often have difficulty sustaining the impact placed on the body during practice and competition, it is essential that injured athletes, returning to activity, have some means of ensuring a safe return and complete recovery. According to Chu (1998), research have showed eccentric strength to be crucial to the return of injured athletes to their sports. Before an injured athlete can return to plyometric training, there has to be an interval of training that focuses on the development of stability and eccentric strength in the lower extremities. Plyometric drills and skill activities can serve as functional tests to determine whether an injured athlete is ready to return to play (Lloyd, 2001). The environment of the competition places severe mental and physical stress on participants. Being unsure of the athlete's physical ability, is to risk a disastrous performance and, worse, re-injury (Chu, 1998).

2.8.4 Plyometric training and aerobic training

Aerobic capacity is a valuable component of most fitness programmes. However, plyometric training, by the nature of the energy systems being utilized, is not intended to develop aerobic capacity. Plyometric training is strictly anaerobic in nature and utilises the creatine phosphate energy system, allowing maximum energy to be stored in the muscle before a single explosive act, that requires maximum power, is performed (Blazevich, 2003). It is a programme that exploits quality of movement. A single repetition requires maximal effort. Recovery should be complete between each repetition of the exercise and between each set of repetitions. When sufficient recovery is not allowed, the activity moves toward being aerobic, but quality of movement and explosiveness is sure to suffer (Chu, 1998).

2.8.5 Warm-up: Submaximal plyometric drills

An important basic tenet of all exercise programmes is that major efforts of training should be preceded by lower-level activities. These “warm-up” activities can take on different forms and could be general or specific in nature. The choice of exercises when using plyometrics should be specific and related to the larger efforts. These exercises are not classified as true plyometrics as they require less effort, focus and concentration to complete. They are, however, used to develop fundamental movement skills and are therefore helpful in establishing motor patterns that directly carry over to speed development and jumping ability (Chu, 1998). Gambetta (1993) stated that activities fitting into the warm-up (or submaximal plyometrics category), should be performed as skill enhancement drills aimed at teaching or rehearsing certain motor patterns and not as conditioning drills. Therefore, they are performed over distances of 10 to 20 meters, with a relatively long recovery period between exercises.

Chu (1998) recommended several (eight to 12) of the following exercises, which could be grouped into “sets” of three repetitions each, to truly become warm-up activities that will both raise the athlete’s core temperature and aid in motor development.

Marching drills are intended to mimic running movements. They deliberately break down the act of running into its components. This allows the coach to stress components such as posture, joint angles, range of motion, foot placement and other biomechanical features, often overlooked when the whole activity is simply asked to be performed (Chu, 1998).

Jogging drills comprise many variations that can be modified into being plyometric in nature and used to emphasise speed development, for example, jogging on the toes with special emphasis on quick ground reaction by not allowing the heel to touch the ground, is a mini-plyometric activity. Similarly, jogging with straight legs and limiting knee flexion prepares the athlete to expect the sharp impact of performing a maximal-effort plyometric drill (Chu, 1998).

Skipping drills can be used to warm up the athlete and prepare him or her for more complex plyometric skills. The synchronisation of limb movements is basic to normal motor development. So-called reciprocal movements occur between the legs and arms during running. Generally, efficient running requires a runner to move his left arm and right leg backward as the left leg comes forward, the limb movements then switch to the opposite side of the body as the runner moves forward. Skipping is an ideal submaximal plyometric activity because of the requirement to perform reciprocal limb movements with the emphasis on quick take-off and landing (Chu, 1998).

Footwork drills such as the shuttle drills, multidirectional side shuffle drills, and “drop” step drills are all considered excellent submaximal plyometric drills (Chu, 1998).

Lunging drills are exercises taken from the basic exercise movement known as the “lunge”. When used as submaximal drills, lunging drills can take on many forms, known as forward, sideward, crossover, multidirectional, reverse, and walking lunges. They can, and should always, be used as preparation before doing long amplitude jumps (Chu, 1998).

Alternative movement drills include those movements not previously classified, for example, backward running and Carioca. The carioca is a very familiar movement to football coaches. This exercise is used to improve hip rotation and foot placement. The upper body is held relatively stationary as the player travel down a line sideways, then the feet are switched from a crossover position to a reversed position in a rapid fasion. Each activity is aimed at a specific area of the body with a special effect in mind when doing the drill (Chu, 1998).

2.8.6 Plyometric exercises

Plyometric exercises are focused on the development of a shorter amortisation phase (Siff & Verkhoshansky, 1993). Chu (1998) reasoned that plyometric training was very specific in nature but very broad in application. For the lower extremities, the athlete develops either vertical or horizontal acceleration, all movements in running and jumping being simply the exertion of some vertical or horizontal force against the ground. Even changing direction falls into this category. Medicine ball exercises train the upper extremities and can also be used in combination with lower extremity training (Reilly, 1997).

Specificity is the key concept to keep in mind when planning a plyometric training programme (Blazevich, 2003). The sport and the skill to be developed must be analysed carefully to select suitable exercises. For instance, to develop starting speed from a crouched position, for example, an offensive line-man in American football, it does not make sense to spend too much time on depth-jumping skills, which develop vertical power. A more worthwhile exercise would be the standing long jump or double leg hops, which develops horizontal force (Chu, 1998).

Early jump-training exercises were classified according to the relative demands they placed on the athlete. All jump-training exercises can, however, be progressive in nature, with a range of low to high intensity in each type of exercise (Young, 1991). Kessel (2002) pointed out that high-intensity plyometric drills include repetitive hops or jumps using only one leg or both legs with additional external resistance provided by a medicine ball or barbell. The variety of running and jumping, as well as medicine ball exercises that is part of plyometric training will be discussed briefly below.

Jumps-in-place: Young (1991) stated that a jump-in-place is a jump completed by landing in the same spot where it started. These exercises are relatively low in intensity, yet they provide the stimulus for developing a shorter amortisation phase by requiring the athlete to rebound quickly from each jump.

Standing jumps stress single maximal effort, either horizontally or vertically (Young, 1991).

Multiple hops and jumps combine the skills developed by jumps-in-place and standing jumps (Young, 1991).

Bounding: Bounding exercises exaggerate the normal running stride to stress a specific aspect of the stride cycle. They are used to improve stride length and frequency and are typically performed for distances greater than 30m (Young, 1991).

Box drills combine multiple hops and jumps with depth jumps. They can be low in intensity or extremely stressful, depending on the height of the boxes used (Young, 1991).

Depth jumps use the athlete's body weight to exert force against the ground. Depth jumps are performed by stepping out from a box and dropping to the ground, then attempting to jump back up to the height of the box. The key to performing this exercise and decreasing the amortisation phase, is to stress the "touch and go" action off the ground (Young, 1991).

Drop jumps: Athletes perform drop jumps by jumping from a raised platform and, upon touching the floor, executing a maximal vertical jump (Baca, 1999). Drop jumps are exercises in which the athlete, by forced eccentric contraction, attempts to enhance subsequent exercise performance (Baca, 1999). Matavulji *et al.* (2001) maintained that drop jumps could prove to be a powerful tool for improving jumping performance in high-level athletes. A study by Walshe and Wilson (1997) found numerous mechanisms that influenced drop jump achievement. These findings offer important additional insight into the limitations of the dynamic stretch-shortening cycle performance. They stated that muscle-tendon complex stiffness may well be an important link to performance inhibition at high eccentric loads. This in turn may have implications on the development of flexibility training programmes for activities incorporating these contractions. Stiffer performances recorded significantly poorer drop jump achievement under high stretch-shortening-cycle load conditions when compared to more compliant subjects. This finding could possibly be ascribed to greater Golgi-tendon inhibition, or a less functional response to the effects of elastic recoil on contractile mechanics, consequently retarding the stretch-shortening cycle ability (Walshe & Wilson, 1997). Furthermore, Baca (1999) found that video-based methods seem to be a promising means to analyse drop jumps.

Squat jumps: Driss, Vandewalle, Quièrvre, Miller and Monod (2001) compared the effects of external loading, on power output in a squat jump, on a force platform in athletes specialising in strength and power events and in sedentary individuals. These results indicated that the effect of external loading on power output in a squat vertical jump depends on physical activity. During squat jumps, mean and peak power decreased with increasing load in sedentary individuals. The magnitude of this decrease was similar to that previously reported for the same loads during vertical jump with counter-movement in sedentary individuals. In contrast, mean power was significantly higher with a 5 kg load in power-trained athletes. Peak power did not vary significantly in the three load conditions (0,5 and 10 kg) in power-trained athletes. These results suggest that peak power is independent of load, provided that peak velocity is higher than the optimal velocity for power output. The velocity of the centre of mass at the peak power was significantly lower in the sedentary individuals than in the strength and power athletes. It is presumed that peak power on a force platform underestimates maximal power in sedentary individuals (Driss *et al.*, 2001).

In a study by Humphries *et al.* (1995) it was found that the use of an electronic braking device on the plyometric power system was effective in reducing vertical ground impact force (155%) and the passive impact impulse at landings (200%). These results indicate that by successfully reducing these impact parameters, the likelihood of sustaining an injury from excessive impact forces could be decreased. It was furthermore found that the braking mechanism did not interfere with the dynamic concentric nature of the jumping action. The use of the braking device, therefore, not only has the potential to reduce injury, it can also be used in dynamic closed kinetic chain movements, such as squat jumps, which could then be performed without large impact forces (Humphries *et al.*, 1995).

2.8.7 Training considerations

Programmes must be prudently planned and administered. Plyometric training is a relatively high-stress method that needs to be progressively incorporated into the athlete's programme (Kessel, 2002). One of the major tasks is to conduct a needs analysis, taking into account the athlete's sport and specific movements to participate effectively. The results of the study by Brown *et al.* (1986) emphasise the importance of sports specificity, especially for in-season training. Other issues to consider are the athlete's age, experience and athletic maturity. The actual combination of drills and volume of repetitions will depend on the athlete's level of conditioning and the specific types of power the athlete wants to work on (Kessel, 2002). The best coaches are not always successful, but they do make training an enjoyable, organised, and progressive activity that ultimately takes the athlete to higher performance levels (Chu, 1998).

According to Chu (1998) the myth that females must train differently than males still exists in some circles. It was stated that there is no reason why female athletes cannot perform plyometrics with the same degree of skill, proficiency, and intensity as males. The controlling factor of having a strength base is applicable to both sexes. Any athlete who chooses to ignore complementary strength training is headed for difficult times and possibly injuries (Chu, 1998).

Age: Children will always run and jump while playing. As adults we tend to take this element of play – also known as fun – out of training programmes by rigidly applying specific regimens (Blazevich, 2003; Chu, 1998).

Young athletes: Elementary school children can successfully perform plyometric training as long as the coach does not call it plyometrics. Young athletes can benefit more from direct training as they approach pubescence (Blazevich, 2003).

Pubescent athletes: Plyometrics for this group should always start off as gross motor activities with low intensity. They should be introduced into warm-ups and then added to sport-specific drills (Blazevich, 2003).

Adult athletes: As athletes approach the stage of individualization, they can begin to look at developing off-season and pre-season training programmes as preparation for performance (Blazevich, 2003; Chu, 1998).

According to Siff & Verkhoshansky, (1993) coaches can add a new dimension to an athlete's programme with an effective and efficient training method. Eccentric training might be one way to respond to an athlete's training schedule. Research suggests that this way of training might be the most efficient form of exercise, yielding greater overall strength gains, with less effort, than other methods. Finding ways to integrate eccentric training into sessions may help athletes to perform more work while exerting less effort, accomplish more in each workout by reducing the time spent on an exercise and reduce overall strength training time, allowing more time for flexibility and cardiovascular training in same workout period.

- Isokinetic power of the shoulder internal rotators increased isokinetic power, but neither isokinetic nor plyometric training resulted in a functional improvement of the softball throw (Heiderscheit *et al.*, 1996).

- Differences exist between male and female knee deceleration, although they are not sufficient to explain the rate of injury. In the two-leg landing females exhibited significantly greater hip flexion while males tended towards greater dorsiflexion and eversion. This may suggest that at landing the males were executing different strategies for stability on landing. In the study it was suggested that the action of the two joint muscles that act on the knee and hip might have an important impact on what ultimately occurs at the knee (Shapiro *et al.*, 2001).

- Research suggests that limb alignment may influence neuromuscular timing and activation patterns (Shultz *et al.*, 2001). This study was, however, done on a limited number of subjects, with no attempt to control for gender balance between groups or the influence of other lower extremity malalignments that may confound the results obtained (Shultz *et al.*, 2001).

- Gender differences exist in active muscle stiffness. There is, however, no theory to explain these differences (Granata *et al.*, 2001).

- Stiffness recruitment strategies may be utilised during functional tasks to influence neuromuscular and biomechanical factors to compensate for reduced effective muscle stiffness (Granata *et al.*, 2001).

- There is a difference between the two genders pertaining to both biomechanical and neuromuscular variables during landing activities (Lephart *et al.*, 2001).

- Male athletes have a greater amount of knee flexion when subsequent to impact. The larger flexion displacement serves to attenuate impact forces, reducing loads imposed on the knee joint. The absence of controlled knee flexion in females may be related to the weaker quadriceps and hamstring group, which leads to stiffening of the knee joint and the promotion of anterior cruciate ligament (ACL) injuries in the female athlete (Lephart *et al.*, 2001).

2.8.8 Precautions of plyometrics

- Plyometric training is not without any risks of injury. When performed properly it can be a safe and effective workout. A number of precautions is, however, very important before one explores this type of training :
  - A good level of conditioning before beginning plyometric exercises is essential. Endurance conditioning is an absolute must, since fatigue during plyometric training can lead to an injury. Strength conditioning (through weight training) is

important since it may help to reduce injuries to the muscles, tendons and ligaments.

- Overtraining should be avoided. Plyometric work should be performed for quality, not quantity. The correct execution of plyometric exercises is really important and not the amount or distance that you do. It is quite a common phenomenon for humans to compete, compare and to try to improve themselves the whole time. Therefore, it is important to focus on the execution of the exercises rather than the quantity.
- Adequate rest is very important. Allow one to three minutes rest between sets, at least 48 hours between workouts.
- Progression should be planned to ensure improvement over a period of time and to prevent injuries and overtraining. Start with simple exercises and slowly progress to more advanced exercises. For example, the participant should start with two-legged hops before progressing to one-legged hops.
- A resilient surface is important for plyometric training. Plyometric training should be done on grass or a firm mat.
- Proper clothing should be worn during plyometric training. Proper athletic shoes should be worn to prevent impact injuries. Normal T-shirts and sport shorts are adequate for plyometric training (Phillips, 1990).

2.8.9 Programme development

Voight *et al.* (1995) refer to researchers that subdivided an athlete's training session in a preparation period, competition period and the first and second carrying-over period. To prevent injury plyometric training sessions have to be well planned and incorporated into an athlete's training schedule. Long-term goals are very important to prevent over training whilst still developing maximum power. The goals are influenced by factors like adaptation of periodisation, an increased training load and the adaptation of the programme setting.

Plyometric exercises can be defined as the quick eccentric loading (taxing) of the muscle skeletal complex (Mackenzie, 2002). Plyometric exercises have to condition the neuromuscular skeletal system to be able to handle the increasing power load. Over-exertion of the stretch reflex improves the ability of the nervous system to respond maximally through lengthening of the muscles. In that way the ability of the muscles to shorten concentrically with maximal power is imshowed. Since plyometric training leads to the adaptation of the neuromuscular skeletal system, the exercises have to be developed in a sport-specific manner (Voight *et al.*, 1995). This will prepare the body to handle the expected tension. It is very important that the athlete had followed a power training programme, before a plyometric training programme is be incorporated (Santos, 1987).

According to Yessis (1991), coaches have to keep the following factors in mind before including plyometric exercises into a programme with power and other types of exercises:

- The athlete will always start the session with speed, agility and technique work.
- Power training needs to be done second followed by exercises that improves endurance.
- If plyometric training is planned for a specific day, it has to be done before power exercises. It is very important not to do plyometric exercises and technique work afterwards. Plyometric exercises can be done in the same session as power exercises, if the amount is minimal, and if it is used as a final warm-up before power exercises.

According to Hilyer and Hunter (1989), one should do basic plyometric training in the pre-season, intense plyometric training in the pre-competition phase and maintenance of average plyometric training during the competition phase. No plyometric training is recommended in the post-competition phase and minimal plyometric training is recommended during the off-season. To prevent the risk of potential injuries, an athlete has to undergo some testing. Medical history, structural evaluation and functional testing is of great importance (Chu, 1992; Mackenzie, 2002).

2.8.10 Development of power programmes

Power training has to be seen as an essential part of good performance, but it is important to know that power training is only one of the ingredients that can lead to success. Power training plays an essential role in the general training programme of successful sports people. According to Yessis (1991) it is not advisable to do plyometric- and power training during the pre-competition period. These two training systems can be included into the training programme in the preparation phase that follows the base training phase. Research has showed that sports people need to complete a base-training phase where they prepare or strengthen the muscles and joints to be able to do plyomertric training and thereby intensify their power training. The development of power is based on the principle of overload. This researcher did not include power training, to be able to determine the effectiveness of the six-week intervention programme.

2.9 PROGRESSION

Well-defined progression will help to prevent the risk of injury when doing plyometric exercises. It is very important to ensure that the athlete knows step-by-step how to execute the specific exercise. The key to success is quality and not quantity. In the beginning double foot jumps are better than single foot jumps. You can include advanced levels in every step for the athlete to execute the exercise according to his specific training level. As the athlete's training level improves, the movement levels will progress. Right through the different training phases emphasis should be put on coordination, fluent movement patterns and correct execution (Gambetta, 1993).

During the phase of the experiment design, Chu's warning about variability, produced by small group size and other side factors was fully accounted for. To overcome these potential problems two groups, comprising equally trained athletes were selected. At the beginning of the investigation, both groups were equally fit, experienced, skillful and both continued to undertake similar rugby training. One group (the control group) did only their usual rugby training; the other group (experimental group) undertook additional plyometric training. By this route, it was expected that the true developments, due to plyometrics, could be unimpeded by extraneous factors.

2.10 RUGBY

2.10.1 A general summary of Rugby

Rugby is a team game immediately identified because it uses an oval-shaped ball. Rugby Union has teams 15 strong (+ 6 reserves), whilst Rugby League is played with teams of 13 players. Historically, both forms of rugby teams have been divided into "forwards" usually eight players and "backs" the remainder (or "charger" and "runners" as defined at the founding of the game). Modern rugby is blurring these historic divisions between team members (Biscombe *et al*., 1998: 1-8)

In rugby today, forwards must be able to run and sidestep on demand. Similarly "backs" are becoming more ferocious and harder tacklers. Players have to fight harder than ever for ball possession. This "total commitment rugby", of the modern professional game, both initiated the " blurring" of the traditional game and simultaneously defined the need for multi-capable players. Modern players are no longer uniquely defined by their body size or according to their positions, but by the total package of skills and abilities. Plyometrics offer the most certain route to add speed and agility to big men and similarly enable smaller, lighter players to tackle as hard as forwards traditionally could (Biscombe, *et al*., 1998: 1-8).

Rugby Union is moving towards becoming a "12 months per year" sport, away from its historic winter-time role. This movement requires much longer and more continuous levels of hard physical contact; thus the role of injury prevention is becoming more important. Plyometric training has a substantial role to play in the prevention of injury; thus the employment of plyometric training becomes more important.

2.10.2 The game of Rugby

> "Nothing is more electrifying than a rugby player changing direction with precise, controlled side-steps, hitting an opponent with balanced force and then twisting out of a defensive tackle to explode through a gap in the defensive line and set up, or score a try. The six foot five inch second row jumps and is then assisted into the air at a line out. The player returns to the ground, turns, runs a support loop, side-step to avoid bodies lying on the ground, receives a pass, gives a pass and supports the play by using great agility to step over his team-mate to pick up the ball that has been placed on the ground.
>
> A good rugby game includes speed, power, acceleration, agility, contact and lightening quick responses, all of which make it one of the most exiting and intensive games on earth. These acts of speed, agility and quickness determine success and failure. These physical capacities are deemed to be crucial aspects of the modern game of rugby.
>
> Speed: A crucial part of any player's game is the ability to cover the ground efficiently and economically over the first few meters, and then open the stride length and increase stride frequency when working over 40-50 meters. The best sprinters spend very little time in contact with the ground, and what contact they do make is extremely efficient and powerful. Focusing on the mechanics of running helps control this power sparingly" (Pearson, 2001: vii-x).

2.10.3 The game of Rugby and its requirements

To train for rugby the player needs to understand the principles of fitness training and the specific demands of the game. A rugby game lasts 80 minutes. On average a player will cover 6-11 kilometers during a high-level game, whilst approximately 80% of the distance is covered at around 70-80% of maximum speed with the remaining 20% split between full speed and substantially less than full speed. The length of the time spent working before the next stoppage in play varies between five – 30 seconds for the majority of the game. Coupled with these aerobic and anaerobic demands are strength demands that occur at the tackle, in the loose, the line-outs and scrums. Players must be fit and durable enough to deal with these demands in order to play well. In a typical game the ball is in play for about 30 minutes, with an average of less than 40 seconds recovery time between activities. An average game consists of 15–20 scrums and 20-30 line-outs, each of 15-20 seconds. Forwards spend 50% of their activity in scrums and line-outs and 50% on support. Forwards cover six to nine kilometers during the game and backs cover six to eight kilometers in a game, 30% sprinting (Mason, 2003).

Modern rugby is one of the most demanding sports in terms of the physical fitness level needed to play at the highest levels. The game requires high levels of speed, agility, strength, power and endurance. This combination of requirements is rare in the sporting arena, and offers a considerable challenge to those who wish to play the game to the best of their ability (Pearson, 2001).

According to Anon (2003) fitness is very important in rugby as the best technical scrummager will not be effective if he is not able to perform after the first few minutes due to fatigue. Similarly a scrum-half who cannot be at every breakdown to begin the next phase of play after every ruck or mall, will never reach the top. If he is not powerful enough to exploit the space around the base of the scrum, his game will lack dimension. Above-mentioned are two examples highlighting some of the positional demands of the players. However, every player (regardless of their position) needs to be able to work at continuous high intensities for 80 minutes with small breaks.

The days are over when forwards tackled and backs had to run; every player needs to be powerful in the tackle, be agile enough to avoid contact where necessary, and explosive enough to break through the defense line.

2.10.4 The role of plyometrics in the development of certain selected physical capacities

The quotation by Pearson (2001) reflects some of the physical capacities that the player of the modern game of rugby needs to excel in the game. According to Bloomfield *et al.* (1994) various sports have different demands and only tests that are highly specific to the sport should be used. Sport scientist use selective physiological tests for different types of sports or events. It is stated that the following capacities are normally profiled in the sport: height, body mass (weight), somatotype, body composition, proportionality, strength, explosive power, speed of movement, flexibility, posture, balance and agility. These capacities are also applicable to rugby. Many of these measured capacities are greatly enhanced by plyometric training.

2.11 SUMMARY

The literature reviewed shows that plyometric training has a valuable contribution to make to sport, especially sports that includes powerful and explosive reactions.

Due to the fact that rugby requires explosive power, speed and agility, the necessity of testing the effect of a plyometric-training programme on selected physical capacities of rugby players is highlighted.

CHAPTER THREE

METHODS AND PROCEDURES

3.1 INTRODUCTION

This chapter covers the methodological framework used in this study. The objective of the study was to look into the effects of a plyometric training programme on specific physical capacities, considered to be beneficial to rugby players. These skills include explosive power, agility and speed, which are to be measured by means of the following biomotor skills tests:

- Agility test (T-drill)
- Ten-meter speed test
- Sargent vertical jump test
- Depth jump test
- Standing triple jump
- Rugby agility run
- Medicine ball chest pass

In addition to the above-mentioned biomotor abilities, a plyometric training programme is expected to produce beneficial physiological changes and an improvement in the physical fitness of the study group. Therefore, the hypothesis is that the six-week plyometric training programme would influence the explosive power, agility and speed skills as well as the physical fitness and the following physiological aspects of the experimental group positively:

- Body fat percentage
- Girth measurements

Aspects pertaining to physical fitness include cardiovascular fitness and muscle endurance and which, for the purpose of this study, was measured by means of the following:

- Three-minute step test
- Push-up test
- Sit-up test

Questionnaires were used to gather biographical information, in order to describe the sample and to ascertain whether the subjects meet the criteria for participation in the study. For this, their health status was determined by means of an evaluation consisting of a background check of their medical history and a physical examination (weight, sitting blood pressure and heart rate).

In this chapter the compilation of the sample is described followed by the inclusion criteria. Thereafter the research design is outlined briefly, before the instruments or tests and data collection, as well as the data analysis procedures and techniques are described. Information pertaining to the plyometric exercise session are given. A detailed description of the exercise sessions, which were specifically designed for the development of speed, agility and explosive power of rugby players, and which include warm-up, plyometric and cool-down exercises, as well as the analysis of these exercises are included as appendixes (Appendix A and B, respectively).

3.2 COMPILATION OF THE SAMPLE

The original study group consisted of a sample of 30 male rugby players. Only 28 of these players completed the exercise programme, as two, from the experimental group, withdrew from the programme due to injuries.

All subjects were scholars from the Paul Roos Gymnasium. Their ages ranged between 16 and 18 (ξ: 18) years and all subjects were healthy individuals at the commencement of the programme (no current hip, knee and ankle problems or injuries). Their health status was confirmed after the subjects underwent a rigorous evaluation consisting of a background check (medical history) and a physical examination (weight, sitting blood pressure and heart rate).

The subjects were divided into two groups:

Group 1 (experimental group): Healthy rugby players (n =15) from the 1st rugby team of the Paul Roos Gymnasium.

Group 2 (control group): Healthy rugby players (n =15) from the 2nd rugby team of the Paul Roos Gymnasium.

Group 1 participated in a six-week plyometric training programme. Groups 1 and 2 participated in the pre- and post-test measurements. The statistical analysis indicated that the pre-test averages were the same for the experimental and control group. Both the groups had the same coach and followed the same training programme. On request of the coach and headmaster, the 1st and 2nd team members stayed in their teams for the study. The study was completed before the competitive season.

3.3 INCLUSION CRITERIA

For the purpose of this programme, the inclusion criteria were defined as: “Apparently healthy individuals” who play in the 1st or 2nd rugby team for the Paul Roos Gymnasium. These individuals should not have had recent history (past four months) of lower extremity musculoskeletal injury (any physical debilitation or pathology of the hip, thigh, knee, leg, ankle or foot). Each subject completed a pre-test questionnaire (Appendix C) and prior to participation, an informed consent form as recommended by the American College of Sports Medicine was signed (American College of Sports Medicine, 2000) (Appendix D).

Information pertaining to the health status of the subjects are presented in two tables and include weight, heart rate and blood pressure of the experimental group (Table 1) and the control group (Table 2) (Appendix E and F, respectively).

3.4 RESEARCH DESIGN

This research design called for a study that consists of three phases:

Phase one is the initial testing period (two weeks), in which subjects were tested and/or measured pertaining to: body fat percentage, girth measurements, agility (T-drill), ten-meter speed, vertical jump, depth jump, standing triple jump, rugby agility run, medicine ball chest pass, as well as the tree-minute-step, and push-up and sit-up tests. These tests and measurements were taken as pre-tests in order to compare results after intervention.
Phase two consisted of the six-week plyometric programme. All the subjects in the experimental group exercised twice per week. Each session consisted of a 10-minute warm-up, a 30-minute plyometric training session and a 10-minute cool-down. All the training sessions were lead by the researcher. All exercises were explained and demonstrated to ensure correct execution and technique. Subjects in both the experimental and control group continued with traditional rugby training sessions.

Phase three was the post-testing period (two weeks) in which the tests of phase one was repeated.

In April 2002, after obtaining the necessary consent from the Department of Sport Science of Stellenbosch University, as well as all the test centres involved, the subjects were submitted to phase one and phase two. All subjects were tested and measured at the sport facilities of Markotter Sports Grounds. Phase three was applied six weeks later, at the beginning of June 2002. To ensure reliability and consistency the researcher conducted all the tests and measurements personally.

3.5 INSTRUMENTS AND DATA COLLECTION PROCEDURES

For the collection of data all the specific tests and measurements for physical changes, physical fitness, as well as biomotor skills mentioned above (see section 3.1), were taken and all necessary information recorded as set out in phases one and three of the study.

The subjects were informed as to which measurements were to be taken and were required to complete a consent form in this regard. For quick and efficient measurements, the subjects were asked to present themselves in minimal clothing (T-shirt and sport shorts and running shoes).

Instruments or equipment and data collection procedures used to determine the health status of the participants in the study, as well as their physical changes and biomotor performance skills, will be described in more detail below:

3.5.1 Questionnaire with biographical information

The Physical Activity Readiness Questionnaire (PAR-Q) was used to obtain information on the subjects' sporting background, injury background as well as daily sleeping and eating habits (Appendix C).

Purpose:

The purpose of the questionnaire was to identify and exclude individuals with medical contraindications to exercise.

Identification of individuals at increased risk for disease because of age, symptoms, and/or risk factors that should undergo a medical evaluation and exercise testing before starting an exercise programme. The questionnaire also helps the researcher to identify persons with clinically significant diseases who should participate in a medically supervised exercise programme (American College of Sports Medicine, 2000).

3.5.2 Health status

3.5.2.1 Blood pressure and heart rate in a sitting position

Purpose:

To determine the individual's resting heart rate and his systolic and diastolic blood pressure in a sitting position.

Equipment:

Palm aneroid sphygmomanometer, Rappaport stethoscope.

Procedure:

Measurement of resting blood pressure (BP) was an integral component of the present evaluation. After allowing the subject to sit down for two minutes to allow the heart rate and blood pressure to stabilise, the blood pressure was measured. The cuff was wrapped firmly around the left upper arm at heart level, and aligned with the brachial artery. (American College of Sports Medicine, 2000).

A standard stethoscope was placed below the antecubital space over the brachial artery. The cuff was quickly inflated to ± 200 mmHg and the pressure then slowly released, with the researcher noting when the thumping sound started (systolic blood pressure) and disappeared (diastolic blood pressure). Optimal blood pressure with respect to cardiovascular risk is systolic BP < 120 mmHg and diastolic BP < 80 mmHg. All the raw data pertaining to the experimental and control groups are presented in Appendixes E and F, respectively.

The heart rate was recorded with a Polar heart rate monitor (X-trainer plus). The heart rate monitor indicates the heartbeat at that moment. The subjects were in a resting position after their blood pressure had been recorded.

3.5.2.2 Weight

Purpose:

To determine the individual's body weight. Body mass exhibits diurnal variation of about 1 kg in children and 2 kg in adults.

Equipment:

A portable Krups electronic scale (maximum = 130 kg) incorporating a load cell was used. The scale is accurate to within 100 g.

Procedure:

Weight was measured while the subjects were bare footed and lightly clothed. The subject stood on the centre of the scale without support and with the weight distributed evenly on both feet. The head was up and the eyes looked straight ahead. The most stable values are those obtained routinely in the morning twelve hours after food was consumed and after voiding. The subjects were tested at 14:00 in both the pre- and post-tests. (American College of Sport Medicine, 2000).

3.5.3 Physiological aspects

3.5.3.1 Body fat percentage

Purpose:

To determine the individual's lean body mass and the percentage of body fat.

Equipment:

Harpenden skinfold calliper.

Procedure:

Measurement of body fat percentage, both before and after the six-week plyometric training programme, was performed by using the pinch method. Thickness of the skin held between two fingers were measured with a calliper to the nearest millimeter. Six points were measured to produce the average, which became the reported measurement. All measurements were taken in the same body areas on each subject. Skinfold measurements were recorded at the triceps-, subscapilaris-, chest, supra-iliac, abdominal and thigh sites with a Harpenden skinfold calliper with a constant jaw pressure of 10g/square millimeter. All measurements were taken on the right-hand side if the subjects were right handed and vice versa (Norton & Olds, 1996).

Anatomical landmarks for skinfolds:

Triceps: The skinfold was raised with the thumb and the index finger on the marked posterior mid-Acromiale-Radiale line. The fold is vertical and parallel to the line of the upper arm. The skinfold was measured on the most posterior surface of the arm over the triceps muscle.

Subscapular: The skinfold was raised with the thumb and index finger at the marked site 2 cm along a line running laterally and obliquely downwards from the subscapulare landmark at an angle (approximately 45°) as determined by the natural fold of the skin.

Iliac crest: The skinfold was raised immediately superior to the iliocristale on the ilio-axilla line. The fold runs slightly downwards toward the medial aspect of the body.

Abdominal: This is a vertical fold raised 5 cm (approximately in the midline of the belly

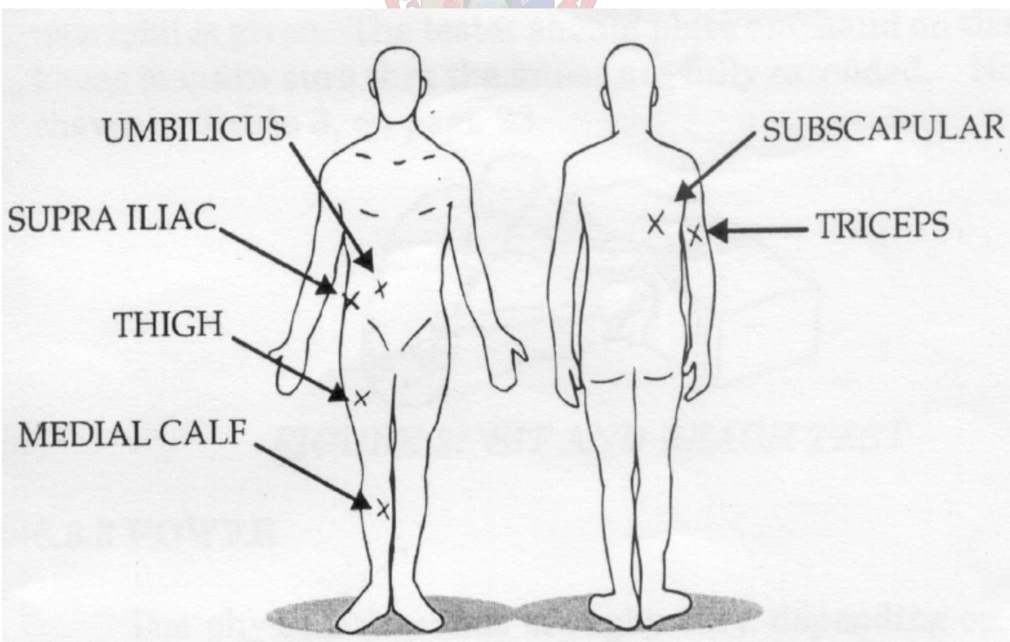

Figure 3.1: Some of the sites for taking skinfold measurements (Turnbull, Coetzee & McDonald, 1995).

of the Rectus Abdominis) from the midpoint of the omphallon (midpoint of the navel).
Front thigh: This site was marked parallel to the long axis of the femur at the midpoint of the distance between the inguinal fold and the superior border of the patella (while the leg is bent).
Chest: This skinfold was taken in a diagonal line midway between the axillary fold (armpit) and the nipple (American College of Sports Medicine, 2000).

The raw data and sum of the six skinfolds were noted in Appendix H. The sum of the six skinfolds (mm) were used in comparisons.

3.5.3.2 Girth measurements

Purpose:
To determine the circumference of the different body segments of the subject.
Equipment:
A flexible tape measure and black measuring pen.
Procedure:
The subjects were measured at the following sites: chest, arms, waist, hips, thighs, and calves (Norton & Olds, 1996). (Appendix J and K, respectively).
The girth of the chest was measured at the mesosternal level. The girth of the upper arm (hanging in a relaxed position at the side of the body) was measured at the level of the mid-acromiale-radiale. The tape measure should be positioned perpendicular to the long axis of the humerus. The waist measurement was taken at the level of the narrowest point between the lower costal (rib) border and the iliac crest. This measurement was taken at the end of normal expiration. The hip (gluteal) measure was taken at the level of the greatest posterior protuberance of the buttocks. The subject stood with feet together while the gluteal muscles are relaxed. The girth of the thigh was measured 10 cm above the tibialis externum point. The calf girth measurements were taken at the point where the circumference was at its widest (Norton & Olds, 1996).

3.5.4 General fitness (cardiovascular fitness and muscle endurance)

3.5.4.1 Three-minute step test

Purpose:

The three-minute step test was used to determine aerobic capacity. It is a practical and easy test to administer.

Equipment:

Step-up box, 30 cm high and wide enough to put both feet on at the same time.

A metronome set at 96 beats per minute.

A stopwatch and recording/ test sheet.

Procedure and scoring:

The subject had to step up and down from the step-up box at a set cadence of 96 beats per minute, in a four-beat stepping cycle. The subject faced the step-up box while the metronome was set at 96 beats per minute. The timer was then activated for a 3-minute recording. The subject could start with any foot and the leading foot could be changed during testing. The subject first steps on the up portion of the cycle, changing feet on the step on the down portion of the cycle. Both feet had to make contact with the floor on the down portion of the cycle, before starting the next cycle. The subject's one-minute recovery pulse was taken on completion of the test, within 5 seconds of completing the step exercise for three minutes. The recorded pulse rate was compared to the norms given in the Physical Fitness Evaluations (American College of Sports Medicine, 2000).

3.5.4.2 Push-up test

Purpose:

The test was used to assess muscle endurance, but it also provided information regarding upper-body strength.

Procedure and scoring:

The subject had to perform the maximal number of push-ups (hands shoulder-width apart) in a rhythmic manner with no rest in-between push-ups, while there was no time limit to the test. Any stoppage, however, signaled the end of the test. The subject starts in the "up" position, with the arms fully extended, then lowered the body to a position where the body was 5 cm above the floor. Only the hands and feet were in contact with the ground. A fist or small item could be used as the 5 cm marker. The subject had to touch the marker or the effort would not be counted. The results were recorded for age and total number of push-ups performed during a single uninterrupted effort (American College of Sport Medicine, 2000).

3.5.4.3 Sit-up test

Purpose:

The aim of this test was to assess abdominal strength and endurance.

Equipment:

The subject had to lie on an exercise mat or grass athletics track. A stopwatch and a recording sheet were used.

Procedure and scoring:

The subject had to lie supine (on back) with knees bent and fingertips touching just behind the ears. The subject's feet were held stable during the activity. As many sit-ups as possible had to be executed in one minute. The number of sit-ups completed during the one minute was noted (American College of Sport Medicine, 2000).

3.5.5 Biomotor abilities

3.5.5.1 Agility Test (T-drill)

Purpose:

For the assessment of agility and body control.

Equipment:

Four cones

Stopwatch (0.1 sec)

Hard grass athletic track

Procedure:

Four cones were arranged as seen in Figure 3.2, and marked points A, B, C and D. Subjects had to do adequate stretching and warm-up exercises before this test was done. A subject started at point A on the verbal ”Go” command, sprints to point B and touched the base of the cone with the right hand. The subject then shuffled to the left for 5 m and touched the base of the cone at point C with the left hand. When shuffling, subjects had to face the front and were not allowed to cross their feet. The subject then shuffled to the right for 10 m and touched the base of the cone at point D with the right hand. Thereafter the subject shuffled to the left for 5 m and touched the base of the cone at point B with the left hand. The subject then had to run backwards past point A. The timer stopped the watch when the athlete passed the cone at point A. For safety reasons, a spotter and gym mat had to be placed several meters behind point A to catch the athlete who might fall. Each athlete had to complete two trials for the T-test, and the better trial to the nearest 0.1 second was recorded. The floor layout is given in Figure 3.2 (Bloomfield, Ackland & Elliott, 1994).

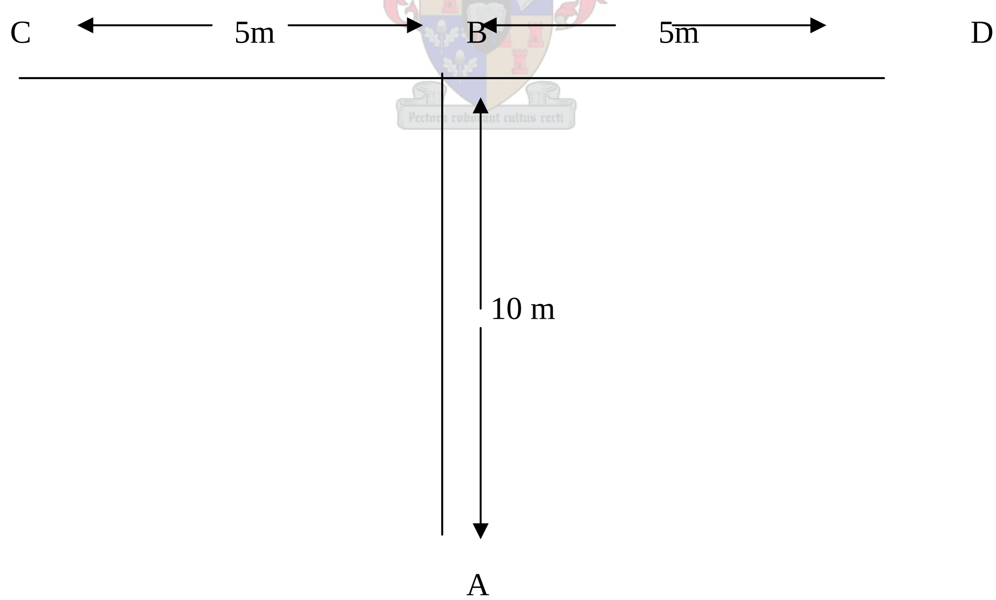

Figure 3.2: Floor layout for the T-test (Bloomfield, Ackland & Elliott, 1994).

Reasons for disqualification:

Subjects were disqualified if they did not touch the base of any cone, crossed their feet when shuffling, or failed to face the front at all times.

3. 5. 5.2 Ten-meter speed test

Purpose:

To test for speed, agility and balance require that the subject be dressed appropriately for maximal performance. Lightweight clothing and training shoes had to be worn for all general tests of speed and agility, whereas the normal playing attire had to be worn for specific sport tests. Ideally, the test had to be administered prior to any vigorous training sessions so that subjects were not limited by fatigue or soreness. In addition, it was preferable that the subjects did not ingest food within a two-hour period preceding the tests. A thorough warm-up involving aerobic activity and muscle-stretching exercises plus other activities to prevent injury and permit the recording of a maximal effort was required. The purpose of the 10-meter sprint for rugby players was to determine the player's ability to accelerate from a stationary position and the speed of movement over ten meter, with a standing start.

Equipment:

Tape measure

Stopwatch

Procedure:

A 10-meter track was marked out with cones on a suitable, level surface. The track could be set up crosswind to negate any environmental influence on the obtained scores. The subject stood behind the starting line and on the signal to start (a verbal command – 'go', as well as a visual action such as a sudden drop of the hand), sprints past the 10-meter mark. Two recorders with stopwatches were positioned at the 10-meter mark and began timing on the starter's signal. The watches were stopped as the runner's trunk passed the 10-meter mark and an average time for the two recorders was noted. Two trials were permitted and the lower mean score was recorded to the nearest 0,1 second. For greater accuracy and measurement precision, photoelectric cell timing gates could be employed in the administration of the test and this obviates for stopwatches (Bloomfield *et al*., 1994).

3.5.5.3 Sargent vertical jump test

Purpose:

To measure the subject's instantaneous explosive leg power.

Equipment:

Mounted calibrated measuring board

Chalk powder

Procedure:

The subject, wearing athletic shoes, stood with the right side (hip) against a wall onto which a calibrated measuring board was mounted. The subject then reached with the right hand to touch the board at the highest point possible, keeping feet stationary, with heels on the ground. This point was recorded as "reaching height". The subject then put the chalk on the fingertips of the dominant hand. Then, from a two-footed take-off position, the player flexed at the hip and knee joints and, using his arms for momentum, attempted to extend as high as possible. At the top of the jump the player touched and marked the board with his fingertips (Bosco, 1985).

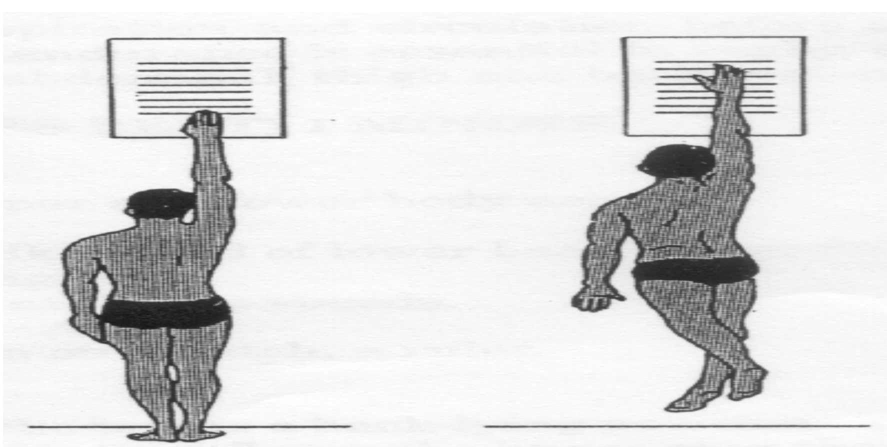

Figure 3.3: Administration of the Sargent Vertical jump test (Turnbull, Coetzee & McDonald, 1995).

Scoring:

The score for the jump was the difference between the reaching height and the jump height. The highest of three separate trials was recorded as the subject's maximum score. It should be noted that if the player takes any form of step or shuffle prior to the jump, the score would be rendered invalid. Values of 93 cm were recorded by the Russian National handball team in 1988 (Turnbull *et al.*, 1995).

3.3.5.4 Depth jump test

Purpose:

To determine the individual's foot-peed and explosive power.

Equipment:

A 3 m high wall and 30 cm high step.

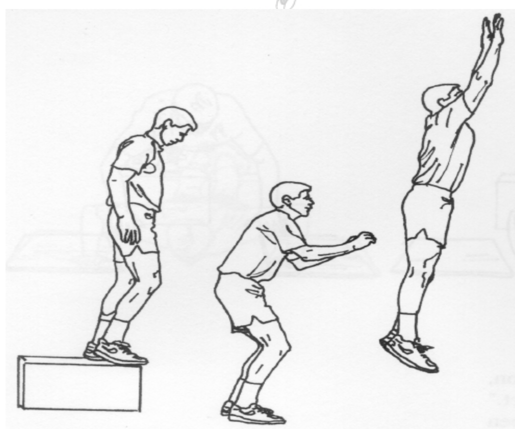

Figure 3.4: Administration of the Depth jump test (Bloomfield, Ackland & Elliott, 1994).

Procedure and scoring:

The subject stood on a 30 cm high box with toes close to the edge. The subject then stepped from the box and dropped to land on the balls of the feet. The subject had to try to anticipate the landing and then jumped again as quickly as possible. In this way ground contact was minimised in order to "bounce" off the ground and to prevent heel contact. The "touch down" time of the feet on the ground had to be kept as short as possible. The subject had to then explode vertically upwards and touch the mounted calibrated measuring board on the wall, to determine the maximum height after jumping from the 30 cm step (Bloomfield *et al.*, 1994).

3.5.5.5 Standing triple jump test

Purpose:

This test measures explosive leg power over a horizontal distance. The aim of the jump was to obtain as much horizontal distance as possible.

Equipment:

Tape measure

Chalk

Procedure:

A starting line was drawn on the ground. The subject began with both feet approximately shoulder-width apart and toes on the starting line. The subject jumped forward from a two-footed take-off position flexing at the hip, knee and ankle joint prior to take-off, using the arms for momentum. The subject then pushed from both legs, projecting almost linearly. The subject landed on one foot (hop), immediately projecting linearly to land on the opposite foot (step), and concludes by jumping from that foot to a two-footed landing (jump) (Bloomfield *et al.*, 1994).

Scoring:

The distance traveled could be measured to the nearest centimeter at the heel of the back foot. Two trials were taken and the better of the two was recorded.

3.5.5.6 Rugby agility run test

Purpose:

The rugby agility run is designed to measure the ability of a player to accelerate and change direction (Bloomfield *et al.*, 1994).

Equipment, procedure and scoring:

An example of the course is set out in Figure 3.5. Cones were used to mark positions A to G and the finishing line. Tall markers, which were constructed of plastic tubing and were approximately 1500 x 30 x 30mm in size to simulate opponents, were located at positions H to L. The tester had to stand at the finishing line to ensure the most accurate timing. A subject started by lying on his back with his head on the starting line at cone A. On the command to ‘go’, the subject got up and sprinted around cone B, cuts back to cone C and performed a shoulder roll at cone D. Quickly accelerating from the roll to cone E, the subject then picked up a rugby ball, paced around cones F and G and accelerated toward the tall markers. The subject had to weave around the tall markers H to L and then sprinted to the finishing line to score a try. Two trials were permitted and the fastest time was recorded to the nearest 0,1 second.

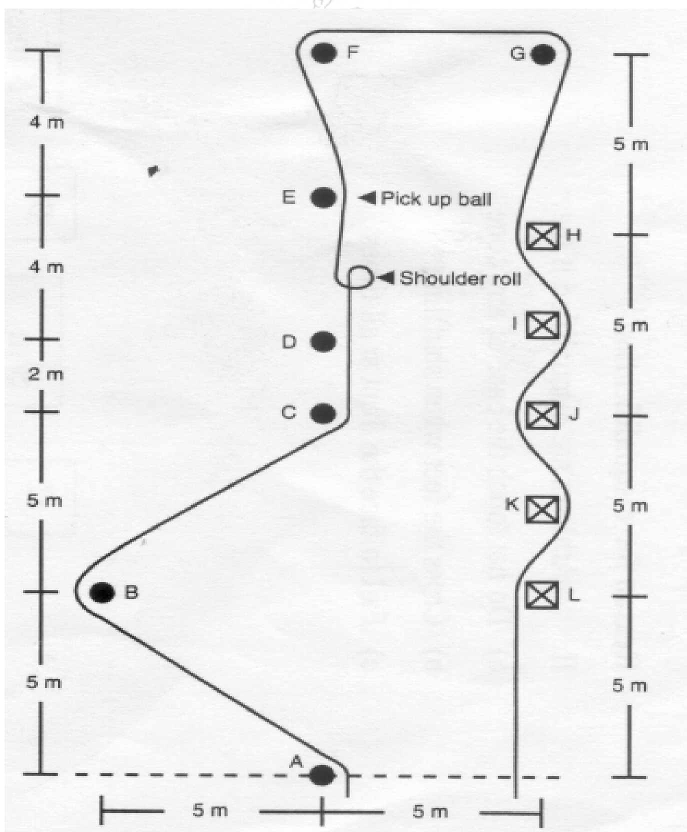

Figure 3.5: Sport specific agility test (Bloomfield, Ackland & Elliott, 1994).

3.5.5.7 Medicine ball chest pass test

Purpose:

To determine the explosive power and power of the individual's upper body.

Equipment:

Medicine ball (3 kg)

Procedure:

The subject had to sit with legs straight and back against a perpendicular wall. The player then began by holding the 3 kg medicine ball with both hands at chest level, elbows pointing outwards. The ball was passed forward in a straight line, as hard as possible, in an explosive movement. The distance that the ball was thrown was measured from the wall against which the player was sitting (Tenke & Higgins, 1996).

Scoring:

The distance the individual pushes the 3 kg medicine ball was used as the score for the chest pass. Each individual got two chances, and the further distance was recorded.

3.6 PLYOMETRIC EXERCISE SESSION

All the training sessions consisted of 10-minute warm-up exercises and stretching, 30 minutes of plyometric exercises and 10 minutes of cool-down exercises and stretching. The plyometric programme was designed after careful analysis of these test results and previous studies executed under quite similar conditions and circumstances (Chu, 1998). The plyometric training programme was also designed and set up from Chu's (1992) work on sport-specific exercises.

The plyometric training programme was done twice every week for six weeks on a grass athletics track. The researcher presented the exercise programmes and monitored progression and correct execution. It was seen to that the movements were executed correctly and that the correct posture was maintained to prevent injury. All plyometric exercises were done at the Markotter Sport grounds. A description of the plyometric exercises with the different levels of intensity of each, as well as the warm-up and cool-down exercises are set out in Appendix A. The analysis of the different plyometric exercises that constitute the plyometric training programme is set out in Appendix B.

The plyometric exercises were set out in differing levels of intensity. Each subject had to complete all the sessions (twice a week for six weeks = 12 sessions) within the six weeks in order to complete the intervention programme. The first three sessions were introductory sessions where the basic principles of plyometrics were mastered before the subject started the more advanced movements (higher intensity).

It was apparent to the researcher that all the subjects enjoyed the plyometric exercise sessions. It was also interesting to note that the subjects claimed and therefore perceived themselves to be able to respond and run faster and to have more control over their bodies when they execute exercises or movements during the game situation. An indication of their enjoyment and positive perception towards plyometric exercise sessions was that they won all their games and that the individuals improved their game and abilities and all the subjects continued with plyometric training sessions for the rest of the season, after completion of the research programme. See Appendix B for the description of the exercise.

3.7 DATA ANALYSIS

The Statistical Package, Statistica Version 6 was used to analyse the pre- and post-test data.

In the statistical analysis of this study the repeated measures ANOVA was used as well as the Bonferroni post hoc tests.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

A total of 30 subjects volunteered to participate in the six-week plyometric training project. These subjects were divided into two groups, the experimental group (n=15), the first rugby team, and the control group (n=15), the second rugby team of Paul Roos Gymnasium. Only the first team (15 participants) took part in the six-week intervention programme as well as continued with the conventional rugby training. The remaining 15 subjects persisted with conventional rugby training. Two subjects did not complete the six-week intervention programme for the following reasons:

- One subject developed patella tendonitis.
- One subject suffered an injury to the medial ligaments of the right knee.

Both subjects that did not complete the intervention programme were members of the experimental group. Thirty subjects completed the pre-tests, 15 from the experimental group and 15 from the control group, while 28 players completed the post-tests, 13 from the experimental group and 15 from the control group.

In this chapter the health status, with regards to the medical history, physical examination of height, weight, sitting blood pressure and heart rate will first be discussed briefly. The results of the pre- and post-tests pertaining to the physiological aspects, namely weight, body fat percentage and girth measurements as well as the results pertaining to cardiovascular fitness and muscle endurance will be presented visually and discussed thereafter. The results with regards to biomotor performance tests considered to be beneficial to rugby players, namely explosive power, agility and speed will then be presented visually and discussed. The biomotor performance tests representing these capabilities include the rugby agility run, agility test (T-drill), 10-meter speed test, Sargent vertical jump test, depth jump test, standing triple jump test, medicine ball chest pass test.

4.2 HEALTH STATUS

After a thorough evaluation of the subjects' medical history their health status was confirmed as being apparently healthy with no physical problems or injuries and thereafter declared fit for participation in the study.

Descriptive data of both groups with regards to their medical history, weight, blood pressure and heart rate, were recorded on data sheets during the pre-and post-test (Appendixes E and F). The heart rate and blood pressure of both the experimental and control groups were recorded prior to the pre- and post-test and noted on the heart rate report form (Appendix O and P).

4.3 PHYSIOLOGICAL ASPECTS

4.3.1 Body fat percentage

The pre- and post-test averages for body fat percentage of the experimental and control group is presented in Figure 4.1.

From Figure 4.1 it is clear that there was a significant interaction between the two groups over time ($p<0.01$). The control group average pertaining to body fat percentage stayed constant between the two tests (Bonferroni $p=1.0$) and the experimental group average percentage body fat decreased significantly (Bonferroni $p<0.01$). See Appendix M and N for detailed tables of the analyses.

From the statistical analysis it was clear that the body fat percentage decrease was greater for the experimental group than for the control group. This was primarily due to the structured and intense nature of the exercise programme given to the experimental group, which contributed to this reduction in body fat percentage.

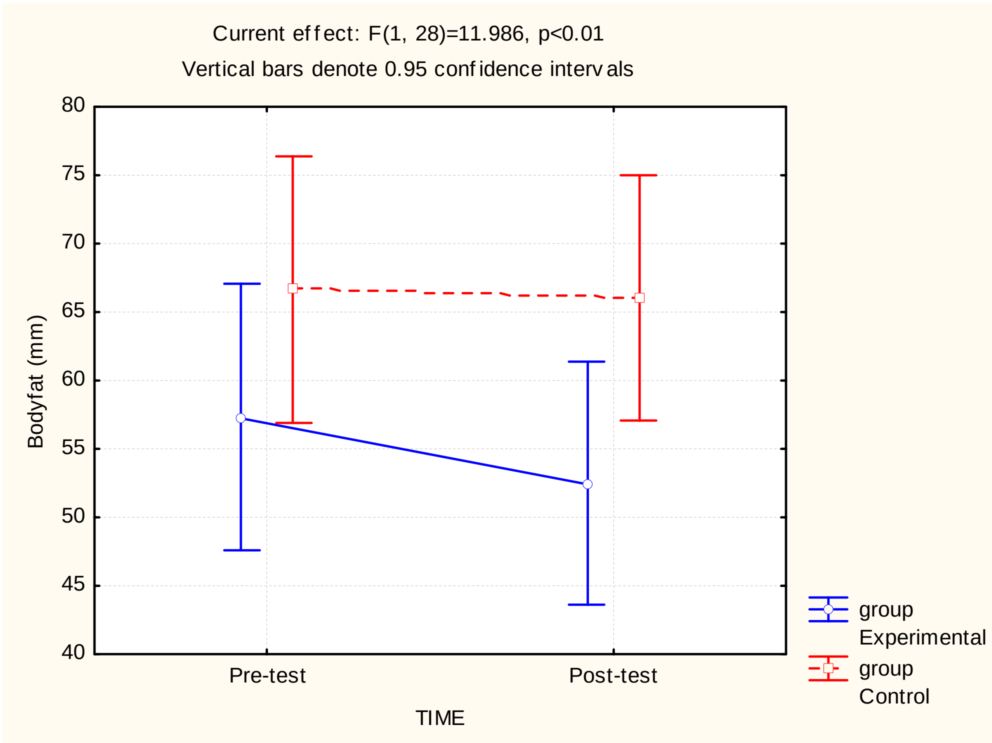

Figure 4.1: Pre- and post-test averages for body fat percentage of the experimental and control group.

Plyometrics are strenuous exercises, leading to muscle hypertrophy and decreasing body fat percentage. The proportion of body fat to lean body weight is important to the rugby player. Lean body weight refers to all body tissue, which is not fat, while body fat represents "dead weight". A certain amount of body fat is, however, important to ensure normal body functions. Forwards, on average, will carry more body fat than backs because of their genetic make up and this may also serve to protect them during vigorous contact (Turnbull *et al*., 1995).

It was concluded that although the exercise programme of the school rugby could have contributed to the decrease in body fat percentage, the six-week plyometric-training programme could lead to an overall significant decrease in body fat percentage of the experimental group.

4.3.2 Girth measurements

4.3.2.1 Thigh circumference

The pre- and post-test averages for thigh circumference of the experimental and control group are presented in Figure 4.2 (a), for the right thigh and Figure 4.2 (b), for the left thigh.

Ideally the thigh girth measurements should show a slight increase after the six-week intervention period. Research have shown that plyometric exercise, when combined with power training, leads to hypertrophy of the specific muscle being used (Turnbull *et al*., 1995).

From Figure 4.2 (a) and Figure 4.2 (b) it is evident that there was a tendency for interaction between the two groups over time ($p=0,05$) for the right and ($p=0,03$) for the left leg. The control group average thigh circumference stayed constant between the two tests (Bonferroni $p=1.0$) and the experimental group average thigh circumference did not show a statistical significant improvement over the six-week period (Bonferroni $p=0.6$) for the right leg and (Bonferroni $p=0,3$) for the left leg. See Appendix G and H for detailed tables of analyses.

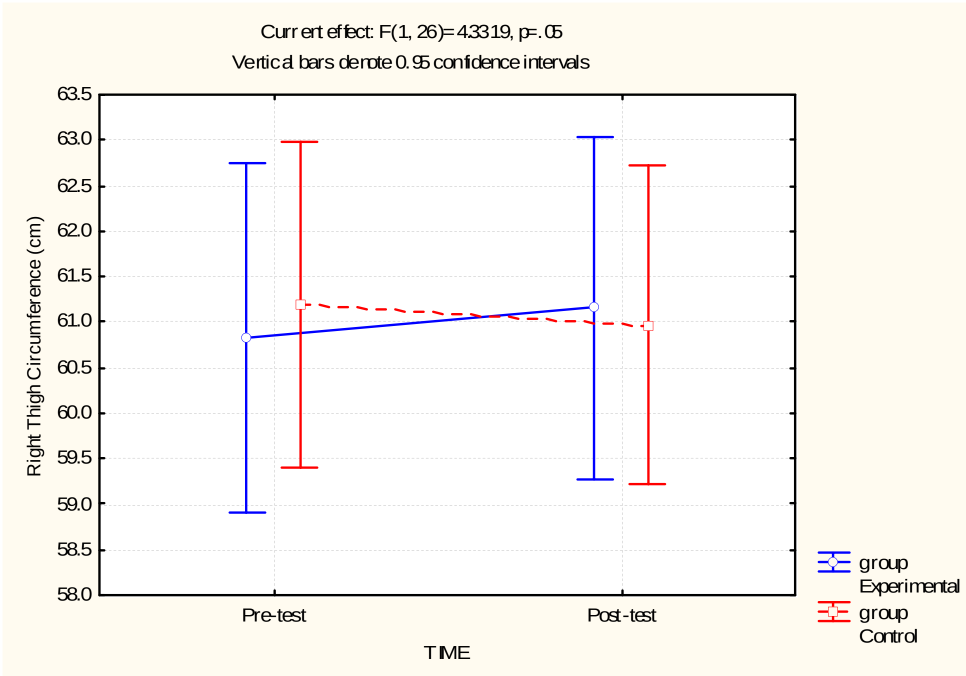

Figure 4.2 (a): Pre- and post-test averages for right thigh circumference of the experimental and control group.

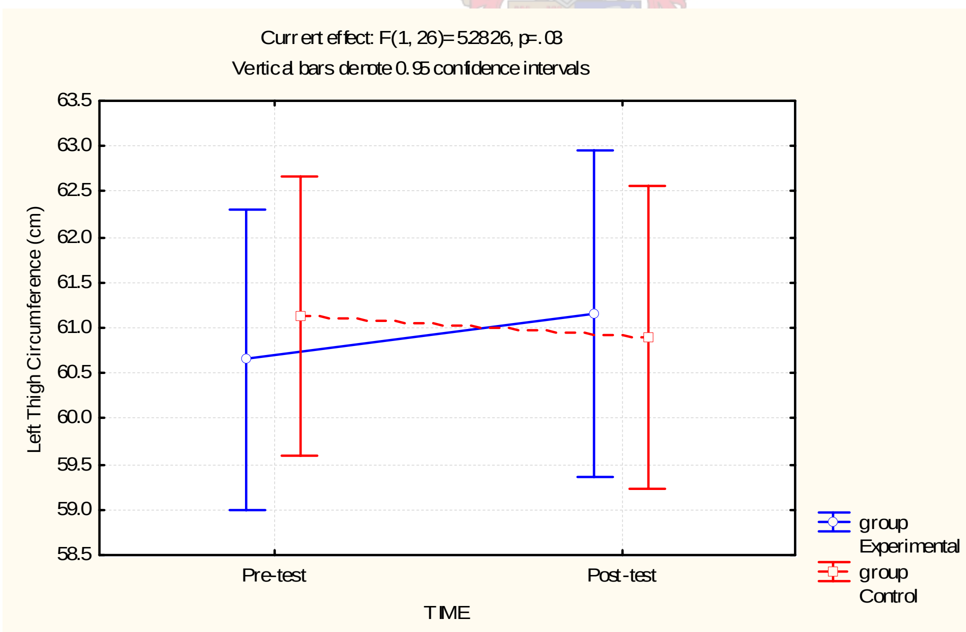

Figure 4.2 (b): Pre- and post-test averages for left thigh circumference of the experimental and control group.

The graphs of the experimental group show a steep increase to the right [Figure 4.2 (a) and Figure 4.2 (b)]. The graphs of the control group show a decrease to the right. When the averages of the experimental group are compared, no statistical significant improvement was found. When the averages of the control group were compared, no statistically significant change was found. The possibility of atrophy of the thigh muscles could be caused by increased aerobic activity, which was not combined with weight training or strength training. Comparing these two graphs it can be seen that the gradient of the experimental group is steeper, and in the opposite direction than that of the control group, which also indicates a greater improvement over the six-week period.

Previous research proved that the eccentric and concentric muscle contractions are needed for muscle hypertrophy (De Vries & Housh, 1994: 427). The researcher found that, because of the short period of the intervention programme, there was a tendency for the experimental group to improve, but no statistical significant improvement was found in their thigh circumference.

Plyometric jumps involve the projection of the entire mass of the body. Maximal impact plyometrics will generally increase muscle tension to a great extent. Sub-maximal impact plyometrics can serve as a preparatory tool for maximal impact plyometrics or for enhancing other functional and structural qualities. These qualities include strength, muscle hypertrophy, muscle endurance and speed-strength endurance (Siff & Verkhoskansky, 1993).

4.2.2.2 Calf circumference

The pre- and post-test averages for calf circumference of the experimental and control group are presented in Figure 4.3 (a), for the right calf and Figure 4.3 (b), for the left calf.

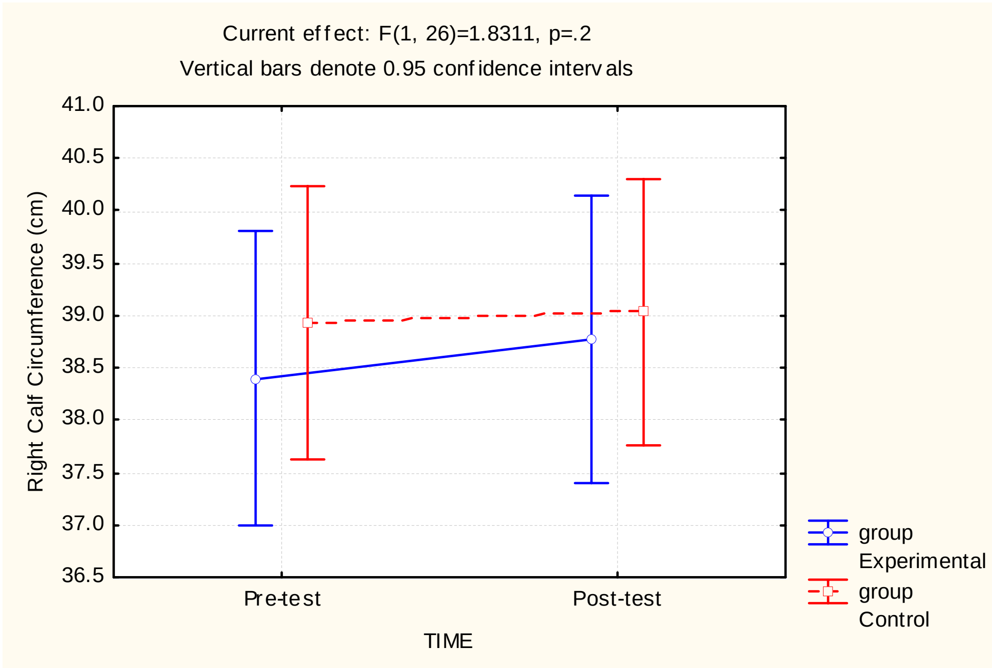

Figure 4.3 (a): Pre- and post-test averages of the right calf circumference of the experimental and control group.

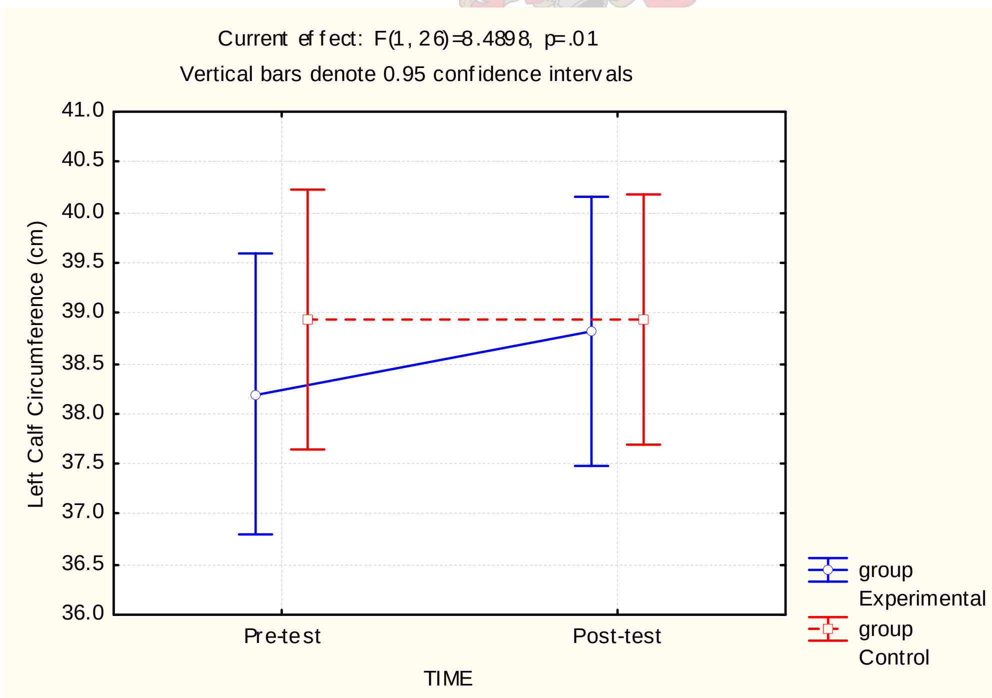

Figure 4.3 (b): Pre- and post-test averages of the left calf circumference of the experimental and control group.

From Figure 4.3 (a) it seems that there could be a significant interaction between the two groups over time, but there was no significant interaction (p=0.19). From Figure 4.3 (b) it is evident that there is a significant interaction between the two groups over time (p<0,01). The control group average calf circumference stayed constant between the two tests (Bonferroni p=1). The graph [Figure 4.3 (a)] of the experimental group shows an increase to the right that could indicate a slight improvement, but is not statistically significant (Bonferroni p=0,11). Most subjects were right-leg dominant, which means that the right calf was already stronger and more developed than the left (bigger in circumference). The left calf circumference improved drastically, since the plyometric intervention programme included single-leg, as well as, double-leg exercises. The left leg of the experimental group improved drastically over the six-week period (Bonferroni p<0,01). See Appendix G and H for detailed tables of analyses.

The graph of the experimental group shows a steep increase to the right [Figure 4.3 (a) and Figure 4.3 (b)]. The graph of the control group seems to stay level. When the averages of the experimental group were compared, a statistical significant improvement was found in the left calf circumference (Bonferroni p<0,01). When the averages of the control group are compared, the calf sizes stay constant (Bonferroni p=1,0).

Literature states that the calf muscles are utilised during plyometric activity (Siff & Verkhoskansky, 1993). Plyometric activity consists of different phases and it is apparent that the calf muscle contracts concentrically during the push-off phase, isometrically during the air phase and eccentrically during the landing phase, thus, this exercise contains the criteria (i.e. concentric and eccentric contractions) that is needed for muscle hypertrophy (McArdle, *et al.*, 1996; Siff & Verkhoshansky, 1993).

One explanation for the significant differences in calf circumferences of the experimental and control group is that there was an improvement in average calf circumference of the experimental group over the six-week period. It can be that, although the calf muscles worked concentrically and eccentrically a reduction in body fat percentage was found as well as an increase in the circumference of the calf muscle which indicates hypertrophy of the calf muscle.

Research indicates (Chu, 1992) that the calf muscle group plays a very important role in plyometric activity. To create the so-called “hotplate” effect one needs a muscle group that will respond quickly and explosively to stimuli. The calf group, consisting of the gastrocnemius and soleus, does just that. These muscles have the ability to respond quickly and are very powerful. With the calf muscle group being in either concentric or eccentric contracted state, the result will be hypertrophy of this muscle group.

4.3.2.3 Arm circumference

The pre- and post-test averages for arm circumference of the experimental and control group are presented in Figure 4.4 (a), for the right arm and Figure 4.4 (b), for the left arm.

In all the years of research on sport performance, researchers found that a combination of power and explosive power exercises lead to the hypertrophy of the athletes’ muscle fibres. An example of explosive power exercises being used, is the explosive push-up (Siff & Verkhoshansky, 1993).

Although the interaction between the two groups are strictly statistically significant for the right arm ($p=0,03$), when looking at the more detailed Bonferroni results a significant difference was found between the experimental group averages over the six-week period (Bonferroni $p<0,01$). The control group averages of the right arm circumference stayed consistent between the two tests (Bonferroni $p=1$). See Appendix G and H for detailed tables of analyses. No statistically significant interaction was found between the two groups for the left arm ($p=0,16$). When looking at the more detailed Bonferroni results no statistically significant difference was found between the experimental (Bonferroni $p=0,06$) and control group (Bonferroni $p=1$) average left arm circumference over the six-week period. See Appendix G and H for detailed tables of analyses.

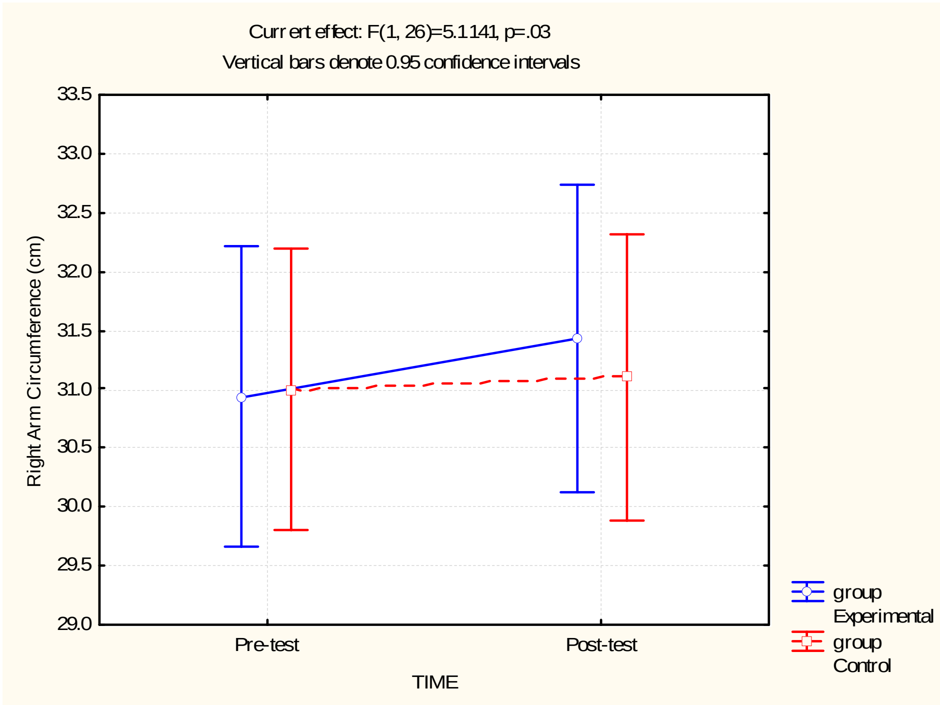

Figure 4.4 (a): Pre- and post-test averages of the right arm circumference of the experimental and control group.

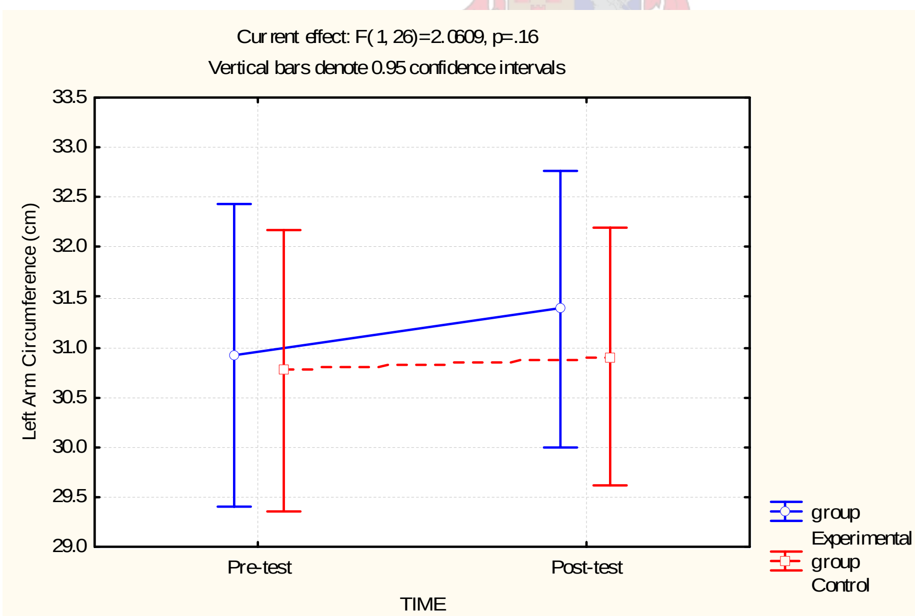

Figure 4.4 (b): Pre- and post-test averages of the left arm circumference of the experimental and control group.

The graph of the experimental group [Figure 4.4 (b)] shows a slight increase to the right, which would indicate an improvement. According to the Bonferroni test (p=0,06) no statistically significant improvement was found.

When comparing the graphs of the right and left arm of the experimental group it is evident that there was an improvement over the six-week intervention period. This visual improvement was, however, not statistically significant for the (left arm circumference) experimental group.

Ideally the arm girth measurements should show a slight increase after the intervention period. Although the six-week intervention training programme focused on using the lower body muscle groups as prime movers and stabilizers, the plyometric programme also included upper body exercises. Rugby requires short bursts of high intensity, such as pushing in the scrum, tackling and sprinting. It is a game for powerful rather than strong players. The rate (speed + power = plyometric activity) at which work is done is known as power. Improved power will improve, amongst others, the player's ability to drive in a tackle, as well as drive in the scrums, mauls and rucks (Turnbull *et al*., 1995).

Although lower body plyometric actions have been referred to above in the form of depth jumps, the same principles may be applied to the upper body impulsive methods with medicine ball catching and throwing, plyometric push-ups, plyometric bench pressing and similar actions, using loaded swings or other specialised apparatus (Siff & Verkhoshansky, 1993).

4.3.2.4 Hips circumference

The pre- and post-test averages for hip circumference of the experimental and control group are presented in Figure 4.5.

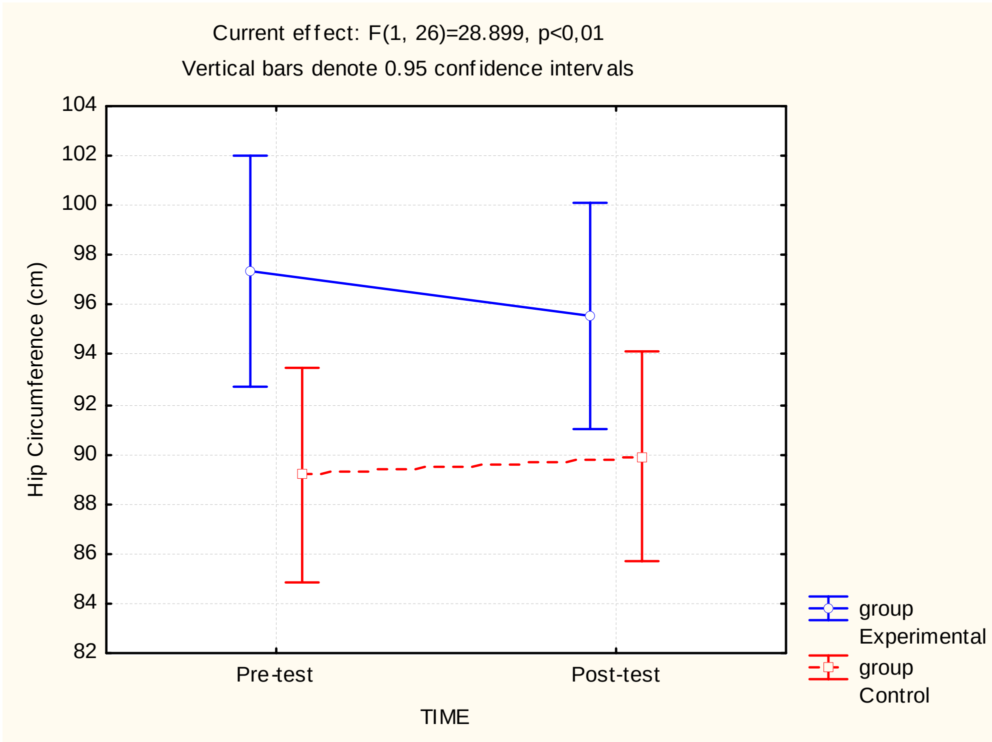

Figure 4.5: Pre- and post-test averages of the hip circumference of the experimental and control group.

From Figure 4.5 it is clear that there is a significant interaction between the two groups over time ($p<0.01$). The control group average hip circumference stayed more or less constant between the two tests (Bonferroni p=0,17) and the experimental group average hip circumference decreased significantly (Bonferroni $p<0.01$). See Appendix G and H for detailed tables of analyses.

When comparing the averages of the pre- and post-test of the experimental group a statistically significant improvement ($p<0.01$) was found. When comparing the average hip circumference of the pre-and post-test of the control group no statistically significant difference was found (p=0,17).

Ideally the hip girth measurements should show either a slight decrease or remain constant. A slight decrease would indicate fat loss during the six-week intervention programme. A large decrease in hip size after the six-week intervention-training programme was measured. A lot of body fat accumulates around the midsection of males and females. During the six-week intervention programme a decrease in body fat percentage was found which explains the decrease in hip girth measurements. Sequences of plyometric exercises are very demanding on the muscles and joints because of their explosiveness. Since subjects had lost body fat percentage during the intervention period, it could be stated that this could have contributed to the decrease in hip size (Turnbull *et al*., 1995**).**

4.3.2.5 Waist circumference

The pre- and post-test averages for waist circumference of the experimental and control group are presented in Figure 4.6.

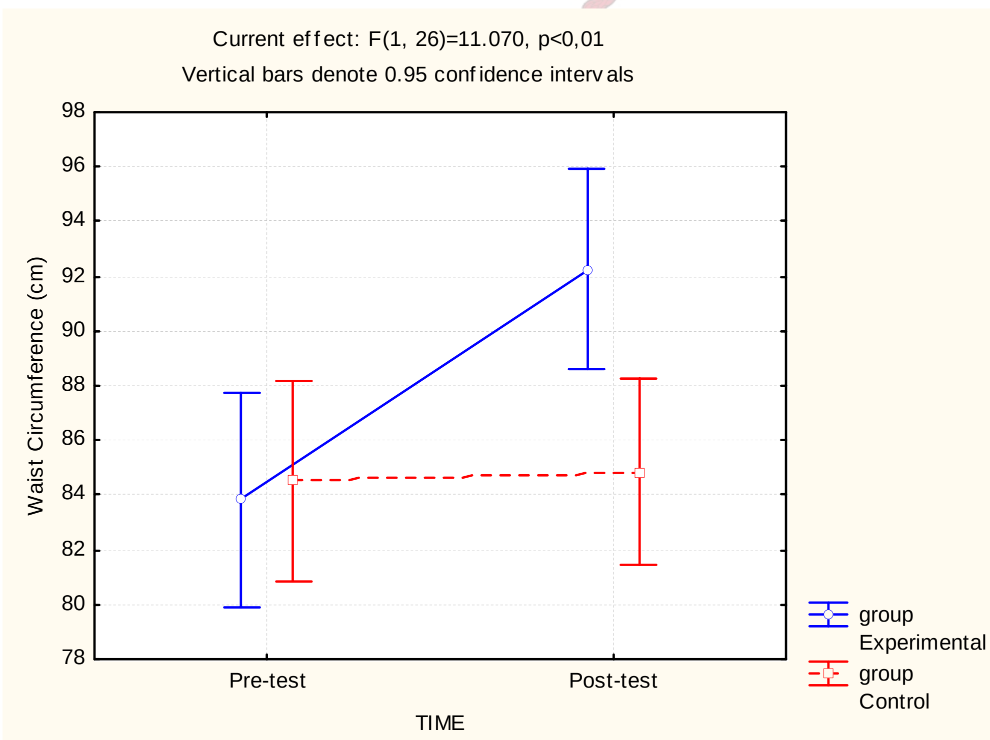

Figure 4.6: Pre- and post-test averages of the waist circumference of the experimental and control group.

Figure 4.6 indicates a significant interaction between the two groups over time ($p<0.01$). The control group average waist circumference stayed constant between the two tests (Bonferroni $p=1.0$) and the experimental group average waist circumference increased significantly (Bonferroni $p<0.01$). See Appendix G and H for detailed tables of analyses.

During the explosive activities of plyometric exercises it is found that core-stability plays a very important role in the correct execution of the different exercises. The core muscles which include the erector spinae, quadratus lumborum, rectus abdominus, transverse-abdominus, internal and external oblique muscles need to be very strong to prevent injury (Siff & Verkhoshansky, 1993).

The statistical analysis shows significant differences in waist circumference when comparing the subjects within each group and between the experimental and control group. The internal and external oblique muscles have a stabilizing function with the abdominal muscle group keeping the human body stable and upright to execute movements. The increase in the experimental group's waist circumference can be ascribed to hypertrophy of the internal and external obliques, which were activated isometrically during the plyometric training programme. Since a decrease in body fat percentage was found, the increase in waist size could only be contributed to hypertrophy of the core stabilizing muscles.

Ideally the waist girth measurements should show a slight decrease after the intervention period. Although the six-week training programme focused on explosive power, speed and agility, which concentrated on the lower limbs, the waist was also utilised, but mostly in an isometrically contracted state.

4.3.2.6 Chest circumference

The pre- and post-test averages for chest circumference of the experimental and control group are presented in Figure 4.7.

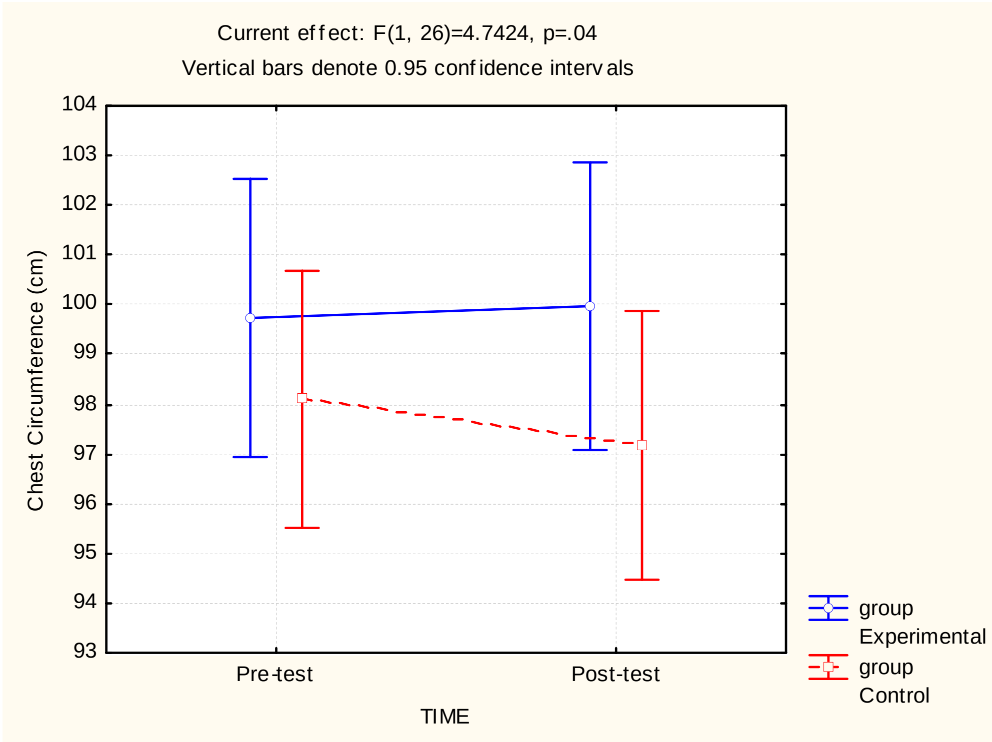

Figure 4.7: Pre- and post-test averages of the chest circumference of the experimental and control group.

Although the interaction is strictly statistically significant (p=0,04), when looking at the more detailed Bonferroni results no statistical difference was found between the experimental (Bonferroni p=1) and control group (Bonferroni p=0,1) averages over the six-week period. Appendix G and H for detailed tables of analyses.

Ideally the chest girth measurements should show a slight increase after the intervention period. Although the six-week plyometric-training programme focused on the lower body, the chest muscles were utilized, once more mainly in an isometrically contracted state (Siff & Verkhoshansky, 1993).

The statistical analysis shows no significant differences in chest circumference when comparing the subjects within each group and between the groups. Although the warm-up activity before the plyometric training sessions included upper body activity like explosive push-ups, the actual programme was focused on the lower body muscle groups and explosive power.

The pectoral group was mostly activated in an isometric way during the plyometric activity. Contrary to expectation, there was a significant decrease in the chest circumference of the control group. The decrease of the chest circumference of the control group could be ascribed to the loss of body fat, or a lack of motivation to train.

The results pertaining to the physical aspects indicate that the plyometric-training programme had a positive effect on the experimental group, compared to the control group. The experimental group's body fat percentage decreased and the circumferences of their thighs, calves, arms and waist increased while their hip circumferences decreased. Their chest circumferences, however, did not increase, possibly due to the fact that the plyometric training was more specifically aimed at the lower body.

4.3.2 PHYSICAL FITNESS

4.4.1 Three-minute step test

Aerobic capacity is a valuable component of most fitness programmes. However, plyometric training, by the nature of the energy system being utilized, is not intended to develop aerobic capacity. Plyometric training is strictly anaerobic (without oxygen) in nature and utilizes the creatine phosphate energy system, allowing maximum energy to be stored in the muscle before a single explosive act, using maximum power, is performed. It is a programme that exploits a quality of movement compatible with single repetition of the exercises. If sufficient recovery is not allowed, the activity may move toward being aerobic, but then the quality and explosiveness of movement are sure to suffer (Chu, 1998).

With this intensity of execution of the plyometric exercises, the researcher found an intense tiredness during and after plyometric activity. This could perhaps be ascribed to the fact that the resting periods between the different exercises were limited to 45-60 seconds.

The pre- and post-test averages of the three-minute step test of the experimental and control group are presented in Figure 4.8.

Although the interaction between the two groups are strictly statistically significant (p=0,05), when looking at the more detailed Bonferroni results no significant difference was found between the experimental (Bonferroni p=0,2) and control group (Bonferroni p=1). See Appendix I and J for detailed tables of analyses.

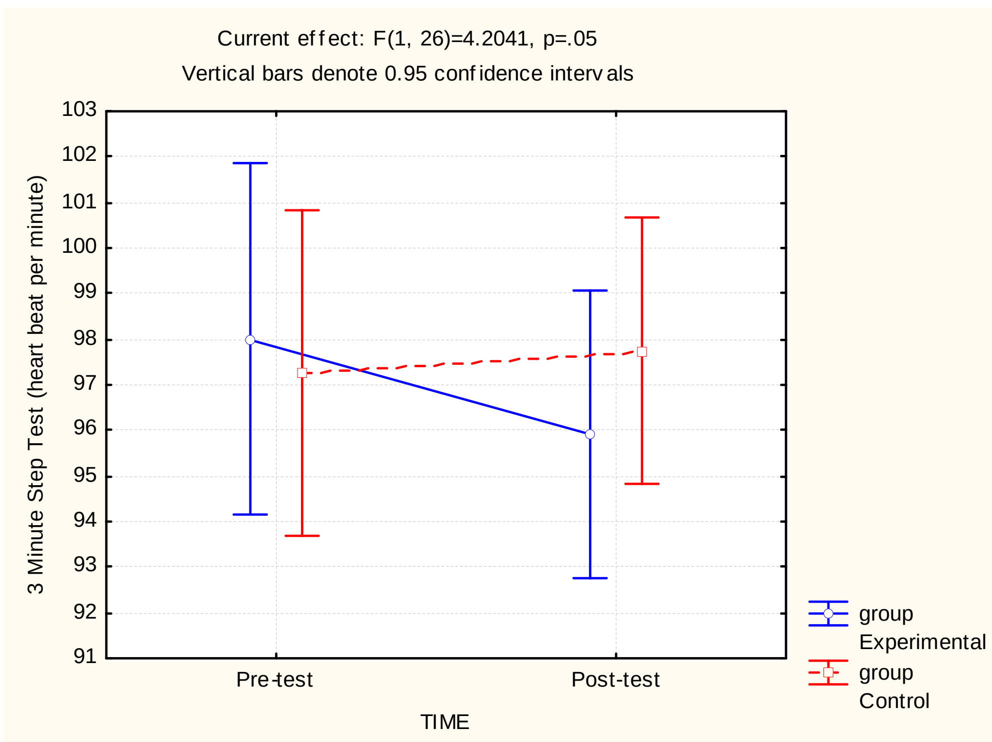

Figure 4.8: Pre- and post-test averages of the three-minute step test of the experimental and control group.

When the graphs were examined, it was evident that the graphs changed direction from the pre- to the post-test averages. In the case of the experimental group there is an indication of improvement (according to the gradient of the graph) in the subjects' relative aerobic fitness over the six-week period. No statistically significant difference was found (Bonferroni p=0,2). It seems as if there is an indication of a decrease in the relative aerobic fitness of the control group. No statistically significant difference was found (Bonferroni p=1).

Some of the subjects of the experimental group also attended training sessions with the different levels of the under-19 provincial teams. That explains the possibility of an increase in aerobic fitness over the six-week period (Turnbull *et al*., 1995). The control group did not follow the plyometric programme and they lost interest in training close to their mid-year examination, which started one week later.

4.4.2 Push-up test

The pre- and post-test averages of the push-up test of the experimental and control group are presented in Figure 4.9. There is a strictly significant interaction between the two groups over time (p=0.02) [Figure 4.9]. The control group average number of push-ups increased significantly between the two tests (Bonferroni p<0,01) and the experimental group average number of push-ups stayed constant over the six-week training period (Bonferroni p=1). See Appendix I and J for detailed tables of analyses.

This test is used to assess muscle endurance, but it also provides information about upper-body strength. The push-up is a quite common exercise in sports that require upper body strength and strength-endurance. Push-ups are included in basically all warm-up routines as well as fitness sessions (Biscombe & Drewett, 1998). The control group showed an improvement over the six-week period. This can be explained by the fact that they continued with their conventional rugby training sessions, which included a lot of fitness training sessions. The control group averages were lower than that of the experimental group at the pre-test. It was easier for the members of the control group to show an improvement, since they were under-trained, and the smallest amount of exercise would mean a big difference. Being members of the second team, these subjects did not train as seriously and consistently as the experimental group subjects before the season. The indication of improvement could ascribed to the fact that the control group got a lot more exercise during the conventional rugby sessions, which caused the improvement. Ideally the number of push-ups should show a slight increase after the intervention period. Although the six-week training programme focused on the explosiveness, power and speed of the muscles of the lower body, the researcher found no improvement in the upper-body strength and endurance of the experimental group. The researcher expected an improvement in upper-body strength and endurance, because of the inclusion of push-ups as a warm-up activity, especially explosive power push-ups (Siff & Verkhoshansky, 1993).

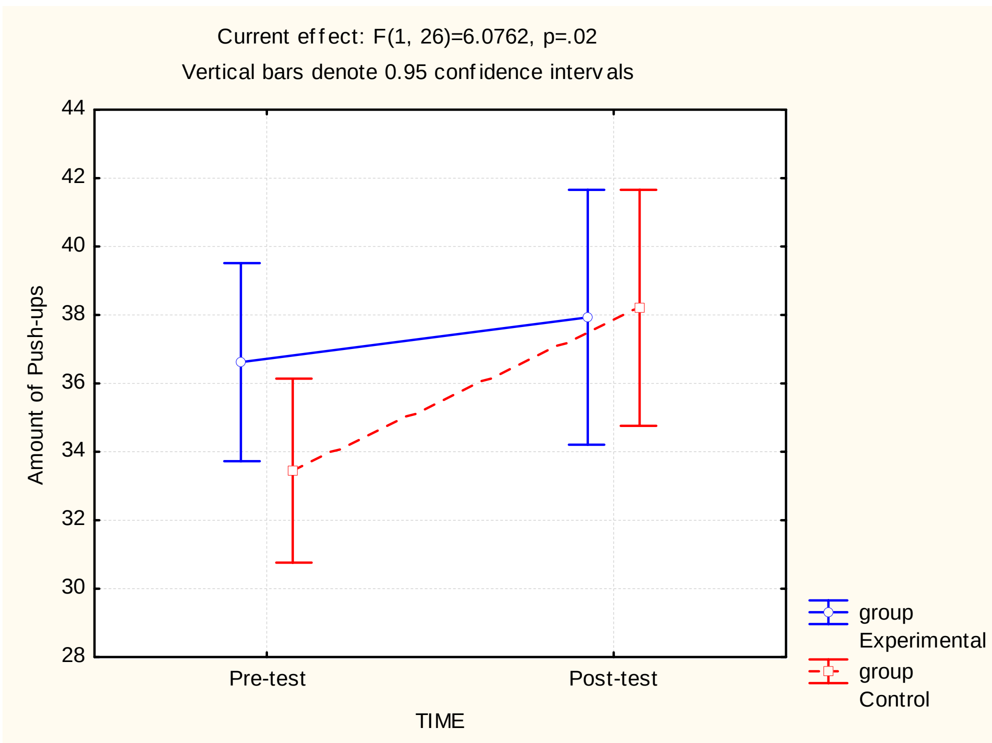

Figure 4.9: Pre- and post-test averages of the push-up test of the experimental and control group.

The researcher found a more significant improvement in the control group. This could be ascribed to the level of motivation, which may have improved during the season. The greater improvement demonstrated by the control group over the six-week period, could also be ascribed to the fact that these subjects have never trained scientifically and as regularly in the previous years.

4.4.3 Sit-up test

The pre- and post-test averages of the sit-up test of the experimental and control group are presented in Figure 4.10.

From Figure 4.10 it is evident that there is a no significant interaction between the two groups over time (p=0.12). According to the more detailed Bonferroni test neither the experimental group (Bonferroni p=1) nor the control group (Bonferroni p=0,79) averages changed over the six-week period. See Appendix I and J for detailed tables of analyses.

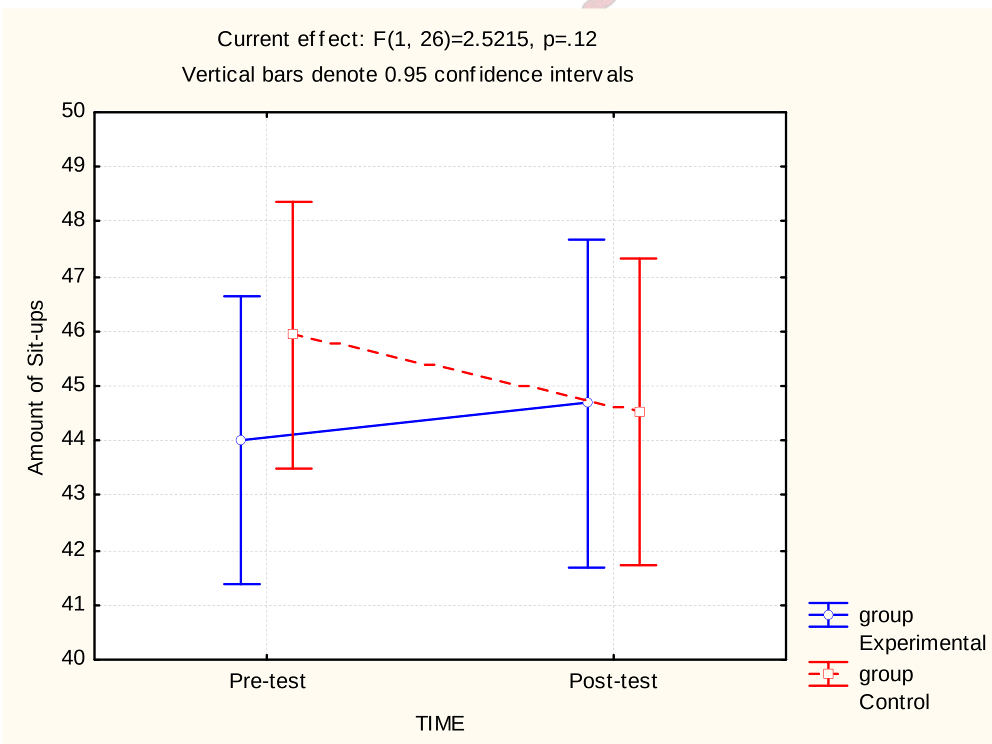

Figure 4.10: Pre- and post-test averages of the sit-up test of the experimental and control group.

In contrast to the experimental group, the control groups' graph changed direction from the pre-test to the post-test. Where the experimental groups' graph had a tendency to indicate improvement, the control groups' graph had a tendency to indicate a decrease in amount of sit-ups being executed.

The test is used to assess strength endurance of the abdominal region. Ideally the amount of sit-ups should show an increase after the intervention period. During plyometric activity the researcher focused on the execution of the different exercises. Research shows that the trunk stabilizers play a very important role in the execution of the exercises. The abdominal muscles have a prime mover and stabilizing function. The abdominal group was taxed during the execution of the exercise routine, as well as in the warm-up activity prior to the session (Turnbull *et al.*, 1995).

The results pertaining to the physical fitness aspects were mixed. There was a tendency to improvement in the cardiovascular fitness of the experimental group while that of the control group declined. Both groups had a tendency to show an improvement in upper-body strength due to the push-ups. Only the control group showed a statistically significant improvement in the push-up test. There was a tendency to improvement in the sit-up test of the experimental group while that of the control group indicated a decline.

4.5 BIOMOTOR PERFOMANCE RESULTS

4.5.1 Agility test (T-drill)

The agility test is designed to measure the ability of the players to accelerate and change direction from a vertical plain to moving in a horizontal plain (Bloomfield *et al.*, 1994). In this specific test the player is tested on power, speed explosiveness and agility. Lateral, forward and backward acceleration is tested. The prime movers play a very important role, but the adductor, abductor and stabilizers are also being taxed (Siff & Verkhoshansky, 1993).

The pre- and post-test averages of the agility test of the experimental and control group are presented in Figure 4.11.

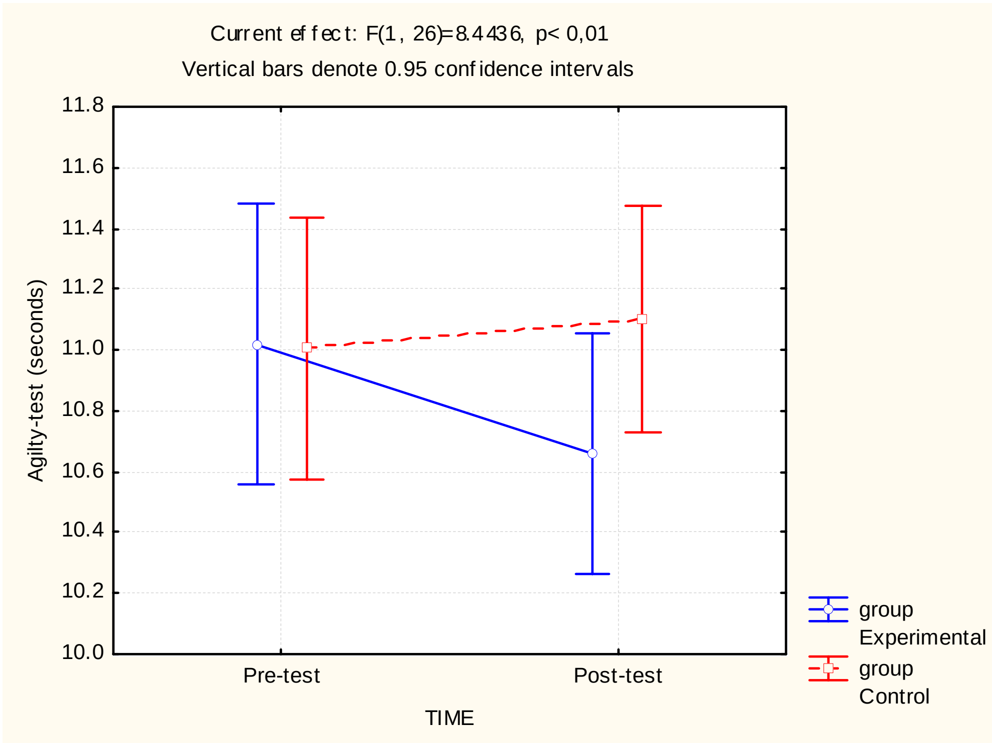

Figure 4.11: Pre- and post-test averages of the agility test times of the experimental and control group.

From Figure 4.11 it is evident that there is a significant interaction between the two groups over time ($p<0.01$). The control group average times for the T-drill stayed constant between the two tests (Bonferroni $p=1.0$) and the experimental group average time for the T-drill decreased significantly (Bonferroni $p=0.03$). See Appendix K and L for detailed tables of analyses.

The visual presentation [Figure 4.11] indicates a definite change in direction of the two graphs from the pre-test to the post-test. The more detailed Bonferroni test indicates a statistically significant improvement in the experimental group (Bonferroni $p=0.03$) over the six-week period in the agility test.

When one compares the averages of the pre-test and the post-test of the control group, in this specific test, it is found that there was actually an increase in their times in the agility test. This can be possibly due to the loss of motivation.

Relevant agility test scores of players in different positions, from various rugby teams, are presented in Table 4.1. The researcher compared the results of this study to the results of the South African national squad, the South African provincial squad and the South African under-19 squad. It is evident that the experimental group had similar scores before the intervention programme, but improved to even better scores over the six-week period.

Table 4.1: Agility test scores of players in different positions from various rugby teams.

	Time in Seconds								
	South African National Squad (Pre-season)		**South African Provincial (Pre-season)**		**South African Under 19 (Pre-season)**		**This study-Experimental Group**		
							Pre-test		**Post-test**
Position	**n**		**n**		**n**		**n**		
Props and Locks	6	11,75	5	11,96	2	12,15	5	11,54	10,96
Loose-Forwards	5	11,27	6	11,03	4	10,90	3	10,83	10,48
Fly-halves and Centres	4	10,84	6	10,86	5	11,23	4	10,81	10,55
Fullbacks and Wings	3	10,74	7	10,60	1	11,19	3	10,60	10,53

4.5.2 Ten-meter speed test

The purpose of this test is to determine the subject’s ability to accelerate from a stationary position and move quickly over a ten-meter distance. In rugby a player must be able to produce speed under conditions of fatigue. This would be relevant in the second and third phase of the game and beyond (Turnbull *et al*., 1995).

The pre- and post-test averages of the ten-meter speed test of the experimental and control group are presented in Figure 4.12.

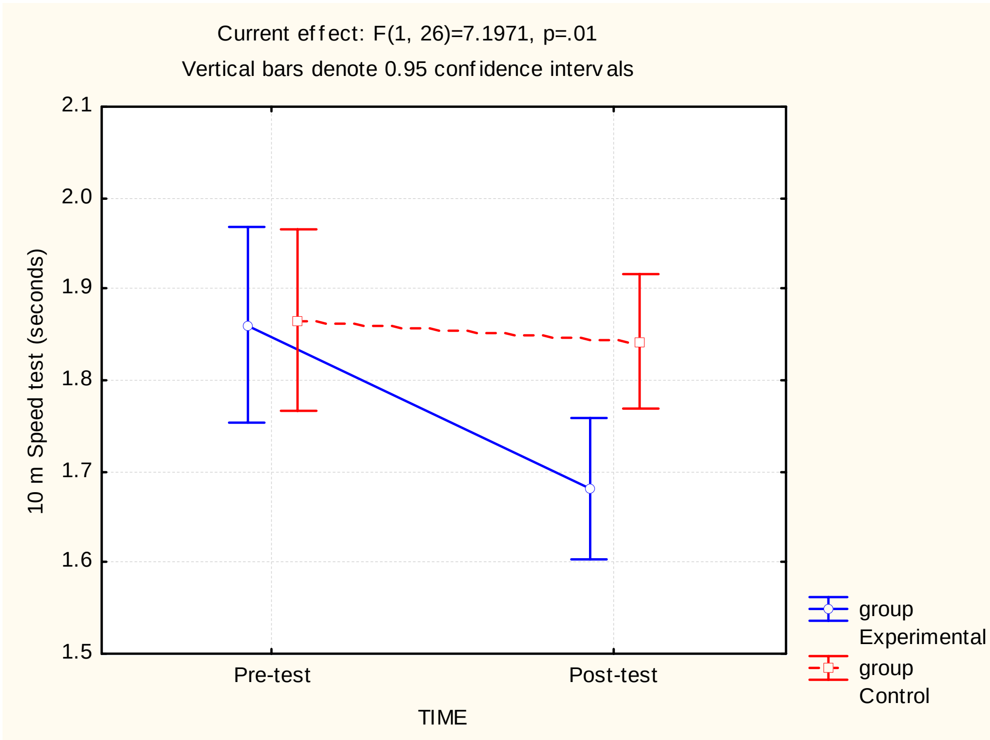

Figure 4.12: Pre- and post-test averages of the ten-meter sprint times of the experimental and control group.

There was a significant interaction between the two groups over time ($p<0.01$) [Figure 4.12]. The control group average time for the execution of the ten-meter sprint stayed constant between the two tests (Bonferroni $p=1.0$) and the experimental group average time for the ten-meter sprint decreased significantly (Bonferroni $p<0.01$). See Appendix K and L for detailed tables of analyses.

When compared, the statistically significant improvement of the experimental group's average time for the ten-meter speed test gives a clear indication of the type of advantages a plyometric programme holds for rugby players.

The sprinting times for various positions in a rugby team is set out in Table 4.2. The researcher compared the results of this study to the results of the South African squad. It is evident that the experimental group had similar scores before the intervention programme, but improved to even better scores over the six-week period.

Table 4.2: Sprinting times (seconds) from stationary start for players from a variety of teams

Team			**This Study – Experimental Group**	
Rugby Union			**Pre-test**	**Post-test**
South African Squad (Pre-season)	**n**	**10 m**		
Props and Locks	6	1,83	1,94	1,68
Loose-forwards and Scrum-halves	5	1,86	1,93	1,79
Fly-halves and Centres	4	1,80	1,75	1,62
Fullbacks and Wings	4	1,81	1,66	1,63

4.5.3 Sargent vertical jump test

The pre- and post-test averages of the Sargent vertical jump test of the experimental and control group are presented in Figure 4.13.

Figure 4.13 shows that there is a significant interaction between the two groups over time ($p<0.01$). The control group average vertical jump height increased slightly between the two tests, but is not statistically significant (Bonferroni $p=1.0$) and the experimental group average vertical jump height increased significantly (Bonferroni $p<0.01$). See Appendix K and L for detailed tables of analyses.

Literature states that plyometrics is an excellent training regime to improve explosive power in the legs (Siff & Verkhoshansky, 1993). Ideally the six-week plyometric-training programme should therefore lead to an increase in vertical jump height.

The vertical jump test is one of the most famous tests employed to give an indication of the explosive power of an athlete's legs. The statistically significant improvement in the experimental group's vertical jump height gives a clear indication of the way in which a six-week plyometric training programme could improve the explosive leg power of rugby players.

The vertical jump test gives an indication of a rugby player's ability to jump in a lineout. This test also focuses on a rugby player's ability to drive in mauls, rucks and in the scrum. Furthermore, the test will indicate the player's ability to tackle as well as to accelerate from standing start (Turnbull *et al*., 1995).

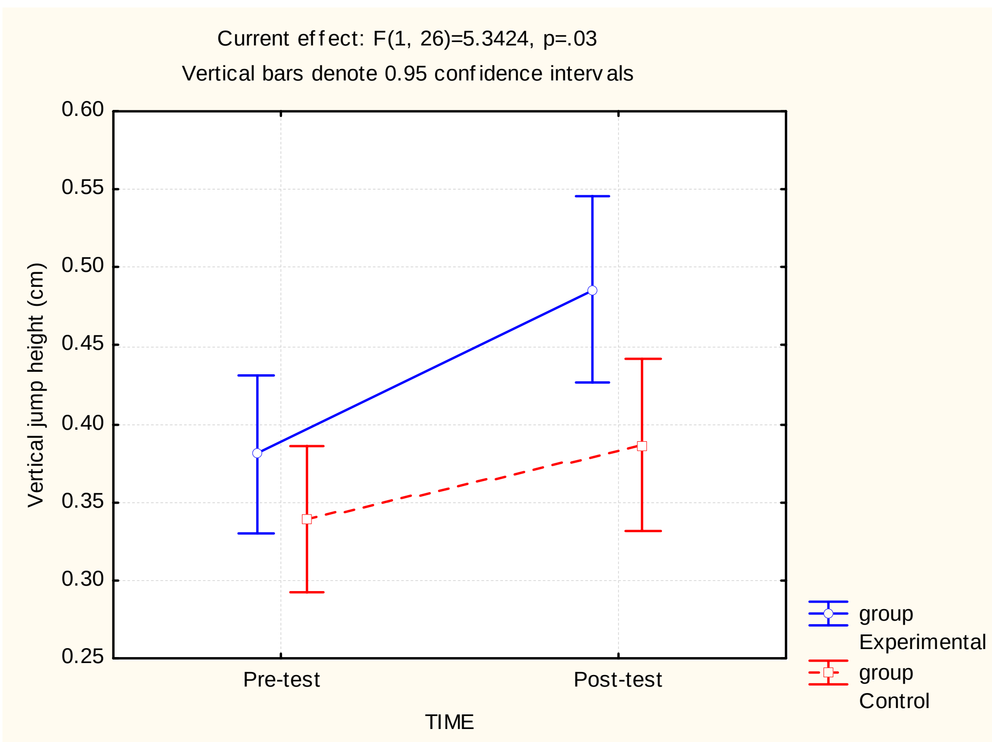

Figure 4.13: Pre- and post-test averages of the Sargent vertical jump height of the experimental and control group.

4.5.4 Depth jump test

According to the literature an athlete drops (does not jump) to the ground from a raised platform or box, then immediately jumps up and touch the mounted calibrated measuring board on the vertical wall in front of them. The downward drop causes a pre-stretch of the leg muscles and the vigorous drive upward affects the secondary contraction. The effectiveness of the exercise will be greatly enhanced if the time that the feet are in contact with the ground is shortened significantly. In the experiment of the depth jump the height that the subjects reached, was taken (Chu, 1998; Fowler & Lees, 1990).

The pre- and post-test averages of the depth jump height of the experimental and control group are presented in Figure 4.14.

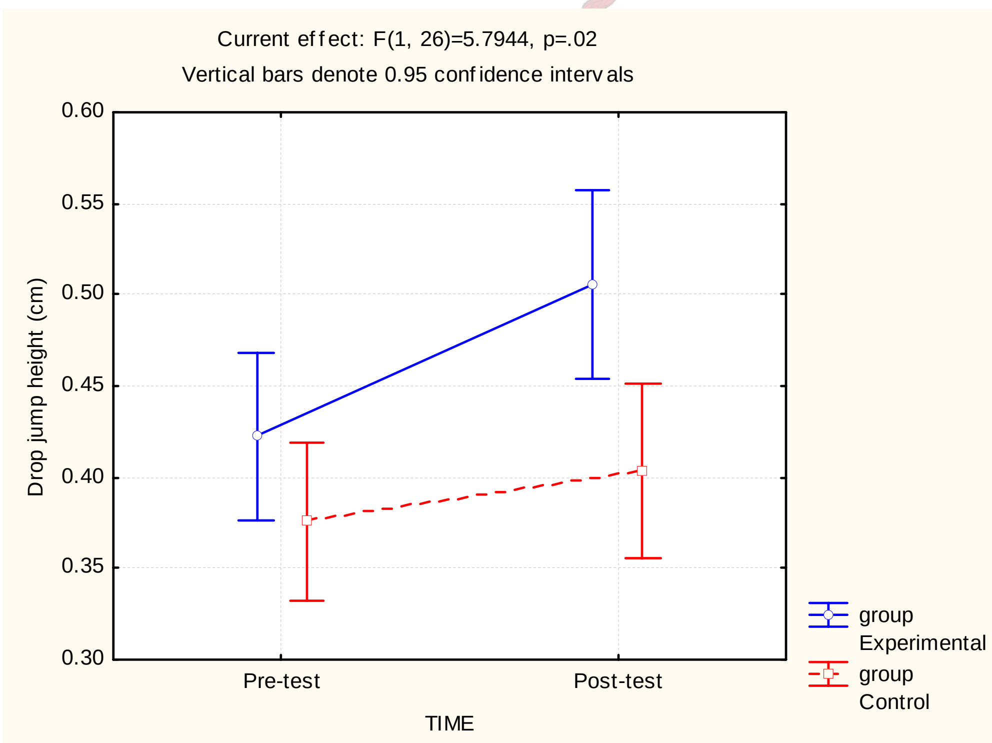

Figure 4.14: Pre- and post-test averages of the depth jump height of the experimental and control group.

From Figure 4.14 it is evident that there is a strictly significant statistically interaction between the two groups over time ($p=0.02$). The control group average has a tendency to indicate an improvement, but is not statistically significant (Bonferroni $p=0,6$). The experimental group average increased significantly (Bonferroni $p<0.01$). See Appendix K and L for detailed tables of analyses.

The visual presentation [Figure 4.14] indicates that both the group averages improved over the six-week period. It is clear that the experimental team had a bigger improvement when comparing the gradient of the graphs.

The control group showed little improvement in this exercise, although they did not participate in the plyometric-training programme, but the improvement was not statistically significant.

In the pre-test a difference in the average depth jump heights of the experimental and control group was noted. This was probably due to the fact that the experimental group subjects were more developed, trained and in better physical condition. They also spent more time training and in addition trained with stronger teams. The improvement of the depth jump height was statistically significant for the experimental group, but not for the control group. This could be ascribed to the six-week period of the plyometric intervention programme.

4.5.5 Standing triple jump test

In this test the subject's ability to accelerate from a standing start, speed and power over 15 to 30 meters and the ability to drive in a rolling maul as well as the ability to change direction at high speed, is measured (Turnbull *et al*., 1995).

The pre- and post-test averages of the standing triple jump test of the experimental and control group are presented in Figure 4.15. Figure 4.15 illustrates a significant interaction between the two groups over time ($p<0.01$). The control group average distance jumped, indicate a tendency to improve, but no statistically significant improvement was noted between the two tests (Bonferroni p=0,4). The experimental group average distance increased significantly over the six-week period (Bonferroni p<0.01). See Appendix K and L for detailed tables of analyses.

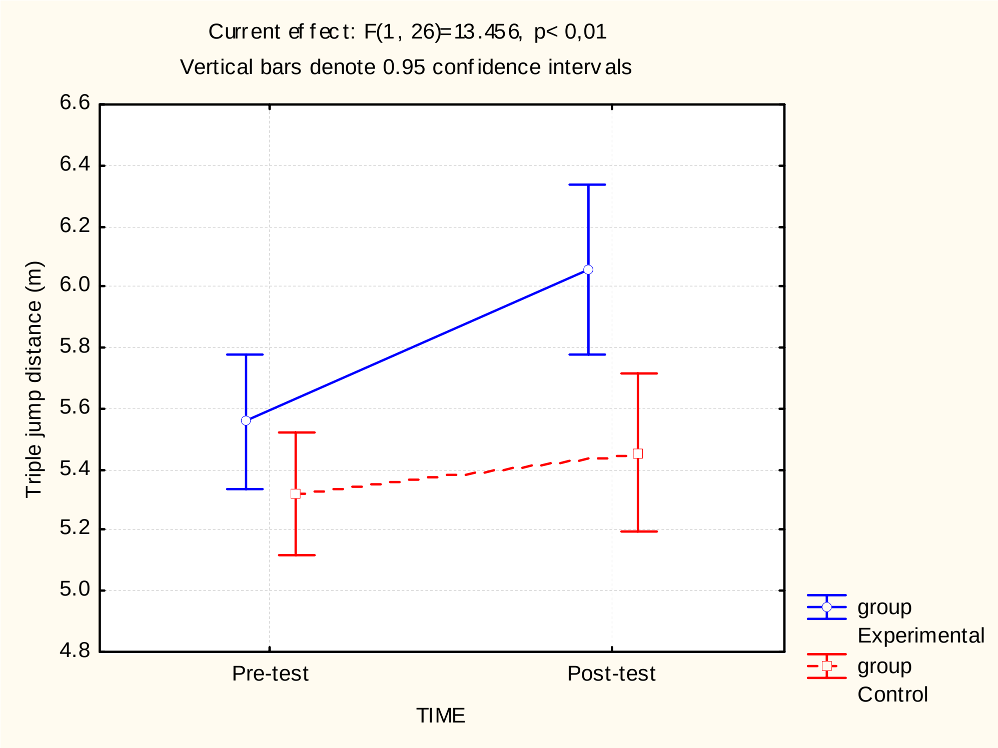

Figure 4.15: Pre- and post-test averages of the standing triple jump distance of the experimental and control group.

After the plyometric-training programme, the experimental group showed a much greater improvement in the distance achieved in the standing triple jump than the control group. This improvement must be due to the six-week plyometric training intervention programme that the experimental group followed.

The control group showed only a slight improvement between pre-test to post-test of the triple jump distance. According to the detailed Bonferroni test the improvement was not statistically significant (Bonferroni p=0,4). The improvement could be ascribed to the level of excitement, adrenaline and previous experience.

4.5.6 Rugby agility run test

The pre- and post-test averages of the rugby agility run of the experimental and control group are presented in Figure 4.16.

Good rugby is played with speed, but unlike an athlete the player has to perform his speed without the normal arm action. Sometimes the ball has to be held in both hands in front of the body, under the one arm, close to the chest, or abdomen in a lowered body position. The player has to sprint in an exclusive way to avoid a tackle or may have to change direction quickly (Turnbull *et al*., 1995).

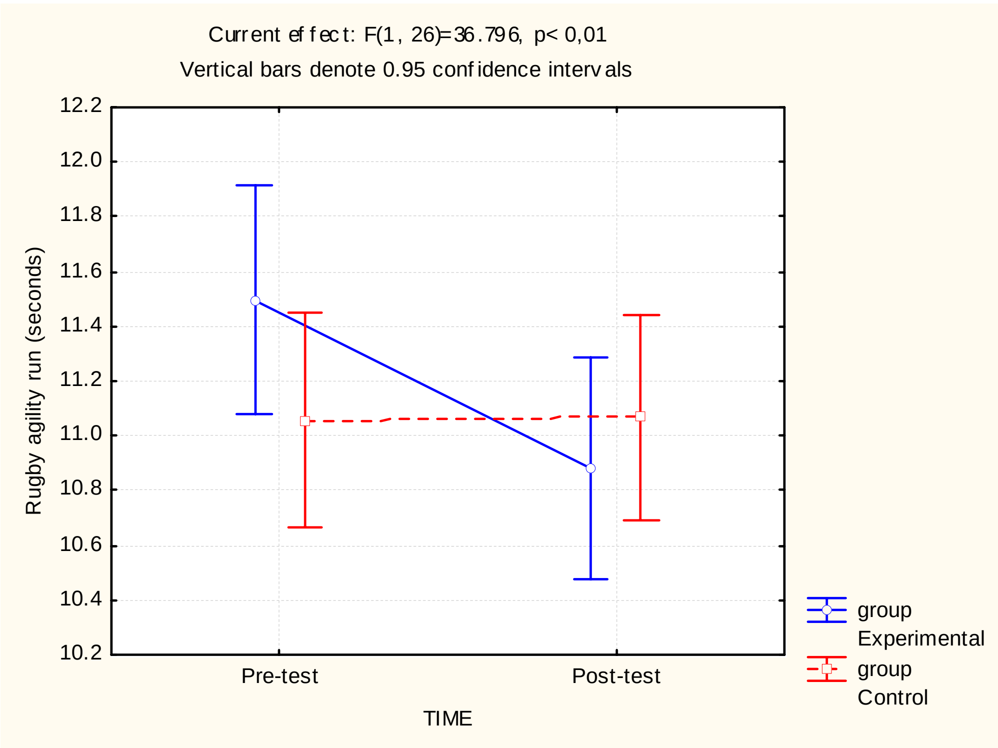

Figure 4.16: Pre- and post-test averages of the rugby agility run times of the experimental and control group.

Figure 4.16 indicates a significant interaction between the two groups over time ($p<0.01$). The control group average time for the rugby agility run stayed constant between the two tests (Bonferroni $p=1.0$) and the experimental group average time for the rugby agility run decreased significantly (Bonferroni $p<0.01$). See Appendix K and L for detailed tables of analyses.

When the averages of the pre-and post-test times for the rugby agility run, of the experimental group are compared a statistically significant improvement is evident. The players gained the ability to accelerate from a static position as well as agility and speed while running with a rugby ball. The results indicate that the above-mentioned vital skill improved as a result of the six-week plyometric intervention programme. The control group on the other hand, showed no improvement in average times for the rugby agility run in the pre- and post-test.

Normative data pertaining to the evaluation of the rugby agility run is set out in Table 4.3 (Bloomfield & Drewett, 1994). It is a compilation of scores from Western Australian Rugby Union State representatives as well as selected players from Sydney's (New South Wales) first grade clubs. The results are reported for players in various positions and the differences in mean scores reflect their respective roles. The tight five group (Group A) includes the props, hookers, and second rows, while group B contains the lock and breakaways, Group C composes of scrum-half and fly-half, whereas group D include the centres, the wings and the fullback (Bloomfield & Drewett, 1994). The sprinting times for various positions in a rugby team is set out in Table 4.3. The researcher compared the results of this study to the results of the Western Australian Rugby Union State representatives as well as selected players from Sydney's (New South Wales) first grade clubs. It is evident that the experimental group had better scores before the intervention programme, but improved even more over the six-week period.

Table 4.3: Normative data for rugby players on the agility run (Bloomfield, Ackland & Elliott, 1994).

		This Study – Experimental Group	
		Pre-Test	**Post-Test**
Group time (s)	**Mean agility run**		
A	15,78	11,62	11,20
B	14,41	11,22	10,85
C	14,50	11,38	10,93
D	14,68	11,22	10,62

4.5.7 Medicine Ball Chest Pass test

The pre- and post-test averages of the medicine ball chest pass distance of the experimental and control group are presented in Figure 4.17.

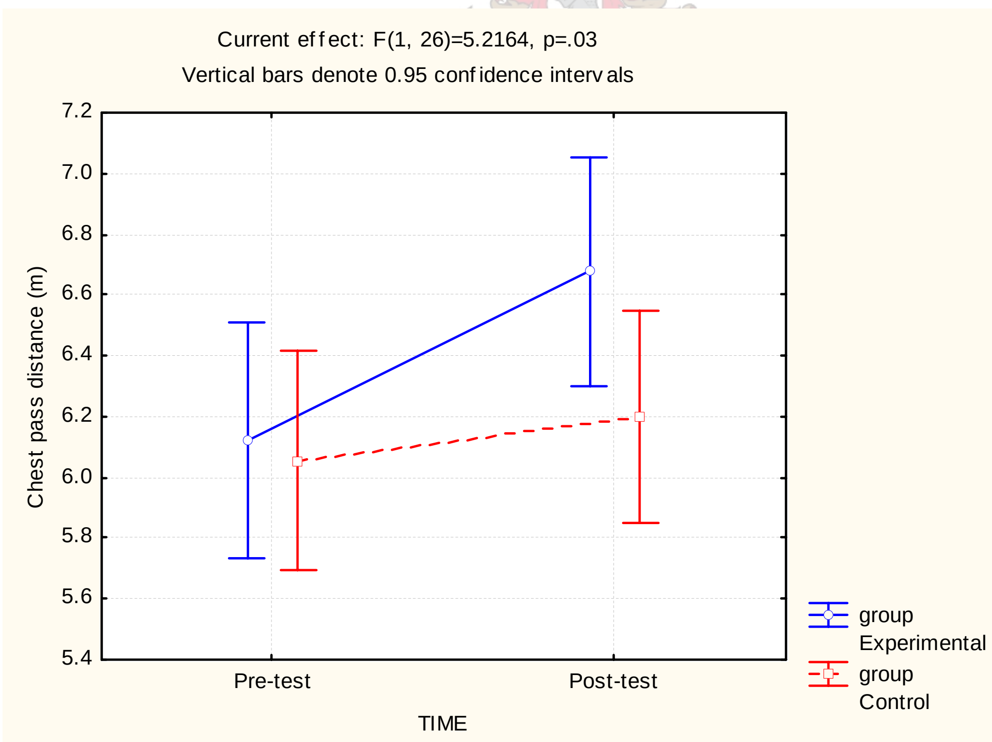

Figure 4.17: Pre- and post-test averages for medicine ball chest pass distance of the experimental and control group.

Figure 4.17 indicates a strictly statistical significant interaction between the two groups over time (p=0,03). The control group average for the medicine ball chest pass stayed constant between the two tests (Bonferroni p=1.0) and the experimental group average for the medicine ball chest pass distance increased significantly (Bonferroni p<0.01). See Appendix K and L for detailed tables of analyses.

The statistically significant improvement in the experimental group's medicine ball chest pass distance is probably the result of the six-week plyometric programme. Push-ups with a hand-clap in between is a particularly vigorous way to condition the arms and chest. They formed part of the plyometric-training programme and could have contributed to the significant improvement in the medicine ball chest pass distance of the experimental group (Siff & Verkhoshansky, 1993; Tenke & Higgins, 1996). The pre-stretch takes place as the hands arrive back on the ground and the chest sinks, as this is followed by the explosive upwards action.

The results pertaining to the biomotor performance skills indicated that the plyometric-training programme had a positive effect on the experimental group, compared to the control group. The experimental group's vertical jump height, depth jump height, standing triple jump distance, agility run time, rugby agility run time and ten-meter speed time, improved. The control group's results showed such a small improvement that was not noted as being statistically significant.

It is, however, extremely important to state that the small sample size of each group had a limiting effect on the statistical power. This restricted the ability to detect small differences, as well as non-significant changes.

CHAPTER FIVE

CONCLUSION

The aim of this study was to look into the effect of a plyometric-training programme on the explosive power, agility and speed of high school rugby players aged between 16 and 18 years. In addition to the biomotor skills, the effect of the plyometric training on certain physiological characteristics as well as physical fitness were also determined.

The original study group consisted of a convenience sample of 30 male rugby players. This method of sampling makes no pretense of being representative of a population, but is affordable and easily executable. Twenty-eight (28) of the players completed the exercise programme as two from the experimental group withdrew due to injuries. The study group was divided into two groups. The experimental group [n=15] participated in the six-week plyometric intervention programme in addition to conventional rugby training and the control group persisted only with conventional rugby training.

From the analysis of the results of this study it was clear that:

1. Even a relatively short programme of plyometric training produced positive changes in the abilities of rugby players.
2. Plyometrics produce positive results in the physical capabilities of those using this training (these physical capabilities were a compound aggregate of: explosive power [demonstrated by the triple jump, depth jump and vertical jump], speed [ten-meter speed test] and agility [agility runs]).
3. Equally, the plyometric programme also produced positive and beneficial anthropometric changes (demonstrated by body composition and girth measurements) for rugby players.
4. This short plyometric programme also improved cardiovascular fitness (as tested by the three-minute step test) and lower body muscle endurance (as tested by the sit-up test) though upper body muscle groups (as tested by the push-up test), did not

improve, probably due to the type of plyometric exercises that targeted lower body muscle groups more specifically.

It could therefore be concluded that a relatively short programme of specific plyometric training would be beneficial to young rugby players in the sense that it would improve explosive power, speed and agility considerably, bring about positive anthropometric changes as well as cardiovascular fitness and muscle endurance of muscle groups specifically targeted in the plyometric exercises.

The programme also provided a much-needed cross–training regime, which elicited a positive social and physiological effect from the participants. Especially those subjects who did not feel comfortable with the traditional training programmes, consisting of jogging, showed great enjoyment of the programme.

The researcher highly recommends a plyometric-training programme to rugby players at any fitness level and participation, provided that participants undergo an extensive pre-screening investigation to rule out the possibility of aggravation of previous injuries. The possible negative effects of a plyometric-training programme are insignificant in comparison with the proven beneficial results thereof, not only as a functional cross-training regime, but also as a possible preventative mechanism for various injuries.

The study had the following limitations:

1. It must be stated that the small sample size of each group had a limiting effect on the statistical power. This restricted the ability to detect small differences, as well as non-significant changes.

2. The subjects were not always able to exercises at the same time of the day, because they were busy preparing for the mid-year examination. The subjects had to exercise when they were able to fit it into their schedule. Sometimes the exercise sessions took place in the early morning, and at other times it was in the late afternoon.

3. The subject’s physical activity levels outside of the plyometric-training programme could not be controlled. The subjects of this study had to participate in the conventional rugby training sessions, which not only included the basic functional training sessions, but also fitness training, gym training and other sporting activities offered by the school. A few of the subjects were also selected for regional teams, which meant that they participated in, not only the school training session, but also the regional training sessions. The inability to control the activity of the subjects, also made it impossible for the researcher to control the physical state of the subjects with regards to injuries. During the six-week training period, two subjects could not continue with the plyometric training sessions due to ankle (1) and knee (1) injuries. Both these subjects were from the first team. They were replaced by two players from the third team. Both subjects got injured while playing touch rugby as a warm-up prior to their rugby training session.

The following recommendations are made for further work:

1. Further work ought to utilize a larger number of subjects over a wider age range in both the experimental and control group.
2. A larger and more intensive and targeted plyometric programme, suited specifically to different positions in the game of rugby as well as a longer plyometric-training programme.
3. The influence of plyometric training in the prevention of knee and ankle injuries should be defined.
4. Further research to show that aquatic plyometric training could be an alternative to enhance sport performance.

The value of the enjoyment of the plyometric exercises and the positive motivational effect on the players and the quality of their game in general should not be underestimated. It would therefore be an interesting and important dimension to add to any research project of this nature.

APPENDIX A

ANALYSIS OF WARM-UP, PLYOMETRIC AND COOLDOWN EXERCISES DESIGNED FOR THE DEVELOPMENT OF SPEED, AGILITY AND EXPLOSIVE POWER IN RUGBY

Exercise	Time	Sets	Rest
Weeks 1,2			
Day one			
1. Spot hopping	**5 seconds**	**2**	**1 minute**
2. Vertical jumps	**5 seconds**	**2**	**1 minute**
3. 360° jumps	**5 seconds**	**2**	**1 minute**
4. Multiple long jumps	**5 seconds**	**2**	**1 minute**
Day two			
5. Tuck jumps	**5 seconds**	**2**	**1 minute**
6. Heel to Buttocks	**5 seconds**	**2**	**1 minute**
7. Lateral hops	**5 seconds**	**2**	**1 minute**
8. Double-leg bounding	**5 seconds**	**2**	**1 minute**
Week 3,4			
Day one			
9. Squat jumps	**7 seconds**	**2**	**1 minute**
10. Alternative-leg bounding	**7 seconds**	**2**	**1 minute**
11. Tuck jumps	**7 seconds**	**2**	**1 minute**
12. Single-leg hopping	**7 seconds**	**2**	**1 minute**
Day two			
13. Vertical jumps	**7 seconds**	**2**	**1 minute**
14. Double-leg Bounding	**7 seconds**	**2**	**1 minute**
15. Alternative-leg Bounding	**7 seconds**	**2**	**1 minute**
16. Single-leg hopping	**7 seconds**	**2**	**1 minute**
Week 5,6			
Day one			
17. Squat jumps	**10 seconds**	**2**	**1 minute**
18. Alternative-leg bounding	**10 seconds**	**2**	**1 minute**
19. Single-leg bounding	**10 seconds**	**2**	**1 minute**
20. Lateral hops	**10 seconds**	**2**	**1 minute**
Day two			
21. Vertical jumps	**10 seconds**	**2**	**1 minute**
22. Tuck jumps	**10 seconds**	**2**	**1 minute**
23. Double-leg (Back and Forth)	**10 seconds**	**2**	**1 minute**
24. Single-leg hops	**10 seconds**	**2**	**1 minute**

APPENDIX B

DESCRIPTION OF THE PLYOMETRIC EXERCISES

1. SPOT-HOPPING
Keep hands on the hips
Hop vertically on the spot as rapidly as possible
2. VERTICAL JUMPS
One or two-foot take-off
Jump for the maximum height
Immediately repeat upon landing
Keep back straight
3. 360° JUMPS
Two-foot take-off
360° jump after take-off
Repeat next jump in the opposite direction
Perform as quickly as possible
4. MULTIPLE LONG JUMPS
Two-foot take-off
Jump for distance
Short rest between repetitions
5. TUCK JUMPS
Grabbing the knees in the air
Repeat immediately upon landing
6. HEEL KICKS
Two-foot take-off
In the air, kick heels back and touch the hands
Repeat immediately upon landing
7. LATERAL HOPS
One or two-foot take-off
Over a cone and back
Repeat immediately upon landing
8. BOUNDING
Long strides for distance
High knees, powerful leg drive

9. SQUAT JUMPS
Two-foot take-off
Hands on hips
Deep knee flexion when landing
10. DOUBLE-LEG BACK AND FORTH
Two-foot take-off
Over cone front then backwards
Repeat upon landing

APPENDIX C

PRE-TEST QUESTIONNAIRE

1. In which sports do you participate for leisure?………………………..
2. In which sports do you take part competitively? (Which team, and your position, if you participate in a team sport)………………………
3. Have you ever had any knee, ankle, or lower back problems?………..
4. If so, how long ago and how did the injury occur?……………………
5. Did you receive any treatment for the injury, by whom?……………..
6. Highest achievement in sport? (Which sport) ………………………...
7. Do you have normal eating habits (that is regular balanced meals)?….
8. Do you eat breakfast? What?…………………………………………...
9. Do you eat lunch? What?………………………………………………
10. Do you eat supper? What?……………………………………………...
11. Have you recently gained or lost more than 3 kg?……………………...
12. Do you use any supplements? (Creatine Monohydrate, Meal replacements, Protein Shakes?)……………………………………..
13. Do you participate in regular aerobic exercises? (eg. Jogging, swimming etc.)………………………………………………………
14. Have you participated in a plyometric training programme before?……………..
15. Do you think you will benefit from a plyometric programme?……….
16. How long do you sleep?……………………………………………..
17. Are you on permanent medication?…………………………………….
18. Do you have any permanent disease (eg. Diabetes)?…………………..
19. Why do you want to participate in this research project?……………...

APPENDIX D

Informed consent form as recommended by the American College of Sports Medicine

1. Purpose and explanation of tests and programme

I hereby consent to voluntary engage in exercise tests to determine my heart rate, blood pressure, fitness assessment (push-ups, sit-ups, sit and reach test), body fat percentage, girth measurements, T-test, Rugby agility run, 10 meter speed test, vertical jump test, triple jump test, chest pass as well as being part of the experimental group in a six-week plyometric training programme which consist of two sessions a week for 45 min. each.

Before I undergo the tests, I certify to the programme that I am in good health and have currently now injury. I understand that it is important that I provide complete and accurate response to the test supervisor and recognise that my failure to do so could lead to possible injury to myself during the tests and during training programme.

It is my understanding and I have been clearly advised that it is my right to request that a test/training session be terminated at any point if I experience discomfort or fatigue. My wishes in this regard shall be absolutely carried out.

I realise that a true determination of my capacity during above-mentioned tests and training programme depends upon me performing them to the best of my ability.

2. Risks

I understand and have been informed that there exists the possibility of changes during and after the tests and training programme. The changes could include delayed onset muscle soreness (muscle stiffness). I understand that there are minimal risks of injury as a result of my performance of the tests and training programme, but knowing those risks, it is my desire to proceed to undertake the tests and participate in the training programme.

3. Benefits to be expected

The results of these tests and training programe may or may not benefit me. Potential benefits could include a lower percentage body fat, improved explosive power, speed and agility and improved core stabilisation.

4. Confidentiality and use of information

I have been informed that the information obtained in these exercise tests and training programme will be treated as privileged and confidential and will consequently only be used for research and statistical purposes.

5. Inquiries and freedom of consent

I have been given the opportunity to ask questions as to the procedures. I further understand that there are remote risks associated with these procedures, but I still wish to proceed with the test and training programme.

I acknowledge that I have read this document in its entirety.

Dated at: _______________

Signed: Parent _________

Scholar _________; Position _________; Weight _______; Team _______

Full names (please print): ____

APPENDIX E

TABLE 1: RAW DATA OF THE PHYSICAL CHARACTERISTICS OF THE EXPERIMENTAL GROUP; WEIGHT, RESTING HEART RATE, BLOOD PRESSURE

Subject	Weight (kg)	Heart Rate	BP Sysitolic	Bp Diastolic
1	103,00	64	124	82
2	81,40	64	124	80
3	107,40	72	122	88
4	97,80	80	124	78
5	94,40	72	124	80
6	85,60	65	124	78
7	84,00	64	130	76
8	94,20	70	124	84
9	76,00	72	120	80
10	80,00	60	118	78
11	79,00	62	120	82
12	71,25	65	116	76
13	77,90	70	118	78
14	78,25	72	120	80
15	101,20	68	122	82

APPENDIX F

TABLE 2: RAW DATA OF THE PHYSICAL CHARACTERISTICS OF THE CONTROL GROUP; WEIGHT, RESTING HEART RATE, BLOOD PRESSURE

Subject	**Weight(kg)**	**Heart Rate**	**BP Sysitolic**	**Bp Diastolic**
1	84,35	64	124	82
2	82,40	64	124	80
3	102,00	72	122	88
4	87,00	80	124	78
5	92,60	72	124	80
6	92,00	65	124	78
7	84,00	64	130	76
8	80,00	70	124	84
9	80,00	72	120	80
10	70,80	60	118	78
11	79,80	62	120	82
12	82,60	65	116	76
13	83,00	70	118	78
14	78,50	72	120	80
15	88,60	68	122	82

APPENDIX G

TABLE 3: RAW DATA OF THE PHYSICAL CHARACTERISTICS OF THE CONTROL GROUP; WEIGHT, RESTING HEART RATE, BLOOD PRESSURE AND GIRTH MEASUREMENTS (PRE-AND POST TEST)

PRE TEST (CONTROL)					GIRTH MEASUREMENTS								
PLAYER	WEIGHT	PRESSURE			CHEST	WAIST	HIPS	ARMS		THIGHS		CALVES	
	(kg)	RHR	SP	DP				R	L	R	L	R	L
1	84,35	74	120	78	100.0	96.0	103.0	31.0	31.0	61.0	60.5	39.0	40.0
2	82,40	64	120	74	102.0	83.0	102.0	31.0	31.0	60.5	60.5	38.0	38.0
3	102,00	68	118	80	109.5	98.5	96.5	37.0	38.0	66.5	66.5	44.0	45.0
4	87,00	70	116	82	102.0	94.5	96.0	33.0	32.5	62.0	61.5	40.0	39.5
5	92,60	61	119	80	101.0	90.0	97.0	30.5	30.5	61.5	61.0	38.5	39.0
6	92,00	64	120	80	99.5	83.0	89.0	32.5	31.5	63.0	64.0	40.5	39.5
7	84,00	60	122	82	98.5	82.0	88.0	31.0	31.5	62.5	62.5	39.0	39.0
8	80,00	58	120	78	96.0	81.0	85.0	30.0	28.0	59.0	59.0	39.5	39.0
9	80,00	60	120	77	97.0	83.5	85.0	32.0	31.5	61.0	61.5	37.5	36.5
10	70,80	64	124	79	92.0	73.5	78.0	29.0	30.5	54.0	55.0	35.0	35.0
11	79,80	65	120	80	96.5	78.0	80.0	30.5	30.5	59.0	58.0	37.5	37.5
12	82,60	66	117	80	96.0	79.5	82.0	30.0	30.0	62.0	61.0	36.0	37.5
13	83,00	70	118	80	97.0	80.5	84.0	30.0	29.5	60.5	61.0	42.0	42.0
14	78,50	72	120	78	94.5	82.0	86.0	29.0	27.0	62.5	62.0	38.5	38.0
15	88,60	68	120	78	90.0	83.0	86.0	28.5	28.5	63.0	63.0	39.0	38.5

POST TEST(K)					GIRTH MEASUREMENTS								
PLAYER	WEIGHT	PRESSURE			CHEST	WAIST	HIPS	ARMS		THIGHS		CALVES	
	(kg)	RHR	DP	SP				R	L	R	L	R	L
1	85,00	76	118	80	100.0	96.0	103.5	31.0	31.0	61.0	60.5	39.5	40.0
2	81,50	62	120	76	101.0	84.0	103.5	31.5	31.5	60.5	60.0	38.0	38.0
3	103,50	65	120	80	110.5	99.0	95.5	37.5	38.0	66.5	66.0	44.0	44.5
4	87,00	72	118	80	100.0	95.0	96.5	33.0	32.5	61.5	61.5	41.0	39.5
5	92,15	62	122	78	98.5	90.0	97.5	30.5	30.5	61.0	61.0	39.5	39.0
6	91,15	60	124	80	97.0	84.0	90.5	32.5	31.5	64.0	64.0	40.5	40.0
7	84,00	60	120	78	98.0	83.0	89.5	31.0	31.5	62.0	62.5	39.0	39.5
8	80,50	60	122	78	95.5	80.0	87.0	30.0	29.0	60.0	60.0	39.0	39.0
9	78,00	58	120	82	95.0	84.0	86.5	31.5	31.5	60.0	60.0	37.5	37.0
10	71,00	60	126	84	90.0	75.0	79.5	30.5	30.0	55.0	55.5	35.5	35.5
11	78,35	62	120	80	96.5	78.5	81.0	30.0	30.0	58.0	58.0	37.0	37.0
12	82,50	68	122	82	96.0	80.0	81.5	30.5	30.0	61.0	61.0	36.5	36.5
13	81,50	65	120	80	95.5	81.0	83.5	30.0	30.0	60.0	60.5	41.5	42.0
14	78,50	68	118	80	94.5	81.5	86.5	29.0	28.0	61.5	61.0	38.0	38.0
15	88,25	66	122	82	89.5	81.5	86.5	28.0	28.5	62.5	62.0	39.0	38.5

APPENDIX H

TABLE 4: RAW DATA OF THE PHYSICAL CHARACTERISTICS OF THE EXPERIMENTAL GROUP; WEIGHT, HEART RATE, BLOOD PRESSURE (PRE-AND POST TEST)

PRE TEST (EXPERIMENTAL GROUP)					GIRTH MEASUREMENTS								
PLAYER	WEIGHT	PRESSURE			CHEST	WAIST		HIPS	ARMS		THIGHS		CALVES
	(kg)	RHR	SD	DD				R	L	R	L	R	L
1	103,00	64	124	82	108,00	93,00	109,00	36.00	36.50	67.50	65.50	39.50	38.00
2	81,40	64	124	80	97,50	85,00	97,50	31.00	31.00	63.50	64.00	42.50	43.00
3	107,40	72	122	88	106,00	93,00	108,50	34.20	36.00	68.20	65.50	42.70	42.50
4	97,80	80	124	78	102,00	91,00	108,00	32.00	32.50	62.00	62.00	38.00	38.50
5	94,40	72	124	80	102,00	85,00	100,00	31.00	30.50	65.00	65.50	39.00	40.00
6	85,60	65	124	78	100,00	87,00	88,00	32.50	32.50	62.00	62.00	38.50	38.00
7	84,00	64	130	76	97,00	75,00	91,00	30.00	31.00	60.00	59.50	41.00	40.50
8	94,20	70	124	84	103,50	85,00	104,00	29.00	27.50	62.00	61.00	39.50	38.00
9	76,00	72	120	80	95,00	87,00	94,00	29.00	29.00	60.00	60.00	40.00	40.00
10	80,00	60	118	78	97,00	79,00	93,50	30.00	29.50	58.00	60.00	35.00	36.00
11	79,00	62	120	82	92,00	78,00	90,00	29.50	29.00	59.50	59.50	36.00	35.50
12	71,25	65	116	76	94,50	76,00	91,00	28.50	28.50	55.50	56.50	35.00	36.00
13	77,90	70	118	78	96,00	74,00	87,00	29.00	29.00	55.00	55.00	35.50	35.00
14	78,25	72	120	80	98,00	75,00	90,00	28.50	29.00	57.50	57.50	36.00	36.00
15	101,20	68	122	82	107,00	87,00	105,00	33.00	32.00	60.00	60.00	41.00	40.00

POST TEST (EXPERIMENTAL GROUP)					GIRTH MEASUREMENTS								
PLAYER	WEIGHT	PRESSURE			CHEST	WAIST		HIPS	ARMS		THIGHS		CALVES
	(kg)	RHR	DP	SP				R	L	R	L	R	L
1	106,00	62	120	82	108,00	92,50	107,00	36.0	36.0	68.0	68.0	39.0	39.0
2	81,50	60	122	82	97,00	85,50	95,50	31.0	31.0	64.5	64.5	42.5	42.5
3	107,50	65	124	78	107,00	92,00	105,50	35.0	36.0	68.0	67.5	43.0	43.0
4	96,50	76	126	80	103,00	90,00	106,50	33.0	33.0	62.0	62.0	38.0	38.0
5													
6	85,50	65	120	80	95,00	85,00	87,00	33.0	33.0	62.5	62.5	39.5	40.0
7													
8	94,00	72	126	80	104,00	84,50	102,50	30.0	30.0	62.0	61.5	39.5	39.0
9	77,00	70	120	82	96,00	95,00	95,00	29.5	29.0	60.5	60.5	41.5	40.5
10	81,00	58	120	80	98,00	96,00	90,00	30.0	30.0	59.0	59.5	36.0	36.5
11	80,60	60	122	82	93,00	90,00	90,00	29.5	29.0	58.0	58.0	36.5	36.5
12	73,00	64	124	80	96,50	93,50	90,00	29.0	29.0	55.5	56.0	35.5	36.0
13	78,00	65	120	80	95,50	94,50	86,00	30.0	30.0	56.0	56.0	35.5	36.0
14	79,00	70	118	78	99,00	95,50	85,00	29.0	29.0	58.0	58.0	36.5	36.5
15	98,00	65	124	80	107,50	105,50	102,50	33.6	33.0	61.0	61.0	41.0	41.0

APPENDIX I

TABLE 5: RAW DATA OF FITNESS ASSESSMENT OF THE CONTROL GROUP

PRE TEST (CONTROL GROUP)				
PLAYER	FITNESS ASSESSMENT			
	SIT AND REACH TEST	PUSH-UPS	SIT-UPS	3-min step test
1	10	25	43	110
2	13	30	43	100
3	3	26	46	105
4	10	34	48	102
5	12	38	50	98
6	14	40	50	105
7	2	36	48	91
8	5	37	50	92
9	14	35	46	100
10	12	39	45	94
11	3	34	45	98
12	12	32	40	100
13	6	30	40	89
14	1	30	45	90
15	-2	36	50	85

POST TEST (CONTROL GROUP)				
PLAYER	FITNESS ASSESSMENT			
	SIT AND REACH TEST	PUSH-UPS	SIT-UPS	3-min step test
1	8	29	40	105
2	7	38	39	102
3	2	32	36	100
4	12	35	45	105
5	10	46	48	100
6	15	51	56	100
7	3	46	48	95
8	4	45	50	100
9	12	45	45	95
10	14	38	40	96
11	3	34	42	100
12	12	34	38	100
13	6	32	45	90
14	4	32	46	90
15	0	36	50	88

APPENDIX J

TABLE 6: RAW DATA OF THE FITNESS ASSESSMENT OF THE EXPERIMENTAL GROUP

PRE TEST (EXPERIMENTAL GROUP)				
PLAYER	FITNESS ASSESSMENT			
	SIT AND REACH TEST	PUSH-UPS	SIT-UPS	3 min step test
1	12	32	40	97
2	-3	34	39	101
3	23	30	36	102
4	-9	34	45	104
5	-12	40	48	107
6	0	43	56	106
7	5	45	48	96
8	8	46	50	89
9	8	47	45	90
10	13	40	40	100
11	10	35	42	102
12	4	30	38	107
13	8	34	45	96
14	10	35	46	90
15	18	36	50	90

POST TEST (EXPERIMENTAL GROUP)				
PLAYER	FITNESS ASSESSMENT			
	SIT AND REACH TEST	PUSH-UPS	SIT-UPS	3-min step test
1	12	32	37	95
2	0	38	41	98
3	20	32	40	96
4	-6	35	45	102
5		46	50	
6	2	50	50	104
7		48	50	
8	6	44	54	90
9	9	50	48	90
10	10	38	43	95
11	2	34	40	102
12	6	36	40	105
13	10	32	45	90
14	11	36	48	90
15	12	36	50	90

APPENDIX K

TABLE 7: RAW DATA OF THE BIOMOTOR ABILITY TESTS OF THE CONTROL GROUP

PRE TEST (CONTROL GROUP)								
PLAYER:	CP	RAR	T-test	10m	VJ	DJ	TJ	RH
1	5,20	12,20	12,20	2,15	0,15	0,27	6,00	2,33
2	5,80	10,96	10,37	1,73	0,27	0,34	5,90	2,31
3	5,80	12,45	12,10	2,00	0,26	0,41	5,52	2,34
4	6,80	12,25	12,25	1,87	0,26	0,28	5,25	2,42
5	6,50	11,65	12,45	1,90	0,21	0,21	4,85	2,49
6	6,70	11,41	10,65	1,94	0,32	0,37	5,00	2,33
7	5,90	11,35	11,15	1,92	0,40	0,44	4,95	2,27
8	6,50	10,71	10,48	1,90	0,37	0,35	5,12	2,33
9	5,70	9,34	10,41	1,72	0,35	0,37	5,25	2,33
10	5,60	10,91	10,50	1,75	0,23	0,25	5,45	2,49
11	6,30	10,13	11,00	2,00	0,51	0,52	4,90	2,23
12	6,60	10,63	10,53	1,81	0,39	0,41	5,12	2,29
13	6,20	10,87	10,50	1,47	0,40	0,42	5,85	2,30
14	5,50	10,20	10,65	1,89	0,48	0,50	5,50	2,24
15	5,70	10,78	9,87	1,93	0,49	0,50	5,15	2,26

POST TEST (CONTROL GROUP)								
PLAYER:	CP	RAR	T-test	10m	VJ	DJ	TJ	RH
1	5,20	12,25	12,20	2,10	0,17	0,27	6,10	2,33
2	6,00	11,00	10,30	1,72	0,48	0,51	5,95	2,31
3	6,90	12,40	11,98	1,92	0,46	0,49	5,54	2,34
4	6,90	12,20	12,30	1,90	0,28	0,28	5,25	2,42
5	6,70	11,70	12,35	1,95	0,21	0,24	4,80	2,49
6	6,80	11,50	10,55	1,87	0,35	0,37	5,05	2,33
7	6,00	11,35	11,20	1,92	0,45	0,48	4,90	2,27
8	6,60	10,70	10,50	1,95	0,42	0,47	5,20	2,33
9	5,70	9,50	10,40	1,72	0,35	0,39	5,15	2,33
10	5,75	10,90	11,05	1,87	0,16	0,20	5,50	2,49
11	6,50	10,20	10,25	1,80	0,55	0,47	5,05	2,23
12	6,00	10,60	11,17	1,92	0,46	0,45	5,20	2,29
13	6,60	10,90	10,81	1,48	0,47	0,47	6,05	2,30
14	5,50	10,15	11,32	1,62	0,49	0,46	6,00	2,24
15	5,80	10,70	10,15	1,90	0,49	0,50	6,05	2,26

CP	**CHEST PASS**	**meter**
RAR	**RUGBY AGILITY RUN**	**seconds**
T-TEST	**AGILITY TEST (T-DRILL)**	**seconds**
10 m	**10 METER SPEED TEST**	**seconds**
VJ	**SARGENT VERTICAL JUMP TEST**	**centimeter**
DJ	**DROP JUMP TEST**	**centimeter**
TJ	**TRIPLE JUMP TEST**	**meter**
RH	**REACH HEIGHT**	**centimeter**

APPENDIX L

TABLE 8: RAW DATA OF THE BIOMOTOR ABILITY TESTS OF THE EXPERIMENTAL GROUP

PRE TEST (EXPERIMENTAL GROUP)								
PLAYER	**CP**	**RAR**	**T-test**	**10m**	**VJ**	**DJ**	**TJ**	**RH**
1	6,70	11,50	11,05	1,88	0,30	0,34	5,50	2,36
2	5,20	12,40	11,76	1,76	0,48	0,58	5,85	2,17
3	7,70	12,15	12,60	2,31	0,30	0,38	5,50	2,42
4	6,10	11,40	11,83	1,95	0,35	0,40	6,00	2,45
5	6,10	10,65	10,78	1,81	0,32	0,32	5,25	2,46
6	5,20	11,17		2,17	0,47	0,47	6,20	2,33
7	6,50	10,50	10,90	1,72	0,30	0,38	5,00	2,40
8	6,50	12,00	10,75	1,87	0,35	0,40	5,85	2,45
9	5,20	12,25	11,54	1,95	0,35	0,40	5,55	2,33
10	6,00	10,50	11,44	1,79	0,39	0,36	5,15	2,49
11	6,10	11,25	11,15	1,74	0,41	0,45	5,45	2,27
12	6,30	11,60	10,17	1,95	0,41	0,45	5,05	2,29
13	5,50	11,20	10,10	1,56	0,42	0,45	4,85	2,30
14	5,50	10,75	10,50	1,72	0,35	0,38	5,95	2,35
15	7,61	11,30	10,14	1,53	0,37	0,43	5,35	2,49

POST TEST (EXPERIMENTAL GROUP)								
PLAYER	**CP**	**RAR**	**T-test**	**10m**	**VJ**	**DJ**	**TJ**	**RH**
1	6,90	11,40	10,72	1,65	0,49	0,53	6,52	2,36
2	5,80	11,20	10,48	1,60	0,57	0,60	6,25	2,17
3	8,00	11,60	11,27	1,66	0,47	0,52	5,83	2,42
4	6,30	10,60	11,35	1,82	0,45	0,50	6,73	2,45
5								2,46
6	7,60	10,20	10,25	1,66	0,57	0,63	7,00	2,33
7								2,40
8	6,70	11,50	10,70	1,85	0,51	0,47	6,50	2,45
9	6,00	11,50	11,25	1,87	0,38	0,45	6,00	2,33
10	6,20	10,35	11,36	1,68	0,41	0,42	5,50	2,49
11	6,50	11,00	11,10	1,70	0,60	0,43	5,85	2,27
12	6,50	10,35	9,55	1,69	0,53	0,59	5,83	2,29
13	6,20	10,90	10,05	1,50	0,46	0,47	5,25	2,30
14	6,00	10,50	10,40	1,68	0,40	0,42	6,00	2,35
15	8,10	10,35	10,10	1,50	0,48	0,55	5,50	2,49

CP	**CHEST PASS**	**meter**
RAR	**RUGBY AGILITY RUN**	**seconds**
T-TEST	**AGILITY TEST (T-DRILL)**	**seconds**
10 m	**10 METER SPEED TEST**	**seconds**
VJ	**SARGENT VERTICAL JUMP TEST**	**centimeter**
DJ	**DROP JUMP TEST**	**centimeter**
TJ	**TRIPLE JUMP TEST**	**meter**
RH	**REACH HEIGHT**	**centimeter**

APPENDIX M

TABLE 9: RAW DATA OF THE PERCENTAGE BODY FAT OF THE CONRTOL GROUP

PRE TEST (CONTROL GROUP)							
PLAYER	% BODY FAT						SUM OF 6
	CHEST	THIGH	ILIUM	ABDOMEN	TRICEP	SCAPULA	SKINFOLDS
1	11	16	12	19	15	15	88
2	10	16	10	21	10	14	81
3	10	15	15	20	11	13	84
4	11	17	12	18	9	12	79
5	6	14	7	10	9	8	54
6	10	14	14	19	12	10	79
7	8	16	10	17	9	12	72
8	4	10	5	8	6	7	40
9	12	14	12	20	13	11	82
10	5	10	6	9	6	8	44
11	6	13	7	9	7	6	48
12	5	14	7	10	7	7	50
13	6	10	9	13	8	8	54
14	5	9	8	8	10	10	50
15	14	18	16	21	12	14	95

POST TEST (CONTROL GROUP)							
PLAYER	% BODYFAT						SUM OF 6
	CHEST	THIGH	ILIUM	ABDOMEN	TRICEPS	SCAPULA	SKINFOLDS
1	11	16	12	18	14	14	85
2	10	16	11	20	10	14	81
3	9	16	15	18	11	13	82
4	11	16	12	18	10	12	79
5	7	14	8	10	9	8	56
6	11	14	14	17	11	11	78
7	9	16	9	17	10	13	74
8	5	10	6	8	7	6	42
9	13	12	12	15	12	11	75
10	6	11	7	9	7	8	48
11	6	13	8	9	7	7	50
12	6	13	8	9	8	8	52
13	5	10	8	13	8	8	52
14	5	9	9	8	9	9	49
15	13	17	14	20	10	13	87

APPENDIX N

TABLE 10: RAW DATA OF THE PRECENTAGE BODY FAT OF THE EXPERIMENTAL GROUP

PRE TEST (EXPERIMENTAL GROUP)							
PLAYER	% BODY FAT						SUM OF 6
	CHEST	THIGH	ILIUM	ABDOMEN	TRICEPS	SCAPULA	SKINFOLDS
1	11	12	13	24	10	10	80
2	7	12	10	13	11	10	63
3	12	15	14	24	11	14	90
4	9	15	1412	20	14	11	1481
5	10	10	8	18	10	10	66
6	8	12	6	11	9	8	54
7	4	10	15	6	7	9	51
8	10	17	8	20	14	14	83
9	6	8	8	9	6	6	43
10	6	10	7	10	7	7	47
11	5	8	5	8	5	7	38
12	4	7	6	6	5	5	33
13	6	8	7	10	6	5	42
14	7	9	7	11	6	6	46
15	5	9	6	9	7	7	43

POST TEST (EXPERIMENTAL GROUP)							
PLAYER	% BODYFAT						SUM OF 6
	CHEST	THIGH	ILIUM	ABDOMEN	TRICEPS	SCAPLULA	SKINFOLDS
1	10	11	12	21	9	9	72
2	7	12	9	12	10	9	59
3	11	13	12	22	10	12	80
4	8	14	13	18	12	11	76
5	9	11	10	18	9	9	66
6	7	11	8	10	8	8	52
7	4	10	6	7	6	8	41
8	9	15	13	16	12	12	77
9	6	7	8	9	6	6	42
10	5	9	8	9	7	6	44
11	5	7	7	8	4	6	37
12	4	6	5	6	4	5	30
13	5	7	5	8	5	5	35
14	6	7	6	8	6	5	38
15	6	7	5	8	6	6	38

APPENDIX O

PRE-TEST
PLYOMETRIC TRAINING PROJECT

Subject personal record

Date						
Resting HR						
Systolic Bp						
Diastolic Bp						

GIRTH MEASUREMENTS: (in cm)

Date	Biceps	Chest	Waist	Hips	Thigh	Calf

FITNESS TESTING

Date	Push–up test 20 sec	Sit-up test 20 sec	Sit & Reach test	3-min. Step Test

% BODY FAT:

Date					
Body weight (kg)					
Body fat (mm)					
Body fat (%)					
Biceps					
Triceps					
Sub-scapular					
Supra-iliac					
Abdominals					
Quadriceps					
Calves					
Chest					

APPENDIX P

POST-TEST
PLYOMETRIC TRAINING PROJECT

Subject personal record

Date						
Resting HR						
Systolic Bp						
Diastolic Bp						

GIRTH MEASUREMENTS: (in cm)

Date	Biceps	Chest	Waist	Hips	Thigh	Calf

FITNESS TESTING

Date	Push–up test 20 sec	Sit-up test 20 sec	Sit & Reach test	3-min. Step Test

% BODY FAT:

Date					
Body weight (kg)					
Body fat (mm)					
Body fat (%)					
Biceps					
Triceps					
Su- scapular					
Supra-iliac					
Abdominals					
Quadriceps					
Calves					
Chest					

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