ASSESSMENT OF THE EFFECT OF PLYOMETRIC TRAINING ON SKILL-RELATED COMPONENTS OF FITNESS AMONG MALE ADOLESCENTS IN LOKOJA METROPOLIS, NIGERIA

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DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY ZARIA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE (M.sc) IN EXERCISE AND SPORT SCIENCE. DEPARTMENT OF HUMAN KINETICS AND HEALTH EDUCATIONAHMADU BELLO UNIVERSITY ZARIA.

MARCH, 2020

DECLARATION

I hereby declare that this Dissertation titled "Assessment of the Effect of Plyometric Training on Skill-Related Components of Fitness of Male Adolescents in Lokoja Metropolis, Nigeria" has been written by me in the Department of Human Kinetics and Health Education under the supervision of Professor E.A Gunen and Professor M.A Chado. It has not been presented in any previous application for higher degree. All sources of information are specifically acknowledged by means of references.

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Stephen ADEGBE Date

(P14EDPE8023)

CERTIFICATION

We certify that this Dissertation titled 'Assessment of the Effect of Plyometric Training on Skill Related Components of Fitness of Male Adolescents in Lokoja Metropolis, Nigeria' by Stephen Adegbe meets the regulations governing the award of Master of Science (M.sc) degree in Exercise and Sport Science , Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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Chairman, supervisory committee

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Prof M.A. Suleiman Date
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Prof. Sani Abdullahi Date
Dean, School of Postgraduate Studies

DEDICATION

This Dissertation is dedicated to my mother, father and sisters for their love.

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ABSTRACT

The study was conducted to assess the effect of plyometric training on the skill-related components of fitness of male adolescents in Lokoja metropolis, Nigeria. The School population comprised of 105 Secondary Schools in Lokoja metropolis. A sample size of 50 male adolescents was drawn from the population using purposive sampling technique. A pre-posttest experimental design was adopted for the study. The participants were pre-tested in the skill-related fitness components, which includes explosive power, speed and agility. The participants underwent plyometric training, for 12 weeks, 3 times per week on alternate days. Training duration was increased from an initial 25 minutes for 4 weeks and was increased to 30 minutes and 35 minutes after the 4^{th} and 5^{th} week respectively. Training intensity was raised from an initial 40% of HRmax to50% and 55% respectively. Three researches questions and null hypothesis were formulated for this study. The data collected were statistically analyzed using SPSS version 20. Descriptive statistics of mean and standard deviation were used to describe the demographic characteristics of the participants and the observed variables of the study. The null hypotheses were tested using depended-t test to test for significant effect between the pre and post-tests at 0.05 alpha level of significance. The findings of this study showed that plyometric training significantly improved on explosive power (P =0.01), agility (P=0.04) of male adolescents in Lokoja metropolis. However, plyometric training had no significant effect on speed (P =0.18) of male adolescent in Lokoja metropolis. On the basis of these findings, it was recommended that students should be encouraged to engage in plyometric training as part of their structured daily physical activity to improve skills related components of fitness.

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OPERATIONAL DEFINITION OF TERMS

Some terms used in this study were defined in their operational sense as follows:

Adolescent: This is the age between 10 and 18 of male adolescents in Lokoja Metropolis Area of Kogi State.

Skill Related Fitness: Consist of those components of physical fitness that have a relationship with proficiency in physical activities of male adolescents in Lokoja Metropolis.

Physical Fitness: Is an integral part of good and wholesome health of the male adolescents in Lokoja metropolis.

Plyometric: is a training that increase the explosive for production through powerful contractions of a muscle group immediately following a stretching or eccentric (lengthening) phase of male adolescents in Lokoja Metropolis.

ABBREVIATIONS

<: Less Than

>: Greater Than

ACSM: America College of Sport Medicine

BMI: Body Mass Index

KG: Kilogram

N: Number of participants

REE: Resting Energy Expenditure

RPE: Rate of Perceived Exertion

RM: Rate of Motion

SD: Standard Deviation

SEM: Standard Error of Mean

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Plyometric has been a very popular training technique used by many coaches and training experts to improve speed, explosive power, reaction time and eccentric muscle control during dynamic movements (Coetzee, 2007; Davies, Murphy, Whitty, &Watsford, 2013). It is considered a high-intensity physical training method, consisting of explosive exercises that require muscle groups to adapt rapidly from eccentric to concentric contractions (Chu, 2011).
Plyometric training (PT) consists of physical exercises in which muscles exert maximum force at short intervals to increase dynamic performance. In this training, muscles undergo a rapid elongation followed by an immediate shortening (stretch-shortening contraction), utilizing the elastic energy stored during the stretching phase. There is consensus on the fact that when used, PT contributes to improvement in vertical jump performance, acceleration, leg strength, muscular power, and overall sport-specific skills.

Adolescence is a time of many transitions for the teens and the family. During the teen years, adolescents experience changes in their physical development at a speed unparalleled since infancy. The biological changes include increase in the individual's height (Steinberg, 2008), weight (Tanner, 2015) and body fat distribution and muscle mass. Physical development includes rapid gains in height and weight. During a one-year growth spurt, boys and girls can gain an average of 4.1cm and 3.5cm in height respectively (Steinberg, 2007; Cossor & Mason, 2012). This spurt typically occurs two years earlier for girls than for boys. Weight gain results from increased muscle development in boys and body fat in girls. During puberty, changing hormonal levels play a role in activating the development of secondary sex characteristics. These include growth of pubic hair; menarche (first period for girls), voice changes (for boys);

growth of underarm hair; facial hair growth (for boys); and the increased production of oil, increased sweat gland activity and the beginning of acne (Tanner, 2015).

Currently, typical plyometric training comprises three phases in which the first phase is a rapid muscle lengthening movement known as the eccentric phase. The second phase involves a short resting period known as the amortization phase and the third phase involves an explosive muscle shortening movement, termed the concentric phase which primarily improve muscular, tendon and nerve functions. The increase in physical power make athletes run faster, jump higher and hit harder and develop specific skills relative to specific practiced sport (Tanner, 2015).

Power is the ability to move body parts swiftly while applying the maximum force of the muscles with the combination of both speed and muscular strength.For example, fullbacks in football their way through other players and speeding to advance the ball and volleyball players getting up to the net and lifting their bodies high into the air, thus a high level of strength can determine the rise in power, resulting in an increased level of speed, swiftness and agility (Lyttle & Benjanuvatra, 2016).

Agility is an important aspect of almost every sport. One way to improve this attribute is through plyometric training (Tanner, 2013). They reported that plyometric training when incorporated in a sport performance training programme of elite athletes, supplemented with plyometric exercises, appear to improve adolescent agility and power. Agility is defined as the ability of a fast whole-body movement involving the changing of direction or speed in response to a given stimulus (Matavulj. Kukoli, Ugarkovic, Tihanyi, & Jaric, 2017). Speed is the quickness of movement of limb legs of an athlete, or the arm of the shot putter. Speed forms an integral part of every sport and can be expressed as one of the combination of maximum speed and elastic strength for individual to perform a movement or cover a distance in a period of time (Chu, 2011).

Therefore, plyometric training is inherently dangerous, but the highly focused and intense movements used in repetitions may increase the potential level of stress on joints and musculotendinous units. Thus, safety precautions are strong prerequisites to this particular method of exercise. Low-intensity variations of Plyometric Training are frequently utilized in various stages of injury rehabilitation, indicating that the application of proper technique and appropriate safety precautions can make plyometric safe and effective for many categories of people (Ozmun, Mikesky, &. Surburg, 2017). However, guidelines have been prescribed to assist in developing appropriate programmes for adolescents. To reduce the risk of injury and facilitate the performance of plyometric exercises, programmes must initially focus upon technique using low impact exercises before progressing onto higher impact activities (Tanner, 2015).

1.2 Statement of the Problem

Plyometric training are used to develop an athlete's power, increase response time from stationary, promote agility, and increase acceleration and therewith, ultimate speed (Blazevich, 2009). Plyometric exercises are suitable for improving various measures and components of muscle power such as vertical jumping ability, speed and acceleration (Ebben, VanderZanden, Wurm, & Petushek, 2010). Despite the hundreds of research studies that investigated the effects of this kind of exercises on vertical jumping performance and running velocity, the vast majority of them have performed to adults (Chu, 2011). Few studies have accomplished to prepubertal boys (Kotzamanidis, 2006). The relevant studies have reported that plyometric exercises improve jumping power and running velocities (Tanner, 2015). Studies on plyometric training on boys have not been conducted using sprint test and jump have not been conducted on male adolescents. Furthermore, there is uncertainty as to whether exercise training sessions alone will offer enough stimuli to develop short-speed and agility performance, development of muscular skeletal system, and increase muscular strength and power (Meylan & Malatesta, 2009); Findings supporting the benefits of repeated and intense physical efforts in young subjects and adolescents, thereby improving motor skills and body composition in terms of reducing fat mass and enhanced bone health (Diallo, Dore, Duche & Van Praagh, 2014).

Prospective studies showed that muscular strength improvement from childhood to adolescence are inversely associated with regular involvement in exercise training (Myer, Ford, Palumbo & Hewett, 2000; DiStefano, Padua, Blackburn, Garrett, Guskiewicz & Marshall, 2010).Plyometric training is a short-term programme that could also be effective for the increment of fitness in adolescent. Thus, it would be interesting for coaches and practitioners to investigate whether the programme would have any effect on speed, muscular strength, power and agility performance of adolescent’s athletes (Lyttle & Benjanuvatra, 2016).

As previously reported by Chu et al, (2006) that plyometric training improved jumping performance in teenage basketball players and Committee on Sports Medicine and Fitness. (2009), reported that plyometric training enhanced jumping performance and running velocity in prepubertal boys. None has been conducted to investigate skill related components (Muscular Strength, Speed) in Nigeria. With this fact, little research has been conducted on adolescent athletes to investigate the skill related components using 10m sprint and jump test among adolescent’s boys in Lokoja Metropolis. Therefore, the study was undertaken to investigate the effects of plyometric training and selected skill-related components (agility, explosive power and speed) among adolescent boys in Lokoja Metropolis, Nigeria.

1.3 Purpose of the Study

The purpose of this study was to determine the effects of plyometric training among adolescent boys in Lokoja Metropolis, Nigeria. The study had the following objectives:

i To assess the effect of plyometric training on agility among male adolescent in Lokoja Metropolis, Nigeria.

ii To assess the effect of plyometric training on explosive power among male adolescent in Lokoja Metropolis, Nigeria.

iii To assess the effect of plyometric training on speed ability among male adolescent in Lokoja Metropolis, Nigeria.

1.4 Research Question

The following research questions were raised for the study:

i Would participation in plyometric training improve agility of male adolescents in Lokoja Metropolis, Nigeria?

ii Would participation in plyometric training improve explosive power of male adolescents in Lokoja Metropolis, Nigeria?

iii Would participation in plyometric training improve speed of male adolescents in Lokoja Metropolis, Nigeria?

1.5 Basic Assumptions

The following assumptions were made for the study:

1. Plyometric training enhances motor unit recruitment which decreases the amount of time needed to produce work, thus leading to improved power output.
2. Plyometric training is an efficient training exercise to increase sport performance of adolescents in competitive events.
3. It is assumed that plyometric training exercise improve power of adolescents.
4. Plyometric training enhances motor unit recruitment which decreases the amount of timeneeded to produce work, thus leading to improved power output.

1.6 Hypotheses

On the basis of the research questions, the following hypotheses will be tested

Major Hypothesis

There is no significant effect of plyometric training on skill-related components of fitness of adolescent boys in Lokoja metropolis, Nigeria.

Sub-Hypothesis

i There is no significant effect of plyometric training on agility of male adolescent in Lokoja Metropolis, Nigeria.

ii There is no significant effect of plyometric training on explosive power of male adolescent in Lokoja metropolis, Nigeria.

iii There is no significant effect of plyometric training on speed of adolescent boys in Lokoja Metropolis, Nigeria.

1.7 Significance of the study

This study served as a platform for ministry of education, youth and sport development to evolve strategies and policies that were contribute to the development of skill related component of fitness among adolescents in Nigeria using plyometric training. Creating awareness among the adolescents and the general populace on the effect of plyometric training in enhancing skill related component of fitness. Were also enable physical educators, coaches and exercise and sport scientists to establish basis for including plyometric programme in Lokoja metropolis Nigeria. Were also contribute to the existing body of knowledge on the effects of plyometric training programme on skill related component of fitness among adolescents, by serving as a useful reference material on how plyometric training programme can be integrated in secondary school curriculum in Lokoja metropolis.

1.8 Delimitation

This study was delimited to the following;

i. Male adolescent between the ages of 13 and 14 years in Lokoja Metropolis, Nigeria.

ii. Skill-related component fitness of agility, power, speed was tested on adolescent's boys in Lokoja Metropolis, Nigeria

iii. Plyometric training exercise was undertaken for a duration of 12 weeks.

iv. The participants was have no underlying health risk factors which could posed a threat to the participants in carrying out the exercise programme

CHAPTER TWO

REVIEW OF THE RELATED LITERATURE

2.0 Introduction

The main purpose of this study is to determine the effects of plyometric training among adolescent boys in Lokoja Metropolis, Nigeria. These skill-selected components are muscular strength, power, speed, flexibility and agility on selected skills related components fitness among adolescent boys. This chapter reviewed some of the related literature on plyometric training.

The review is conducted under the following subtitles.

2.1 Plyometrics

2.2 Fundamentals of Plyometrics

2.3 Plyometric Exercises

2.4 Plyometric Skill Components

2.5 Plyometric Training and its effects on Performances of Adolescents

2.6 Studies conducted on adolescent on Plyometric Training

2.7 Plyometric programme development and intervention

2.8 Summary

2.1 Concept of Plyometric Training

Plyometric training is defined as a quick, powerful movement involving an eccentric contraction, followed immediately by an explosive concentric contraction (Bosco, Viitasalo, & Komi, 2010; Verhoshanski, 2012; Wilt, 2012).

Plyometric training is a specific exercise regime that is needed to develop muscles that contract maximally in the shortest possible time (Chu, 2013; Siff & Verkhoshansky, 2010). Plyometric training is also defined as quick, powerful movements, which lead to the activation of the stretch-shortening cycle (Voight, Draovitch & Tippett, 2012). 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; Faigenbaum, Farrell, Radler, Zbojovsky, Chu, Ratamess, Kang, & Hoffman, 2015). Plyometric 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, 2009; Brown, Mayhew & Boleach, 1986; Faigenbaum, Kraemer, Blimkie, Jeffreys, Micheli, Nitka, & Rowland, 2014).

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, 2009). Sport-specific exercises, when combined with plyometric training, have been shown to effectively correspond with power training (Jacoby & Gambetta, 1989; Siff & Verkhoshansky, 2010). 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, 2012). There are numerous phases in rugby where speed, stamina, power and agility are required and in many cases fairly simultaneously (Anon, 2009; Pearson, 2001; Guy, 2009). 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, 2013). There is, however, no information available on systematic investigation of plyometric as applied to rugby. This may be due to "team secrecy", a problem that had previously occurred in plyometric research (Siff & Verkhoshansky, 2010).

The relative importance of stamina, speed, power and agility will vary according to playing position (Turnbull, *et al,* 2012; Haga, 2010). 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, 2008; Ingle, Sleap, & Tolfrey, 2010).

Skill selected components of fitness games players have different body types and positional requirements (Biscombe & Drewett, 2012). The nature of this sport is physical, therefore, players have to be physically strong and sturdy (Bloomfield, Ackland & Elliott, 1994; Levac, Wishart, Missiuna, & Wright, 2013). 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, 2008).

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, 2008; Greene, 2017).

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.*, 2012). 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, 2012). 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, 2008; Kotzamanidis, 2014).

According to Hawley and Burke (2012) previous research highlighted the sustained high-intensity pattern of team sports and the stochastic (stop-start) nature of skill selected games. Explosive events that include jumping, throwing or speed movements, benefit from the use of plyometric exercises. These observations have been extensively confirmed by Gambetta (2010), Matavulji *et al.* (2001), Robberds (2012) and Yessis, (1991), although Gambetta (2010) commented that plyometric 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, 2010). A combination of weight training and plyometric exercises has gained popularity as a strategy to improve muscle power and athletic performance (Ebben, 2012).

2.2 Development and Fundamental of plyometric

Plyometric, when first developed in success-hungry Eastern European countries, was initially termed “jump training” (Chu, 2012). As Eastern Block successes in track and field events, gymnastics and weightlifting began to accrue, the training methods employed were scrutinized. In the West, plyometric was referred to as the “Russian Training Secret”, a term that did not demystify the training system (Siff & Verkhoshansky, 2010). 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, 2012). Much earlier sport physiological work used different terms to describe what is now termed “plyometric”, the most popular being “stretch-shortening”. “Plyometric”, as a training term, was wined in America, deriving from the Latin term meaning “measurable increases”. Plyometric was responsible for the increasing competitiveness and growing superiority of Eastern Block athletes in track and field events (Chu, 2011). Driven by the success of the Eastern Block athletes, plyometric training became essential for all power athletes (Siff & Verkhoshansky, 2010). As a conditioning method, plyometric became widely employed for the development of leg power (Young, 1991).

Plyometric is valuable due to the different ways in which muscle group contract and are manipulated to maximize the “load up” before explosive movements (Blazevich, 2009; Kessel, 2012). 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 emphasized (Chu, 2011).

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, 2011).

2.2.1 Fundamental of Plyometric Theory

Plyometric is designed to enable muscles to contract to the maximum extent in the shortest possible time (Chu, 2013). This training involves quick, powerful movements that require stretching or counter movements to activate the stretch-shortening cycle (Siff & Verkhoshansky, 2010). During this training, the athlete’s neuromuscular system showed reactions to stimuli by the training of their nervous system (Voight *et al*., 2012). Normal daily and sport requirements of stretch-shortening exercises produce the need for functional exercises undertaken before sport-specific plyometric. Theoretically, plyometric can close the gap between speed and power (Voight *et al*., 2012). 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, 2010). 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.,* 2012). 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, 2008). 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 amortize in about 0.12 seconds (Duda, 2008). Plyometric exercises have been developed to minimize the amortization phase, although the duration of their phases have been demonstrated to also depend on learning. Therefore athletes may shorten their personal amortization phase by learning from skills training within strength development (Chu, 2012).

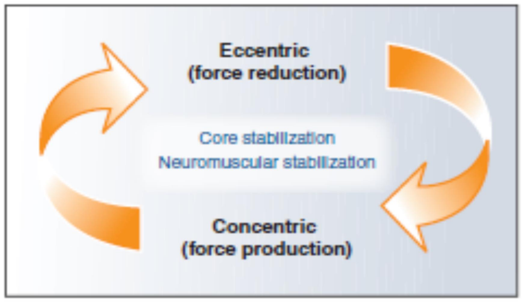
It is well recognized that whilst many coaches realize the importance of explosive power as an ingredient of sport performance, very few of them are familiar with the functioning of the mechanism that develops and improves this essential power (Brown *et al.*, 1986; Markovic, 2014).

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 showed performance in sport, which, according to Gambetta (2010) is indispensable for a thorough understanding of plyometric.

2.3 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, 2010).

Wilson, Murphy and Giorgi (2013) as well as Bosco (2012) 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, 2009). This is accomplished through the stretch-shortening cycle or an eccentric-concentric coupling phase. The eccentric concentric coupling phase is also referred to as the integrated performance paradigm (Fig. 1), which states that in order to move with precision, forces must be loaded (eccentrically), stabilized (isometrically), and then unloaded/accelerated (concentrically). Plyometric exercise stimulates the body's proprioceptive and elastic properties to generate maximum force output in a minimum amount of time (Voight & Brady, 2009).



Adopted from American College of Sports Medicine. (2010)
Figure 1: Integrated Performance diagram

Plyometric training is an effective mode of training as it enhances motor learning and neuromuscular efficiency by promoting the excitability, sensitivity, and reactivity of the neuromuscular system to increase the rate of force production (power), motor-unit recruitment, firin frequency (rate coding), and synchronization. Muscles produce the necessary force to change the direction of an object's center of mass (Voight & Brady, 2009). All movement patterns that occur during functional activities involve a series of repetitive stretch shortening cycles. The neuromuscular system must react quickly and efficiently following an eccentric muscle action to produce a concentric contraction and impart the necessary force (or acceleration) in the appropriate direction. Therefore, specific functional exercises that emphasize a rapid change in direction must be utilized to prepare each athlete for the functional demands of a specific activity.

Plyometric training provides the opportunity to train specific movement patterns in a biomechanically correct manner at a more functionally appropriate speed. This provides functional strengthening of the muscle, tendon, and ligaments specific to the demands of everyday activities and sports. The ultimate goal of plyometric training is to improve the reaction time of the muscle action spectrum (eccentric deceleration, isometric stabilization, and concentric acceleration).

The speed of muscular exertion is limited by neuromuscular coordination. This means that the body will move most effectively and efficiently within a range of speed that the nervous system has been programmed to allow. Plyometric training improves both neuromuscular efficiency and the range of speeds set by the central nervous system. Optimum reactive performance of any activity depends on the speed at which muscular forces can be generated (Wilkerson, Colston, & Short, 2008).

2.3.1 Types & Phases of Plyometric Exercise

There are three distinct phases involved in plyometric training including the eccentric, or loading, phase; the amortization, or transition, phase; and the concentric, or unloading, phase (Chmielewski, Myer & Kauffman, 2006).

A. The Eccentric Phase

The first stage of a plyometric movement can be classified as the eccentric phase, but it has also been called the deceleration, loading, yielding, countermovement, or cocking phase (Lundin, 2010). This phase increases muscle spindle activity by pre-stretching the muscle prior to activation (Kubo, Kanehisa, & Kawakami, 2012). Potential energy is stored in the elastic components of the muscle during this loading phase. A slower eccentric phase prevents taking optimum advantage of the mystatic stretch reflex (Verhoshanski, 2012).

B. The Amortization Phase

This phase involves dynamic stabilization and is the time between the end of the eccentric contraction (the loading or deceleration phase) and the initiation of the concentric contraction (the unloading or force production phase) (Wilk, Voight, & Keirns, 2014). The amortization phase, sometimes referred to as the transition phase, is also referred to as the electromechanical delay between the eccentric and concentric contraction during which the muscle must switch from overcoming force to imparting force in the intended direction (Voight & Wieder, 2010). A prolonged amortization phase results in less-than-optimum neuromuscular efficiency from a loss of elastic potential energy (Chimera, Swanik, & Swanik, 2009). A rapid switch from an eccentric contraction to a concentric contraction leads to a more powerful response (Wilk, Voight, & Keirns, 2014).

C. The Concentric Phase

The concentric phase (or unloading phase) occurs immediately after the amortization phase and involves a concentric contraction (Wilk, Voight, & Keirns, 2014; Voight & Wieder, 2010), resulting in enhanced muscular performance following the eccentric phase of muscle contraction. This occurs secondary to enhanced summation and reutilization of elastic potential energy, muscle potentiation, and contribution of the myotatic stretch reflex (Gollhofer, Strojnik & Rapp, 2009; Fukunaga, Kawakami, & Kubo, 2012)

2.3.2. Physiological Principles of Plyometric Training

Plyometric training utilizes the elastic and proprioceptive properties of a muscle to generate maximum force production (Wilk, Voight, & Keirns, 2014; Voight & Wieder, 2010) by stimulating mechanoreceptors to facilitate an increase in muscle recruitment in a minimal amount of time. Muscle spindles and Golgi tendon organs (GTOs) provide the proprioceptive basis for plyometric training. The central nervous system then uses this sensory information to influence muscle tone, motor execution, and kinesthetic awareness (Lundin, 2010). Stimulation of these receptors can cause facilitation, inhibition, and modulation of both agonist and antagonist muscle activity. This enhances neuromuscular efficiency and functional strength (Fig. 2) (Astrand, Rodahl & Dahl, 2009; Jacobson, 2008; O'Connell & Gardner, 2004).

2.3.3 The basics of Plyometric Training

According to Heiderscheit *et al.* (2013), plyometric 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, 2010). 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 plyometric 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 amortization phase - which results in shortened response time, coupled with powerful movement, is a very specific training system in its own right. Siff and Verkhoshansky (2010) 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, 2009). 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 plyometric. Plyometric 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, 2010). 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, 2012). 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 organized into a discreet training programme for reactive ability development and explosive strength as well as important training considerations will be discussed.

2.3.4 The development of Explosive Strength and reactive ability

Siff and Verkhoshansky (2010), 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 organized 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, 2012). 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 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, 2012). 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.

2.3.7 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 plyometric should be specific and related to the larger efforts. These exercises are not classified as true plyometric 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, 2012). Gambetta (2010) stated that activities fitting into the warm-up (or submaximal plyometric 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 (2012) 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, 2012).

Jogging drills comprise many variations that can be modified into being plyometric in nature and used to emphasize 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, 2012).

Skipping drills can be used to warm up the athlete and prepare him or her for more complex plyometric skills. The synchronization 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, 2012).

Footwork drills such as the shuttle drills, multidirectional side shuffle drills, and “drop” step drills are all considered excellent submaximal plyometric drills (Chu, 2012).

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, 2012).

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 fashion. Each activity is aimed at a specific area of the body with a special effect in mind when doing the drill (Chu, 2012).

2.3.8 Plyometric exercises

Plyometric exercises are focused on the development of a shorter amortization phase (Siff& Verkhoshansky, 2010). Chu (2012) 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, 2009; Rubley, Haase, Holcomb, Girouard, & Tandy, 2009). The sport and the skill to be developed must be analyzed 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, 2012).

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; Saez-Saez de Villarreal, Requena, & Newton, 2009). Kessel (2012) 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) and US Department of Health and Human Services (2010). 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; Witzke & Snow, 2012).

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; Witzke & Snow, 2012).

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 amortization 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; Witzke & Snow, 2012). 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 specializing 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 countermovement 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; Witzke & Snow, 2012).

In a study by Humphries *et al.* (2012) 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.*, 2012).

2.3.9 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, 2012). 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 Witzke & Snow (2012), emphasized 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, 2012). The best coaches are not always successful, but they do make training an enjoyable, organized, and progressive activity that ultimately takes the athlete to higher performance levels (Chu, 2012).

According to Chu (2012) 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 plyometric 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, 2012).

Age: Children will always run and jump while playing. As adults we tend to take thiselement of play – also known as fun – out of training programmes by rigidly applying specific regimens (Blazevich, 2009; Chu, 2012).

Young athletes: Elementary school children can successfully perform plyometric training as long as the coach does not call it plyometric. Young athletes can benefit more from direct training as they approach pubescence (Blazevich, 2009).

Pubescent athletes: Plyometric 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, 2009).

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, 2009; Chu, 2012).

According to Siff & Verkhoshansky, (2010) 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.*, 2013).

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; Witzke & Snow, 2012).

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 misalignments 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; Witzke & Snow, 2012).

Stiffness recruitment strategies may be utilized 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; US Department of Health and Human Services, 2010).

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).

2.3.10 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), Witzke & Snow, (2012) and US Department of Health and Human Services (2010), 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.

2.4 Plyometric Skill Components

2.4.1 Agility

Agility is the ability of a player to make changes in body direction and position rapidly and accurately without losing balance, in combination with fast movements of limbs (Ellis *et al.*, 2000; Kent, 2004). Roozen (2004) found what determined agility was the ability to combine muscle strength, starting strength, explosive strength, balance, acceleration, and deceleration. Agility requires rapid force development and high power output, as well as the ability to efficiently utilize the stretch shortening cycle in ballistic movements (Plisk, 2008; US Department of Health and Human Services, 2010). Plyometric training reduces the time required for voluntary muscle activation, which may facilitate faster changes in movement direction

Miller *et al.* (2006) studied the effects of a six-week plyometric intervention on agility performance. Untrained male and female participants were divided into two groups, a plyometric training (PT) (n=14; age: 22.3 ± 3.1 years) and a control-group (n=14; age: 24.2 ± 4.8 years). All participants participated in two agility tests, the T-test and the Illinois Agility Test, and a Force Plate Test for ground reaction times both pre- and post-testing. PT-group had quicker post-test times compared to the control-group for the agility tests. T-test times improved by 4.86% ($p<0.05$), with a significant group effect ($p=0.0000$). The Illinois agility test improved by 2.93% ($p<0.05$), with a significant group effect ($p=0.000$). The PT-group reduced time on the ground on the post-test compared to the control-group. Ground contact times measured by a force plate, improved 10% ($p<0.05$), with a significant group effect ($p=0.002$). PT improved performance in agility tests either because of better motor recruitment or neural adaptations. Therefore, PT showed to be an effective training technique to improve an athlete's agility.

Contrary to the above research, Wrotniak, Epstein, Dorn, Jones, & Kondilis, (2017), showed no significant improvements in T-test times after the completion of a six-week combined plyometric and pre-season basketball conditioning programme by female basketball players. Greater measurable performance changes in agility for this trained population would have been detected with a longer training period for both the PT experimental group and control-group, which just completed basketball pre-season conditioning. The above literature indicated that PT could be utilized as an effective training modality to improve an athlete's agility. PT induced performance in agility may be due to better motor recruitment or neural adaptations in the PT-trained participants. Significant improvements in agility can also be attributed to using untrained male and female participants than trained participants, where the degree of improvement was smaller.

2.4.2 Power

Power is the product of strength and speed and refers to the ability of the neuro muscular system to produce the greatest possible impulse in a given time period (Stolen *et al*.,2005:503). According to Wisloff*et al*. (2004), muscle strength of lower limbs is significantly associated with vertical jump height. Stolen *et al*. (2005:503) acknowledged that maximal strength is one basic quality that influences power performance, because an increase in maximal strength is usually connected with an improvement in relative strength hand, therefore, improvement of power abilities. Different studies have shown that the leg power of football players measured with vertical jumps is between 38 and 45 cm (Cometti*etal*., 2001; Tumilty, 1993). Various vertical jump heights have been reported by previousstudies, up to 55 cm in English (Shephard, 1999; Strudwick, Reilly & Doran, 2002;Wisloff*et al*., 2004) and Norway elite football players, whereas lower jump heights(39.5 cm) were observed in Icelandic elite football players, as noted by Arnason *et al*.(2004:280). In contrast to these studies, Dowson, Cronin and Presland (2002) found that younger players have jumped shorter heights. In the study done by Arnason*et al*. (2004), a significant relationship was observed between the team average for jump height (counter-movement jump and standing jump)and team success (final league standing). Gissis *et al*. (2006) also found that the jumping ability of national-level football players is significantly higher than the ability of players at sub-elite and recreational levels. A study done by Reilly *et al*. (2000) has also shown significant differences in vertical jump height among football players of different competition levels. Interestingly, McMillan *et al*. (2005) noted that after a 10 week high-intensity aerobic training intervention, squat jump (SJ) increased from 37.7 (6.2) to 40.3 (6.1) cm and counter-movement jump (CMJ) increased from 52.0 (4) to 53.4 (4.2) cm, thus concluding that the addition of high-intensity interval training at 90-95 % HRmax will have no negative interference effects on strength, jumping ability and sprint performance.

2.4.3 Speed

Sprint running, in varying degrees, is an essential element of successful performance in many sports. It represents a complex ballistic movement and multidimensional movement skill. It requires both concentric and SSC explosive force production of most leg extensor muscles. It follows that, sprint performance could benefit from plyometric training (PT) (Rimmer & Sleivert, 2000; Markovic & Mikulic, 2010). For the transfer of PT to sprinting, it is likely that the greatest improvements in sprinting will occur at the velocity of muscle action that most closely matches the velocity of muscle action of the plyometric exercises employed in training (Rimmer & Sleivert, 2000). Rimmer and Sleivert (2000) studied the effects of a plyometric programme on sprinting performance in a group of 26 male participants (age: 24 ± 4 years), consisting of 22-rugby players and four touch-rugby players, playing at elite or under- 21 level of competition. Participants were divided into a plyometric-group (n=10) performing sprint-specific plyometric exercises, a sprint-group (n=7), performing sprints and a control-group (n=9). All three groups performed sprint tests before and after the eight week intervention (15-sessions), consisting of three to six maximal sprint test efforts between 10- and 40-metres (m). During the 40-metre sprint, time was also recorded, at the 10-, 20-, 30-, and 40-m marks. The stride frequency was determined with a video camera in the 10- and 40-m sprints. Ground reaction time was measured with a force plate platform between the seven and 10-m marks, and also between the 37- and 40-m marks. The plyometric-group showed a significant decrease in time over the 0–10-m (2.6%; p=0.001) and 0–40-m (2.2%; p=0.001) distances, with the greatest improvement within the first 10-m of the sprint. These improvements were not significantly different from those observed in the sprint-group. However, there were no significant improvements in the sprint-group. The control group also showed no improvements in sprint times. There were no significant changes in stride length or frequency for any of the groups during the study. PT-group was the only group to show a significant decrease (4.4%) in ground contact time, and this only occurred between the 37-m and 40-m mark. The results showed that sprint specific plyometric exercises can improve sprint performance to the same extent as regular sprint training, especially over the first 10-m (acceleration phase) of the sprint, possibly due to shorter ground reaction times. In sports where speed up to 40-m are important, benefits would be derived by adding sprint-specific exercises to a regular sprint training programme, especially when acceleration adds to enhanced performance.

Rimmer and Sleivert (2000) concluded that PT with its greater emphasis on powerdevelopment but lesser specificity was as effective as the sprint training with its greater specificity but lesser potential for power development. In contrast, Markovic *et al.* (2007b) showed sprint training to be significantly superior to PT in improving 20-m sprint performance time (p=0.02), in a 10-week plyometric and sprint training comparative study. PT exercises used in the study were not sprint specific, which possibly made the power transfer from PT to sprint performance more difficult. This study supports the use of sprint training as an applicable training method for improving explosive performances of athletes in general.

On the other hand, a plyometric intervention within an athlete's periodization does not always improve a player's sprint speed. Thomas *et al.* (2009) compared the effect of either DJ or CMJ six-week, bi-weekly PT intervention upon trained adolescent soccer players. For this sport-specific population, sprint speed was assessed for 20-m with five metre splits, from a standing start. Post-training analysis showed that both groups experienced no change in sprint speed performance ($p>0.05$), nor was a significant difference shown between the intervention groups. These results were potentially due to the fact that plyometric exercises were not performed at sprint-specific velocities of muscle action or movement. In accordance with the velocity specificity principle of training, the ground contact times were not short enough to elicit an increased ability to generate explosive ground-reaction forces during sprinting.

From the findings of the above three-studies, there appears to be no evidence that PT was superior to traditional sprint training for speed improvement (Markovic & Mikulic, 2010). In terms of specificity, sprint training has been shown to improve explosive performances significantly greater than PT in a 20-m sprint in untrained male university students. Sprint-specific plyometric exercises did improve sprint performances to the same extent as regular sprint training in elite rugby players, over the first 10-m, and up to 40-m. PT must be performed at sprint-specific velocities of movement, to decrease ground contact times to enhance explosive sprint performances.

2.5 Plyometric Training and its effects on Performances of Adolescents

Primarily used by martial artists, sprinters and high jumpers to improve the performances of athletes, PT has emerged in two forms that have evolved since 1980. An original version defined as the ‘shock method’ was created by the Russian scientist Yuri Verkhoshansky, the second version is widely used in the United States. In the first form, the athlete is required to drop down from a height and experience a ‘shock’ upon landing. This in turn led to a forced eccentric contraction, which was then immediately switched to a concentric contraction as the athlete jumped upward. The landing and take-off were executed in an extremely short period of time (0.1–0.2 sec). The shock method is the most effective method used by athletes to improve their speed, quickness, and power after development of a strong strength base. The second version of plyometric widely used in the United States, relates to doing any form of jump regardless of execution time. This involves jumps that are lower in intensity and execution, while the time required for transitioning from eccentric to the concentric contraction is much greater.

2.6 Studies conducted on adolescent on Plyometric Training

The study of Eskandar, Asghar, &Ebrahim, (2014), investigated the effect of plyometric and resistance training on agility, speed and explosive power in soccer players. The results showed that eight weeks of plyometric training had significant effects on agility records reduction. The results were consistent with Tanner (2015) but did not match with Alemaglu et al (2012). Plyometric training affects muscle spindles, Golgi-tendon, tendons, joints, balance and body position controlling. Maybe neuromuscular adaptations caused by plyometric exercises affects muscle spindles, Golgitendon, tendons, joints, balance and body position controlling favorably and this led to agility improvement in these athletes. The results showed that eight weeks of plyometric training had significant effects on speed records reduction. These results were consistent with Chu (2012) but did not match with Lyttle & Benjanuvatra, 2016. A number of factors such as muscle length, strength, age, gender, temperature, body shape, force and flexibility can have profound impacts on speed. Probably plyometric exercises led to speed improvements by affecting muscle length, force, muscle temperature, strength and flexibility during the eight weeks.

The results showed that eight weeks of plyometric training increased explosive power significantly. The results were consistent with Lyttle & Benjanuvatra, 2016 but did not match with Tanner, 2015. Plyometric is a training method, which is widely used to improve muscular strength to generate explosive power. This method led to increased explosive power in subjects by rapid strength production and nervous system improvement after eight weeks.

The results showed that eight weeks of resistance training had significant effects on reducing agility records. These results were consistent with Miller et al (2006) but did not match with Tartibyan *et al*., (2012). Agility along with other factors such as balance, coordination, speed, power, and reaction speed is one of the physical fitness factors related to skills. Probably, muscle fibers hypertrophy due to resistance training led to the subjects' ability to change situation and direction rapidly without losing precision and balance. The results showed that eight weeks of resistance training had not significant effects on reducing speed records. The results were consistent with Tartibiyan *et al.,*(2012) but did not match with Shahidi *et al.,* (2012).

Research results show that resistance training improves speed in professional soccer players by affecting leg extensor muscles. Apart from increasing power, other factors such as muscle length and temperature, body shape and flexibility also should be noted in speedy performances. The results showed that eight weeks of resistance training had significant effects on increasing explosive power. These results were consistent with Shahidi *et al*., (2009) but did not match with Lamontage *et al.,* (2011). Nerves adaptation improves strength in the first 3-4 weeks of resistance training. Muscle hypertrophy creates an increase in the size and function of muscle fibers after 8-12 weeks of resistance exercise. Probably neural adaptations and hypertrophy caused by resistance exercises, improved explosive power in these subjects. The results showed that the plyometric group registered better records in agility, speed and explosive power compared with the resistance group after eight weeks. Maybe neuromuscular adaptations caused by plyometric exercises affected muscle spindles, Golgi-tendon, tendons, joints, balance and body position controlling more favorably and this led to agility improvements in these athletes. Also in the plyometric group maybe the increased speed of message transfer from muscle to the nerve center and vice versa led to better records in speed test compared with the resistance training group.

Moreover, about explosive power, probably fast twitch motor units are more called in plyometric exercises in comparison to resistance exercises. By calling for this type of fiber the larger motor units which have higher discharge, frequencies will be involved and they produce more power than other types of muscle fibers.

2.6.1 Upper body plyometric training

Upper body plyometric training (PT) is essential for athletes who require upper body power (Wilk *et al.*, 1993; Newton *et al.,* 1997). Any exercise using an eccentric prestretch followed by an explosive concentric contraction is plyometric in nature. Various forms of exercise can be used to exploit the stretch reflex, as the musculature of the upper body possesses the same physiological characteristics of the lower body (Potash & Chu, 2008). The push-up exercise can be used within a simple PT programme to develop power in the shoulder girdle region (Voight *et al.*, 1995). Vossen, Kramer, Burke and Vossen (2000) compared the effects of dynamic push-up training and plyometric push-up training on upper body strength and power. A group of 35 recreationally active women were randomly divided into a dynamic push-up group (n=17) and a plyometric push-up group (n=18), completing 18-training sessions, three days per week, over a six-week period. The participants performed two-tests of measuring the power and strength of shoulder and chest, before and after the six-week intervention. Tests included the two-handed medicine ball put, and one repetition maximum (1RM) seated chest press. In the medicine ball put, the plyometric push-up group experienced significantly greater increases than the dynamic push-up group ($p<0.05$).

In the chest press, the plyometric push-up group demonstrated a slightly greater improvement than the dynamic push-up group pre-to post-test, but there were no significant differences between the two groups. These results showed that the plyometric push-up was more effective than dynamic push-up in developing upperbody power and strength. It still remains unclear whether upper body PT could translate into improvements in athletic performance. Santos and Janeira (2011) studied the effects of PT explosive strength in adolescent male basketball players (age: 14 to 15 years). An experimental group and control group were utilized. The experimental group performed a 10-week in-season PT programme, twice weekly, along with regular in-season basketball practice.

Simultaneously, the control-group participated in regular basketball practice only. Forthe upper-body, explosive strength test-battery in the 3-kg medicine ball throw, the experimental group improved 14.9% pre- to post-testing, as against the control improving 5.5% after the 10-week intervention. This shows a significant difference between the groups ($p<0.001$). Conclusively, PT showed positive effects on upper and lower-body explosive strength in adolescent male basketball players. Faigebaum *et al.* (2007) showed similar results in a study exploring the effects of combination training (PT and weight training) as against weight training (WT) only, in adolescent participants. For the upper-body explosive power test, the combination training group improved 14.4% upon the 3.6-kg medicine ball throw pre- to post-testing, versus the WT of 5.6% in the six-week intervention. It was thus significantly greater than the WT ($p<0.05$).

The above upper body PT literature found the plyometric push-up could be a more effective in developing upper-body power and strength than a dynamic push-up, in recreationally active females. In active adolescent males, upper body power was significantly improved with concurrent in-season training and additional PT than participants just maintaining in-season training. Furthermore, combination training demonstrated greater gains in upper body explosive power than WT alone, in adolescent males.

Upper body PT is acknowledged as a highly viable, useful, and necessary PT modality, but was not the focus of this theoretical review of lower body plyometric. Further study would be highly recommended for exploring upper body PT alone, or alternatively, combined with lower body PT in trained and untrained athletes participating in power-based sports such as rugby union. The use of upper body PT in water compared to land-based upper body PT would be a useful addition to research.

2.6.2 Combination training for athletic performance

An effective optimal training strategy to enhance dynamic athletic performance appears to be a hybrid; plyometric training (PT) combined with other training modalities, most commonly with some form of weight training (WT). The combination of these exercises may better facilitate the neural and mechanical mechanisms that enhance performance in activities that require maximal force. WT protocols have been modified by incorporating more dynamic and explosive movements aimed toward power development. WT protocols are becoming increasingly effective in improving mechanical power in movements requiring explosiveness (Komi & Bosco, 1978; Wilson *et al.,* 1993). For example, the combination of PT and WT appears to have a greater potential to enhance vertical jumping (VJ) performance when compared with PT alone (Markovic & Mikulic, 2010; Sáez-Sáez De Villarreal *et al.,* 2010). Kubo *et al.* (2007) studied the effect of PT and WT on the mechanical properties of the muscle–tendon complex and muscle activation during jumping. Results showed that PT improved concentric and stretch-shortening cycle (SSC) jump performances through changes in mechanical properties of the muscle-tendon complex. WT-induced changes occurred only in the concentric jump performances due to increased muscle hypertrophy and neural activation of plantar flexors.

Faigebaum *et al.* (2007) further explored the effects of a six-week combination training (PT and WT) compared with static stretching and WT, on performance variables in adolescent male participants aged between 12- to 15 years. Performance variables tested pre-to post-testing were vertical jump, long jump, 3.6-kg medicine ball toss, 9.1-m sprint, pro agility shuttle run and sit-and-reach flexibility. The combination training-group made significantly ($p<0.05$) greater improvements than WT in long jump (10.8 cm versus 2.2 cm), medicine ball toss (39.1 cm versus 17.7 cm) and Pro-agility shuttle run time (-0.23 s versus -0.02 s) following training. Results established that adding PT to a resistance training programme was more effective than resistance training and static stretching, in improving upper and lower body power performance in boys. Therefore combination training would be a valuable addition to a conditioning programme aimed at maximizing power performance in youth.

Fatourus *et al.* (2000) also supported the use of combination training comprising of traditional and Olympic-style weightlifting exercises and plyometric drills to improve VJ ability and explosiveness in untrained men. The combination training (PT plus WT) group exhibited significantly ($p<0.05$) better performance than the PT and the WT groups in VJ height, jumping mechanical power and flight time. Leg strength was measured by the leg press and barbell back squat. The combination-group presented significantly ($p<0.05$) greater improvement compared to the PT-group but not to the WT-group. WT showed greater improvement than PT in maximal leg strength measured by the leg press, whereas maximal strength measured by the back squat showed equal increases in both groups. These findings were attributed to the nature and specificity of the plyometric and WT exercises prescribed during the intervention.

However, the structure of the 12-week intervention, with three days per week training would be unpractical within an in-season intervention for a power-based sport, and would be far more beneficial in a off-season or pre-season periodization. Athletic training programmes must be varied between PT, WT, and combination of both modalities to fully complement an athlete's physical conditioning and preparation for in-season competition. Mihalik, Libby, Battaglini and McMurray (2008) studied the efficacy of two forms of combination training programmes (complex and compound) for enhanced VJ height and increased lower body power production. A group of 31 competitive club volleyball players (11 men and 20 women; age: 20.6 ± 2.3 years) were assigned to either a complex training group or a compound training group, based on gender, or matching the participants on pertaining vertical jump height (VJH). Both groups trained twice a week for four weeks. The complex training group alternated WT and PT on each training day, whereas the compound training group consisted of WT on one day and PT on the other. The participants underwent a single test of a VJ (with countermovement arm swing) upon a force platform measuring the VJ height and lower body power output. VJ testing sessions were performed pre-training, post weeks one, two, three, and four of training. Both groups improved significantly for VJH ($p<0.0001$) and power production ($p<0.0001$) over the four weeks of training. The complex training group increased VJH by 5.4%, while the compound training group increased VJH by 9.1%. The complex training group increased mean power output by 4.8%, while the compound training group increased mean power output by 7.5%. Neither group improved significantly better than the other, nor did either group experience faster gains in vertical leap or power output ($p>0.05$). Compared to pre intervention measures, both groups significantly increased VJH and power in the post week three and four sessions. VJH was significantly higher for men in both groups ($p< 0.0001$). Men jumped 24.8% and 22.3% higher than their female counterparts in the complex and compound training groups. Power outputs were significantly higher in the men for both groups ($p<0.0001$). The complex training group was 31.4% greater and the compound training group was 26.4% greater. No significant difference in the rate of improvements in VJH or power output occurred between genders ($p>0.05$).

Mihalik *et al.* (2008) found that both forms of training resulted in similar improvements in VJH and power for both genders, regardless of training experience. A minimum of three weeks of either complex or compound training was effective for improving VJH and power output. The choice of training programme might therefore be dependent upon how the WT and plyometric fit best into the overall training programme of a team or athlete's periodization.

Combination of PT and WT may better facilitate the neural land mechanical mechanisms to enhance performance requiring maximal force, and developing power through more dynamic and explosive movements. Combination of PT and WT could have a greater potential to significantly enhance VJ performance than with PT alone in both trained and untrained populations (US Department of Health and Human Services, 2010).. Combination training also produced significant results in upper and lower power, agility and sprint speed, in adolescent males. Combining WT with upper body and lower body PT produced greater improvements than WT-trained boys in VJ, long jump, medicine ball toss, 9.1 m sprint, and an agility shuttle run. Complex or compound training produces similar results in VJ height and leg power in trained male and female volleyball players.

2.7 Plyometric programme development and intervention

Gambetta (2007) and US Department of Health and Human Services (2010), stated that plyometric training (PT) is appropriate for virtually any sport if properly applied in the context of the sport. The goals of PT are to raise explosive power, better attenuate ground reaction forces, and learn to tolerate stretch loads. There is not a sport that could not profit from one or all three goals. The most important consideration in implementing and administering a land-based plyometric training (PT) programme is the athlete. Age, experience, and athletic maturity are all important criteria in establishing and modifying PT (Chu, 2011). Development of a plyometric programme should begin with establishing an adequate strength base that will allow the body to withstand the large stresses during ground contact (Voight & Tippett, 2004; US Department of Health and Human Services, 2010). An effective PT programme must accomplish specific goals through the manipulation of these factors: mode, intensity, frequency, duration, recovery, and progression (Chu, 2011; Potash & Chu, 2008).

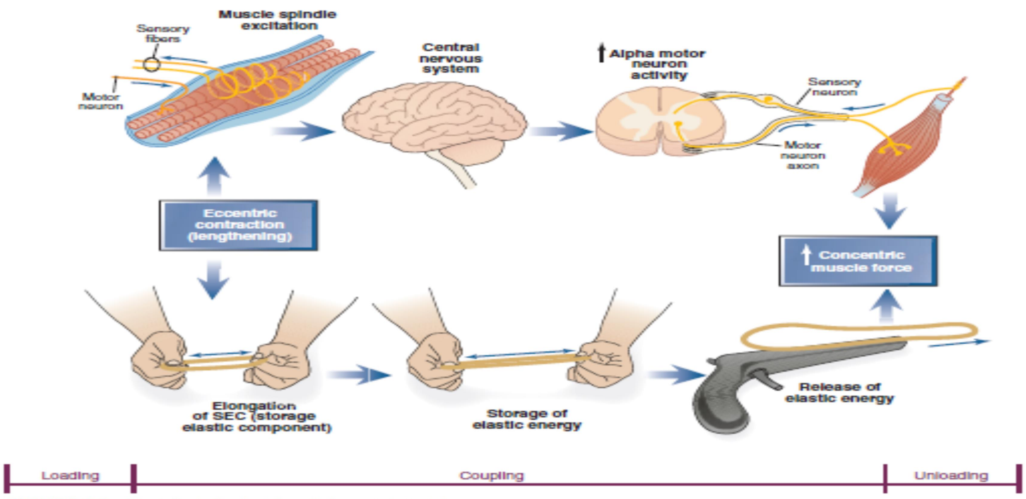
The only reported recommendations for implementing an aquatic plyometric programme were from Witzke & Snow (2012). These recommendations advised that an aquatic plyometric training (APT) programme should be based on the same principles as those of land-based PT with regards to the rules for intensity, volume, height of jumps, and frequency (Miller *et al.*, 2001). Although the study by Martel *et al.* (2005) was the first to combine sport specific conditioning with an APT programme. This APT programme provided a useful template for power-based sports, especially those where power endurance was important. Miller *et al.* (2001) also provided training guidelines for PT performed within the aquatic environment. With the physical properties of water in mind, these training guidelines optimized APT programme prescription, and included the use of aquatic plyometric equipment, as well as safety considerations for the participant performing these explosive exercises.

2.7.1 The Elastic Properties of Muscle

The concept of plyometric is based on the three-component model of muscle. Muscle is modeled with a contractile element and two elastic elements that are named according to their relationship to the contractile element—one in line with (the series elastic element) and one in parallel (the parallel elastic element). When a muscle contracts, tension is not directly transmitted to the ends of the tendon and the load is not overcome, leading to movement. This would only happen if the connection between the contractile element and its insertion were rigid and inelastic.

In reality, the contractile element develops tension, stretching the series elastic element; the degree of stretch is dependent on the load to be moved. After sufficient tension has been generated the tension at the ends of the muscle is sufficient to overcome the load and the load is moved. When a load is applied to a joint (eccentric phase), the elastic elements stretch and store potential energy (amortization phase) prior to the contractile element contracting (concentric phase). An eccentric contraction immediately preceding a concentric contraction significantly increases the force generated concentrically as a result of the storage of elastic potential energy (Bosco, Viitasalo, & Komi, 2010).

During the loading of the muscle, the load is transferred to the series elastic components and stored as elastic potential energy. The elastic elements then contribute to the overall force production by converting the stored elastic potential energy to kinetic energy, which enhances the contraction (Bosco, Viitasalo, & Komi, 2010; Asmussen & Bonde-Petersen, 2010). The muscle's ability to use the stored elastic potential energy is affected by the variables of time, magnitude of stretch, and velocity of stretch. Increased force generation during the concentric contraction is most effective when the preceding eccentric contraction is of short range and is performed without delay (Wilson, Wood & Elliott, 2010). A simple example of the use of the energy stored in the elastic element is the basic vertical, or countermovement, jump. The initial squat (the countermovement) is the eccentric phase that stretches the elastic elements and stores elastic energy (amortization phase). When the jump is performed (the concentric phase), the stored energy is "added" to the tension produced leading to a higher jump. The amount of stored energy used is inversely proportional to the time spent in the amortization phase.



Adopted from American College of Sports Medicine. (2010)
Figure 2: Physiological principles of Plyometric training

When doing a vertical jump, the longer one waits at the end of the countermovement before performing the jump, the lower the eventual jump height due to the inability to recover the stored elastic energy. The improved muscular performance that occurs with the pre-stretch in a muscle is the result of the combined effects of both the storage of elastic potential energy and the proprioceptive properties of the muscle. The percentage that each component contributes is unknown at this time, but the degree of muscular performance, as stated earlier, is dependent upon the time in transition from the eccentric to the concentric contraction. Training that enhances neuromuscular efficiency decreases the time between the eccentric and concentric contraction, thereby, improving performance.

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, 2009). Chu (2013), Wilt (1976), Wilson *et al.* (2013), Voight *et al.* (2012) 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 cross bridges 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, 2009). 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; Witzke, & Snow, 2012). 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.,* 2013). 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; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2017).

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; Markovic, 2014). The muscles resist overstretching. Through stimulation of the stretch receptors of the muscle spindle, which causes the proprioceptive 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, 2008). This is called the stretch/miotic reflex (Wilt, 1976; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2017). 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; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2017). 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; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2017).

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; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2017). 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, 2012).

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, 2009). 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, 2013). 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, 2012).

According to Jacoby and Gambetta (1989) and Kotzamanidis (2014), 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, 2009; Kotzamanidis, 2014).

The power produced during a concentric contraction, after a series of small eccentricmovements, 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; Kotzamanidis, 2014). 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).

Kotzamanidis, (2014) and Faigenbaum, Farrell, Radler, Zbojovsky, Chu,, Ratamess, Kang, & Hoffman (2015), supports the research done by Hennessy (1990) 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 jumping skills and an increase in power.

According to Voight *et al.* (2012) 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 showed 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, 2013; Maarten 1990; Voight *et al.*, 2012; 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*., 2012). The additional stiffness allows the muscular system to use more of the external tension in the form of elastic reaction (Voight *et al.,* 2012). 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*. (2012), Bosco (2012) and Komi (2011) 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 musculoskeletal system. Plyometric exercises could help to improve muscular performance, centred on 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*., 2012).

2.7.2 Application of muscle physiology in plyometric training

In many sport skills eccentric (lengthening) muscle contractions are rapidly followed by concentric (shortening) contractions. Duda (2008) 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, 2008).

Duda (2008) compared these muscle contractions to the functioning of a spring. Inbasketball, 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 (2012) 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 (2012), 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, 2012). Apart from the response time, the strength of response should also be considered when determining the relationship between plyometric 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.

2.7.3 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.,* 2013). 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.,* 2013).

2.7.4 Energy repair

The recovery of elastic energy depends to a great extent on the time between the stretch shortening phases. 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.,* 2013). Therefore, the stretch-shortening cycle of movements has to be executed with minimal delay between the stretch-shortening phases. The recovery of the stored energyseems to occur relatively quickly during the shortening phase. Adams (2012), Faigenbaum, Farrell, Radler, Zbojovsky, Chu, Ratamess, Kang, & Hoffman (2015), Chu (2013) and Gambetta (2010) 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.

2.7.5 Plyometric and Sport Performance

A considerable amount of research has been undertaken to show the positive effects of plyometric on sports performance. Brown *et al.* (1986) and Faigenbaum, Farrell, Radler, Zbojovsky, Chu, Ratamess, Kang, & Hoffman (2015), 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 showed 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 (2012) 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 bio motor 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, and 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; Faigenbaum, Farrell, Radler, Zbojovsky, Chu, Ratamess, Kang, & Hoffman, 2015).

A study by Schultz, Perrin, Gansneder, Granata, Adams and Arnold (2001), and Diallo, Dore, Duche, & Van Praagh, (2014), 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 misalignments may confound their results obtained. In a study by Diallo, Dore, Duche, & Van Praagh, (2014), 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 utilized to influence neuromuscular and biomechanical factors to compensate for reduced effective muscle stiffness (Granata *et al.*, 2001). Faigenbaum, Farrell, Radler, Zbojovsky, Chu, Ratamess, Kang, &Hoffman (2015), 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 (2013) 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.*, 2013). Research has also been undertaken to compare different types of training to enhance performance. Wilson *et al.* (2013) 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*., 2013).

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 (2012) 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.

Diallo, Dore, Duche, & Van Praagh, (2014), examined the effects of a plyometric training programme on freestyle tumble turns. Forty (40) 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 plyometric 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 (2012) 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 (2012) 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 (2013) are of the opinion that plyometric training may affect knee stabilization 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 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 maneuvers.

Hewett and Stroupe (2013) 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 (2013) conclude that plyometric training may have a significant effect on knee stabilization and prevention of serious knee injury among female athletes.

Other research focused on methods of analyzing 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 focused 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 analyzed, 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 (Davies, Murphy, Whitty, &Watsford, 2013).

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, 2010).

In a study by Humphries, Newton and Wilson (2012) 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 utilizing 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 recognized 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.,* (2012) 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 plyometric on rugby performance could be found, though it seems such an obvious sport to benefit from plyometric exercises.

2.7.8 PROGRESSION OF PLYOMETRIC TRAINING

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, 2010).

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, and 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 plyometric, could be unimpeded by extraneous factors.

2.7.9 Safety Precautions of Plyometric Training

• 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 (Davies, Murphy, Whitty, &Watsford, 2013).

2.7.10 Programme development

Voight *et al*. (2012) 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 periodization, 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, 2012). Plyometric exercises have to condition the neuromuscular skeletal system to be able to handle the increasing power load. Overexertion 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 showed. 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.*, 2012). 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, 2014). According to Yessis (1991), and as recommended by Atkins, Best, Briss, Eccles, Falck-Ytter, Flottorp, Guyatt, Harbour, Haugh, Henry, Hill, Jaeschke, Leng, Liberati, Magrini, Mason, Middleton, Mrukowicz, O'Connell, Oxman, PhillipsSchunemann, Edejer, Varonen, Vist, Williams, Jr, & Zaza (2010), 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 Chu *et al*, (2006), 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 (Mackenzie, 2012).

2.8 Summary

Based on the various literature reviewed by the researcher, plyometric training had significant effect on skill related component of fitness (speed, flexibility, agility, muscular strength and power) among male adolescent, and this type of exercise was found to be effective in promoting cardiorespiratory performance and endurance of athletes.

More so, from the literature reviewed, plyometric training can also be used by coaches, physical Educators and trainers to train male adolescent to improve skill related components qualities in sport competitions.

The literature reviewed showed a positive relationship between plyometric training and skill related component of fitness among male adolescent. The improvement in skill related component of fitness following plyometric training could be due to the ability to use and store elastic energy. 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 cycles is minimal causing maximum energy storage.

The positive role of plyometric training in improving skill related component of fitness in healthy male adolescent proved that plyometric exercise can be considered as an important component of fitness for male adolescents.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

The purpose of this study was to assess the effects of plyometric training on selected skill-related components of fitness among adolescent boys in Lokoja Metropolis, Nigeria. This chapter focused on the procedures used by the researcher.

3.1 Research Design

In this study, a Pre-test – Post-test experimental research design was adopted for the study. The main strength of this research is the initial randomization which ensures that the two groups are equally treated (AAPHERD, 2014). Pre-test and post-test measurement of agility, power and speed of the group will be administered before the commencement of training and immediately at the end of the training duration. The average difference between pre-test and post-test were used to determine the effectiveness of the plyometric training on agility, power and speed at the end of 12 weeks of the study (Vossen, 2014).

3.2 Population of the Study

The population of the study consisted of 1,497 junior secondary school male students between ages of 12- 17 years in Lokoja, Nigeria (Kogi State Education Board, 2017).

3.3 Sample and Sampling Techniques

The sample size of this study was 50. The participants were drawn from the population (1,497) of junior secondary school male students between ages of 12- 17 years in Lokoja. To obtain the sample size from the population, the researcher employed the sample size procedure proposed by Sambo (2008) who suggested that in a finite population, the sample size can be derived using 5% of the population where confidence level is 95%.

3.4 Instrumentation

The following facilities, instruments/equipment were used in this study for data collection;

i. **Stadiometer:** The Holtain stadiometer, made of two metal planes set at right angle with an adjustable pointed arrow head, model NJ07072, manufactured by Pfister import-export Inc. USA was used to measure the height of subjects in meters, while standing bare-footed against the instrument (Ross &Marful-Jones, 2013).

ii. **400m athletic track**: was used to train the subjects in sprint test in an open ground for different training session.

iii. **Tape measure (30 meter):** was used to measure distance.

iv. **Weighing Scale:** A portable weighing scale known as Hanson scale, model BIDOIA, made in Ireland, was used to measure the subjects weight (in kg), while lightly dressed without wearing shoes or ornaments (AAHPERD; 1990)

v. **Stop Watches:** Five (5) professional digital sports timers made in china was used to time the duration of subjects workouts to the nearest seconds on each training day, performances in the speed, sit-ups and shuttle run for agility (Sharkey; 1995).

vi. **Step Test Box:** the step box was used for preparation of subject flexibility on lower part of the body, and cardiorespiratory endurance before the commencement of the training session.

3.5 Plyometric Training Protocol

12 -weeks of plyometric training program was adopted for this study and had been used in previous studies (ACSM, 2012; Rumpf, Cronin, Pinder, Oliver & Hughes, 2012). When

developing the protocol, Piper and Erdmann (2011) and Miller et al. (2001) recommended a gradual approach to aquatic plyometric training.

The training program was commence from low volume plyometric drills and progressively increased in volume and intensity until the completion of the study.

3.6 Training Protocol

- ✓ **Side to side ankle hop**

The athlete uses both feet, jump from side to side, the jump should cover a span of 2 to 3 feet (61-91 cm) produce the motion from the ankles. This keep the feet apart and land on both feet at the same time.

- ✓ **Standing jump and reach**

The athletes were squat slightly and explode upward, reaching for a target or object do not step by jump example jumping to make a basket in basketball.

- ✓ **Front cone hop**

The athletes keep the feet shoulder – width apart, jump over each barrier, landing on both feet at the same time. Use a double- arm swing and work to decrease the time spent on the ground between each barrier.

- ✓ **Lateral Jump Over Barriers**

The athletes jump sideways down the row of cones, landing on both feet. In clearing the last cone, land on the outside foot and push off to change direction, then jump two footed back down the row of cones sideways. At the last cone push off again on the outside foot and change direction keep movement smooth and even, try not to pause when changing direction.

✓ **Lateral cone hop**

This training protocol, the athlete jumps vertically but pushing sideways off the ground bringing the knees up to jump sideways over the barrier example it is applicable in hurdle races.

✓ **Depth jump to prescribe height**

The athlete steps off the box, landing on to the second box, landing lightly, the jump from the ground should be as quick as possible.

✓ **Double leg hops**

The athlete squat down and jump up as far forward as possible. Immediately after touching down, jump forward again. Use quick double arm swings and keep landing short. Do in multiple of three to five jumps.

Week 1

The Plyometric drills to be includes side to side ankle hop, stand jump and reach, and front cone hops. The training volume of 90% was maintained, 45% to heart rate maximum and rate of perceived exertion (RPE) of 10-11 were maintained, Set of repetition were 2x15, 2x15, 6x5, 5 minute resting period were observed and the training intensity will be maintained at low level although.

Week 2

The Plyometric drills includes side to side ankle hop, stand jump and reach, Lateral jump over barrier, double leg hops. The training volume 120% were maintained, with 45% heart rate maximum (HRmax) and Rate of perceived exertion (REP) of 10-11 will still be maintained, set of repetition were 2x15, 2x15, 6x5 and 10x3 5 minutes resting period were absences and the training intensity were maintained at low and medium level respectively.

Week 3/4

The Plyometric drills to be performed includes side to side ankle hop, standing long jump, Double leg hops, lateral cone hop, single leg bounding, lateral jump over barrier and tuck jump with knees. The training volume of 120% - 140% were maintained, with heart Rate maximum of 55% and Rate of perceived exertion of 12-14 will be maintained, set of repetition were 1x12, 6x4, 3x10, 8x4, and 8x3 resting period of 5miuntes were observed and the training intensity were maintained at low, medium and high level.

Week5/6

The Plyometric drills to be performed includes single leg bounding, Jump to box, depth jump to prescribed height, lateral cone hops, tuck jump with knees up, literal jump single leg. The training volume of 140, and 120 with heart rate maximum of 65% and rate of perceived exertion (RPE) 14-15 were maintained. Set of repetition were 2x6, 2x10, 3x10, 2x12, 6x3, 4x5, resting period of 10 minutes i.e 5+5 =10 were observed. The training intensity will be maintained at low , medium, and high, level respectively.

Week7/8

The Plyometric drills to be performed includes Jump to box, depth jump to prescribed height, double leg hops, lateral cone hop, truck jump with knees up, and lateral jump single leg. The training volume of 120, and 90 were maintained of 75% and the rate of perceived exertion (RPE) of 15-20 were maintained. Set of repetition will be 3x10, 2x12, 4x5, 6x3, 6x5, 2x15. Resting period of 10minutes i.e. 5+5=10 were observed, the training intensity were maintained at low, medium high, medium.

Week9/10

The Plyometric drills to be performed includes jump to box, double leg hops, lateral cone hops, tuck jump with knees up, depth jump to prescribed height. The training volume of 90 and 120 will be maintained with heart rate maximum of 85% and the rate of perceived exertion (RPE) of 20 and 25 will be maintained set of repetition were 2x15, 4x5, 6x5 3x10, 2x10, 4x5. Resting period of 10 minutes, i.e 5+5 =10 will be observed. The training intensity were maintained at low, medium high, high.

Week 11/12

The Plyometric drills to be performed includes depth jump to prescribed height, double leg hops lateral cone hops, lateral jump single leg, jump to box. The training volume of 120-90 were maintained with heart rate maximum (HR max) 95% and the Rate of perceived of exertion (RPE) 25 and 30 were maintained set of repetition were 3x10, 2x15, 6x5 4x5. Resting period of 10 minutes i.e 5+5 =10 will be observed. The training intensity were maintained at low, medium High, High.

Plyometric Training Schedules as recommended by Rumpf, Cronin, Pinder, Oliver & Hughes (2012).

Training week	Training volume	Training Intensity	Plyometric Drills	Sets x Repetitions	Resting Period	Training Intensity
Week 1	90	45% HR_{max} (RPE 10-11) 45%-50%	Side to side ankle hop Standing jump and Reach Front Cone hops	2x15 2x 15 6x5	5min	Low Low Low
Week 2	120		Side to side ankle hop Standing jump and Reach Lateral Jump Over barrier Double leg hops	2x15 2x15 6x5 10 x3	5min	Low Low Medium Medium
Week 3	120	55% HR_{max} (RPE 12-14) 50%-55%	Side to side ankle hop Standing long Jump Double leg hops Lateral cone hop	2x12 6x4 8x3 2x12	5min	Low Low Medium Medium
Week 4	140		Single leg bounding Standing long jump Lateral jump over barrier Lateral cone hops Tuck jump with knees up	2x12 2x12 3x10 8x4 3x10	5min	High Low Medium Medium High
Week 5	140	65% HRmax (RPE 14-15) 55%-60%	Single leg bounding Jump to box Double leg hops Lateral cone hops Tuck jump with knees up Lateral jump over barrier	4x6 2x10 2x10 6x3 2x12 6x5	5min	low Low Medium medium
Week 6	120		Jump to box Depth jump to prescribed height Double leg hops Lateral cone hops Tuck jump with knees up Lateral jump single leg	3x10 2x10 4x5 6x3 2x10 4x5 2x10	5min	Medium Medium Medium High High High
Week 7	120	75% HRmax (RPE 15-20 60%-65%	Jump to box Depth jump to prescribed height Double leg hops Lateral cone hops Tuck jump with knees up Lateral jump single leg	3x10 2x12 4x5 6x3 6x5 2x10 2x12	5min	Low High Low High High Low Low
Week 8	90		Jump to box Depth jump to prescribed height Double leg hops Lateral cone hops Tuck jump with knees up Lateral jump single leg	2x15 2x15 2x 15 6x5 3x10 2x10 4x5	5min	High High Medium Medium High High High
Week 9	90	85% HRmax RPE 20 – 25 70 – 75%	Jump to box Depth jump to prescribed height Double leg hops Lateral cone hops Tuck jump with knees up Lateral jump single leg	2x15 2x15 2x 15 6x5 3x10 2x10 4x5	5 min	High High Medium Medium High High High

Week 10	120	85% HRmax RPE 20 – 25 70 – 75%	Side to side ankle hop Standing long Jump Double leg hops Lateral cone hop	2x12 6x4 8x3 2x12	5 min	Low Low Medium Medium
Week 11	120	95% HRmax RPE 25 – 30 80 – 85%	Side to side ankle hop Standing jump and Reach Lateral Jump Over barrier Double leg hops	2x15 2x15 6x5 10 x3	5 min	Low Low Medium Medium
Week 12	90	95% HRmax RPE 25 – 30 80 – 85%	Side to side ankle hop Standing jump and Reach Front Cone hops	2x15 2x 15 6x5	5 min	Low Low Low

3.7 Administration of Test

Height

Height was measured using a wall-mounted stadiometer (Butterfly, Shanghai, China) recorded to the nearest 0.5 centimeter. Body mass was measured to the nearest 0.1 kg using a digital scale (BC-554 Ironman Body Composition Monitor, Tanita, Illinois, USA). The body mass index (BMI) was determined by dividing body mass by the square height of the subject (kg/m2). The subjects were carefully familiarized with the test procedures during several submaximal and maximal actions a few days before the performance measurements were taken (four learning sessions during two weeks).

The subjects were complete several explosive type actions to become familiar with the exercises used during training. In addition, several warm-up muscle actions were performed prior to the actual maximal and explosive test actions. All tests were carried out before and after 7 weeks of plyometric training. The study was completed during winter. The performance tests were completed in four days. On day 1, the following tests was completed: height, body mass, SJ and CMJ for maximal vertical distance (cm), DJ (from 20, 40, and 60 cm) for reactive strength (cm/ms). On day 2, the 20-m sprint test was carried out; on day 3, the 5-repetition maximum (5RM) test was completed, and on day 4, the Illinois agility test (23) was completed. Ten minutes of standard warm-up (5 minutes of submaximal running with several displacements, stretching exercises for 5 minutes, and 2 submaximal jump exercises of 20 vertical jumps and 10 longitudinal jumps) were executed before each testing day.

Muscular Strength (MS).

A parallel squat test was selected to provide data on maximal dynamic strength of the lower extremity muscles. Muscular strength was assessed using concentric-eccentric 5RM parallel squat action. Parallel squat tests were completed using free weights, with the subject assuming an initial erect position with the bar behind the shoulders. Then, the subjects lowered the bar until the upper portion of the thighs was parallel with the floor (determined visually by the investigators).

Finally, the subject was perform a concentric leg extension (as fast as possible) to reach the full extension of 180° against the resistance determined by the weight. This action was repeated five times, with the maximum weight possible. Warm-up consisted of a set of 10 repetitions at loads of 40- 60% of the perceived maximum. After one minute of rest and mild stretching, subjects performed a second set of 3-5 repetitions at loads of 60-80% of the perceived maximum. Thereafter, the subjects were having a maximum of 5 separate attempts to find their 5RM. The last acceptable 5 consecutive repetitions with highest possible load (kg) were determined as 5RM. The rest period between the actions was always between 3-5 minutes.

Explosive Strength (ES).

The subjects were perform Distance Jump (DJ) from a 20-, 40-, and 60-cm high platform, using an electronic contact mat system (Globus Tester, Codogne, Italy) with a precision of 0.01 m. The subjects were instructed to place their hands on their hips and step off the platform with the leading leg straight to avoid any initial upward propulsion ensuring a drop height of 20, 40, and 60 cm. They were jump for maximal height and minimal contact time, in order to maximize jump reactive strength. The subjects were again be instructed to leave the platform with knees and ankles fully extended and to land in a similarly extended position to ensure the validity of the test. Four basic techniques was stressed: (i) correct posture (i.e., spine erect, shoulders back) and body alignment (e.g., chest over knees) throughout the jump; (ii) jumping straight up with no excessive side-to side or forward-backward movement; (iii) soft landing including toe-to-toe heel rocking and bent knees; and (iv) instant recoil for the concentric part of the jump. Phrases such as “on your toes”, “straight as a stick”, “light as a feather”, and “recoil like a spring” were used as verbal and visualization cues during the DJ. The instruction given to the subjects was “jump as high as you can, with minimum ground contact time”. Three repetitions were executed from each height, with 10-15 seconds between repetitions. The best performance trial was used for the subsequent statistical analysis. Trials with contact times over 250ms were not recorded. The infraclass correlation coefficient (ICC) was 0.97 (0.96-0.98) for 20-cm DJ, 0.97 (0.96-0.98) for 40-cm DJ, and 0.97 (0.96-0.98) for 60-cm DJ.

Squat Jump (SJ). A Squat Jump (SJ) was also used to assess maximal vertical jump height performance. The SJ test was performed using an electronic contact mat system (Globus Tester, Codogne, Italy) with a precision of 0.01 m. Jump height was determined using an acknowledged flight-time calculation (5,7). During SJ, the subject was instructed to rest his hands on his hips, foot and shoulders wide apart, adopt a flexed knee position (approximate 90º) during 3 s (25), and followed by a maximal effort vertical jump. All subjects were instructed to land in an upright position and to bend the knees following landing. Three trials were completed, with 10-15 s of rest between them, and the best performance trial was used for the subsequent statistical analysis.

Countermovement Jump (CMJ). A Countermovement Jump (CMJ) was used in order to assess maximal jump height performance requiring slow SSC action. The CMJ test was performed using an electronic contact mat system (Globus Tester, Codogne, Italy); with a precision of 0.01 m. Jump height was determined using an acknowledged flight-time calculation (5). During CMJ, the subject was instructed to rest his hands on his hips, foot and shoulders wide apart; subjects were perform a downward movement [no restriction was imposed over the knee angle achieved (30)] followed by a maximal effort vertical jump. All subjects were instructed to land in an upright position and to bend their knees following landing. Three trials were completed, with 10-15 s of rest between them, and the best performance trial was used for the subsequent statistical analysis. 10-m Sprint Time. Sprint times was then be recorded for 10-m distances. The 10-m sprint test was conducted indoors on a wooden running surface.

For all sprint tests, the subject started using a crouch start and commenced sprinting with a random sonorous sound. Infrared beams were positioned at the sprint distance, 1-m over the floor, to be measured with photoelectric cell (Globus Tester, Codogne, Italy). Subjects were given 2 practice trials performed at half speed after a thorough warm-up to familiarize them with the timing device. Three trials were completed, and the best performance trial was used for the subsequent statistical analysis. Three minutes of rest were permitted between 20-m trials. Times were recorded to the nearest 0.01 second.

Agility. Agility times was recorded for the Illinois agility test. The test was used to determine the ability to accelerate, decelerate, turn in different directions, and run at different angles. The Illinois agility test is set up with four cones forming the agility area (10 m long × 5 m wide). A cone was placed at each point A) to mark the start, B and C) to mark the turn spots, and D) to mark the finish. Another four cones were placed in the center of the testing area, 3.3 m from each other. The test was conducted indoors on a wooden running surface.

For all agility tests, the subject starts on the floor, face down, and was in with a random sonorous sound. The subjects must complete, as fast as possible, the agility circuit. Infrared beams were positioned at the finish point, 1-m over the floor, to take measurements with a photoelectric cell (Globus Tester, Codogne, Italy). Subjects were given two practice trials performed at half speed after a thorough warm-up to familiarize them with the circuit and timing device. Two trials were completed, and the best performance trial was used for the subsequent statistical analysis. Three minutes of rest were permitted between agility trials. Times were reported to the nearest 0.01 second (23).

Step Up

The Participant stands in front of a 6 inches step bench with back, legs and arms straight, feet hip-distance apart. With the right leg, participant step onto the center of the bench and straighten the right leg at the top. Opposite leg would remain behind for counter balance. And finally, slowly bend the right knee and step back down with the left and then the right foot to complete on rep. This was done repeatedly until the time schedule was up.

Treatment

The plyometric training was taking place two days per week (with at least 48 hours of rest between sessions) for the plyometric training groups, during 7 weeks of treatment. Each session lasted 30-45 minutes. Ten minutes of standard warm-up (i.e. 5 minutes of submaximal running and several displacements, stretching exercises for 5 minutes, 20 submaximal vertical jumps and 10 submaximal longitudinal jumps) was used prior to the main part of the training session. The plyometric exercises was consist of DJ (bounce drop jumps), with a total of 60 DJ per session (2 series of 10 jumps from a 20 cm box, 2 series of 10 jumps from a 40 cm box, and

2 series of jumps from a 60 cm box) for the MVG, and MVGHS groups, and a total of 120 DJs per session (4 series of 10 jumps from a 20 cm box, 4 series of 10 jumps from a 40 cm box, and 4 series of jumps from a 60 cm box) for the HVG group. The rest period between repetitions was approximately of 5 s, and between series was 1.5 minute. The control group was not performing any training intervention. This group was undergoing the same testing protocols as the other groups. The training was performed on a wood gymnasium floor with a restitution coefficient of 0.8 (MVGHS) or on a 3 cm thick athletic mat (7) with a restitution coefficient of 0.5 (MVG and HVG). The subjects were instructed to place their hands on their hips and step off the platform with the leading leg straight to avoid any initial upward propulsion, ensuring a drop height of 20, 40, and 60 cm. They were instructed to jump for maximal height and minimum contact time in every jump. These instructions were intended to maximize reactive strength. A researcher was always present during training sessions, motivating subjects to give their maximum effort in each jump.

3.8 Test Item Selection and Testing Procedure

Six (6) different skill selected components was administered to each subject throughout the duration of study. These tests are;

i. Height
ii. Speed
iii. Agility
iv. Power (leg power)

Before these tests is administered, written informed consent forms was given to subjects which was filled, duly signed and returned. The subjects were certified to be medically fit to undertake the tests

3.9 Experimental/Research Controls

In order to avoid the influence of extraneous and intervening variables on the results of this study. The following conditions was observed and controlled;

1. The researcher ensured that all measurements are carried out on the same day and time to allow for equal testing conditions for all subjects.
2. The purposes of each test item were explained to the subjects before the commencement of the test and exercise training programme.
3. The time for commencement of tests range from either 6.00am to 10.00am or 4.00pm to 7.00pm each test and training day. This is because these times of the day are more suitable and temperature friendly for carrying out physical activities.
4. Subjects were advised to have their meal as normal during the training period.
5. All subjects were encouraged to wear sport outfits that was appropriate for tests and training conditions.
6. All trainings were preceded by ten (10) minutes warm-up activities.

3.10 Research assistants

Three research assistants were involved in this research. The research assistants assisted in conducting and monitoring the exercise procedures.

3.11 Statistical Techniques

i. Descriptive statistic of mean and standard deviation were used to describe the demographic characteristics and average performance of the participant skill related fitness (agility, muscular strength, explosive power, flexibility and speed).

ii. Inferential statistic of t-test to test the hypothesis formulated to determine the effect of plyometric training on agility, explosive power and speed.

iii. The decision to reject or retain the null hypotheses formulated were made at 0.05 alpha level of significance.

v. All statistical analyses were performed using SPSS, IBM version 20.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Introduction

The purpose of this study was to assess the effect of plyometric training on skill related components of fitness among male adolescent in Lokoja Metropolis, Nigeria. These skills related components are power, speed and agility.

4.2 Results

Fifty (50) male adolescents participated in the study for duration of 12 weeks. Training was conducted on three alternate days per week. Information on the physical characteristics (age, weight and height and body mass index (BMI) of the participants used in this study is presented in the table 4:1

Table 4.1: Physical Characteristics of the Participants (n = 50)

Variables	Mean	SD	SE
Age (yrs)	13.52	1.61	0.33
Weight (Kg)	59.75	5.50	1.34
Height (m)	1.99	0.09	0.01
BMI (Kg/m^2)	24.71	1.78	0.31

Note: BMI = Body Mass Index in kilogram per metre square (kg/m^2)

The mean age of the participants is 13.52±1.61 years with an average height, weight and BMI of 1.59±0.09m, 59.75± 5.50kg and 24.71±1.78kg/m^2 respectively.

Testing of Hypotheses

Sub-hypothesis 1: There is no significant effect of plyometric training on explosive power of male adolescents in Lokoja metropolis, Nigeria.

Table 4.2: Paired t-test of the pre and post test scores of explosive power of the participants

Variable	Testing Period	Mean	SD	SE	Df	*T*	*p-value*
	Pre test	39.66	6.11	4.34			
Power					49	-8.35*	.001*
	Post test	48.33	6.45	4.02			

* = significant

Table 4.5 shows the paired t-test analysis of the pre-posttest scores of the explosive power of the participants. An observation of the result showed that 12 weeks of plyometric training significantly improved the explosive power of the participants (P = 0.001). Explosive power markedly improved by 21.86% from baseline data. Therefore, the null hypothesis which states that there is no significant effect of plyometric training on explosive power of male adolescents in Lokoja metropolis, Kogi State was rejected.

Sub-hypothesis 2: There is no significant effect of plyometric training on speed of male adolescents in Lokoja metropolis, Nigeria.

Table 4.3: Paired t-test of the pre and post test scores of speed of the participants

Variable	Testing Period	Mean	SD	SE	Df	*t*	*p-value*
	Pre test	3.41	0.14	0.63			
Speed					49	1.63	0.18
	Post test	2.98	0.25	0.67			

* = significant

Table 4.6 shows the paired t-test analysis of the pre-posttest scores of the speed of the participants. An observation of the result showed that 12 weeks of plyometric training had no significant effect on the speed of the participants (P = 0.18). Although speed improved by 12.61%. From the baseline data, it was not statistically significant. Therefore, the null hypothesis which states that there is no significant effect of plyometric training on speed of male adolescents in Lokoja metropolis, Kogi State was retained.

Sub-hypothesis 3: There is no significant effect of plyometric training on agility of male adolescents in Lokoja metropolis, Nigeria

Table 4.4: Paired t-test of the pre and post test scores of agility of the participants

Variable	Testing Period	Mean	SD	SE	Df	*t*	*p-value*
	Pre test	11.13	0.72	0.37			
Agility					49	6.00*	.004*
	Post test	12.35	0.75	0.32			

* = significant

Table 4.8 shows the paired t-test analysis of the pre-posttest scores of the agility of the participants. An observation of the result showed that 12 weeks of plyometric training had significantly improved the agility of the participants (P = 0.004). Agility markedly improved by 9.88% from baseline data. Therefore, the null hypothesis which states that there is no significant effect of plyometric training on agility of male adolescents in Lokoja metropolis, Kogi State was rejected.

Discussion

This study investigated the effect of plyometric training on selected skills related component of physical fitness of male adolescents in Lokoja Metropolis. Training was conducted three (3) times per week for duration lasting between 25 – 40 minutes at moderate intensity for a period of 12 weeks.

The findings of this study revealed an improvement in the mean values of explosive power of the participants who participated in plyometric training in Lokoja metropolis. The explosive power of the participants increased from 39.66±6.11 to 48.33±6.45 which represents increment of 21.86%. The results showed that twelve weeks of plyometric training increased explosive power significantly. The results were consistent with the study of Eskandar, Asghar,

&Ebrahim, (2014),who investigated the effect of plyometric and resistance training on agility, speed and explosive power in soccer players. It is also in consistence with the study of Lenhart*et al.,* (2009and (2011).

The results also showed that twelve weeks of resistance training had significant effects on increasing explosive power. These results were consistent with Shahidi*et al.,* (2009) but did not match with Lamontage*et al.,*&Hosseini*et al.,* (2011). Nerves adaptation improves strength in the first 3-4 weeks of resistance training. Muscle hypertrophy creates an increase in the size and function of muscle fibers after 8-12 weeks of resistance exercise (Johnson, Sburns, Azevedo, 2013).

Probably neural adaptations and hypertrophy caused by resistance exercises, improved explosive power in these subjects. Plyometric is a training method, which is widely used to improve muscular strength to generate explosive power (Haghighi, Moghadasi, Nikseresht, Torkfar, Haghighi, 2012). This method led to increased explosive power in subjects by rapid strength production and nervous system improvement after twelve weeks.

The findings of this study revealed an improvement in the mean values of speed record reduction of the participants who participated in plyometric training in Lokoja metropolis. The speed of the participants increased from 3.41±0.14 to 2.98±0.25 which represents increment of 12.61%.

The results showed that twelve weeks of plyometric training had no statistically significant effects on speed records reduction but thus showed improvement on speed of the participants. These results were consistent with Mohebi*et al.,* (2012) but did not match with Hosseini*et al.,* (2011).

This study is also in accordance with that of Rimmer and Sleivert (2000) who studied the effects of a plyometric programme on sprinting performance in a group of 26 male participants (age: 24

± 4 years), consisting of 22-rugby players and four touch-rugby players, playing at elite or under- 21 level of competition. But this is in contrary to the study by Shahidi*et al.,* (2012) and Thomas *et al.,* (2009) who compared the effect of either DJ or CMJ six-week, bi-weekly plyometric training intervention upon trained adolescent soccer players.

Research results show that resistance training improves speed in professional soccer players by affecting leg extensor muscles (Haghighi, Moghadasi, Nikseresht, Torkfar, Haghighi, 2012). Apart from increasing power, other factors such as muscle length and temperature, body shape and flexibility also should be noted in speedy performances. A number of factors such as muscle length, strength, age, gender, temperature, body shape, force and flexibility can have profound impacts on speed (Mokhtari&Rostami, 2003).

Probably plyometric exercises led to speed improvements by affecting muscle length, force, muscle temperature, strength and flexibility during the twelve weeks.

The findings of this study revealed an improvement in the mean values of agility record reduction of the participants who participated in plyometric training in Lokoja metropolis. The agility of the participants improved from to 11.13±0.72 to 12.35±0.75which represents an increment of 10.36%. The results showed that twelve weeks of resistance training had significant effects on improving agility records. This is also supported by the research conducted by Miller *et al.,* (2006) who studied the effects of a six-week plyometric intervention on agility performance.

The results is in contrary to a research by Wrotniak, Epstein, Dorn, Jones, &Kondilis, (2017), which showed no significant improvements in t-test times after the completion of a six-week combined plyometric and pre-season basketball conditioning programme by female basketball players.

Agility along with other factors such as balance, coordination, speed, power, and reaction speed is one of the physical fitness factors related to skills (Lotfi&Gaeini, 2003). Probably, muscle fibers hypertrophy due to resistance training led to the subjects' ability to change situation and direction rapidly without losing precision and balance.

The positive role of plyometric training in improving skill related component of fitness in healthy male adolescent proved that plyometric exercise can be considered as an important component of fitness for male adolescents.

The result in this research demonstrated that plyometric training has significant influence on some skills selected components of physical fitness parameters of adolescents' male in Lokoja metropolis, Nigeria.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION, AND RECOMMENDATION

5.1 Summary

The study was conducted to assess the effect of plyometric training on some selected skills related component of physical fitness of male adolescent in Lokoja metropolis. The training programme lasted for 12weeks. Fifty (50) male participants were used for this study.

They were divided equally into two groups using simple random techniques with each group consisting of 25 participants. Group A which is the experimental group underwent plyometric training for 12 weeks and Group B served as control group and thus did not participate in the training programme. The participants who met the inclusion criteria were all given informed consent forms to fill and give their readiness and willingness to undergo the training procedures. A written permission was obtained from Ahmadu Bello University Zaria, Ethical Committee, and from all the schools that were used for this study who granted the permission to carry out the study.

The physical characteristics of the participants were assessed before any training intervention. The explosive power, speed and agility of both groups were assessed before the training programme. The training was done for three for alternate days (Monday Wednesday and Friday).

All statistical analyses were done using statistical package for social science (SPSS) version 20 package. The hypotheses were tested at 0.05alpha-level of significance under relevant degree of freedom.

From the research conducted, explosive power increased from 39.66±6.11 to 48.33±6.45 which represents increment of 21.86% (P_{value} =0.001). Similar increases were observed on speed from

3.41±0.14 to 2.98±0.25 (12.61%), (P_{value} =0.18), agility from to 11.13±0.72 to12.35±0.75 (9.88%) with (P_{value} =0.04).

From the results above it could be concluded that plyometric training has significant effects on some skills selected components of physical fitness of male adolescent in Lokoja metropolis, Nigeria.

5.1.1 Summary of Findings

The analysis of data collected for the study revealed the followings:

(i) The participation in plyometric training had significant improvement on explosive power of male adolescent (P = 0.01*).

(ii) The participation in plyometric training had no significant improvement on speed of male adolescent (P = 0.18)

(iii) The participation in plyometric training had significant improvement on agility of male adolescent (P = .004*)

5.2 Conclusion

Based on the limitations of this study, it was concluded that plyometric training

(i) Improved explosive power of male adolescents in Lokoja metropolis.

(ii) Did not improved speed of male adolescents in Lokoja metropolis.

(iii) Improved agility of male adolescents in Lokoja metropolis.

5.3 Contributions to knowledge

This study contributes to knowledge as follows:

(i) Participation in plyometric training improve agility of male adolescent in Lokoja Metropolis, Nigeria

(ii) Participation in plyometric training did not improve power of male adolescent in Lokoja Metropolis, Nigeria

(iii) Participation in plyometric training improve speed of male adolescent in Lokoja Metropolis, Nigeria?

5.4 Recommendation

On the basis of conclusion drawn, the following recommendations are made;

(i) Parents/ward should encourage their children to participate in plyometric training to improve their skills, fitness and also help them develop mentally.

(ii) There is a need for school authority should increase the duration of the training programme to elicit enough response through exercise intervention

(iii) Corporate organization should help by partnering with the federal government agencies to providing a proper awareness about the health benefit of plyometric training and also assist in building fitness laboratories and amusement parks where sporting facilities are available for adolescents and the general public to use

(iv) There is a need for government and policy makers to mandate it for public and private schools to inculcate the plyometric training in their school curriculum this will also promote academic excellence.

(v) The finding of the study will provide prospective researchers with relevant information and literatures for further studies on plyometric training.

References

Adams, K.; O'shea, J.P.; O'shea, K.L. & Climstein, M. (2013). The effect of Eight weeks of Aquatic plyometric training on power production. *Journal of Applied Sport Science Research*, 6 (1): 36–41.

Adams, T. (2012). Jumping into strength training: Using plyometric to increase leg power. *Swimming Technique*, 22(3):25-26.

American College of Sports Medicine (ACSM). (2000). *Guidelines for exercise testing and prescription*. Fifth Edition. Baltimore: Williams & Wilkins.

American College of Sports Medicine. (2010). Plyometric Training concepts for performance Enhancement. ACSM Publication.

Anon (2009). "Scrum fitness" [Hyperlink http://www.scrum.com/fitnesstesting/default.asp]. 27 October 2009.

APA (2012). *Developing adolescents: A reference for professionals.* Washington, DC: American Psychological Society.

Arazi, H. & Asadi, A. (2011). The effect of aquatic and land plyometric training on strength, sprint, and balance in young basketball players. *Journal of Human Sport and Exercise*, 6 (1): 101-111.

Arnett, J. J. (2012). Emerging adulthood: A theory of development from the late teens through

Asmussen, E. & Bonde-Petersen, F. (2010). Storage of elastic energy in skeletal muscles in man. *Acta Physiol Scand* 91:385–92.

Astrand, P.; Rodahl, K. & Dahl, H. (2013). Textbook of Work Physiology, 4th ed. Champaign, IL: Human Kinetics.

Atkins, D, Best, D, Briss, PA, Eccles, M, Falck-Ytter, Y, Flottorp, S, Guyatt, GH, Harbour, RT, Haugh, MC, Henry, D, Hill, S, Jaeschke, R, Leng, G, Liberati, A, Magrini, N, Mason, J, Middleton, P, Mrukowicz, J, O'Connell, D, Oxman, AD, Phillips, B, Schunemann1 HJ, Edejer, TT, Varonen, H, Vist, GE, Williams, JW Jr, and Zaza, S. (2010). Grading quality of evidence and strength of recommendations. Bio Med Cent 328: 7454–7490, 2004. Available at: www.biomedcentral. com/1471-22888/6/52.

Baca, A. (1999). A comparison of methods for analyzing drop jump performance. *Medicine and Science in Sports and Exercise,* 31(3): 437-442.

Baker, D. & Nance, S. (2009). The relation between running speed and measures of strength and power in professional rugby league. *Journal of Strength and Conditioning Research,* 13 (3): 230-235.

Balciunas, M.; Stonkus, S.; Abrantes, C. &mpaio, J. (2006). Long term effects of different training modalities on power, speed, skill and anaerobic capacity in young basketball players. *Journal of Sport Science and Medicine*, (5): 163-170.

Bar-O, O. (2008). The Wingate anaerobic test: an update on methodology, reliability and validity. *Sports Medicine*, (4): 381-394.

Beachle, R.T. & Earle, R.W. (2010). *Essentials of strength training and conditioning.* Second Edition. Champaign, Illinois: Human Kinetics.

Behm, D.G. & Sale, D.G. (2013). Velocity specificity of resistance training. *Sports Medicine*, 15 (6): 374-388.

Berzonsky, M. D. (2014). Identity style, parental authority, and identity commitment. *Journal of Youth and Adolescence, 33*(3), 213-220.

Biscombe, T. & Drewett, P. (2012). *Rugby: Steps to success*. Champaign, Illinois: Human Kinetics.

Bishop, M.; Fiolkowski, P.; Conrad, B.; Brunt, D. & Horodyski, M. (2006). Athletic footwear, leg stiffness, and running kinematics. *Journal of Athletic Training,* 41(4): 387–392

Blazevich, A. (2009). “Plyometric training for PDHDE” [Hyperlink http;//members.ozemail.com.au/~cjhay/pdhpe/conference200/anthonyblazevich.htm]. 18 November 2009.

Blazevich, A.J. (2014). The influence of running surface properties on lower limb injury in human athletes. In: SOULSBY, E.J.L. & WADE, J.F. (Ed.) Proceedings of a Workshop on “Sporting injuries in horses and man: a comparative approach”, Lexington, United States of America: September 2004. Salem, MA: R & W Communications: 32-35.

Bloomfield, J.; Ackland, T. R. & Elliott, B. C. (20144). *Applied anatomy and biomechanics in sport.* London: Blackwell Scientific Publications.

Blos, P. (2009). *The adolescent passage: developmental issues*. New York: International

Bosco, C; Viitasalo, J,T; & Komi, P.V. (2010). Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. *Acta Physiol Scand* 114:557–65.

Bosco, C. (2012). Stretch-shortening cycle in skeletal function and physiological considerations on explosive power in man. *Atletica Studies*, 1: 7-113.

Bosco, C.; Komi, P.V.; Thihany, J.; Fekete, G. & Apor, P. (1983). Mechanical power test and fiber composition of human leg extensor muscles. *European Journal of Applied Physiology*, (51):129–135.

Boyle, M. (2014). *Functional training for sport*. Champaign, Illinois: Human Kinetics.

Brown, M.E.; Mayhew, J.L. & Boleach, L.W. (1986). Effect of plyometric training on vertical jump performance in high school basketball players. *Journal of Sports Medicine and Physical Fitness*, 26(1): 1-4.

Byrne, C. & Eston, R. (2012). The effect of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance.*Journal of Sports Sciences,* 20: 417-425.

Cairney, J, Hay, J, Faught, B, Wade, T, Corna, L, & Flouris, A. (2012). Developmental coordination disorder, generalized self-efficacy toward physical activity, and participation in organized and free play activities. J Peds 147: 515–520, 2005.

Chimera, N.J; Swanik, K.A & Swanik, C.B. (2009). Effects of plyometric training on muscle-activation strategies and performance in female athletes. *J Athl Train* ;39:24–31.

Chmielewski, T.L.; Myer, G.D.; Kauffman, D. & Tillman, S.M. (2006). Plyometric exercise in the rehabilitation of athletes: physiological responses and clinical application. *Journal of Orthopaedic & Sports Physical Therapy,* 36 (5): 308-319.

Chmielewski, T.L; Myer, G.D. & Kauffman, D. (2006). Plyometric exercise in the rehabilitation of athletes: physiological responses and clinical application. *J Orthop Sports Phys Ther* ;36:308–19.

Chu, D.A. (2011). *Jumping into Plyometric*(2nd ed.). Champaign, Illinois: Human Kinetics.

Chu, D.A. (2012). *One hundred exercises for power and strength. Jumping into Plyometric*. Second Edition. Champaign, Illinois: Human Kinetics.

Chu, D.A. (2013). *Jumping into plyometric*. Champaign, Illinois: Human Kinetics.

Coetzee, B. (2007). An overview of plyometric as an exercise technique. *South African Journal for Research in Sport, Physical Education and Recreation,* 29(1): 61-82.

Cohen, J. (2010). The effect size index: d. In: Statistical Power Analyses for the Behavioral Sciences (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc,

Colado, J. C.; Garcia-Masso, X.; González, L-M.; Triplett, N. T.; Mayo, C. & Merce, J. (2010). Two-leg squat jumps in water: an effective alternative to dry land jumps. *International Journal of Sports Medicine,* (31): 118 – 122.

Colado, J.C. & Triplett, N.T. (2009). Monitoring the intensity of aquatic resistance exercises with devices that increase the drag force: an update. *Strength and Conditioning Journal,* 31(3): 94-100.

Colado, J.C.; Tella, V. & Llop, F. (2006). Response to resistance exercise performed in water versus on land. *Rev Port Cien Desp*, 6 (Supplement 2): 361 – 362.

Colado, J.C.; Tella, V. & Triplett, N.T. (2008). A method for monitoring intensity during aquatic resistance exercises. *Journal of Strength and Conditioning Research,* 22 (6): 2045–2049.

Colado, J.C.; Tella, V.; Triplett, N.T. & Gonzalez, L.M. (2009). Effects of a short-term aquatic resistance program on strength and body composition in fit young men. *Journal of Strength and Conditioning Research,* 23(2): 549 – 559.

Collier, I. (2008). National coaching scheme. In *The Australian Rugby Football Union*. Sport Science Institute.

Committee on Sports Medicine and Fitness. (2009). Strength training by children and adolescents. J Peds 107: 1470–1472, 2001.

Cossor, J. & Mason, B. (2012). Swim start performances at the Sydney 2000 Olympic games. Available at: www.coachesinfo.com/category/swimming/143.

Cossor, J.M.; Blanksby, B.A. & Elliot, B.C. (1999). The influence of plyometric training on the freestyle tumble turn. *Journal of Science and Medicine in Sport*, 2(2): 106-116.

Davies B. A.; Murphy, A. Whitty, & Watsford, M. (2013). The effects of plyometric training on the swimming block start. *Australian Conference of Science and Medicine in Sport*. Available at: http://www.ausport.gov.au /fulltext/2001/acsms/papers/DAVB.pdf.

De Vries, H. & Housh, T.J. (1994). *Physiology of exercise.* Fifth Edition. Madison, Wisconson: Brown & Benchmark.

Diallo, O, Dore, E, Duche, P, & Van Praagh, E. (2014). Effects of plyometric training followed by a reduced training programme on physical performance in prepubescent soccer players. J Sports Med Phys Fitness 41: 342–348, Diallo, O.; Dore, E.; Duche, P. & Van Praagh, E. (2001). Effects of plyometric training followed by a reduced training programme on physical performance in prepubescent soccer players. *Journal of Sports Medicine and Physical Fitness*, (3): 342-348.

Dick, F.W. (2012). *Sports training principles*. Fourth Edition. London: Blackwell Scientific Publications.

Dick, F.W. (2012). *Sports training principles*. Second Edition. London: Blackwell Scientific Publications.

DiStefano, L.F, Padua, D.A, Blackburn, J.T, Garrett, W.E, Guskiewicz, K.M, & Marshall, S.W.(2010). Integrated injury prevention program improves balance and vertical jump height in children. J Strength Cond Res 24: 332–342.

Donoghue, O.A.; Shimojo, H. & Takagi, H. (2011). Impact forces of plyometric exercises performed on land and in water. *Sports Health,* 3 (3): 303-309.

Dowson, M.N.; Nevill, M.E.; Lakomy, H.K.A. (2011). Modelling the relationship between isokinetic muscle strength and sprint running performance. *Journal of Sports Science,* (16): 257-265.

Drinkwater, E.J.; Lane, T. & Cannon, J. (2009). Effect of an acute bout of plyometric exercise on neuromuscular fatigue and recovery in recreational athletes. *Journal of Strength and Conditioning Research,* 23(4): 1181–1186.

Driss, T.; Vandewalle, H.; Quièrvre, J.; Miller, C. & Monod, H. (2001). Effects of external loading on power output in a squat jump on a force platform: A comparison between strength and power athletes and sedentary individuals. *Journal of Sports Sciences*, (19): 99-105.

Duda, M. (2008). Plyometric: A legitimate form of power training. *Physician and Sports Medicine*, 16(3): 213-218.

Duthie, G.M.; Pyne, D.B. & Hooper, S. (2003). The applied physiology and game analysis of rugby union. *Sports Medicine*, (33): 973–991.

Dutton, M. (2008). *Orthopaedic Examination, Evaluation, and Intervention.* (2nd ed.) New York: McGraw-Hill Companies

DynaMed (2015). Male delayed puberty/Female delayed puberty. Retrieved from http://www.dynamed.com/home/

Ebben, W.P, Simenz, C, & Jensen, R.L. (2012). Evaluation of plyometric intensity using electromyography. J StrengthCondRes 22: 861–868, 2008.

Ebben, W.P, VanderZanden, T, Wurm, B.J, & Petushek, E.J. (2010). Evaluating plyometric exercises using time to stabilization. J Strengt Cond Res 24: 300–306.

Ebben, W.P. (2012). Complex training: A brief review. *Journal of Sport Science and Medicine, 2(1): 42-46.*

Elliott, B. (1999). *Training in sport. Applying sport science*. London: Wiley.

Elliott, G. R., & Feldman, S. S. (1990). Capturing the adolescent experience. In S.S. Feldman & G.R. Elliot (Eds.), *At the threshold: The developing adolescent* (pp. 1-13). Cambridge: Harvard University Press.

Ellis, L; Gastin, P.; Lawrence,S.; Savage, B.; Shiels, A.; Stapff, A.; Timilty, D.; Quinn, A.; Woolform, S.N. & Young, W. (2000). Protocols for the physiological assessment of team sports. In: Gore, C.J. (Ed.), *Physiological tests of elite athletes* (128-144). Champaign, IL: Human Kinetics Publishers.

Eskandar T; Asghar, N. & Ebrahim, K. (2014). The effect of 8 weeks of plyometric and resistance training on agility, speed and explosive power in soccer players. *European Journal of Experimental Biology*, 2014, 4(1): 383-386

Faigenbaum, A, Farrell, A.C, Radler, T, Zbojovsky, D, Chu, D.A, Ratamess, NA, Kang, J, & Hoffman, J. (2015). PlyoPlay'' A novel program of short bouts of moderate and high intensity exercise improves physical fitness in elementary school children. Phys Educ 66: 37–44.

Faigenbaum, A, Kraemer, W.J, Blimkie, C.J.R, Jeffreys, I, Micheli, L.J, Nitka, M, & Rowland, T.W. (2014). Youth resistance training: Updated position statement paper from the national strength and conditioning association. J Strength Cond Res 23: 60–79.

Faigenbaum, A.D.; Mcfarland, J.E.; Keiper, F.B.; Tevlin, W.; Ratamess, N.A.; Kang, J. & Hoffman, J.R. (2007). Effects of a shortterm plyometric and resistance training program on fitness performance in boys age 12 to 15 years. *Journal of Sports Science and Medicine*, (6): 519-525.

Fatouros, I.G.; Jamurtas, A.Z.; Leontsini, D.; Taxildaris, K.; Aggelousis, N.; Kostopoulos, N. & Buckenmeyer, P. (2000). Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *Journal of strength and conditioning research,* 14(4):470–476.

Ferreira, S. (2010). Personal correspondence with a lecturer at the Department of Sport science, 5 October. Stellenbosch: Stellenbosch University.

Flanagan, E.P. & Comyns, T.M. (2008). The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. *Strength and Conditioning Journal*, 30(5): 32-38.

Foran, B. (2001). *High Performance Sports Conditioning.* Champaign, Illinois: Human Kinetics

Fowler, N.E. & Lees, A. (1990). A comparison of the kinetic and kinematic characteristics of plyometric dorp-jump and pendulum exercises. *Journal of Sport Science*, 13(4):260-267.

Fukunaga, T; Kawakami, Y. & Kubo, K.(2002). Muscle and tendon interaction during human movements. *Exerc Sport Sci Rev* 2002;30:106–10.

fundamentals of pediatrics (3rd ed., pp. 747-795): McGraw-Hill.

Gabbett, T.J. (2002). Influence of physiological characteristics on selection in a semi-professional rugby league team: a case study. *Journal of Sports Science,* 20 (5): 399–405.

Gambetta, G. (2007). *Athletic development: The art & science of functional sports conditioning.* Champaign, Illinois: Human Kinetics

Gambetta, V. (2009). "Leg strength for sport performance." [Hyperlink http//www.elitetrack.com.gambettastrength.htm]. 23 January 2009.

Gambetta, V. (2010). Leaps and bounds. *Sports Coach***,** Summer: 14-18.

Gamble, G. (2004). Physical Preparation for Elite-Level Rugby Union Football. *Strength and Conditioning Journal,* 26(4):10–23.

Gehlsen, G.M., Grigsby, S.A., & Winant, D.M. (1984). Effects of an aquatic fitness program on the muscular strength and endurance of patients with multiple sclerosis. *Physical Therapy,* (64): 653-657.

Gehri, D.J.; Richard, M.D.; Kleiner, D.M. & Kirkendall, D.T. (2011). A comparison of plyometric training techniques for improving vertical jump and energy. *Journal of Strength and Conditioning Research,* 12(2): 85-89.

Giedd, J.N. (2015). The amazing teen brain. *Scientific American, 312,* 32-37. doi:10.1038/scientificamerican0615-32

Gollhofer, A; Strojnik, V & Rapp, W. (2009). Behaviour of triceps surae muscle-tendon complex in different jump conditions. *Eur J Appl Physiol.* 64:283–91.

Graber, J. A., & Brooks-Gunn, J. (1996). Transitions and turning points: Navigating the passage from childhood through adolescence. *Developmental Psychology, 32*(4), 768-776.

Graber, J. A., Brooks-Gunn, J., & Petersen, A. C. (Eds.). (1996). Transitions through adolescence: Interpersonal domains and context. Mahwah, NJ: Lawrence Erlbaum.

Granata, K.P; Wilson, S.E. & Padua, D.A (2001). Gender differences in active muscle elastic stiffness: quantification in controlled measurements. *Clinical Biomechanics*, 16: 942-943.

Grantham, N (2004). "Plyometric and sports injuries". *Sports Injuries Bulletin.* [Hyperlink http://www.sportsinjurybulletin.com/archive/1022-plyometricinjuries.htm].

Grantham, N. (2002). Plyometric in the pool: New research suggests that athletes can boost muscle strength and power with less risk of injury by exercising in water. *Sports Injury Bulletin,* (20): 8–10.

Greene, D.A. (2017). Adaptive skeletal responses to mechanical loading during adolescence. Sports Med: 36:723–732.

Greenfield, P. M., Keller, H., Fuligni, A., & Maynard, A. (2003). Cultural pathways through

Grumbach, M. M., & Styne, D. M. (2011). Puberty: Ontogeny, neuroendocrinology, physiology, and disorders. In W. J. et al. (Ed.), *Williams textbook of endocrinology* (9th ed.). Philadelphia: W.B. Saunders.

Gulick, D.T.; Libert, C.; O'melia, M. & Taylor, L. (2007). Comparison of aquatic and land plyometric training on strength, power and agility. *The Journal of Aquatic Physical Therapy*, 15 (1): 11-18.

Guy, J.A. (2009). Strength training for children and adolescents. J Am Acad Orth Surg 9: 29–36.

Haga, M. (2010). Physical fitness in children with high motor competence is different from that in children with low motor competence. Phys Ther 89: 1089–1097.

Harman, E. (2008). Biomechanics of resistance exercise. In: Earle, R.W. and Baechle, T.R., (Eds.), *Essentials of Strength Training and Conditioning.* (3rd ed.) (65-91). Champaign, IL: Human Kinetics.

Harman, E. A. & Garhammer, J. (2008). Administration, scoring, and interpretation of selected tests. In: Earle, R.W. and Baechle, T.R., (Eds.), *Essentials of Strength Training and Conditioning.* (3rd ed.) (250-292). Champaign, IL: Human Kinetics.

Harman, E. A.; Rosenstein, M. T.; Frykman, P. N.; Rosenstein, R. M. & Kraemer, W. J. (1991). Estimation of human power output from vertical jump. *Journal of Applied Sport Science Research*, (5): 116–120.

Harrison, A. J. & Gaffney, S. D. (2004). Effects of muscle damage on stretch-shortening cycle function and muscle stiffness control. *Journal of Strength and Conditioning Research,* 18(4): 771–776.

Harrison, R.A. & Bulstrode, S. (1987). Percentage weight bearing during partial immersion in the hydrotherapy pool. *Physiotherapy Practice,* (3): 60-63.

Harrison, R.A.; Hilman, M. & Bulstrode, S. (2013). Loading of the lower limb when walking partially immersed: implications for clinical practice. *Physiotherapy,* (78): 164.

Harry, P.L. (2008). National coaching scheme. In *The Australian Rugby Football Union*. Sports Science Institute.

Hartwig, T.B.; Naughton, G. & Searl, J. (2011). Motion analyses of adolescent rugby union players: A comparison of training and game demands. *Journal of Strength and Conditioning Research,* 25(4): 966–972.

Hawley, J. & Burke, L. (2012). *Peak Performance*. New Zealand: Allen & Unwin.

Hay, J.G. & Reid, J.G. (1988). *Anatomy, Mechanics, and Human Motion.* (2nd ed.). New Jersey: Prentice Hall.

Heiderscheit, B.C.; Mclean, K.P. & Davies, G.J. (2013). The effects of isokinetic vs. plyometric training on the shoulder internal rotators. *Journal of Orthopaedic and Sports Medicine Physical Therapy*, 23(2): 125-133.

Hennesy, L. (1990). Plyometric: Important technical considerations. *Athletics Coach,* 24(4): 18-21.

Hewett, T.E. & Stroupe, A.L. (2013). Plyometric training in female athletes. *American Journal of Sports Medicine*, 24(6): 765-776.

Hewett, T.E.; Lindenfeld, T, N.L.; Riccobene, J.V. & Noyes, F.R. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. *American Journal of Sports Medicine*, 27(6):699-705.

Hilyer, J. & Hunter, G.R. (1989). A year round strength development and conditioning program for men's basketball. *NSCA Journal* , 11(6): 16-19.

Hoffman, J.R.; Epstein, S.; Einbinder, M. & Weinstein, Y. (2000). A comparison between the wingate anaerobic power test to both vertical jump and line drill tests in basketball players. *Journal of Strength and Conditioning Research*, 14(3): 261–264.

Hoogenboom, B. & Lomax, N. (2004). Aquatic therapy in rehabilitation. In: Prentice, W.E., (Eds.). *Rehabilitation techniques for sports medicine and athletic training. (*4th ed.) (326-346). New York: McGraw-Hill Companies.

Hortobagyi, T.; Havasi, J. & Varga, Z. (1990). Comparison of two stretch-shortening exercise programmes in 13-year-old boys-nonspecific training effects. *Journal of Human Movement Studies,* 18 (4): 177-88.

Hughes, M.G; Lloyd, R & Meyers, R. (2012). Sprinting and Plyometric Ability in Youths: The Effect of Natural Development and Training. New York: Nova Science Publishers, Inc.

Humphries, B.J; Newton, R.U. & Wilson, G.J. (2012). The effect of a braking device in reducing the ground impact forces inherent in plyometric training. *International Journal of Sports Medicine*, (16): 129-133.

Hunter, J.P. & Marshall, R.N. (2012). Effects of power and flexibity training on vertical jump technique. *Medicine and Science in Sports and Exercise*, 34(3): 478- 486.

Hutchinson, M. R.; Tremain, L.; Christiansen, J. & Beitzel, J. (2011). Improving leaping ability in elite rhythmic gymnasts. *Medicine & Science in Sports & Exercise*, 30 (10): 1543-1547.

Impellizzeri, F. M.; Rampinini, E.; Castagna, C.; Martino, F.; Fiorini, S. & Wisloff, U. (2008). Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *British Journal of Sports Medicine*, (42): 42-46.

Inbar, O. & Bar-O, O. (1986). Anaerobic characteristics in male children and adolescents. *Medicine & Science in Sports & Exercise*, 18(3): 264-269.

Ingle, L, Sleap, M, & Tolfrey, K. (2010). The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys. J Sports Sci 24: 987–997.

Irmischer, B.S.; Harris, C.; Pfeiffer, R.P.; Debeliso, M.A.; Adams, K.J. & Shea, K.G. (2004). Effects of a knee ligament injury prevention exercise program on impact forces in women. *Journal of Strength and Conditioning Research,* (4): 703 – 707.

Jacobson, M. (2008). Developmental Neurobiology. New York: Rinehart & Winston, Inc;

Jacoby, E. & Gambetta, V. (1989). Strength development. *The Athletic's Congress's track and field coaching manual,* 19: 11-30.

Jamurtas, A.Z.; Fatouros, I.G.; Buckenmeyer, P.; Kokkinidis, E.; Taxildaris, K.; Kambas, A. & Kyriazis, G. (2000). Effects of plyometric exercise on muscle soreness and plasma creatine kinase levels and its comparison with eccentric and concentric exercise. *Journal of Strength and Conditioning Research,* 14(1):68–74.

Jenkins, D. (2008). National coaching scheme. In *The Australian Rugby Football Union*. Sport Science Institute.

Jennings, C.L.; Viljoen, W.; Durandt, J. & Lambert, M.I. (2005). The reliability of the FitroDyne as a measure of muscle power. *Journal of Strength and Conditioning Research,* 19(4):859–863.

Jensen, R.L. & Ebben, W.P. (2007) Quantifying plyometric intensity via rate of force development, knee joint, and ground reaction forces. *Journal of Strength and Conditioning Research,* 21(3): 763 – 767.

Johnson, B.L. & Nelson, J.K. (1979). Practical measurements for evaluation in Physical Education. Burgess: Minneapolis, Minnesota.

Jones, D. (2008). *Comparing land versus aquatic plyometric and agility interms of balance and agility in female athletes.* Unpublished MSc. thesis. Buckhannon: West Virginia Wesleyan College.

Kemp, F. (2012). *Die effek van 'n gekombineerde pliometriese en gimnasium program op die ratsheid en plofkrag van netbalspelers*. Unpublished Masters Thesis. University of Stellenbosch.

Kent, M. (2004). *Oxford Dictionary of Sport Science and Medicine.* (2nd ed). New York: Oxford University Press.

Kessel, B. (2012). “Functional plyometric training to enhanceperformance”. [Hyperlink http://wwwvitaljkd.com/articles/Functional%20Plyometric%20 Training %20.pdf].

Kidd, M. (2011). Personal correspondence with a consultant statistician at the Department of Statistics and Actuarial Sciences, 5 July. Stellenbosch: Stellenbosch University.

Komi, P.V. & Bosco, C. (1978). Utilization of stored elastic energy in leg extensor muscles by men and women. *Medicine & Science in Sports & Exercise*, 10(4): 261-265.

Komi, P.V. (2003). Stretch Shortening Cycle. In P.V. Komi; The International Federation of Sports Medicine & IOC Medical Commission (Eds.), *Strength and power in sport* (2nd ed.) (184-202). Melbourne, Australia: Blackwell Scientific Publications.

Komi, P.V. (2011). *Exercise and Sport Science Reviews: Physiological and biochemical correlates of muscle function, effects of muscle structure and stretch-shortening cycle on force and speed.* Lexington: Collamore Press.

Kotzamandisis, C. (2006). Effect of plyometric training on running performance and vertical jumping in prepubertal boys. *Journal of Strength and Conditioning Research,* (2):441–445.

Kotzamanidis, C. (2014). Effect of plyometric training on running performance and vertical jumping in prepubertal boys. J Strength Cond Res 20: 441–445, 2006.

Kubo, K.; Morimoto, M.; Komuro, T.; Yata, H.; Tsunoda, N.; Kanehisa, H. & Fukunaga, T. (2007). Effects of plyometric and weight training on muscle–tendon complex and jump performance. *Medicine & Science in Sports & Exercise*, 39 (10): 1801–1810.

Kubo, K; Kanehisa, H & Kawakami, Y. (2012). Influence of static stretching on viscoelastic properties of human tendon structures in vivo. *J Appl Physiol,* 90:520–27.

Kyröläinen, H.; Avela, J.; Mcbride, J.M.; Koskinen, S.; Andersen, J.L.; Sipilä, S.; Takala, T.E.S. & Komi, P.V. (2005). Effects of power training on muscle structure and neuromuscular performance. *Scandinavian Journal of Medicine and Science in Sports,* 15(1): 58-64.

Lathrop, M.C.,. Brown, E.W; Womack, C.J; Ulibarri, D; Paton, C. & Osmond, P. (2014). Biomechanical and physiological effects of plyometric training on adolescent cross-country runners. *Int. J. App Sports Sci*. 13: 12-26.

Lephart, S.; Ferris, C.; Riemann, B.; Myers, J. & Fu, F. (2001). Gender differences in neuromuscular patterns and landing strategies. *Clinical Biomechanics*, 16: 941-942.

Lerner, R. M., & Castellino, D. (2002). Contemporary developmental theory and adolescence: A developmental systems and applied developmental science. *Journal of Adolescent Health, 31*(6S), 122-135.

Levac, D,Wishart, L, Missiuna, C, & Wright, V. (2013). The application of motor learning strategies within functionally based interventions for children with neuromotor conditions. Ped Phys Ther 21: 345–355.

Lloyd, D.G. 2001. Rationale for training programs to reduce anterior cruciate ligament injuries in Australian football. *Journal of Orthopaedic and Sports PhysicalTherapy,* 31(11): 645-654.

Lockwood, K.J, & Brophey, P. (2015). The effect of a plyometric training program intervention on skating speed in junior hockey players *The Sport Journal*. 7:3.

Logan, P.; Fornasiero, D.; Abernethy, P. & Lynch, K. (2000). Protocols for the assessment of isoinertial strength. In C.J. Gore (Ed.), *Physiological tests of elite athletes* (200-221). Champaign, IL: Human Kinetics Publishers.

Luebbers, P.E.; Potteiger, J.A.; Julver, M.W.; Thyfault, J.P.; Carper, M.J. & Lockwood, R.H. (2003). Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *Journal of Strength and Conditioning Research,* 17(3): 704- 709.

Luger, D. & Pook, P. (2004). *Complete conditioning for rugby.* Champaign, Illinois: Human Kinetics.

Lundin, P (1989). A review of plyometric training. *Track and Field Quarterly Review*, 89(4): 37-40.

Lundin, P. E.(2010). A review of plyometric training. *Nat Strength Condition Assoc J* 73:65–70.

Lyttle A.& Benjanuvatra, N. (2016). Start Right? A Biomechanical Review of Dive Start Performance. Available at: http://www.coachesinfo.com/category/swimming/321.

Maarten, F.B. (1990). Drop jumping as a training method for jumping ability. *Sports Medicine*, 9(1):7-22.

Mackenzie, B. (2012). “Sports Coach Plyometric.” Plyometric.[Hyperlink http://www.brianmac.demon.co.uk/plyo.htm].

Magee, D.J.; Zachazewski, J.E. & Quillen, W.S. (2007). *Scientific foundations and principles of practice in musculoskeletal rehabilitation.* St. Louis, Missouri: Saunders Elsevier.

Makaruk, H. & Sacewicz, T. (2010). Effects of plyometric training on maximal power output and jumping ability. *Human Movement,* 11 (1), 17–22.

Malisoux, L.; Francaux, M.; Nielens, H. & Theisen, D. (2006a). Stretch-shortening cycle exercises: an effective training paradigm to enhance power output of human single muscle fibers. *Journal of Applied Physiology*, 100 (3): 771-779.

Malisoux, L.; Francaux, M.; Nielens, H.; Renard, P.; Lebacq, J. & Theisen, D (2006b). Calcium sensitivity of human single muscle fibers following plyometric training. *Medicine & Science in Sports & Exercise*, 38 (11): 1901-1908.

Marieb, E.N. (2000). *Essentials of human anatomy and physiology*. Sixth Edition. Redwood City: Benjamin Cummings.

Markovic, G. & Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine*, 40(10): 859-895.

Markovic, G. (2007a.). Does plyometric training improve vertical jump height? A meta-analytical review. *British Journal of Sports Medicine,* (41): 349-355.

Markovic, G. (2014). Does plyometric training improve vertical jump height? A meta-analytical Review. Br J Sports Med 41: 349–355.

Markovic, G.; Jukic, I.; Milanovic, D. & Metikos, D. (2007b.). Effects of sprint and plyometric training on muscle function and athletic performance. *Journal of Strength and Conditioning Research, 21(2):543–549.*

Marshall, J. (2005). In-season periodization with youth rugby players. *Strength and Conditioning Journal*, 27(5): 10–19.

Martel, G.F.; Harmer, M.L.; Logan, J.M. & Parker, C.B. (2005). Aquatic plyometric training increases vertical jump in female volleyball players. *Medicine & Science in Sports & Exercise*, 37(10): 1814-1819.

Mason, G. (2009). George Mason rugby strength and conditioning programme. [Hyperlink http://www.gmu.edu/org/rugby/workout/GMUworkoutprogram.htm].

Matavulj. D, M. Kukoli, D. Ugarkovic, J. Tihanyi, & Jaric, S. (2017). Effects of plyometric training on jumping performance in junior basketball players. *J. Sports Med Phys Fitness*. 41: 159-164.

Matavulji, D.; Kukolj, M.; Ugarkovic, D.; Tihanyi, J. & Jaric, S. (2001). Effects of plyometric training on jumping performance in junior basketball players. *Journal of Sports Medicine and Physical Fitness*, 41(2): 159-164.

Mcardle, D.M.; Katch, FI. & Katch, V.L. (2001). *Exercise physiology: energy, nutrition and human performance* (5th Ed.). Philadelphia, PA: Lippincott Williams and Wilkins.

Mcardle, W.D.; Katch, F.I. & Katch, V.L. (1997). *Exercise physiology. Energy, nutrition and human performance*. Fourth Edition. Philadelphia: Lea & Febiger.

Mcguigan, M.R.; Doyle, T.L.; Newton, M.; Edwards, D.J.; Nimphius, S. & Newton, R.U. (2006). Eccentric utilization ratio: effect of sport and phase of training. *Journal of Strength Conditioning and Research*, 20(4): 992–5.

McLaughlin, E.J. (2001). A comparison between training programs and their effects on fatigue rates in women. *Journal of Strength and Conditioning Research,* 15(1): 25-29.

Meir, R.; Newton, R.; Curtis, E.; Fardell, M. & Butler, B. (2001). Physical fitness qualities of professional rugby league football players: Determination of positional differences. *Journal of Strength and Conditioning Research,* 15(4):450–458.

Meylan, C. & Malatesta, D. (2012). Effects of in-season plyometric training within soccer practice on explosive actions of young players. J Strength Cond Res 23: 2605–2613, 2009.

Mihalik, J.P.; Libby, J.J.; Battaglini, C.L. & Mcmurray, R.G. (2008). Comparing short-term complex and compound training programmes on vertical jump height and power output. *Journal of Strength and Conditioning Research,* 22 (1): 47-53.

Miller, J.A; Hay, J.G. &. Wilson, B.D (2010). Start Techniques of Elite Swimmers. *J. of Sport Sci.* 2 (3)**.** 213-223. 1984.

Miller, M.; Ploeg, A.H.; Dibbet, T.J.; Holcomb, W.R.; Berry, D.C. & O'donoghue, J. (2010). The effects of high volume aquatic plyometric training on vertical jump, muscle power, and torque. *Journal of Strength and Conditioning Research,* 24 (Supplement 1): 1.

Miller, M.G., Berry, D.C., Bullard, S., & Gilders, R. (2002). Comparisons of land-based and aquatic-based plyometric programs during an 8-week training period. *Journal of Sport Rehabilitation, 11,* 269–283.

Miller, M.G., Berry, D.C., Gilders, R., & Bullard, S. (2001). Recommendations for implementing an aquatic-based plyometric program. *Strength and Conditioning Journal, 23*(6), 28–34.

Miller, M.G.; Berry, D.C.; Bullard, S. & Gilders, R. (2002). Comparisons of land-based and aquatic-based plyometric programs during an 8-week training period. *Journal of Sport Rehabilitation*, (11): 268-283.

Miller, M.G.; Berry, D.C.; Gilders, R. & Bullard, S. (2001). Recommendations for implementing an aquatic plyometric program. *Strength and Conditioning Journal*, 23(6): 28-35.

Miller, M.G.; Cheatham, C.C.; Porte, A.R.; Ricard, M.D.; Hennigar, D. & Berry, D.C. (2007). Chest- and waist-deep aquatic plyometric training and average force, power and vertical-jump performance. *International Journal of Aquatic Research and Education*, 1(1):145-155.

Miller, M.G.; Herniman, J.J.; Ricard, M.D.; Cheatham, C.C. & Michael, T.J. (2006). The effects of a six-week plyometric training programme on agility. *Journal of Sports Science and Medicine*, (5): 459-465.

Misson, D. (2008). National coaching scheme. In *The Australian Rugby Football Union*. Sport Science Institute.

Modell, J., & Goodman, M. (1990). Historical perspectives. In S. S. Feldman & G. R. Elliott

Myer, G.D., Ford, K.R.; Brent, J.L. & Hewett, T.E. (2006). The effects of plyometric versus dynamic stabilization and balance training on power, balance, and landing force in female athletes. *Journal of Strength and Conditioning Research,* 20(2): 345–353.

Newton, R.U.; Murphy, A.J.; Humphries, B.J.; Wilson, G.J.; Kraemer, W.J. & Hakkinen, K. (1997). Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *European Journal of Applied Physiology*, (75): 333-342.

Nicholas, C.W. (1997). Anthropometric and physiological characteristics of rugby union football players. *Sports Medicine,* 23(6): 375-96.

Noakes, T. & Du Plessis, M. (2013). *A practical guide to the prevention and treatment of rugby injuries*. Pretoria: Van Schaik Publishers.

Norton, K. & Olds, T. (2013). *Anthropometrica. A textbook of body measurements for sports and health courses*. Sydney: University of New South Wales Press.

O'Connell, A. & Gardner, E. (2004). Understanding the scientific bases of human movement. Baltimore: Williams & Wilkins.

Ozmun, J.C., Mikesky, A.E.&. Surburg, P.R (2017). Neuromuscular adaptations following prepubescent strength training. *Med. Sci. Sport Exerc*. 26: 514. 1994.

Paavolainen, L.; Hakkinen, K.; Ha-Malainen, I.; Nummela, A. & Rusko, H. (1999). Explosive strength training improves 5-km running time by improving running economy and muscle power. *Journal of Applied Physiology*, 86(5): 1527–1533.

Pantoja, P.D.; Alberton, C.L.; Pilla, C.; Vendrusculo, A.P. & Kruel, L.F.M. (2009). Effect of resistive exercise on muscle damage in water and land. *Journal of Strength and Conditioning Research,* 23 (3): 1051-1054.

Pearson, A. (2001). Speed, agility and quickness for rugby. *SAQ Rugby.* London: A & C Black.

Phillips, E. (1990). Plyometric for rugby. *Sports Coach*, July-September: 11-13.

Piper, T.J., & Erdmann, L.D. (2011). A 4 step plyometric program. *Strength and Conditioning Journal,* 20(6): 72-73.

Plisk, S.S. (2008). Speed, agility and speed-endurance development. In: Earle, R.W. and Baechle, T.R., (Eds.), *Essentials of Strength Training and Conditioning.* (3rd ed.) (457-485). Champaign, IL: Human Kinetics.

Potash, D.H., & CHU, D.A.. (2008). Plyometric training. In: Earle, R.W. and Baechle, T.R., (Eds.), *Essentials of Strength Training and Conditioning.* (3rd ed.) (414–455). Champaign, IL: Human Kinetics.

Potteiger, J.A.; Lockwood, R.H.; Haub, M.D.; Dolezal, B.A.; Almuzaini, K.S.; Schroeder, J.M. & Zebas, C.J. (1999). Muscle power and fiber characteristics following 8 weeks of plyometric training. *Journal of Strength and Conditioning Research,* 13(3): 275-279.

Pöyhönen, T.; Sipila, S.; Keskinen, K.L.; Hautala, A.; Savolainen, J. & Malkia, E. (2002). Effects of aquatic resistance training on neuromuscular performance in healthy women. *Medicine & Science in Sports & Exercise*, 34(12): 2103–2109.

Prins, J. & Cutner, D. (1999). Aquatic therapy in the rehabilitation of athletic injuries. *Clinics in Sports Medicine,* 18(2): 447-461.

Quarrie, K.L.; Handcock, P. & Toomey, M.J. (1996). The New Zealand national rugby injury and performance project: IV. Anthropometric and physical performance comparisons between positional categories of senior A rugby players. *British Journal of Sports Medicine,* (30): 53-66.

Radcliffe, J.C. & Farentinos, R.C. (1999). *High-powered plyometric*. Champaign, IL: Human Kinetics

Randell, A.D.; Cronin, J.B.; Keogh, J.W.L.; Gill, N.D. & Pedersen, M.C. (2011). Effect of instantaneous performance feedback during 6 weeks of velocity-based resistance training on sport-specific performance tests. *Journal of strength and conditioning research,* 25(1): 87–93.

References

Reilly, T. (1997). Energetics of high-intensity exercise with particular reference to fatigue. *Journal of Sports Medicine and Physical Fitness*, 15(3): 257-263.

Rimmer, E. & Sleivert, G. (2000). Effects of a plyometric intervention programme on sprint performance. *Journal of strength and conditioning research,* 14(3): 295–301.

Robberds, C. (2012). “Power development”. Neural factors that influence the force and rate of force production. [Hyperlink http://www.elitetrack.com/powerdevelopment.pdf].

Robinson, L.E.; Devor, S.T.; Merrick, M.A. & Buckworth, J. (2004). The effects of land versus aquatic plyometric on power, torque, velocity, and muscle soreness in women. *Journal of Strength and Conditioning Research*, 18(1): 84-91.

Roozen, M. (2004). Action-reaction: Illinois Agility Test. *NSCA’s Performance Training Journal,* 3(5): 5-6.

Rosenthal, S. M., et al., (2002). Pediatric Endocrinology. In A. M. Rudolph (Ed.), *Rudolph's* Universal development. *Annual Review of Psychology, 54*, 461-490. Universities Press.

Rubley, M.D,Haase,A.C, Holcomb,W.R,Girouard, T.J, & Tandy, R.D.(2009). The effect of plyometric training on power and kicking distance in female adolescent soccer players. J Strength Cond Res: 23: 1–6.

Rumpf, M.C; Cronin, J.B; Pinder, S.D; Oliver, J. & Hughes M. (2012). Effect of different training methods on running sprint times in male youth. *Pediatric Exercise Science* 24, 170-186.

Saez-Saez de Villarreal, E, Requena, B, & Newton, R.U. (2009). Does plyometric training improve strength performance? A meta-analysis. J Sci Med Sport 22: 715–725.

Sáez-Sáez De Villarreal, E.; Gonzalez-Badillo, J. J. & Izquierdo, M. (2008). Low and moderate plyometric training frequency produces greater jumping and sprinting gains compared with high frequency. *Journal of Strength and Conditioning Research*, 22(3): 715–725.

Sáez-Sáez De Villarreal, E.; Kellis, E.; Kraemer, W.J. & Zquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *Journal of Strength and Conditioning Research,* 23(2): 495-506

Sáez-Sáez De Villarreal, E.; Requena, B. & Newton, R. U. (2010). Does plyometric training improve strength performance? A meta-analysis. *Journal of Science and Medicine in Sport,* (13): 513–522.

Santos, E.J.A.M. & Janeira, M.A.A.S. (2011). The effects of plyometric training followed by detraining and reduced training periods on explosive strength in adolescent male basketball players. *Journal of Strength and Conditioning Research,* 25(2): 441–452.

Santos, J. (2014). Increasing throwing speed through upper body plyometric. *Track and Field Quarterly Review*, 87(3): 29-33.

Schultz, S.J; Perrin, D.H.; Gansneder, B.M.; Granata, J.M.; Adams, J.M. & Arnold B.L. (2001). Effect of lower extremity limb alignment on muscular activation patterns. *Clinical Biomechanics*, 16: 944-945.

Seeley, R.R.; Stephens, T.D. & Tate, P. (2009). *Anatomy and Physiology.* Sixth Edition. New York: Mc Graw Hill.

Serway, R. & Jewett JR. (2004). *Physics for Scientists and Engineers with Modern Physics* (6th Ed.)*.* Belmont, California: Brooks/ Cole-Thomson Learning

Shapiro, R.; Yates, J.; Mcclay, I. & Ireland, M.L. (2001). Male-female biomechanical differences in selected landing maneuvers*. Clinical Biomechanics*, 16: 956-966.

Sherrill, C. (2004). *Adapted Physical Activity, Recreation, and Sport. Crossdisciplinary and Lifespan* (6th Ed.). New York, New York: McGraw-Hill.

Shiran, M.Y.; Kordi, M.R.; Ziaee,V.; Ravasi, A. & Mansournia, M.A. (2008). Effect of Aquatic and Land Plyometric Training on Physical Training and Muscular Enzymes in Male Wrestlers. *Research Journal of Biological Sciences, 3(5): 457-461.*

Siff, M.C. & Verkhoshansky, Y.V. (2010). *Supertraining*. Denver, Colorado: Supertraining International.

Siff, M.C. (2003). *Supertraining* (6th Ed.). Denver, CO: Supertraining Institute.

Steinberg, D.. (2007). Daily Weighting Techniques on Weight Loss. *Annuals of Behavioural Medical*, 46(1):81-95

Steinberg, D.. (2008). The efficacy of a daily self-weighting weight loss intervention: a systematic review. *International Journal of Behavioural Nutrition and Physical Activity*, 2(4):234-239.

Steinberg, L. (2002). *Adolescence* (6th ed.). Boston, MA: McGraw Hill.

Stemm, J.D. & Jacobson, B.H. (2007). Comparison of land- and aquatic based plyometric training on vertical jump performance. *Journal of Strengthand Conditioning Research,* 21(2):568-571.

Styne, D. M. (2004). Puberty, obesity and ethnicity. *Trends in Endocrinology and Metabolism, 15*(10), Retrieved from http://www.sciencedirect.com.

Tanner, J.T. (2015). Stimulant medication effects on growth and Bone age in children. *Italian Journal of Paediatrics*, 41:51-59.

Tenke, Z. & Higgins, A (2013). *Medicine ball training. A complete book of medicine ball exercises for coaches of all sports*. Toronto: Sports Books.

Thalheimer, W., & Cook, S. (2002). How to calculate effect sizes from published research articles: A simplified methodology. Hyperlink [http://worklearning.com /effect _sizes.htm]. Retrieved November 31, 2002

the twenties. In J. J. Arnett (Ed.), *Readings on adolescence and emerging adulthood* (pp.17-31). Upper Saddle River: Prentice Hall.

Thein, J.M. & Brody, L.T. (2011). Aquatic-based rehabilitation and training for the elite athlete. *Journal of Orthopaedic & Sports Physical Therapy*, (27): 32–41.

Thomas, K.; French, D. & Hayes, PR. (2009). The effect of two plyometric training techniques on muscular power and agility in youth soccer players. *Journal of strength and conditioning research,* 23(1): 332–335.

Tovin, B.J.; Wolf, S.L.; Greenfield, B.H. & Woodfin, B.A. (1994). Comparison of the effects of exercise in water and on land on the rehabilitation of patients with intra-articular anterior cruciate ligament reconstructions. *Physical Therapy,* 74(8): 710-719.

Triplett, N.T.; Colado, J.C.; Benavent, J.; Alakhdar, Y.; Madera, J.; Gonzalez, L.M. & Tella, V. (2009). Concentric and impact forces of single-leg jumps in an aquatic environment vs. on land. *Medicine & Science in Sports & Exercise*, 41(9): 1790-1796.

Turnbull, R.; Coetzee, D. & McDonald, T. (2012). *Rugby fitness testing and training*. Pietermaritzburg: City Printing Works.

Turner, A.M.; Owings, M. & Schwane, J.A. (2003). Improvement invrunning economy after 6 weeks of plyometric training. *Journal of Strength and Conditioning Research,* 17(1): 60–67.

US Department of Health and Human Services. Healthy People. (2010). Summary of objectives: Physical activity and fitness. Available at: http://www.healthypeople.gov/Document/HTML/volume2/22physical.htm.

Verhoshanski, Y. (2012). Depth jumping in the training of jumpers. *Track Technique* 51:1618–619.

Vescovia, J. D.; Canavan, P.K. & Hasson, S. (2008). Effects of a plyometric programme on vertical landing force and jumping performance in college women. *Physical Therapy in Sport,* (9): 185–192

Vissing, K.; Brink, M.; Lønbro, S.; Sørensen, H.; Overgaard, K.; Danborg, K.; Mortensen, J.; Elstrøm, O.; Rosenhøj, N.; Ringgaard, S.; Andersen, J.L. & Aagaard, P. (2008). Muscle adaptations to plyometric versus resistance training in untrained young men. *Journal of Strength and Conditioning Research,* 22(6): 1799–1810.

Voight, M. & Draovitch, P. & Tippett, S. (2012). *Plyometric.* Eccentric muscle training in sports and orthopaedics. New York: Churchill Livingstone.

Voight, M.L & Wieder, D.L. (2010). Comparative reflex response times of astus medialis obliquus and vastus lateralis in normal subjects and subjects with extensor mechanism dysfunction. An electromyographic study. *Am J Sports Med* 19:131–37.

Voight, M.L. & Tippett, S. Plyometric in rehabilitation. (2004). In: *Rehabilitation techniques for sports medicine and athletic training.* (4th ed.). (225-241). New York, USA: Churchill Livingstone

Voight, M.L.& Brady, D. (2009). Plyometric, 4th ed. Onalaska, WI: S&S Publishers; 2013.

Voight, M.L.; Draovitch, P. & Tippett, S. Plyometric. (1995). In: *Eccentric Muscle Training in Sports and Orthopaedics.* M. (2nd ed.). (61-88). New York, USA: Churchill Livingstone.

Vossen, J.F.; Kramer, J.F.; Burke, D.G. & Vossen, D.P. (2000). Comparison of dynamic push-up training and plyometric push-up training on upper body power and strength. *Journal of Strength and Conditioning Research, 14(3): 248–253.*

Walshe, A.D. & Wilson G.J. (1997). The influence of musculotendinous stiffness on drop jump performance. *Canadian Journal of Applied Physiology*, 22(2): 117-132.

Wilk, K.E.; Voight, M.L.; Keirns, M.A.; Gambetta, V.; Andrews, J.R. & Dillman, C.J. (1993). Stretch-shortening drills for the upper extremities: Theory and clinical application. *Journal Orthopaedics and Sports Physical Therapy*, (17): 225–239.

Wilk, K.E; Voight, M.L & Keirns, M.A. (2014). Stretch-shortening drills for the upper extremities: theory and clinical application. *J Orthop Sports Phys Ther* 17:225–39.

Wilkerson, G.B.; Colston, M.A.; Short, N.I.; Neal, K.L.;Hoewischer, P.E. & Pixley, J.J. (2004). Neuromuscular Changes in Female Collegiate Athletes Resulting From a Plyometric Jump-Training Programme. *Journal of Athletic Training*, 39(1):17–23.

Wilkerson, G.B; Colston, M.A & Short, N.I. (2008). Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program. *J Athl Train*;39:17–23.

Wilson, G.J.; Murphy, A.J. & Giorgi, A. (2013). Weight and plyometric training: Effects on eccentric and concentric force production. *Canadian Journal of AppliedPhysiology,* 21(4): 301-315.

Wilson, G.J.; Newton, R.U.; Murphy, A.J.; & Humphries, B.J. (1993). The optimal training load for the development of dynamic athletic performance. *Medicine & Science in Sports & Exercise*, (25):1279–1286.

Wilson, G.J; Wood, G.A, & Elliott, B.C. (2010). Optimal stiffness of series elastic component in a stretch-shorten cycle activity. *J Appl Physiol* 70:825–33.

Wilt F. (2012). Plyometric, what it is and how it works. *Athl J* ;55:76–90.

Wilt, F. (1976). *Plyometric. Track Technique,* 68 (March): 2013, 2022.

Witzke, K. A. & Snow, C. M. (2000). Effects of plyometric jump training on bone mass in adolescent girls. *Medicine & Science in Sports & Exercise*, 32(6): 1051–1057.

Witzke, K.A & Snow, C.M.(2012). Effects of plyometric jump training on bone mass in adolescent girls. Med Sci Sports Exerc 32: 1051–1057.

Wrotniak, B.H, Epstein, L.H, Dorn, J.M, Jones, K.E, & Kondilis, V.A. (2017). The relationship between motor proficiency and physical activity in children. Peds 118s: e1758–e1765,

Yessis, M. (1991). Speed and explosiveness with plyometric. *Scholastic Coach* 60(7): 22-34.

Young, W. (1991). Plyometric for Netball. *Sports Coach*, October-December: 26-28.

Zachargoiannis, E., Paradis, G. & Tziortzis, S. (2004). An evaluation of tests of anaerobic power and capacity. *Medicine & Science in Sports & Exercise*, 36(5): Supplement 116.

Zagatto, A.M., Beck, W.R. & Gobatto, C.A. (2009). Validity of the running anaerobic sprint test for assessing anaerobic power and predicting short-distance performances. *Journal of Strength and Conditioning Research,* 23(6): 1820-1827.

Zajac, A.; Jarzabek, R. & Waskiewicz, Z. (1999). The diagnostic value of the 10- and 30-second Wingate test for competitive athletes. *Journal of Strength and Conditioning Research,* 13(6):16-19.