Comparison of aquatic- and land-based plyometric training on power, speed and agility in adolescent rugby union players

by
David Leslie Fabricius

Thesis presented in partial fulfilment of the requirements for the degree Master of Sport Science at the University of Stellenbosch

Supervisor: Dr. Ranel Venter
Faculty of Education
Department of Sport Science

December 2011

DECLARATION

By submitting this thesis/dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: David Leslie Fabricius

Date: December 2011

SUMMARY

The purpose of the study was to compare the effectiveness of an aquatic- and land-based plyometric programme upon selected, sport-specific performance variables in adolescent male, rugby union players.

A group of 52 rugby players (age: 16.3 ± 0.8 years, height: 176 ± 6.9 cm and body mass: 76.1 ± 11.9 kg) were randomly assigned to one of three groups: aquatic-group (n=18), land-group (n=17), and a control-group (n=17). Prior to and after the seven-weeks of training, the power, agility and speed of participants were assessed by means of Fitrodyne repeated countermovement jumps, the Sergeant vertical jump, the Illinois agility test, a standing broad jump, and a 10- and 40- metre sprint. All three groups maintained their summer extra-curricular sport commitments during the intervention period.

When the three groups were analysed, no significant differences were found between the groups with regard to all tested performance variables. With regard to within-group changes, the aquatic-group improved significantly ($p<0.05$) in the Illinois agility test, performed to the right. The land-group showed significant ($p<0.05$) improvements in peak concentric power during Fitrodyne repeated countermovement jumps. All groups reflected highly significant ($p<0.01$) improvements in the Sergeant vertical jump. None of the groups displayed any improvements in sprint speed. The control was the only group to improve significantly in the standing broad jump ($p<0.05$).

Land-based plyometric training might be a functionally superior training modality for athletes, although aquatic plyometrics could also offer an effective training modality for performance enhancement in power-based sports such as rugby union football. Aquatic-based plyometrics should not completely replace land-based plyometrics, as it might not adequately develop the specific neuromuscular patterns or functional needs of explosive sports.

Keywords: water, plyometric training, power, vertical jump, rugby union

OPSOMMING

Die doel van hierdie studie was om die effektiwiteit van ‘n water- en landgebaseerde pliometriese program met mekaar te vergelyk in terme van geselekteerde, sport-spesifieke uitvoeringsveranderlikes in manlike adolessente rugbyspelers.

‘n Groep van 52 rugbyspelers (ouderdom: 16.3 ± 0.8 jaar, lengte: 176 ± 6.9 cm en liggaamsmassa: 76.1 ± 11.9 kg) is lukraak in een van drie groepe ingedeel: watergroep (n=18), landgroep (n=17), en ‘n kontrolegroep (n=17). Voor en na die sewe-weke oefenprogram, is spelers se plofkrag, ratsheid en spoed getoets deur middel van Fitrodyne herhaalde spronge, Sergeant vertikale sprong, Illinois ratsheidstoets, staande verspring, en ‘n 10- en 40-m spoedtoets. Al drie groepe het vir die duur van die intervensieperiode met hulle somersport aangegaan.

Na analise van die drie groepe se data, is daar geen statisties betekenisvolle verskille tussen die groepe ten opsigte van die prestasieveranderlikes gevind nie. Die water-pliometriese groep se prestasie in die Illinois ratsheidstoets na regs het statisties beduidend ($p<0.05$) verbeter. Die landgroep het betekenisvolle ($p<0.05$) verbetering in die piek konsentriese plofkrag met die Fitrodyne herhaalde spronge getoon. Aldrie groepe het betekenisvolle ($p<0.01$) verbetering getoon in die Sergeant vertikale sprong. Geen groep se spoed het verbeter nie. Slegs die kontrolegroep se staande verspring het statisties betekenisvol verbeter.

Land-gebaseerde pliometriese oefening kan moontlik, vanuit ‘n funksionele oogpunt, ‘n beter oefenmodaliteit vir atlete wees. Watergebaseerde pliometriese oefening kan egter ook ‘n oefenmodaliteit vir sport wat plofkrag vereis, soos rugby, wees. Watergebaseerde pliometriese oefening behoort nie land-gebaseerde pliometriese oefening te vervang nie, omdat dit moontlik nie aan die spesifieke neuromuskulêre patrone en funksionele behoeftes van eksplosiewe sport voldoen nie.

Sleutelwoorde: water, pliometriese oefening, plofkrag, rugby

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to the following people for their assistance and support:

My family who have always supported me in my studies and new endeavours

My supervisor, Dr. Ranel Venter for her time, guidance, patience and passion

My friends and small group, for keeping me on track and keeping life in perspective

Leigh-anne Hoard for affording me the time to complete my Masters, and for always supporting my personal development

Prof. Elmarie Terblanche for assisting me throughout my thesis

Prof. Martin Kidd for completing my statistics and invaluable advice in dire times

SACS boys for committing themselves to the study and giving it their best

Mr. Ken Ball for affording me the opportunity to involve the boys in the project and to use the school's facilities

Prof. Keith Hunt for his guidance, and persistence ensuring I 'immersed' myself in my discipline

Lindall Adams for sourcing my literature from the library

Adv. Joy Wilkin for proof-reading my thesis at such short notice

Karin Hugo at SUSPI for organizing the testing equipment for my study

To my Heavenly father, who is my strength and song. Thank you for your love and grace.

LIST OF ABBREVIATIONS

ANOVA	:	analysis of variance
APT	:	aquatic plyometric training
cm	:	centimetre (s)
CMJ	:	countermovement jump
CK	:	creatine kinase
CSA	:	cross sectional area
DOMS	:	delayed-onset muscle soreness
DJ	:	depth jump
ES	:	effect size
GRF	:	ground reaction forces
IU	:	international unit (s)
$IU \cdot L^{-1}$	:	international units per litre
$^{o} \cdot s^{-1}$	:	joint angular velocity (degrees per second)
kg	:	kilogram (s)
LDH	:	lactate dehydrogenase
LPT	:	land plyometric training
HR_{max}	:	maximum heart rate (beats per minute)
$\dot{V}O_{2max}$	:	maximum oxygen consumption ($L.min^{-1}$, $ml.kg^{-1}.min^{-1}$)
m		metre (s)
$m.s^{-1}$	:	metres per second
MHC	:	myosin heavy-chain
N	:	newtons
1RM	:	one repetition maximum
Epos	:	positive kinetic energy
PT	:	plyometric training
ROM	:	range of motion
RFD	:	rate of force development
RAST	:	running anaerobic sprint test
s	:	seconds

SEC	:	series elastic component
SJ	:	squat jump
SD	:	standard deviation
SBJ	:	standing broad jump
SSC	:	stretch shortening cycle
N·m	:	torque (Newton-meters)
VL	:	vastus lateralis
VJ	:	vertical jump
W	:	watts
WT	:	weight training
WAnT	:	Wingate Anaerobic cycle test

TABLE OF CONTENTS

P.

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

A. Background

To any sport that requires powerful, propulsive movements, such as football, volleyball, sprinting, high jump, long jump, and basketball, the application of plyometric or explosive jump training is applicable (McArdle, Katch & Katch, 2001). Plyometrics has been a very popular training technique used by many coaches and training experts to improve speed, explosive power output, explosive reactivity and eccentric muscle control during dynamic movements (Coetzee, 2007). It is considered a high-intensity, physical training method, consisting of explosive exercises that require muscles to adapt rapidly from eccentric to concentric contractions (Chu, 1998). Plyometric training (PT) has widely been used to enhance muscular power output, force production, velocity, and aid in injury prevention (Robinson *et al*., 2004; Potash & Chu, 2008).

Aquatic plyometric training (APT) is not a new concept, but it has recently become more popular, mostly because of the potential to decrease injuries, compared with land plyometric contractions, by decreasing impact forces on the joints. APT provides a form of training that can enhance performance during a competitive season for a power-based sport (Miller *et al.,* 2002; Robinson *et al.,* 2004). It is suggested that APT has the potential to provide similar or better improvements in skeletal-muscle function and sport-related attributes of explosive and reactive training than land-based plyometrics, with less delayed-onset muscle soreness (Robinson *et al.,* 2004; Martel *et al.*, 2005; Stemm & Jacobson, 2007). According to Coetzee (2007), research has shown that aquatic plyometric programmes provide the same or even more performance enhancement benefits than land plyometric programmes.

B. Motivation for the study

Physiological properties that govern and differentiate training within an aquatic-based or land-based environment are well-known and well-documented in literature. Physical properties of buoyancy, viscosity and gravity, in conjunction with the physiological principles of specificity and specific-adaptation-to-imposed-demand (SAID), created similarities between the two training environments making it possible to perform an effective, comparative intervention study.

APT has the potential to provide a safer and equally effective training modality for power-based sports as land-based plyometric training (LPT). This investigation sought to establish whether APT could provide the same or even more performance enhancement than LPT on explosive leg power, speed of muscle contraction, agility and speed in male, adolescent rugby union players.

The adolescent male, rugby union participant group has opened a new avenue of research into a previously un-investigated population group and sports code of rugby union. The study will contribute to new understanding of whether an APT-based or LPT-based intervention will be a beneficial training modality upon power, speed and agility, as part of a rugby union pre-season component within a school and population.

C. Aim of the study

The aim of the study was to compare the effectiveness of an aquatic-based and land-based plyometric programmes upon selected, sport-specific performance variables in adolescent male, rugby union players.

D. Research questions

The following research questions have been addressed in this study:

1. What are the effects of a seven-week land-based compared to an aquatic-based plyometric training programme upon adolescent rugby union players' leg power?

2. What are the effects of a seven-week land-based compared to an aquatic-based plyometric training programme upon adolescent rugby union players' agility?

3. What are the effects of a seven-week land-based compared to an aquatic-based plyometric training programme upon adolescent rugby union players' speed?

E. Research method

In this experimental outcome study, amateur male high school pupils that participated in regular extra-curricular school rugby union completed a series of tests before and after a plyometric exercise intervention of 14-training sessions, on land and in waist-deep water. Intervention consisted of hops, skips, bounding, repeated countermovement jumps and 40-centimetres depth jumps. Participants underwent the intervention as part of pre-season conditioning, concurrent to the participants' summer sport. Testing of the participants was performed a week prior to and a week after the cessation of the seven-week intervention. Participants were tested for measures of concentric explosive leg power, speed-of-movement, multi-directional agility and sprint speed.

F. Outline of the thesis

Chapter Two consists of the theoretical background for this study and reviews current literature and related studies on comparable physiology for aquatic-based plyometric training (APT) and land-based plyometric training (LPT), physical properties of water, with an overview of rugby union football. In Chapter Three the specific methods for data collection and auxiliary plyometric intervention design are discussed. The results of all the statistical procedures are presented in Chapter Four. Chapter Five contains a discussion of the results found, as well as a conclusion to this study, limitations of this study, and recommendations for future studies.

CHAPTER TWO

THEORETICAL BACKGROUND

A. Introduction

In this chapter, selected literature applicable to this study will be reviewed. The focus will be on comparative views of land-based and aquatic plyometric training, with emphasis upon the physical attributes of power-based sport.

B. Origin and development of plyometric training

Plyometrics is the term now applied to exercises that have their origins in Europe and were first known as 'jump training' (Chu, 1998: 1). It is widely accepted that plyometric training has its origin in the former Soviet Union as far as the early 1960's with the scientific formalisation of the training system, 'shock training' by Dr. Yuri Verkhoshansky (Siff, 2003). In the West, a certain mystique surrounded plyometrics in the early 1970's, as it was thought that plyometrics were responsible for the Eastern bloc countries' rapid competitiveness and growing supremacy in international track and field athletic events (Chu, 1998). The term, 'plyometrics', was first used in 1975 by American track and field coach, Fred Wilt (Chu, 1998). The development of the term is confusing; *Plyo-* is derived from the Greek word *pleythein*, which means to increase. *Plio* is the Greek word for "ore", while *metric* means "to measure". (Wilt, 1975 referenced in Voight, Draovitch & Tippett, 1995). Dr. Verkhoshansky preferred the term 'shock method' instead of the more widely used term of 'plyometric', to differentiate between the naturally occurring plyometric actions in sport and the formal discipline he devised as a training system to develop speed-strength (Siff, 2003). Plyometrics grew rapidly in popularity with coaches and athletes as exercise or drills focused on linking strength with speed of movement to produce power (Chu, 1998).

C. The physiology of plyometric training

1. Introduction

Plyometric exercise are quick, powerful movements that enable a muscle to reach maximal force in the shortest possible time (Potash & Chu, 2008). This is achieved by using a prestretch, or countermovement, that involves the stretch-shortening cycle (SSC) (Wilk *et al.,* 1993; Voight *et al.*, 1995). The purpose of plyometric exercises is to increase the power of subsequent movements by using both the natural elastic components of muscle and tendon and the reflex (Potash & Chu, 2008).

Peak performance in sport requires technical skill and power, where success is dependent upon the speed at which muscular force or power can be generated (Voight & Tippett, 2004). Power combines strength and speed (Radcliffe & Farentinos, 1999). It can be improved by increasing the amount of work or force that is produced by the muscle or by decreasing the amount of time required to produce force. The amount of time required to produce muscular force is an important variable for increasing power output. The training method which combines speed of movement with strength is plyometrics (Voight & Tippett, 2004).

According to Coetzee (2007), plyometric training (PT), or the combination of PT with a sport-specific training programme, have acute and chronic training responses. The acute effects of plyometric programmes include a significant increase in the 1RM leg strength and the delayed onset of muscle soreness. Chronic improvements include increases in explosive power, flight time and maximal isotonic and isometric leg muscle strength, average leg muscle endurance, isokinetic peak torque of the legs and shoulder, range of ankle motion, speed and frequency of muscle stimulation. PT programmes also seem to significantly decrease ground contact time during sprinting activities and the amortization time during execution of plyometric exercises. Literature has also shown that aquatic plyometric programmes provide the same or more performance enhancement benefits than land plyometric programmes (Coetzee, 2007; Colado *et al.*, 2010).

2. Models of plyometric training

According to Coetzee (2007) and Potach and Chu (2008), the production of muscular power is best explained by three proposed models: mechanical, neurophysiological and the stretch-shortening cycle.

2.1 The mechanical model

The mechanical model explains that during an eccentric muscle action, elastic energy in the musculotendinous components is increased with a rapid stretch and then stored (Potach & Chu, 2008). Significant increases in concentric muscle production occur when immediately preceded by an eccentric contraction. This increase might be partly due to this storage of elastic potential energy, since the muscles are able to utilize the force produced by the series-elastic component (SEC) (Voight & Tippett, 2004). SEC in the muscle plays an important role in this model (Coetzee, 2007). Even though all components of the SEC (actin and myosin filaments and tendon) are stretched when a joint is loaded, the tendon is the main contributor to muscle-tendon unit length changes and the storage of elastic potential energy (Chmielewski, Myer, Kauffman & Tillman, 2006). To maximize the power output of the muscle, the eccentric muscle action must be followed immediately by a concentric muscle action (Radcliffe & Farentinos, 1999; Potach & Chu, 2008). If a concentric muscle action does not occur, or if the eccentric phase is too long or requires too great a motion about the given joint, the stored elastic energy is lost as heat, and stretch reflex is not activated (Voight & Tippett, 2004; Potach & Chu, 2008). For example, greater vertical jump height has been attained when the movement was preceded by a countermovement as opposed to a static jump (Voight & Tippett, 2004).

2.2 The neurophysiological model

The neurophysiological model involves the potentiation (force-velocity characteristics of the contractile components change with a stretch) of the concentric muscle action by use of the myotatic or stretch reflex. The stretch reflex is the body's involuntary response to an external stimulus that stretches the muscle (Potash & Chu, 2008). Muscle spindles are amongst the special receptors that play a permanent role in the appearance of the myostatic stretch reflex. These proprioceptive organs are sensitive to the rate and magnitude of a stretch (McArdle *et al.*, 2001).

During plyometric exercise, or when the muscle is rapidly stretched, the stimulated muscle spindles cause a reflexive muscle action. The more rapidly the load is applied to the muscle, the greater the firing frequency of the spindle and resultant reflexive muscle contraction (Voight & Tippett, 2004). This reflexive response increases the activity of the agonist muscle, and increases the amount of force for the resultant concentric muscle action (Potash & Chu, 2008). The rapid lengthening phase in the stretch-shortening cycle produces a more powerful subsequent movement. This is due to a higher active muscle state (greater potential energy) being reached before the concentric, shortening action, and the stretch-induced evocation of segmental reflexes that potentiate subsequent muscle activation (McArdle *et al.,* 2001).

2.3 Stretch-shortening cycle model

The repeated sequence of eccentric (lengthening) contractions followed by a concentric, explosive, powerful muscular contraction is known as the stretch-shortening cycle (SSC) (Komi, 2003). The SSC uses the energy-storing capacity, the SEC and stimulation of the stretch reflex to facilitate a maximal increase in muscle recruitment over a minimal amount of time (Potach & Chu, 2008). An effective SSC can only be achieved if the following basic conditions are met: first, a timed preactivation of the muscles before the eccentric phase occurs; secondly, a short and fast eccentric phase; and finally, an immediate transition (minimal delay) from the eccentric to the concentric phase (Komi, 2003).

The SSC involves three distinct phases: the eccentric or loading phase, amortization or coupling phase, and the concentric or unloading phase. Phase One, the eccentric phase, involves preloading the agonist muscle group(s). Eccentric loading will place load upon the elastic components of the muscle fibers (Voight & Tippett, 2004). The SEC stores elastic energy and muscle spindles are stimulated. As the muscle spindles are stretched, they send a signal to the ventral root of the spinal cord via the Type 1a afferent nerve fibers. Phase Two, the amortization phase, is the electromechanical delay between the first (eccentric) phase and third (concentric) phase where alpha motor neurons then transmit signals to the agonist muscle group. Muscles must switch from overcoming work to acceleration in the opposite direction. The shorter the amortization phase, the greater the amount of force production (Voight & Tippett, 2004; Potach & Chu, 2008). Phase Three, the concentric phase, is the body's response to the eccentric and amortization phases. When the alpha neurons stimulate the agonist muscles, they produce a reflexive concentric muscle action (Potach & Chu, 2008). Most of the force that is produced comes from the fiber filaments sliding over each other (Voight & Tippett, 2004). The stored elastic energy in the SEC during the eccentric phase is used to increase the force of the subsequent isolated concentric muscle action (Potach & Chu, 2008).

Plyometric exercises stimulate proprioceptive feedback to fine-tune for specific muscle-activation patterns. These exercises utilize the SSC, train the neuromuscular system by exposing it to increased strength loads and improve the stretch reflex (Wilk *et al.,* 1993). Increased speed of the stretch reflex and increased intensity of the subsequent muscle contraction will amount to better recruitment of additional motor-units. The force-velocity relationship postulates that the faster a muscle is loaded or lengthened eccentrically, the greater the resultant force output will be (Voight & Tippett, 2004).

D. Land-based plyometric training

1. Explosive leg power

'Plyometric training'' is a colloquial term used to describe quick, powerful movements using a pre-stretch, or countermovement, that involves the SSC (Potach & Chu, 2008). Plyometric training (PT) is a common modality to enhance lower-extremity strength, power and stretch-shortening cycle (SSC) muscle function in healthy individuals (Markovic & Mikulic, 2010). The ability to produce force rapidly is vital to athletic performance. Increases in power output are likely to contribute to improvements in athletic performance (Potteiger *et al.,* 1999). The transfer of these plyometric effects for athletic performance is most likely dependent upon the specificity of the plyometric exercises performed. Specific plyometric exercises can be used to train the slow or fast SSC. Examples of slow SSC plyometrics include vertical jumps and box jumps. Bounding, repeated hurdle hops, and depth jumps, typically, are regarded as fast SSC movement (Flanagan & Comyns, 2008). Athletes who require power for moving in the horizontal plane (e.g. sprinters and long jumpers) mainly engage in bounding plyometric exercises, as opposed to high jumpers, basketball or volleyball players who require power to be exerted in a vertical direction and who perform mainly vertical jump (VJ) exercises (Markovic & Mikulic, 2010). These training adaptations are in accordance with the principle of specificity (McArdle *et al.,* 2001).

In the literature appropriate plyometric training programmes have been shown to increase power output (Luebbers *et al*., 2003), agility (Miller, Herniman, Ricard, Cheatham & Michael, 2006), running velocity (Kotzamandisis, 2006), and also running economy (Turner, Owings & Schwane, 2003).

2. Neuromuscular changes for power development

Current literature suggests that plyometric training (PT), either alone or in combination with other typical training modalities (e.g. weight training [WT] or electromyostimulation), elicits many positive changes in the neural and musculoskeletal systems, muscle function and athletic performance of healthy individuals (Markovic & Mikulic, 2010). The ability of the neuromuscular system to produce power at the highest exercise intensity, often referred as 'muscular power' is an important determinant of athletic performance (Paavolainen, Hakkinen, Ha-malainen, Nummela & Rusko, 1999).

Markovic and Mikulic (2010: 860) summarized as follows: "the adaptive changes in neuromuscular function due to PT are likely to be the result of: (I) an increased neural drive to the agonist muscles; (II) changes in the muscle activation strategies (i.e. improved intermuscular coordination); (III) changes in the mechanical characteristics of the muscle-tendon complex of plantar flexors; (IV) changes in muscle size and/or architecture; and (V) changes in single-fiber mechanics".

Potteiger *et al*. (1999) showed that a plyometric training (PT) programme could bring about significant increases in leg extensor muscle power and whole muscle fiber hypertrophy. In an eight-week, threes day per week plyometric and aerobic exercise programme, changes in muscle power output and fiber characteristics following this intervention were examined. A group of 19-physically active men aged 21.3 ± 1.8 years were randomly selected to either a plyometric-group or combination-group of PT and aerobic exercise. The PT consisted of vertical jumps (VJ), bounding, and 40-centimetres (cm) depth jumps. The aerobic exercise was performed at 70 percent (%) heart-rate maximum (HR_{max}) for 20-minutes immediately following the plyometric workouts. Muscle biopsy specimens were taken from the vastus lateralis (VL) muscle before and after training. Type I (slow twitch) and Type II (fast twitch) muscle fibers were identified and cross-sectional areas (CSA) calculated.

Peak and average muscle power output were measured using countermovement vertical jump (CMJ). No significant differences were found between the groups following training for either peak or average power. Both groups displayed significant increases from pre-testing to post-testing for both peak and average leg extensor muscle power. The plyometric-group increased by 2.8% and 5.5%, for peak power and average power, respectively. The combination-group increased by 2.5% in peak power and 4.8% average power, respectively .VJ height improved in each group from pre-training to post-training. The plyometric-group increased peak power and average power by 2.8% and 5.5%, respectively. Each group demonstrated a significant increase in muscle fiber CSA from pre-training to post-training for Type I (plyometric-group, 4.4%; combination-group 2, 6.1%) and Type II (plyometric-group 7.8%; combination-group 2, 6.8%) fibers, with no differences between the groups. The improved CMJ and increased power output following the PT were most likely due to a combination of the enhanced motor unit recruitment patterns and increased muscle fiber CSA, caused by fiber hypertrophy in both slow twitch and fast twitch fibers.

Malisoux *et al.* (2006a), on the other hand, focused on the contractile properties of single fibers of VL muscle of recreationally active men (n= 8; age: 23 ± 1 years). After eight weeks of PT induced significant increases in peak force and maximal shortening velocity in the myosin heavy chain (MHC) isoforms Type I, IIa and hybrid IIa/IIx fibers, while peak power increased significantly in all fiber types. PT significantly increased maximal leg extensor muscle force, and VJ performance was also improved 12% ($p<0.01$) and 13% ($p<0.001$), respectively. Peak force increased 19% in Type I ($p<0.01$), 15% in Type IIa ($p<0.001$), and 16% in Type IIa/IIx fibers ($p<0.001$). Maximal shortening velocity increased 18, 29, and 22% in Type I, IIa, and hybrid IIa/IIx fibers, respectively ($p<0.001$). Single-fiber CSA increased 23% in Type I ($p <0.01$), 22% in Type IIa ($p<0.001$), and 30% in Type IIa/IIx fibers ($p<0.001$), in VL muscle following the PT-intervention.

Potteiger *et al.* (1999) also reported significant increases in Type I and type II fiber CSA of the VL muscle, but these effects were of lesser magnitude (6–8%). Malisoux *et al.* (2006b) also found a significant increase in the proportion of type IIa fibers of the VL muscle. In contrast, Potteiger *et al.* (1999) did not observe any significant changes in fiber-type composition of the VL muscles.

Contradictory to the above research, Kyröläinen *et al.* (2005) found that 15-weeks of maximal-effort PT performed by recreationally active men (n=23; age 24 ± 4 years) showed no significant changes in muscle fiber type or size. Plantar flexor strength did improve with significant increases in muscle activity, but not the rate of force development (RFD) and without any changes in either the muscle fiber distributions or CSA. Although no changes were found in the maximal strength or muscle activation for knee extensor muscles, the enhancements in jumping performance were due to improved joint control and increased RFD at the knee joint.

In contrast, Kubo *et al.* (2007) showed in a 12-week comparative study of PT and WT upon untrained male participants (n=10; age: 22 ± 2 years), PT induced changes in the strength of plantar flexors, but not in that of the knee extensors. Plantar flexors showed significant hypertrophy and significant increases in maximal voluntary contraction with increased muscular activation.

Studies that showed significant changes in a single fiber function (Malisoux *et al.,* 2006a; 2006b) due to PT were also accompanied by significant improvements in the whole muscle strength and power. The noteworthy results of Malisoux *et al.* (2006a) suggest that PT-induced improvements in muscle function and athletic performance could be partly explained by changes in the contractile apparatus of the muscle fibers, at least in the knee extensor muscles.

Plyometric training (PT) exercises require a high level of eccentric force to stabilize and control the knee and hip joint. A high level of concentric quadriceps and hamstring muscle force development is also needed for perpetuation and momentum during PT movements. To determine the effect of PT on the knee extensor and flexor muscles, Wilkerson *et al.* (2004) studied the neuromuscular changes in 19-university women basketball players (age: 19 ± 1.4 years). A six-week plyometric jump training programme was completed as part of their pre-season conditioning. Concentric isokinetic peak torque of the hamstrings and quadriceps were measured before and after the intervention at $60º·s^{-1}$ and $300º·s^{-1}$. The experimental group (n=11) completed stretching, isotonic WT and structured PT under the supervision of the researcher. The control-group (n=8) also participated in stretching, isotonic WT and a periodic performance of unstructured PT under the supervision of the team's basketball coaches. Data was also collected from the quadriceps and hamstring muscles during a forward lunge test, called the unilateral step-down test. Results showed a significant increase for hamstrings' peak torque at $60º·s^{-1}$ ($p=0.008$) in the experimental group, while only three of the eight participants in the control-group showed an increase. The hamstrings did not show a significant increase at $300º·s^{-1}$ for the experimental group. There were no significant increases in quadriceps muscle torque at either $60º·s^{-1}$ and $300º·s^{-1}$ isokinetic test velocities. Therefore, PT increased the performance capabilities of the hamstring muscles, but not the quadriceps muscles. An improvement in the hamstring muscle strength stabilizes and controls the eccentric movement through the hip and knee whilst the body is in motion.

In the above literature, PT induced significant improvements in neuromuscular function for power development. PT appears to enhance motor unit recruitment patterns, with increases in muscle fiber hypertrophy for optimal maximal power output. PT significantly increased maximal leg extensor muscle force, with improved CMJ performance and increased RFD at the knee joint in recreationally active males. These changes were accompanied with increased muscle fiber CSA in whole muscle and in single fiber studies. PT has also significantly improved maximal shortening velocities of leg extensor muscles. Plyometric exercises can too optimize performance and assist with injury prevention by improving hamstring strength, eccentric control and stability of the pelvis and knee.

3. Vertical jumping performance

A critical physical attribute and key component for successful performance in many athletic events is explosive leg power. An excellent example of this is vertical jumping ability, as there is a strong association between increased lower body power and vertical jump (VJ) height (Potteiger *et al*., 1999).

Some studies have shown that plyometrics training (PT) has improved VJ performance (Kubo *et al.,* 2007; Markovic, Jukic, Milanovic & Metikos, 2007b; Thomas, French & Hayes, 2009), whereas other studies have not found any significant improvements (Sáez-Sáez De Villarreal, Gonzalez-Badillo & Izquierdo, 2008; Vescovi, Canavan & Hasson, 2008). The absence of such significant findings may be due to the difference in training programmes in terms of intensity or volume, and possibly that the training programme was not specifically designed to improve power and enhance performance. There is also the possibility that the VJ test was not sensitive enough to detect small but significant changes in power.

To determine the effect of different plyometric exercises upon VJ performance, Thomas, French and Hayes (2009) found that both depth jump (DJ) and CMJ plyometric training (PT) techniques were effective in improving power and agility in young soccer players. The comparative study used 12-males from a semi-professional football club academy (age: 17.3 ± 0.4 years), randomly assigned to either six-weeks of DJ or CMJ training twice weekly. The participants were assessed for leg power, sprint speed and agility pre-and post six-weeks. Participants in the DJ-group performed DJ (40cm), with instructions to minimize ground-contact time while maximizing height. Participants in the CMJ-group performed jumps from a standing start position with instructions to gain maximum jump height. Post-training data showed that both groups experienced improvements in VJ height ($p<0.05$) without there being any differences between the treatment groups ($p>0.05$). DJ-training revealed a large practical significance of 1.1 and the CMJ-training demonstrated a medium practical significance with an effect size of 0.7. The study concluded that both DJ and CMJ plyometrics are worthwhile training activities for improving vertical power, particularly in trained, adolescent soccer players.

Gehri *et al.* (1998) also established that DJ training was superior to CMJ training for improving both VJ height, and improved concentric muscular performance. The study sought to establish which PT technique was best for improving VJ ability, positive kinetic energy production (E_{pos}), and elastic energy utilization. A group of 28-participants performed 12-weeks of jump training under three conditions of squat jump (SJ), CMJ, and DJ. Participants were randomly assigned to one of three groups, merely control, DJ-training, and CMJ-training. Pre- and post–testing of the SJ, CMJ, and DJ were completed upon a force-plate for vertical ground reaction force computations. VJ height, E_{pos} and elastic energy were calculated using methods from Komi & Bosco (1978). E_{pos} was calculated in the SJ trials which represent contractile performance on a pure concentric contraction. DJ and CMJ participants executed a SSC (eccentric to concentric). For both groups, an increase in E_{pos} over that of the SJ reflected a utilization of stored elastic energy.

Gehri *et al.* (1998) demonstrated that improved VJ ability following CMJ or DJ training was due to improved contractile component rather than elastic component performance. There were significant increases in VJ height for both training groups, although neither of the training methods improved utilization of elastic energy. DJ was superior to CMJ because of its neuromuscular specificity. CMJ training group only improved VJ height and E_{pos} production in the SJ and CMJ, while the DJ training group improved VJ height and E_{pos} production in all three jumping conditions. DJ training more closely approximates sport-specific jumping, with a greater application to sport than SJ or simple CMJ, again due to neuromuscular specificity. From a training stand-point, DJ must still be combined with other sport-specific jumps to further complement the athlete's overall training programme.

It should be noted that in contrast to all the above research, some studies reported no change (Vescovi *et al.,* 2008) or even showed a slight decrease in VJ performance initially following a PT intervention (Leubbers *et al.,* 2003). Leubbers *et al.,* (2003) compared the effect of two PT programmes, of four or seven weeks in duration, on anaerobic leg power and VJ performance followed by a four-week recovery period of no PT. Physically active, college-aged men were randomly assigned to either a four-week (n=19) or a seven-week programme (n=19). The results showed an initial decline in VJ height directly at the end of the PT-intervention. However, after four-weeks of recovery, the participants' performance increased significantly in the four-week plyometric intervention group by 2.8% (67.8 ± 7.9 to 69.7 ± 7.6 cm; $p<0.05$), and increased 4% (64.6 ± 6.2 to 67.2 ± 7.6 cm; $p<0.05$) in the seven-week plyometric-intervention group.

Vescovi *et al.* (2008) did not observe any improvements in jumping performances following a six-week PT intervention in recreationally athletic college-aged women. A group of 20-college-aged, female recreational basketball players were assigned to a training (n=10) or control (n=10) group. The investigators examined the effect of a PT programme on peak vertical ground reaction force as well as on kinetic jumping characteristics of CMJ height, peak and average jump power, and peak jump velocity. The intervention group did show a clinically meaningful decrease in vertical ground reaction force (-222.87 ± 10.9 N) versus the control-group (54±7257.6 N), with no statistical differences between the groups ($p=0.122$). There were no differences in absolute change values between groups for CMJ height (1.0 ± 2.8 cm versus -0.2 ± 1.5 cm; $p=0.696$) or any of the associated kinetic variables following the six-week intervention. Eight of the ten women in the training group reduced vertical ground reaction force by 17–18% but no significant improvements in jumping performance were observed. Small sample size and limited statistical power negated the study's results. The PT-intervention was not focused on jump performance enhancement but to reduce landing forces in recreationally athletic women.

According to two meta-analysis studies into whether plyometric training improves VJ (Sáez-Sáez De Villarreal, Kellis, Kraemer & Zquierdo, 2009; Markovic, 2007a), and a review of physiological adaptations for PT (Markovic & Mikulic, 2010): VJ performance can be assessed using all four types of standard vertical jumps such as squat jumps (SJ), countermovement jumps (CMJ), CMJ with the arm swing (CMJA) and depth jumps (DJ).

Markovic (2007a: 355) summarized: “PT provided both statistically significant and practically relevant improvement in VJ height with the collective mean effect ranging from: 4.7% for both SJ and DJ, over 7.5% for CMJA, to 8.7% for CMJ”. However in a more recent review, Markovic & Mikulic (2010: 876, 880) concluded: “PT considerably improved VJ height; upon a collective mean effect ranging from: 6.9% (range, -3.5% to +32.5%) for CMJA, over +8.1% (range, -3.7% to +39.3%) for SJ, and 9.9% (range, -0.3% to +19.3%) for CMJ, to 13.4% (range, -1.4% to +32.4%) for DJ”.

The relative effects of PT are likely to be higher in fast SSC VJ (DJ) than in slow SSC VJ (CMJ and CMJA) and concentric-only VJ (SJ) (Gehri *et al.*, 1998; Markovic & Mikulic, 2010). The landmark study by Wilson, Newton, Murphy and Humphries (1993) suggested that PT was more effective in improving VJ performance in fast SSC jumps as it enhances the ability of participants to use neural, chemo-mechanical and elastic benefits of the SSC. PT can enhance both slow and fast SSC muscle function, but these effects are specific to the type of SSC exercise used in training (Markovic & Mikulic, 2010). It was therefore more beneficial to combine different types of plyometrics than to use only one form, whereas the best combination was SJs + CMJs + DJs (Gehri *et al.*, 1998; Sáez-Sáez De Villarreal *et al.,* 2009).

The above literature demonstrated that PT could induce significant improvements in VJ. Vertical power was significantly improved using a plyometric intervention of both DJ and CMJ plyometrics exercises. DJ training appeared to be more effective as it more closely approximated sport-specific jumping, with a greater application to sport than SJ or simple CMJ, due to neuromuscular specificity. Furthermore it would be more beneficial to combine different types of plyometrics than to use only one form, whereas the best combination was SJs + CMJs + DJs. Additionally, utilizing combination training of PT and WT could exhibit significantly better VJ performances than with PT or WT alone upon VJ height, jumping mechanical power, and flight time.

4. Horizontal jumping performance

The horizontal jump (e.g., standing broad/ long jump) has long been utilized by athletics coaches as a simple, direct, field-based test for athletic performance in sprinting and long jump athletes. These athletes require rapid, explosive leg power in the horizontal plane specific to their sport, in accordance with the principle of specificity. Movements requiring a powerful thrust from hips and thighs can be improved through the prescription of a biomechanically similar movement during training (Adams, O'Shea, O'Shea & Climstein, 1992). Short-term PT can be significantly beneficial to improve horizontal explosive performances in trained and untrained participants, using sport-specific PT exercises (Adam *et al.*, 1992; Markovic *et al.*, 2007b), a combination training of weight training (WT) and PT (Faigenbaum *et al.*, 2007) or with real-time feedback after PT performances to help maintain training targets and intensity thresholds (Randell, Cronin, Keogh, Gill & Pedersen, 2011).

Faigenbaum *et al*. (2007) compared the effects of a six-week training period of combined plyometric and resistance training (n=13; age: 13.4 ± 0.9 years) and weight training alone (WT, n=14; age: 13.6 ± 0.7 years) on fitness performance in young male participants. The combination-group made significantly ($p<0.05$) greater improvements than the WT-group in the standing long jump, being 10.8 cm (6%) versus 2.2 cm (1.1%). These results possibly indicate that a combination of PT and WT may be beneficial for enhancing horizontal jumping performances.

Previous research of Adams *et al.* (1992) has shown that the use of squat jump (SJ) during training may result in improvements in horizontal jump performances. The initial squat and lower body triple extension movement enhances neuromuscular efficiency, and allows for excellent transfer of biomechanically similar movements, as seen in the VJ and horizontal jumps.

Randell *et al.* (2011) showed that the use of feedback during squat jump training in conjunction with a six-week pre-season conditioning programme, proved beneficial to increasing performances of sport-specific tests, including the horizontal jump. A group of 13 professional rugby players were randomly assigned to either a feedback (group 1; n=7) or a non–feedback group (group 2; n=6). Group 1 was given real-time feedback on peak velocity of the concentric SJ at the completion of each repetition using a linear position transducer, whereas group 2 did not receive any feedback. The feedback group showed a 2.6% improvement in HJ performances versus 0.5% in the non-feedback group. With the use of feedback within training, to optimize performance improvements, a 83% chance of having a positive effect on HJ performance was reported, and a small training effect noted (effect size [ES] = 0.28).

In contrast to the above studies, Markovic *et al.* (2007b) found that short-term sprint training produced similar or even greater training effects in muscle function and athletic performances than PT in untrained college students. The sprint training improved the linear explosive performance of horizontal jumps greater than PT, in the 10-week, three-days per week intervention. A group of 93-male physical education students were assigned randomly to one of three groups: a sprint-group (n=30), a plyometric-group (n=30), and a control-group (n=33). Both experimental groups trained. The sprint-group performed maximal sprints over distances of 10–50 m, whereas plyometric-group performed bounce-type hurdle jumps and depth jumps. The control-group maintained their daily physical activities. Both the sprint- and plyometric-groups significantly ($p<0.001$) improved in standing long jump (3.2%; ES=0.5 versus 2.8%; ES=0.4). These improvements were significantly ($p<0.001$) higher compared with the control-group. No significant differences were found between sprint- and plyometric-groups for the standing long jump ($p=0.78$). In addition to the well-known training methods, such as WT and PT, incorporating sprint training into an overall conditioning programme may assist athletes to achieve high levels of explosive leg power and dynamic athletic performance, such as the horizontal jump.

Hortobagyi, Havasi and Varga (1990) did not support the previously stated assumption that PT can be trained in a specific plane of movement, either vertical or horizontal, in accordance with the principle of specificity. The landmark study by Hortobagyi *et* al. (1990) divided a group of 40-primary school boys (age: 13.4 ± 0.11 years) into two experimental groups to perform two distinctly different PT routines of either vertical or horizontal specific PT. Neither experimental group yielded specific gains in performance. There was too high a degree of generality between the jumping tests performed, as the vertical and horizontal jumping tests were highly correlated thereby negating the notion of movement plane specificity for PT.

PT intervention may significantly improve horizontal explosive performances in trained and untrained participants. Combination training of WT and PT utilizing young, male participants performed significantly better than WT alone in the standing long jump. The use of real-time feedback on peak velocity of SJ performances in professional rugby conditioning programme has produced larger improvements in horizontal explosives performance than non-feedback participants. Although in untrained male, university students, sprint training could be slightly more effective, and practically more significant than PT upon horizontal jump performances.

5. Effect of plyometric training upon muscular strength and endurance

It is suggested that lower limb strength performances can be significantly improved by plyometric training (PT). When plyometric exercises are performed with adequate technique, these training gains are independent of the fitness level or sex of the participant. PT has been shown to improve maximal strength performances, measured by one-repetition maximum (1RM), isometric maximal voluntary contraction (MVC) or slow velocity isokinetic testing (Sáez-Sáez De Villarreal, Requena & Newton, 2010).

Vissing *et al*. (2008) showed that weight training (WT) and PT seemed to lead to similar gains in maximal strength, whereas PT induced far greater gains in muscle power. The study compared the changes in muscle strength, power, and morphology induced by WT versus PT. Young, untrained male participants (age: 25.1 ± 3.9 years) performed 12-weeks of progressive WT (n=8) or PT (n=7). Tests included 1RM incline leg press, 3RM knee extension, and 1RM knee flexion, countermovement jumping (CMJ), and ballistic incline leg press. Muscle strength increased by approximately 20–30% (1–3RM tests) ($p<0.001$), with WT showing a 50% greater improvement in hamstring strength than PT ($p<0.01$). For the 1RM inclined leg press, the WT-group increased leg strength by 29 ± 3% ($p< 0.001$) and PT group improved by 22 ± 5% ($p <0.01$) with no significant differences present between the groups. In the 3RM isolated knee extension, WT increased by 27 ± 2% ($p<0.001$) and PT increased by 26 ± 5% ($p<0.001$). In the 1RM hamstring curl, WT increased by 33 ± 3% ($p<0.001$), which was larger than the 18 ± 4% improvement in PT ($p<0.05$). PT increased maximum CMJ height 10% and maximal power by 9% ($p<0.01$). PT increased maximal power in the ballistic leg press 17% ($p<0.001$) versus WT 4% ($p<0.05$); this was significantly greater than WT ($p<0.01$). Gains in maximal muscle strength were essentially similar between the PT and WT groups, whereas muscle power increased almost exclusively with PT-training.

Fatouros *et al.* (2000) found that athletic training combining both PT with traditional and Olympic-style weightlifting exercises showed significantly greater improvement ($p<0.05$) in 1RM back squat and 1RM leg press when compared with PT alone. In a 12-week intervention of three training sessions per week ($3d \cdot wk^{-1}$), 41-untrained men (age: 20.7 ± 1.96 years) were assigned to one of the four-groups: PT (n=11), WT (n=10), plyometric plus weight training (n=10), and control (n=10). WT showed greater improvements than PT in maximal leg strength measured by the leg press, whereas maximal strength measured by the back squat showed equal increases by both groups. These findings were attributed to the nature and specificity of the plyometric and weight-training exercises prescribed during the 12-week intervention.

Fatouros *et al.,* (2000) also measured average leg muscle endurance by means of repeated jumps using the Vertical Jump test by Bosco *et al.* (1983), pre- to post-test, to calculate jumping mechanical power. This test was selected because it took advantage of the potential for using elastic energy storage in addition to chemical-mechanical energy conversion. The test had a high validity (compared with the Wingate test [WAnT], r=0.87) and reliability (test-retest, r=0.95) coefficients (Bosco *et al.,* 1983). The test calculated mechanical power both for 15- and 60-second jumping intervals. Participants executed maximal, repeated vertical jumps for 15-seconds to calculate average power output and flight time. A 15-second jumping interval was selected, as it reflected real jumping conditions in sports performance and also exhibited a high validity coefficient when compared with the WAnT power test (Bosco *et al.,* 1983). The combination training group (PT plus WT) exhibited significantly (p<0.05) better vertical jump (VJ) performances than the PT- and the WT-groups in VJ height, jumping mechanical power and flight time.

In contrast to the above research, Markovic et al. (2007b) found that short-term sprint training produced even greater training effects in muscle strength than PT. Pre- and post-testing, leg extensor muscle strength was assessed by means of an isometric squat test. After a 10-week intervention, only the sprint-training experimental group significantly improved isometric leg extensor strength by 10% (p=0.002; ES=0.4). This improvement was significantly greater than the PT experimental (p=0.04) or control-group (p=0.02).

In the above literature, muscular strength was improved by PT alone but larger increases in leg strength were attained by WT alone or combination training. In untrained, male participants completing WT alone showed larger improvements in leg extensor and flexor strength than by means of PT alone (Vissing *et al.*, 2008). Combining both PT with traditional and Olympic-style weightlifting exercises displayed significantly higher improvements in 1RM back squat and 1RM leg press when compared with PT or WT alone, in untrained men (Fatouros *et al.*, 2000).

Average leg muscle endurance by means of repeated jumps to calculate jumping mechanical power (Fatouros *et al.*, 2000), indicated that combination training could exhibit significantly better VJ performances than the PT- and WT-groups in VJ height, jumping mechanical power, and flight time On the contrary, short-term sprint training has also produced significantly greater training effects than PT in leg extensor strength by means of an isometric squat test, in untrained university men (Markovic et al., 2007b).

Strength improvements could be significantly higher when plyometrics are combined with other types of exercises (e.g. plyometric + weight-training and plyometric + electrostimulation) than with PT alone. A combination of different types of plyometric jumps with WT would be more beneficial than utilizing a single jump type. Performance outcomes of a PT or combination training programme are very specific to the nature and specificity of the plyometric and weight-training exercises prescribed.

6. 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). 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, Wilkerson *et al.* (2004) 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.

7. 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 power development 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.

8. 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 pre-stretch 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 upper-body 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. For the 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 plyometrics. 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.

9. 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 pretraining 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 plyometrics 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. 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.

10. Proprioception

Myer *et al.* (2006) compared the effects of dynamic stabilization and balance training versus plyometric training (PT) on power, balance, and landing force in adolescent female athletes. A group of 19 high school female athletes (age: 15.9 ± 0.8 years) participated in training three times a week for seven weeks. PT-group (n=8) completed maximum effort plyometric training without any dynamic stabilization and balance exercises. Balance training group (n=11) completed dynamic stabilization and balance training exercises without any maximum effort jumps during training. Each of the groups participated in various types of training per day. Resistance training, speed interval training, PT or balance training, depending on the experimental group. Both PT and balance training were included as a component of a dynamic neuromuscular training intervention that reduced measures related to anterior cruciate ligament (ACL) injury and increased measures of performance. Participants performed tests measuring dynamic landing force (vertical ground reaction force), center-of-pressure sway (medial-lateral; anterior-posterior), explosive leg power and strength measures, before and after the seven-week intervention. Tests included the single leg hop and balance upon a force plate; isokinetic knee extensor and flexor strength; isoinertial strength testing (one repetition maximum) [1RM] performing bench press, hang cleans, and parallel squats; countermovement vertical jump (VJ).

Vertical ground reaction force, pre-to post-test was significantly different between the balance training and PT-groups on the dominant side ($p<0.05$). Balance training group reduced impact forces by 7% while the PT-group increased by 7.6%. The non-dominant side showed similar results, but were not statistically significant (balance training 5.4%; PT 0.3%; $p=0.33$). Percent increase from pre-test to post-test was not different between groups for any of the performance variables ($p>0.05$). Both PT and balance training groups decreased centre-of-pressure sway (medial-lateral) on their dominant side ($p<0.05$) during landing of the single-leg hop on the force plate, equalizing pre-tested side-to-side (dominant to non-dominant) differences. Neither the balance training nor the PT-group training affected centre-of-pressure sway (anterior-posterior) ($p>0.05$). Both groups increased isokinetic hamstrings peak torque ($p< 0.01$), and hamstrings to quadriceps ratio ($p<0.01$). Both training protocols also significantly improved vertical jump ($p<0.001$), and predicted 1RM measures of bench press ($p<0.001$), hang clean ($p<0.001$) and parallel squat ($p<0.001$).

Myer *et al.* (2006) found that both PT and balance training were effective in increasing measures of neuromuscular power and control. Combined plyometric and dynamic stabilization/ balance training may reduce lower extremity valgus measures, contralateral limb asymmetries and impact forces. A combination of PT and balance training would also further maximize the effectiveness of pre-season training for female athletes. As part of a comprehensive training programme, PT corrects neuromuscular imbalances that may predispose female athletes to injury. PT-group demonstrated improved centre-of-mass stabilization when landing from a jump, equalized landing forces between lower extremities and reduced biomechanical measures related to lower extremity injury risk following completion of the training programme.

Witzke and Snow (2000) also found that a long-term PT intervention improved static balance in high school girls (age: 14.6 ± 0.5 years). The nine-month intervention was incorporated into the participants' daily schedule as part of physical education classes with concurrent extra-curricular sport. Controls participated only in extra-curricular sport. The experimental group completing the PT improved medial/lateral balance by 29% and anterior/posterior balance 17% higher in the experimental group, contrary to the findings by Myer *et al.*, (2006). Witzke and Snow (2000) utilized plyometric drills contained lateral movement patterns in their intervention. These drills activated muscles and neural pathways involved in hip abduction and hip adduction, and knee and ankle stabilization. These exercises would also be an invaluable addition to an intervention to challenge the neuromuscular system, controlling coordination and balance. Therefore both PT and balance training are effective at increasing measures of lower extremity neuromuscular power and control, as well as decreasing leg dominance (Myer *et al*., 2006).

PT and balance training programme would be highly advisable as part of an athlete's pre-season training, assisting with injury prevention. As part of a comprehensive training programme, PT could correct neuromuscular imbalances, improve centre-of-mass stabilization upon jump landings, and equalizing landing forces between lower extremities. Both PT and balance training are effective at increasing measures of lower extremity neuromuscular power and control, as well as decreasing leg dominance.

11. Delayed-onset muscle soreness

The intense nature of plyometrics with eccentric contraction loading can result in damage to the muscle and/ or connective tissue that can subsequently lead to muscle soreness (Jamurtas *et al.,* 2000; Harrison & Gaffney, 2004; Drinkwater, Lane, & Cannon, 2009). Over-prescribed high-volume plyometric training (PT) results primarily in peripheral fatigue that substantially impairs force and rate of force development (Drinkwater *et al*., 2009). Jamurtas *et al.,* (2000) studied the effect of plyometric exercise (P), eccentric (E) and concentric (C) exercises on delayed onset of muscle soreness (DOMS) and plasma creatine kinase (CK) levels, in untrained male participants (age: 22 ± 0.6 years). In addition, Jamurtas *et al.* (2000) also investigated whether a repeated exercise session, six-weeks after the initial testing, showed similar effects on DOMS and CK in P compared to E and C.

A group of 24 participants was randomly assigned to P, E, or C groups (n=8 per group). Participants performed two exercise bouts separated by six weeks. The P-group performed six sets of drop and side jumps at 70% of their maximum jumping height, whereas the E- and C-groups performed six-sets of leg extensions and calf raises at 70% of their one repetition maximum (1RM). Overall muscle soreness (DOMS) was assessed using a modified ordinal scale ranging from 1 (no soreness) to 10 (very, very sore). Muscle soreness was assessed before and also 24-, 48-, and 72-hours after the completion of the first and second exercise sessions. Total CK concentration was measured as an indirect method of assessing muscle damage. Blood was collected to determine CK prior to and following each exercise session at 24-, 48-, and 72-hours post-exercise. No significant interactions were found between the three exercise treatments for muscle soreness and plasma CK. Results showed that DOMS was significantly higher ($p<0.05$) in P and E compared with C, when combined over time and sessions in the three groups. DOMS decreased significantly ($p<0.07$) by 33% after the second exercise session (4.0 ± 0.6 versus 2.6 ± 0.6) independent of treatment. CK decreased significantly ($p<0.05$) by 44% after the second session (649 ± 64.2 versus 363 ± 37.2 international units per litre [$IU \cdot L^{-1}$]) independent of treatment. DOMS appeared to be similar in P and E but lower in C, after the intense exercise sessions. Plasma CK responses after a P exercise session were similar to E and C exercises. After the repeated exercise session, six-weeks after the first one resulted in lower DOMS and CK values in all three groups.

Jamurtas *et al.,* (2000) showed that a novel training session with plyometric exercises could reduce the perception of muscle soreness and CK plasma levels. This prophylactic effect lasted up to approximately six-weeks. Therefore, it would be far more beneficial for participants unfamiliar to PT to start with low volume training in order to minimize the initial muscle DOMS, whilst maintaining a positive training effect (Jamurtas *et al.,* 2000; Harrison & Gaffney, 2004). Drinkwater *et al.* (2009) recommended that the volume of PT sessions be carefully monitored to avoid neuromuscular impairments that can result in suboptimal training of athletes.

Over-prescribed high-volume PT results in peripheral fatigue that substantially impairs force and rate of force development. Therefore, the volume of PT sessions should be carefully monitored to avoid neuromuscular impairments that can result in suboptimal training of athletes.

12. Other training responses to plyometric training

The benefits of plyometrics seem to lie in the fact that it may promote changes within the neuromuscular system that enhances neuromuscular efficiency. A cognitive learning effect and increase in the fiber area of type II muscle fibers can also occur due to plyometric training (PT) (Coetzee, 2007)

Makaruk and Sacewicz (2010) showed that irrespective of the level of jumping ability of the participants, maximal leg power output may be significantly improved using specific verbal cueing instructions during PT. These verbal instructions emphasise improving the speed of execution during PT, minimizing ground contact, and significantly improving in maximal power output. Study participants were 44 mixed male and female, untrained university students (age: 20.5 ± 0.5 years). Experimental group performed plyometric exercises for six weeks, whereas the control-group participated only in attending lectures. The study test battery consisted of countermovement (CMJ), depth jump DJ (31cm) and a five-hop test (5JT). Post testing results showed significant increases in relative maximal power output for CMJ ($p \leq 0.05$) and DJ ($p \leq 0.01$). Centre of mass elevation and the 5JT distance length did not change significantly ($p > 0.05$). DJ rebound time was significantly shorter ($p \leq 0.01$) with significantly lower knee flexion angles ($p \leq 0.01$). Thus, performing jumps with the fastest possible rebound and the shortest ground contact time improved maximal power output with no effect from jumping ability. Use of specific verbal cueing significantly affected the direction and size of changes in new skill acquisition of explosive activities such as plyometric exercises.

Hutchinson, Tremain, Christiansen and Beitzel, (1998) suggested that PT improves sports performance because of a cognitive learning effect. Hutchinson *et al.* (1998) used jump training to improve the leaping ability of elite rhythmic gymnasts. A group of six elite female athletes (average age: 16-years) participated in the leap training; researchers included a control-group consisting of two other participants. Testing included reaction time, leap height, explosive power, and was performed on a force plate. Testing was done before the intervention, after one month of training, and after an additional three months training. Three athletes were also retested after one year of maintenance protocol training, although they continued intense training for an international competition. The athletes underwent jump training which included pool training with aquatic plyometric training (one hour, twice a week). They also participated in Pilates' Method classes (twice a week during the first month, and once a week thereafter). After one month of training, the experimental group improved leap height by 16.2%, ground contact time by 50% and explosive power by 220%. After three months of continued maintenance, there were no further significant improvements in any of the tested variables. The control-group showed no significant changes after the first month or an additional three months. The three participants, who were retested after one year, showed that their initial gains were maintained. As there were no additional achievements from pre-training levels after one year, Hutchinson *et al.* (1998) supported the hypothesis that jump training is more likely a cognitive, learned outcome rather than simply a motor strengthening effect.

13. Plyometric training upon non-rigid surfaces

Plyometric training (PT) has commonly been performed on firm surfaces such as grass, athletic tracks and wood. Risks of increased delayed-onset muscle soreness (DOMS) and damage caused by forces generated during ground impact and intense plyometric contraction may be reduced when PT is performed on non-rigid surfaces such as sand or in aquatic conditions. Short-term PT on non-rigid surfaces, either aquatic-based or sand-based, may elicit similar increases in jumping and sprinting performance to traditional PT, with substantially less DOMS (Markovic & Mikulic, 2010).

Impellizzeri *et al.* (2008) studied the effects of four-weeks of PT performed on sand versus grass on vertical jump (VJ), muscle soreness and sprinting performance in soccer players. A group of 44 male, amateur soccer players (age: 25 ± 4 years) were divided into two experimental groups (non control-group). A group of 18 participants completed four-weeks of PT on grass (grass-group) and a group of 19 participants on sand (sand-group). Pre-testing occurred one week prior to the start of the four-week intervention, and post-testing occurred after four-week recovery after the cessation of the intervention (Leubbers *et al.,* 2003). Tests included 10- metre (m) and 20-m sprint time, squat jump (SJ), countermovement jump (CMJ), and eccentric utilization ratio (CMJ/SJ). Muscle soreness was measured using a seven point Likert scale.

PT on both surfaces yielded similar relative improvements in sprint performance. The grass-group improved their 10-m and 20-m by 3.7% and 2.78% respectively, whereas the sand group improved their times by 4.25% and 2.5% respectively. No training surface x time interactions were found for sprint time ($p>0.87$). Sand-based PT demonstrated improvements in SJ (10.2%) and CMJ (6.5%), although these increases were not significant. However, the grass surface was superior in enhancing CMJ performance (4.55%; $p=0.033$) and CMJ/SJ (9%; $p=0.005$); these enhancements were significantly better the sand-based PT ($p<0.001$), while the sand surface induced the greatest improvements in SJ. Similar changes in muscle soreness occurred during the intervention between the groups. No significant PT surface x time interaction was found for muscle soreness measured by the Likert scale during the four-week intervention ($p=0.28$), but the main effect for time was significant ($p<0.0001$). Mean value calculated for the entire training period of the sand-group was lower than that of the grass-group (significant between-participants effect, $p<0.001$). This indicates that the muscle soreness experienced by the sand-group was systematically lower than that of the grass-group.

A significant effect of each training surface was found in the jump characteristics relating to the efficiency of the stretch shortening cycle (SSC). During SJ, no pre-stretch actions occur and this type of jump remains a concentric movement. Jumping on sand requires a more intense concentric push-off phase, probably to compensate for the degradation of elastic energy potentiation caused by sand absorption (Impellizzeri *et al.*, 2008). The grass-group showed a greater improvement in CMJ and eccentric utilization ratio (CMJ/SJ) than the sand-group. The eccentric utilization ratio index indicates greater effectiveness of PT on grass for performances requiring slow SSC actions (McGuigan *et al.,* 2006). PT on sand improved both jumping and sprinting ability and produced less muscle soreness than that on grass during the entire training period. Grass surfaces appear to be superior in enhancing CMJ performance while sand surfaces appear to induce greater improvement in SJ. Performing PT on sand impedes the ability to maximize CMJ performance, but may be equal to grass when trying to improve running speed (Impellizzeri *et al.*, 2008). The results of this study suggest that PT on different surfaces may be associated with different training-induced effects on neuromuscular factors related to the efficiency of the SSC.

Current research justifies the use of aquatic and sand-based PT for rapid movement performance enhancement in healthy individuals, with significantly lower muscle soreness when compared with land-based PT. However, the current results are inconclusive regarding the effects of PT performed on non-rigid surfaces on muscle strength and power. The mechanisms behind performance enhancements of aquatic and sand-based PT are inconclusive. The focus of research in muscle strength/power or athletic performance has been placed more upon neuromuscular and performance adaptations of PT on non-rigid training surfaces (Markovic & Mikulic, 2010).

Markovic and Mikulic (2010: 885) concluded in a recent review that: “further study is required to determine (I) the optimal water level to elicit a training effect with measurement of impact forces; and (II) the mechanisms behind performance changes following aquatic- and sand-based PT.

Excessive amounts of high-volume PT may result in peripheral fatigue that could substantially impair force and rate of force development. Therefore, the volume of PT sessions should be carefully monitored to avoid neuromuscular impairments that can result in suboptimal training of athletes (Drinkwater *et al.,* 2009).

14. Summary

Land-based plyometric training (PT) is a well-documented training modality for enhancing explosive power output, strength and stretch-shortening cycle (SSC) muscle function, particularly for the lower body. Short-term and long-term PT causes adaptive changes in the neuromuscular system, allowing for explosive power development. These changes of increased peak power production, increased fiber shortening velocities, with increased muscle fiber cross-sectional area (CSA) due to hypertrophy of type I and type II muscle fibers of the leg extensors and plantar flexors. These morphological changes appeared to be the most prominent in recreationally active males after an eight-week PT intervention. Although, long term PT could also be a cognitive, learned outcome rather than simply a motor strengthening effect.

Vertical jump (VJ) performances could be improved by utilizing a mixed arrangement of plyometric exercises than a single mode of PT exercise of: squats jump (SJ), countermovement jump (CMJ), countermovement jumps with arms (CMJA) or depth jumps (DJ). Combination training of PT and weight-training (WT) appears to present with the greatest improvements in VJ than WT or PT alone. Combination training could also enhance horizontal and upper body explosive performances. Sprint training appears to be more effective in linear explosive performances than PT. PT-induced improvements in muscle strength could be due to the nature and specificity of PT and WT or their combination of exercises prescribed. Upper body PT may be highly effective for improving upper body explosive power. PT could be an effective training modality for improving agility. No evidence confirms that PT is superior to traditional sprint training for speed improvement. For speed enhancement, prescribed PT must be velocity-specific, with functional movements pertaining to sprinting. The use of PT alone or in conjunction with balance training could be effective at enhancing neuromuscular power, coordination and proprioception. Due to the eccentric nature of plyometric exercises, participants unfamiliar to PT should start with low volume training in to minimize the initial muscle delayed-onset muscle soreness (DOMS), whilst maintaining a positive training effect. Short-term PT on non-rigid surfaces, grass-based, aquatic-based or sand-based, may elicit similar increases in jumping and sprinting performance to traditional PT, with substantially less DOMS.

E. Physical properties of water

1. Introduction

Water offers a unique exercise medium in which reduced-gravity conditions decrease the impact forces on joints, while the water itself creates resistance to movement (Pöyhönen *et al.,* 2002). An aquatic environment offers an effective means for many aspects of a participant's exercise and conditioning programme (Thein & Brody, 1998). Based upon the physical properties of water, land exercise cannot always be converted into aquatic exercise, because buoyancy rather than gravity is the major force governing movement (Thein & Brody, 1998; Hoogenboom & Lomax, 2004). Physiologic changes incurred by the body while immersed, both at rest and during exercise, will be reviewed.

2. Buoyancy

Buoyancy is defined as the upward thrust acting on any partially or fully immersed object in the opposite direction of gravity (Thein & Brody, 1998; Serway & Jewett, 2004). There is a positive force when moving toward the surface of the water and an opposing or negative force when moving away from the surface (Prins & Cutner, 1999). Archimedes' principle of buoyancy states that if the human body is immersed in water, that portion will experience an up thrust which is equal to the weight of the water displaced (Harrison & Bulstrode, 1987). The magnitude of the buoyant force always equals the weight of the fluid displaced by the immersed object (Serway &

Jewett, 2004). Buoyancy has a direct influence upon an immersed object in water reducing the effects of gravity (Prins & Cutner, 1999).

Buoyancy is related to the specific gravity of the immersed object. Specific gravity is the ratio of the mass of one substance to the mass of the same value of water. Specific gravity of water is 1.0, and any body with specific gravity of less than 1.0 will float. Average values for the human body range from 0.97 to 0.95, thereby causing most humans to float. Some participants may have difficulty floating due to their body composition and body fat distribution (Thein & Brody, 1998). The up thrust of buoyancy will counterbalance the weight of those parts immersed and the effective weight of the person passing through their feet will this the weight of the part of the body which is still above the surface of the water. By using Archimedes' principle, weight-bearing can be progressed by walking or training by decreasing depths in water (Harrison & Bulstrode, 1987).

Buoyant properties of water should reduce forces on the musculoskeletal system, thereby decreasing the amount of force and joint compression during landing which could reduce the risk of overuse injuries such as tendinopathy and stress fractures (Gehlsen, Grigsby & Winant, 1984; Tovin, Wolf, Greenfield & Woodfin, 1994; Prins & Cutner, 1999). Axial loading on the spine and weight-bearing joints, particularly the hip, knee, and ankle is reduced with increasing depths of immersion (Prins & Cutner, 1999). The advantage of buoyancy is direct: when a person enters the water, there is an immediate reduction in the effects of gravity on the body (Prins & Cutner, 1999).

3. Effect of depth of immersion on weight bearing

The pioneering study of Harrison and Bulstrode (1987) calculated the percentage weight-bearing of a stationary human body to various anatomical levels during partial immersion in a hydrotherapy pool. A group of 18 participants (males and females) were weighed using a spring balance with a scale on a cross-beam over the water. Measurements were taken at three levels of water immersion: anterior superior spines (ASIS), xiphirsternum (XIPH), and at the seventh cervical vertebra (C7) level. The participants were also weighed on dry land using the same spring balance. From the two readings, the effective weight of each participant, when immersed in water to the different levels, as a percentage value of the participant's weight on dry land was calculated. As an approximate percentage of weight bearing load of total body weight, at an immersion up to C7, both females and male were 8%; at the chest-level, XIPH immersion females were 28% and males 35%, and at waist-deep, ASIS immersion females were 47% and males 54%. However, these numbers reflect static weight bearing, and increasing to a fast walking speed can increase weight bearing by as much as 76% (Harrison & Bulstrode, 1987). The percentage immersion or the percentage of depth immersion against the participant's height, for the anatomical levels was: 85% at C7; was 71% at chest-level, XIPH; was 57% at waist-deep, ASIS of partial immersion (Harrison, Hillman & Bulstrode, 1992). Decreasing the depth of water is one way to progress lower extremity weight bearing (Thein & Brody, 1998).

4. Effects of water temperature

The participant exercising within an aquatic environment cannot always choose the temperature of pool, but the effects of water temperature must be noted to both cold and warm or hot pool temperatures. Exercising in a pool where the water temperature is greater than body temperature can cause increases in core body temperature greater than in a land environment. Exercising in a pool where the water temperatures is less than body temperature, will decrease core temperatures. This decrease will occur faster in athletes than in the general population, due to low body fat of many athletes, and cause shivering (Hoogenboom & Lomax, 2004). Thein and Brody (1998) recommended that the optimal water temperature range should be between 26 and 28℃ (degrees Celsius) for intense training to prevent heat-related complications. A disadvantage of aquatic exercise is that training in water does not allow the participant to improve or maintain their tolerance to heat while on land (Hoogenboom & Lomax, 2004).

5. Fluid dynamics

When fluids are in motion, there are two-types of water flow, namely steady or laminar flow, and turbulent flow. Laminar flow is defined when each particle of the fluid follows a smooth path, with the least amount of resistance so that the paths of different particles never cross each other (Serway & Jewett, 2004). In laminar flow, the velocity of fluid particles passing any point remains constant in time (Serway & Jewett, 2004). Turbulent flow is interrupted flow, as when laminar flow encounters an object, causing the water molecules rebound in all directions (Thein & Brody, 1998). Above a critical speed, fluid flow becomes turbulent and irregular, which is characterized by small whirlpool-like regions (Serway & Jewett, 2004).

6. Fluid resistance

Fluid resistance is the resistive force encountered by an object moving through a fluid (liquid or gas), or by a fluid moving past or around an object or through an orifice (Harman, 2008). An aquatic environment offers a multidirectional resistance and a buoyancy force that will directly influence the physiological responses to the exercises performed within it. This characteristic of water produces a modification in the pattern of muscular activity where there is a predominance of concentric muscle actions during the execution of movements or exercise performed in water (Pantoja *et al.*, 2009). Water acts as an accommodating resistance that matches the participant's applied force or effort because the resistance of the water equals the amount of force exerted. The degree of effort will therefore be determined by the size of the moving body, or limb, plus the speed or velocity of the movement performed (Gehlsen *et al.,* 1984; Tovin *et al.,* 1994; Prins & Cutner, 1999). If the pace of movement increases, the resistance of the water also increases in a quadratic manner (Colado & Triplett, 2009).

6.1 Viscosity

Viscosity is defined as the internal friction occurring between individual molecules in a liquid, causing resistance to flow (Thein & Brody, 1998). Viscosity is only noticeable when there is motion through the liquid and acts as resistance to movement because the liquid molecules adhere to the surface of the body (Thein & Brody, 1998). This internal friction or viscous force is associated with the resistance that two adjacent layers of fluid have to moving relative to each other, causing resistance to flow (Thein & Brody, 1998; Serway & Jewett, 2004). Viscosity is only experienced once an object is in motion through the liquid and acts as resistance to movement, because the water molecules adhere to the surface of the body. Movement in water will experience resistance regardless of buoyancy because water is more viscous than air (Thein & Brody, 1998). The advantage of viscosity of water is indirect, when the person moves through the water, resistance is felt. The degree of effort is determined by the size of the moving body, or limb, plus the speed or velocity of the movement (Prins & Cutner, 1999).

6.2 Resistive forces

Water is 12-times more resistant than air (Hoogenboom & Lomax, 2004). Due to this, exercise performed in water requires higher energy expenditure than the same exercise performed on land. For example, the energy cost for water running is four-times greater than the energy cost for running the same distance on land (Hoogenboom & Lomax, 2004).

A participant performing dynamic movements in water must not only maintain a level of buoyancy and but also overcome the resistive forces of the water. When a participants or an object moves in water, several resistive forces are at work that should be considered. Hoogenboom and Lomax (2004) defined these resistive forces as the cohesive force, the bow force and the drag force.

Cohesive force is the slight and easily overcome force that runs parallel to the water surface. This resistance is formed by the water molecules loosely binding together, creating a surface tension. Surface tension can be seen in still water because the water remains motionless with the cohesive force intact unless disturbed (Hoogenboom & Lomax, 2004). *Bow force* is the force generated at the front of the object during movement. When the object moves, the bow force causes an increase in the water pressure at the front of the object and a decrease in the water pressure at the rear of the object. This pressure change causes a movement of water from the high-pressure area in front to the low-pressure area behind the object. As the water enters the low-pressure, it swirls into the low-pressure zone, forming eddies or small whirlpool turbulences. These eddies impede flow by creating a backward force, or drag force (Hoogenboom & Lomax, 2004). *Drag force* resists the motion of an object moving through a fluid (Kent, 2004). Drag force and bow force acting upon an object can be controlled by changing the shape of the object or the speed of its movement (Hoogenboom & Lomax, 2004). There are three types of drag force that affect the movement of an object through a fluid: surface drag, form drag, and wave drag.

Surface drag is a result of the friction between the surface of an object and fluid through which it is moving (Kent, 2004; Harman, 2008). Fluid particles adjacent to the object slow down, causing turbulent flow (Kent, 2004). Magnitude of the surface drag depends on the velocity of the flow relative to that of the object, the surface area of the object, and the smoothness of the surface- higher the relative velocity, the greater the surface area; the rougher the surface, the greater the surface drag (Hay & Reid, 1988; Pöyhönen *et al.,* 2002). Frictional resistance can be decreased by making the object more streamlined. This change minimizes the surface area at the front of the object. Less surface area causes less bow force, and less change in pressure between the front and rear of the object, resulting in less drag force. In a streamlined flow, the resistance is proportional to the velocity of the object. (Hoogenboom & Lomax, 2004)

Form drag is caused by the separation of the thin layer of water or boundary layer, forms adjacent to the moving object in the water (McArdle *et al.,* 2001; Harman, 2008). It is the pressure differential created in front of and behind an object moving through water (McArdle *et al.,* 2001; Kent, 2004). Form drag of an asymmetrical object depends on its orientation to the direction of the free fluid flow. It increases with the cross-sectional (frontal) area of the body aligned perpendicular to the flow (Kent, 2004; Harman, 2008). Magnitude of the form drag depends on the cross-sectional area of the relative object to the flow, the shape of the object, and the smoothness of its surface. The greater the cross-sectional (frontal) area, the less streamlined the shape and the smoother its surface, the greater the form drag (Hay & Reid, 1988). Streamlining helps to minimize form drag. If the object is not streamlined, a turbulent situation exists (Kent, 2004).

Turbulence experienced at the water surface is called wave drag (Sherrill, 2004). It is caused by waves that build up in front of, and form hollows behind, an object moving through the water at fast velocities. Its influence will increase with faster movement speeds (McArdle *et al.,* 2001). It is more difficult to swim or exercise in turbulent water because the turbulence increases the amount of drag that a body or object will experience travelling through the water (Sherrill, 2004). In a turbulent situation, drag is a function of velocity squared. By increasing the speed of movement two times, the resistance the object must overcome is increased four times. Considerable turbulence can be generated when the speed of the movement is increased, causing the muscle to work harder to keep the movement going. Changes in direction of the object will also increase drag. Turbulence functions as a destabilizer and as a tactile sensory stimulus. Stimulation from the turbulence generated during movement provides feedback and perturbation, aiding in proprioception and balance (Hoogenboom & Lomax, 2004).

7. Altered muscle action and performance in water

Muscle contraction type is a key consideration when performing exercise in water, especially when increasing resistance is based upon viscosity. Exercises performed against the water's resistance almost always elicit concentric contractions (Thein & Brody, 1998). Within an aquatic environment there will be less eccentric muscle activation than on land encountered during exercise, due to the effect of buoyancy. The buoyant properties of water can provide a decreased load during the eccentric phase of the exercise, and the drag properties can provide a resistance load for training during the concentric phase (Miller *et al.,* 2002). Participants may experience the absence of delayed-onset muscle soreness (DOMS) due to limited muscle tissue damage, in contrast to land-based exercise (Pantoja *et al.*, 2009). It has been suggested that buoyancy reduces the stretch reflex and amount of eccentric loading during aquatic plyometric exercise. Due to the viscosity of water, participants exercising in water will experience greater than normal resistance during concentric movements (Martel *et al.,* 2005). Although eccentric muscle actions during lower body exercise movements could be achieved if the water was shallow enough to minimize buoyancy (Thein & Brody, 1998).

8. Fluid-resisted exercise machines

Harman (2008: 82-83) further describes the pro-concentric muscle actions and the controlled movement speeds of using fluid as a means of resistance whilst performing exercise:

> *Fluid resistance in the resistive force encountered by an object moving through a fluid (liquid or gas), or by a fluid moving past or around an object or through an orifice. The phenomenon has become important in resistance training with: the arrival of hydraulic (liquid) and pneumatic (gas) exercise machines, and increasing popularity of swimming pool based exercise and training. Fluid-resisted exercise machines often use cylinders in which a piston forces fluid through an orifice as the exercise movement is performed. The resistive force is*

greater when the piston is pushed faster, when the orifice is smaller, or when the fluid is more viscous. Because fluid cylinders provide resistance that increases with speed, they allow rapid acceleration early in the exercise movement and little acceleration after higher speeds are reached. Movement speed is this kept within an intermediate range. Although some machines can limit changes in velocity to a certain extent, they are not isokinetic (constant speed), as some do claim. Some machines have adjustment knobs that allow the orifice size to be changed. A larger orifice allows the user to reach a higher movement speed because the fluid resistive force curtails the ability to accelerate.

Fluid-resisted machines do not generally provide an eccentric exercise phase; they may if they incorporate an internal pump. With an isotonic or free weight exercise, a muscle group acts concentrically while raising the weight and eccentrically lowering it. With fluid-resisted machines without eccentric resistance, a muscle group acts concentrically while performing the primary exercise movement, and the antagonist muscle group acts concentrically while returning to starting position. Whereas free weights or weight machines involve alternate concentric and eccentric actions of the fluid-resisted machines generally involve alternate concentric actions of antagonist muscle groups; each muscle group rests while the antagonist works. The lack of eccentric muscle action with fluid-resisted machines means such exercise probably does not provide optimal training for many sport movements that involve eccentric muscle actions (e.g., running, jumping, and throwing)."

Siff (2003) warned that explosive water-based training such as aquatic-based plyometric training should not completely replace land-based plyometric training, as it does not adequately develop the specific neuromuscular patterns or functional needs of explosive sports. Contrary to Siff (2003), other recent literature has shown that aquatic-based plyometric programmes can provide the same or even more performance enhancement benefits than land-based plyometric programmes (Triplett *et al.*, 2009; Colado *et al.,* 2010).

F. Aquatic-based plyometric training

1. Introduction

Aquatic plyometric training (APT) has become increasingly popular because it provides a safer and less stressful alternative to land-based programmes (Siff 2003; Donoghue, Shimojo & Takagi, 2011). Performing plyometrics in water also changes the training environment and might motivate athletes and prevent the monotony and repetitiveness of training and conditioning on land (Miller *et al.,* 2002). APT can be used to decrease the landing force and increase the resistance during the recoil or concentric phase of the stretch-shortening cycle (SSC) (Siff, 2003).

"Water enables a participant to strengthen the muscles by providing resistance on the segments that are submerged as each is brought forward and upward through the water. The buoyant force of the water, although decreasing the amount of force and joint compression on landing, does not reduce the amount of force that must be produced to control and stop the eccentric phase of the movement, nor does it reduce the amount of force needed to overcome drag properties of water that provide a resistance load for training during the concentric phase of the movement" (Miller *et al.,* 2002: 269). Depth of water determines the level of resistance, with chest or shoulder high depths offering greater resistance during landing and take-off phases, less intense eccentric muscle activity, smaller impact forces and enhanced safety (Siff, 2003). These low impact activities could be used by obese individuals or athletes with large body masses to improve their explosive force, as performing jumps on dry land greatly increases the risk of joint injuries for these individuals, due to the high impact forces generated when landing (Colado *et al.,* 2010). APT does not provide maximal or shock method plyometric training, but can serve as preparatory or submaximal plyometrics, especially for single-legged drills (Siff, 2003). Plyometric programmes conducted in water appear to have similar positive effects on performance variables when compared with LPT (Miller, Berry, Gilders & Bullard, 2001; Triplett *et al.*, 2009; Colado *et al.,* 2010).

2. Leg power

Buoyancy of water reduces the weight, stretch reflex and amount of eccentric loading experienced during APT, facilitating the concentric muscular component of a plyometric jump, and theoretically shortening the amortization phase of a plyometric task (Behm & Sage, 1993; Colado *et al.,* 2010). Decreased amounts of force applied (load) experienced during landing in APT facilitating a more rapid transition from eccentric to concentric activity may occur. LPT causes heavier loads (no buoyancy effect) at lower velocities and a longer amortization phase, improving strength but not power (Behm & Sage, 1993; Miller *et al.,* 2002; Robinson, Devor, Merrick & Buckworth, 2004; Colado *et al.,* 2010). In accordance with speed specificity of resistance training, a lower load and faster amortization training stimulus would be expected to produce improvements in muscle-power output at higher velocities (Behm & Sage, 1993; Colado *et al.,* 2010). This concept could explain why APT has shown improvements in muscle-power output, and supports the premise that APT might be useful in increasing power performance (Miller *et al.,* 2002).

Optimal pool depth for APT has yet to be validated. This is a fundamental factor when the training objective is to increase muscle power (Miller *et al.*, 2002; Stemm & Jacobson, 2007). APT performed in too deep water might inhibit the stretch reflex and negate plyometric training (PT) benefits (Miller *et al.,* 2007). In addition, there will be increases in arm swing drag experienced during the deepwater jumping. The possibility could exist that participants would be totally submerged when performing jumping activities in water that is too deep (Miller *et al.,* 2001).

Shiran, Kordi, Ziaee, Ravasi and Mansournia (2008) compared the effects of a five-week APT and LPT intervention on physical performance and muscular enzymes in 21-male, club wrestlers (age: 20.3 ± 3.6 years). Effects of the APT and LPT intervention upon anaerobic power was assessed by means of a running anaerobic sprint test (RAST). Results indicated the APT and LPT experimental groups provided similar yet non significant improvements in peak and mean power, without any meaningful difference between the training environments. Both groups increased the fatigue indices from pre-and post-test.

RAST provided a means of measuring anaerobic power more specific to the execution of movements in sporting events that use running as the principle means of locomotion (Balciunas, Stonkus, Abrantes & Sampaio, 2006; Zagatto, Beck & Gobatto, 2009). RAST was adapted and significantly correlated from the original Wingate cycle test (WAnT) to assess anaerobic power and capacity measuring: peak power, mean power, and fatigue index variables (Zachargoiannis, Paradis & Tziortzis, 2004). RAST gave an estimate of the neuromuscular and energy determinants of maximal anaerobic performance. RAST consists of six 35-metre (m) maximal sprints with 10-second recovery. Measurement of body mass and running times determined the power of effort in each sprint (power= (body mass X distance^2)/ time^3) (Balciunas *et al*., 2006). The anaerobic fatigue index (FI) established the percentage decline in power output during the test. FI represents the total capacity to produce ATP via the immediate and short-term energy systems (McArdle *et al*., 2001). The lower the FI, the better the participant's condition (Shiran *et al.,* 2008), and could show a higher level of anaerobic fitness (Hoffman, Epstein, Einbinder & Weinstein, 2000). FI was calculated, as: FI = [peak power- minimum power/ peak power] x 100 (Zagatto *et al.* 2009). Shiran *et al.* (2008) calculated the FI using a modified method called the rest test: FI = maximum power – minimum power/ total time elapsed in the six repetitions of the RAST.

Robinson *et al.* (2004) compared the effect of eight-weeks of APT versus LPT on VJ, muscle strength, sprint velocity, and muscle soreness in 32-active women (age: 20.2 ± 0.3 years). Large, yet significant increases ($p \leq 0.001$) in VJ performance were attained in both APT (32.2%) and LPT (33.5%) experimental groups of similar magnitude, without any significant differences between them.

Miller *et al.* (2002) compared the effects of an eight-week of APT versus LPT on VJ, muscle power, muscular strength, range of motion, and muscle soreness in 42-

recreationally active, male and female university students (age: 22.2 ± 3.9 years). No significant differences were found among the two experimental and control-group for VJ height and estimated power. Only the APT-group showed a significant increase ($p<0.05$; 7.1%) in muscle power (pre-training to post-training) in the Maragria-Kalamen power test. No significant differences were found between the groups for both power tests.

Stemm and Jacobson (2007*)* compared the effects of land-based and aquatic-based (knee-level water) PT on VJ performance. A group of 21 physically active, university-aged males (age: 24 ± 2.5 years) were randomly assigned to one of three groups: APT, LPT or control-groups. APT-group improved countermovement jump with arm swing (CMJA) performance significantly (5.0%; $p<0.05$), and the magnitude of improvement was similarly achieved by the LPT-group. Both the aquatic- and land-based groups significantly ($p<0.05$) outperformed the control-group in the VJ. No significant differences were found between the aquatic- and land-based experimental groups in VJ performance.

Martel *et al.,* (2005) reported a relative improvement in CMJA performance by 8% ($p=0.05$) in female high school volleyball players following six weeks of APT conducted in 1.2-m deep water. Martel *et al*. (2005) added APT to concurrent pre-season volleyball training for the experimental group (n=10; age: 15 ± 1 years), whilst the control-group (n=9; age: 14 ± 1 years) maintained volleyball training, performing flexibility exercises whilst the APT-group trained. The combination of APT and volleyball training resulted in greater improvements in VJ than in the control-group, improving 8% versus 4% pre-test to post-test, respectively.

Gulick, Libert, O'Melia & Taylor (2007) compared the effects of APT versus LPT on peak power, muscular strength, and agility in university students. A group of 42 male and female untrained participants (men: n=24; women: n=18; age: 24.5 ± 3.47 years) were assigned to a control-group, an APT-group, or a LPT-group for the six-week intervention. Gulick *et al.* (2007) calculated peak power from the VJ score using the formula of Harman, Rosenstein, Frykman, Rosenstein and Kraemer (1991: 116): "Peak power (W) = [61.9 x jump height (cm)] + [36 x body mass (kg)] -1822". No significant differences were found among the two experimental groups and control for VJ estimated power. While groups showed an improvement in muscle power, only the APT-group showed a significant increase (2%; $p<0.05$) in muscle power, pretraining to mid-intervention testing at three weeks. Although no significant differences were found between the groups, the APT-group showed the greatest improvement in the VJ estimated power test.

Miller *et al.* (2007) found no significant differences in average force and power with SJ, CMJ, DJ, and VJ height in a comparative study of waist- and chest-deep APT. A group of 29 male and female untrained participants (15-men and 14-women; age: 25.3 ± 7.1 years) were assigned to a control-group, a waist deep aquatic-group, or a chest deep aquatic-group, for the six-week APT intervention. Pre-and post-testing compromised of three maximal jumps (SJ, CMJ, DJ [15cm]) performed upon a force plate. VJ height was recorded separately. With respect to force production, all groups decreased pre- to post test except for the chest-deep group in the SJ (+22.3N), control-group in the CMJ (+25.4N), and chest-deep group in the DJ (+48.1N). For power production, all groups decreased pre- to post test except for the chest-deep group in the SJ (+38.6W), the chest-deep group in the CMJ (+29.3W), and the control-group in the DJ (+65.6W: statistically significant). For VJ height, both the chest- (+1cm) and waist-deep (+2.5cm) groups increased slightly, whereas the control-group decreased slightly (-2.1cm). Miller *et al*. (2007) showed that after six weeks of APT, only slight changes in force and power production were found in the chest-deep group and only slight, non significant differences in the VJ height in the waist-deep group. Participants were previously inactive, untrained, and the APT intervention prescribed was too low in intensity and total training volume. The main findings of this study were that optimal depth for performing APT to enhance power and force production was still inconclusive, and that APT showed similar benefits as LPT.

Miller *et al.* (2010) further studied the viability and effectiveness of high volume APT versus LPT, and APT of similar volumes upon VJ, muscular peak power and torque. A group of 39 participants (16-males; age: 21.8 ± 2.3 years. 23-females; age: 22.4 ± 3.5 years) were randomly assigned to one of four groups: an aquatic-group 1 (APT1, 10 participants), an aquatic-group 2 (APT2, 11 participants), a land-group (LPT1, 8 participants) and a control-group (CON, 10 participants). A six-week PT programme for the three experimental groups was conducted twice a week for approximately 30 minutes per session. APT1 performed a plyometric programme in the aquatic setting, while LPT performed the same protocol on land. APT2 performed double the volume of the plyometric programme in the aquatic setting. Control-group maintained its existing exercise habits. Tests that were performed pre-and post-test were VJ and concentric peak torque and power of the hamstrings and quadriceps using the dominant knee upon an isokinetic dynamometer. Results showed no significant differences in any group for all the tested performance variables. However, APT2 showed the greatest (non significant) improvements of all the training groups. Average VJ improved by 1.3cm, overall peak power values improved by 14.8W for hamstrings and 1.2W for quadriceps and peak torque improved by 3.2 N·m (Newton-metres) for dominant quadriceps. Although there were no significant differences found for any performance variable, improvements showed by group APT2, validate the benefits of APT and use of water as an excellent training environment.

APT improves leg power and it can be explained by the use of buoyancy and fluid resistance. Buoyancy reduces the mass of the participant, for faster total jump time and theoretical reduced ground contact time. And the fluid resistance produces a greater concentric contraction of the SSC. APT has produced better leg power performances than LPT although not significantly different for the Maragria-Kalamen power test in active, university-aged males, and peak power derived from VJ, in male and female untrained university students. APT and LPT have also shown similar results in VJ performance in active women, and peak and mean leg power derived from running anaerobic running test (RAST) in elite wrestlers. Concurrent APT and basketball has also produced significantly better VJ performances than maintaining only basketball training in high-school girls. High volume APT interventions have displayed better VJ results than moderate volume LPT. Optimal pool depth for APT has yet to be validated; this is a fundamental factor when the training objective is to increase muscle power. Incidentally, here has not been any reported research establishing the effect of an APT intervention or comparatively with LPT upon horizontal explosive performances.

3. Leg strength

Performing plyometrics in a pool could boost muscular strength while reducing impact forces and the potential for producing or exacerbating injury (Grantham, 2002). “Weight-bearing activities on land place stress on the lower limbs, and this stress is considerably reduced in water because of its buoyancy. Use of water as a medium for training should thus reduce the impact forces and the potential trauma to the joints and connective tissue while providing resistance to movement well beyond that of air. Increased resistance to movement through the water (drag) requires additional muscle activation to overcome the resistance and produce the same movement that is more easily produced in the air” (Robinson *et al.,* 2004: 84). Strength gains through aquatic exercise are brought about by the increased energy needs of the body working in an aquatic environment (Hoogenboom & Lomax, 2004). Water serves as an accommodating resistance medium. This allows the muscles to be maximally stressed through the full range of motion available (Thein & Brody, 1998).

Arazi and Asadi (2011) studied the effects of eight weeks of aquatic-lased and land-based plyometric training on leg strength (one repetition maximum [1RM] leg press), sprint speed (36.5- and 60-metres [m]), and dynamic balance 5-m-timed-up-and-go-test in young basketball players (age: 18.81 ± 1.46 years). No significant differences were found in the magnitude of increase in 1 RM leg press at 8 weeks between the APT-group and the LPT-group (18.33 kg versus 16.00 kg) ($p>0.05$). APT-group displayed significantly larger increases than the control-group for 1RM leg press

($p<0.05$). There was a significant difference in relative improvement between the APT and control in the 1RM leg press ($p<0.05$).

Shiran *et al.* (2008) showed that the effects of five-weeks of an APT and LPT significantly improved 1RM maximal back squat in professional wrestlers. APT-group improved leg strength by 9.32% ($p=0.03$), and the LPT improved by 12.21% ($p=0.005$). No significant differences were found between the experimental groups.

Gulick *et al.* (2007) found that both APT and LPT improved concentric quadriceps strength (pre- to post-testing). This comparative study assessed muscular strength via maximal isometric (concentric) torque of the quadriceps muscles set at 45 degrees (º) knee flexion. Both experimental groups showed large improvements in measured knee extensor strength, with only APT showing significant improvements in mid-test (19.7%; $p<0.05$) and post-test scores (30.55%; $p<0.05$), versus LPT (22.5%; $p>0.05$). No significant differences were found between the experimental groups.

Robinson *et al.,* (2004) reported significant increases ($p\leq0.001$) in concentric and eccentric knee extensor/flexor muscle strength (+25–52%) in both the aquatic- and land-based experimental group. Eccentric and concentric isokinetic peak torque of the quadriceps and hamstrings were measured before, during and after the intervention at $60º\cdot s^{-1}$. Post-testing results showed that the APT-group improved peak torque, concentrically for the knee extensors and flexors, by 24.84 and 44.84% ($p\leq0.001$), respectively. LPT-group improved peak torque: concentrically for the knee extensors and flexors by 25.16 and 45.1% ($p\leq0.001$), respectively. APT-group improved peak torque eccentrically for the knee extensors and flexors by 52.8 and 25% ($p\leq0.001$), respectively. LPT-group improved peak torque: eccentrically for the knee extensors and flexors by 44.51 and 24.32% ($p\leq0.001$), respectively. Therefore, the APT-group showed similar, significant improvements in concentric and eccentric peak torque to the LPT-group, with no significant differences reported between the experimental groups.

Martel *et al.,* (2005) reported that both the APT and control indicated similar significant improvements (all $p<0.05$) in non-specific concentric peak torque (N·m) unilaterally during knee extension and flexion at 60°·s^{-1} and 180°·s^{-1} after six-week' training, pre-to post-test. The experimental group performed APT and the control performed flexibility exercises whilst maintaining concurrent volleyball pre-season training. Testing of the non-dominant leg for both groups revealed the same pattern of improvement as the dominant leg, except that the APT-group displayed significantly larger increases (38.4%) than the control-group (14.2%) for knee extension at 180°·s^{1} ($p<0.05$). Therefore APT can produce significant increases in concentric leg strength in female high school participants.

Miller *et al.* (2002) reported no significant difference at any speed (angular joint velocity) between the APT, LPT and control-group for peak torque measured during knee flexion and extension and ankle dorsiflexion and plantar flexion. Pre-test to post-test results showed knee-flexion peak torque significantly improved ($p<0.05$) at 360°·s^{-1} in the APT-group (13.74%) and LPT-group (24.19%). Pre-test to post test results also showed ankle dorsiflexion peak torque significantly improved ($p<0.05$) at 360°·s^{-1} in the APT-group (73.77%) and LPT-group (32.72%). There were slight but no significant improvements ($p>0.05$) for both knee extensors and ankle plantar flexors for all three groups.

APT improves leg strength by the imposed training effect of additional muscle activation to overcome the increased resistance to movement through the water. Both APT and LPT have produced similar yields in leg strength for 1RM leg press in adolescent basketball players and 1RM back squat in elite wrestlers. Similar leg strength enhancements for both APT and LPT have been evident in: improved concentric quadriceps strength in both high school females and, increased concentric and eccentric knee extensor/flexor muscle strength in untrained adult females. APT has shown significantly improved ankle dorsiflexion peak torque although not significantly different from LPT.

Arazi and Asadi (2011: 107) concluded that: "both aquatic and land plyometrics appear to cause an effective increase in the recruitment of motor units of agonist muscles, therefore improve muscular strength. Additional muscle force stimulus experienced by previously physically active or moderately trained individuals during PT can be effective for maximal strength development. Therefore, PT with additional loads might increase strength development. An aquatic environment provides resistance to movement, stimulus and additional muscle activation to impose a training effect and consequently, enhance muscular strength improvement".

4. Agility

Physical properties of water could be attributed to similar improvements in agility performance of aquatic-based plyometric training (APT) (Gulick *et al.,* 2007; Jones, 2008. Since water is denser than air, movement resistance in water is greater than on land. Viscosity and cohesion of water increases this resistance, providing an important training stimulus for agility in an aquatic environment (Miller *et al.*, 2001; Gulick *et al.,* 2007). Horizontal or lateral jumps performed in water would have greater than normal resistance because of the viscosity of water (Miller *et al.,* 2002; Martel *et al.*, 2005). This allowed the muscles to adapt to the imposed demands of the water which is possibly transitioned to increased agility on land (Jones, 2008). Collective effects of speed specificity, repetitive training with the shorter amortization phase could too result in improved agility (Behm & Sage, 1993; Gulick *et al.,* 2007).

In the unpublished study of Jones (2008) compared the effects of aquatic- and land-based plyometric training upon agility and static balance in female university athletes. A group of 12 trained, female soccer athletes were split into two groups by position: aquatic (n=6) and land (n=6), participated in the six-week intervention. Tests performed prior and after the intervention were the Illinois agility run, T-test, Hexagon test, and stork stand test for static balance. ATP-group significantly improved more than the LPT-group in the Illinois agility run (p=0.048). No significant differences were found between experimental groups in the T-test (p=0.6). Both the LPT- and APT-groups showed similar improvements, pre- to post-test. LPT-group improved significantly more than the APT-group in the hexagon test, without a significant difference between the experimental groups. The greater improvement of the LPT-group in the hexagon test due to prescribed PT-intervention was not intensive enough in the aquatic environment, due to the buoyancy of the water. The PT intervention was far greater in intensity for the LPT than the APT-group.

Gulick *et al.* (2007) also found that both the APT and LPT experimental groups significantly improved agility scores in the T-test ($p<0.05$) in male and female university students. No significant differences were observed between APT and LPT experimental groups. An APT intervention provided similar results to LPT in improving agility performances. Findings of Gulick *et al.* (2007) and Jones (2008) indicate that APT may be an effective alternative approach to enhancing agility.

APT may be an effective alternative approach to enhancing agility. The viscosity and cohesion of water increases this resistance, providing an important training stimulus for agility. The combined effect of: speed specificity, repetitive training with the shorter amortization phase could too result in improved agility. ATP has significantly improved Illinois agility run performances than the LPT-group, in female university soccer athletes. For T-test agility test performances, both the APT and LPT have produced significantly improved their times, pre- to post-testing in male and female university students.

5. Speed

The literature has shown that an appropriately designed aquatic plyometric training (APT) programme was as effective in enhancing sprint times (Shiran *et al*., 2008; Arazi & Asadi, 2011) and running velocity (Robinson *et al.* 2004) as traditional land plyometric training (LPT) programmes.

Shiran *et al*. (2008) found no improvements in 5-metre (m) sprint times in the APT- and LPT-groups. 10- and 20-m times showed an improvement in both experimental groups. 10-m sprint times improved in the APT-group 7% and the LPT-group by 2.8%, respectively. LPT showed the only significant improvement in the 20-m sprint time (3.85%; p=0.006) pre- to post-testing. No significant differences were found between the groups for any of the sprint distances.

Robinson *et al.* (2004) found both the APT and LPT significantly improved in 40-m sprint velocity performances, pre- to post-testing (p≤0.001). Both experimental groups reported similar increases in improvements: APT 6.7% and LPT 6.4%. Aquatic-based PT magnitudes of improvements were not significantly different from those of the LPT- group.

Arazi and Asadi (2011) found both the APT and LPT significantly improved in 36.5-m and 60-m sprint times, pre-to post testing (p<0.05). No significant differences were observed between APT and LPT (-0.7 seconds (s) versus -0.67s in 36.5-m and -0.93s versus -0.8s in 60-m, respectively). Significant differences were found between the APT-group and control-group in 36.5-m and 60-m sprint times (p<0.05).

An appropriate APT prescription can produce similar improvements in sprint times and running velocity. Both APT and LPT have produced similar performances in 10-, 36.5-, 40-, and 60-m sprint performances.

6. Proprioception

Balance is a vital fitness component particularly dynamic balance, joint awareness, and overall proprioception. They are necessary for optimal and safe training and sport performance (Arazi & Asadi, 2011).

Jones (2008) compared the effects of an aquatic and land-based plyometric training (PT) programme on static balance in female athletes. Static balance was tested by means of the timed stork stand test measured before and after the six-week intervention. No significant differences were found between the groups in the stork stand test (left leg: p=0.63; right leg: p=0.4). Land-based plyometric (LPT) group improved balance duration more than the aquatic-based (APT) group, but not significantly. Test selection was the biggest limitation of this study. A stork stand test is a static test that assesses static balance. Participants performed dynamic movements during the plyometric intervention, requiring constant balance throughout. Static balance is uncharacteristically a dependant variable not associated with plyometric training. A dynamic balance test would have shown more accurately how the experimental groups improved in proprioception considering the dynamic nature of PT (Jones, 2008).

Arazi and Asadi (2011) studied the effect of eight-week APT and LPT upon strength, speed and dynamic balance in adolescent basketball players. Participants performed a '5-m-timed-up-and-go-test' as a measure of dynamic balance, pre-test and post-test. The 5-m-timed-up-and-go-test was a timed test to rise from a chair, walk a set distance of five metres, turn around, walk back and sit down. Results showed that both APT and LPT showed improvements in the dynamic balance test. However, LPT-group showed non significant (p>0.05) but greater improvement than the APT-group (-1.87s versus -1.06s, respectively). It was therefore shown that PT can improve balance performances, in accordance with the studies of Witzke and Snow (2000) and Myer *et al.* (2006).

Arazi and Asadi (2011) concluded that APT would not show better dynamic balance performances than LPT because an aquatic environment reduces weight-bearing stress on the legs, reducing impact on the joints and, consequently insufficiently stimulating the proprioceptors.

7. Delayed-onset muscle soreness and pain sensitivity

Damage to muscle fibers or possible damage to musculotendinus junctions could be the sources of the higher perception of muscle soreness that was found after the performance of plyometric exercises. Jamurtas *et al.* (2000) speculated that the eccentric phase of the plyometric exercises produces more microscopic damage to the muscle fibers, thus producing a higher degree of muscle soreness compared with concentric exercises. This damage to muscle fibers can indicate, by changes in blood plasma markers of creatine kinase (CK) and lactate dehydrogenase (LDH) (Jamurtas *et al.,* 2000; Shiran *et al.*, 2008). Subjective feelings and reported tenderness felt in myotendinus areas suggests that damage to connective tissues could be attributed to delayed onset of muscle soreness (DOMS) (Jamurtas *et al.,* 2000).

Miller *et al.* (2002) proposed that performing PT in an aquatic environment will decrease the amount of force applied due to the buoyancy, thus potentially reducing the level of muscle soreness experienced. Robinson *et al.* (2004) successfully showed that the APT programme provided comparable training gains to a LPT programme, with less reported muscle soreness and possibly muscle injury. Effects of LPT versus APT aquatic plyometric training on muscle soreness were examined by evaluating muscle soreness of the rectus femoris, biceps femoris, and gastrocnemius muscles. Muscle soreness was assessed through a self-report muscle soreness ordinal scale ranging from 1 (no soreness) to 10 (very, very sore). Pain sensitivity (palpation) was measured with an algometer, a pressure gauge at baseline (first week of training), and when training intensity was increased at week three and week six at 0-, 48-, and 96-hours post–training bout.

Results showed a significantly higher perception of muscle soreness in the LPT when compared to the APT-group for all muscle sites (rectus femoris, biceps femoris, and gastrocnemius) at 48-hours and 96-hours after a training bout ($p \leq 0.001$). The difference was found during the first week of training and also during the two periods when training intensity was increased. For pain sensitivity, a significant increase in pain sensitivity perception was found for all muscle sites in the LPT-group from 0-hours to 48-hours at baseline, each time the training intensity was increased ($p \leq 0.001$). No significant differences were found in pain sensitivity between the two groups. Therefore APT provided the same performance enhancement benefits as land plyometrics with significantly less muscle soreness.

Shiran *et al.* (2008) also compared the effect of a five week APT and LPT intervention on physical performance and muscular enzymes in professional male wrestlers. Markers of muscle damage being plasma CK and serum LDH were recorded. Post-testing analysis revealed that all groups (APT, LPT, and control) increased CK levels; LPT CK levels increased significantly pre-to-post-test (80.37%; $p=0.02$), and was significantly different from the control-group ($p=0.02$). No differences were found between the APT- and LPT-groups ($p>0.05$). Serum levels of LDH did not increase for any of the groups but decreased in a non-significant manner. APT and LPT had no effect upon on the level of this enzyme; a marker of muscular injury. This decrease in LDH was due to unknown factors. Therefore, LPT produced a significant increase in CK possibly due to muscle soreness (Jamurtas *et al.,* 2000; Shiran *et al.*, 2008). APT produced similar performances to LPT with reduced muscle soreness, confirming the previous hypothesis of Miller *et al.* (2002).

In retrospect to the previous proposition of Miller *et al.* (2002), found no differences or improvements in muscle soreness after an eight-week APT versus LPT study in untrained university students. No significant differences were found in the 24-, 48-, and 72-hour soreness scores for participants in both the aquatic and land training groups (pre-training and post-training). The lack of differences between the experimental groups and control in muscle soreness were attributed to the untrained male and female who were inexperienced in PT. Furthermore, some of the study participants also begun new cardiovascular and weight training programs during the study which would of affected perceived muscle soreness scores during the study.

Buoyancy will decrease the amount of force applied to the leg musculature; negating the eccentric loading, thus potentially reducing the level of muscle soreness experienced during APT. In comparative APT and LPT studies upon untrained females, an APT programme provided comparable training gains to a LPT programme, with less reported muscle soreness and pain sensitivity. In elite male wrestlers, LPT produced a significant increase than APT in creatine kinase possibly due to increased muscle soreness. Further validating, that APT produced similar performances to LPT with reduced muscle soreness.

8. Comparative kinetics of aquatic-based and land-based plyometric training

The literature quantifying aquatic-based plyometric training (APT) kinetics is very limited, with only three studies to date (Triplett *et al.*, 2009 ; Colado *et al.*, 2010; Donoghue *et al.*, 2011) having compared jump propulsion and landing kinetics of APT and land-based plyometric training (LPT). These comparative studies focused upon peak concentric force, rate of force development (RFD), impact force (ground reaction forces [GRF]), time of the jumps, and the quantification of these variables for different plyometric training (PT) exercises.

Donoghue *et al.* (2011) studied the landing kinetics of lower limb plyometric exercises performed on land and in water. Plyometric exercises of varying levels intensity were tested: ankle hops (low), countermovement jump (CMJ) (low), tuck jumps (medium), a single-leg vertical jump (VJ) (high), and a drop jump (DJ) (high) from 30-centimetres (cm). Land and underwater force plates measured peak impact force, impulse, concentric RFD, and time to reach peak force for the landing phase of each jump tested. The participant-group consisted of 18-elite male swimmers (age: 23 ± 1.9 years). In the aquatic testing, jumps were performed at a depth of three centimetres below the xiphoid process when participants were standing upright (approximately 1.3-metres [m]). Results showed significant reductions in performance variables in the water compared with land for the majority of exercises in this study ($p<0.05$).

Peak impact forces (GRF) were significantly reduced (33%-54%) in water for all exercises ($p<0.05$). This was consistent with previous research that had found reductions of 45% and 59% in peak GRF during single- and double-leg squat jumps in water at the level of the xiphoid process (Triplett *et al.*, 2009; Colado *et al.,* 2010). GRF of plyometric exercises performed on land varied from 4.32 to 6.77 body weight (BW), whereas aquatic values varied from 1.99 to 4.05 BW. GRF on each leg was 2.50 to 4.32 BW on land and 1.24 to 2.02 BW in water. Impulse was significantly reduced (19%-54%) in water for all exercises ($p<0.05$), possibly due to the effects of buoyancy. Effect sizes were large or very large for all exercises except CMJ and DJ, which had moderate effect sizes. RFD was significantly reduced (33%-62%) in water for ankle hops, tuck jumps, and the CMJ. Effect sizes were large for the CMJ and moderate for ankle hops and tuck jumps. DJ showed a reduction in RFD, but not significantly. Single-leg VJ showed an improvement in RFD (26%) over land jumps, as previously found by Triplett *et al.* (2009). The time needed to reach impact force (GRF) occurred significantly later in tuck jumps and CMJ but earlier in DJ and single-leg VJ in water. Effect sizes were moderate for tuck jumps and the CMJ and large for the single-leg VJ. Donoghue *et al.* (2011: 308) summarised: "that clear reductions in peak GRF, impulse, and RFD in most of the aquatic plyometric exercises, the level of reduction showed substantial individual variation, possibly attributable to water depth, participant height, body composition and landing techniques".

Two other kinetics studies compared the concentric and impact forces during aquatic and land-based plyometric jumps. Colado *et al.,* (2010) compared the kinetic parameters of *two-leg squat jumps* carried out in three different conditions: on dry land, in water, and in water using devices that increase drag force. Triplett *et al.* (2009) compared the kinetic and the kinematic differences in *single-leg static jumps* on dry land, or in an aquatic environment, with and without devices. In these two separate studies, Triplett *et al.* (2009) and Colado *et al.* (2010) utilized the same participant-group of 12 elite junior female, handball players (age: 16.0 ± 0.7 years). In both studies, test measurements were taken upon land and underwater force plates. In the aquatic testing, jumps were performed in a standing immersion depth of the xiphoid process (approximately 1.3-m). The efficacy of additional devices to increase drag forces in these above mentioned studies is beyond the scope of this theoretical review, and therefore not included in the comparative analysis.

Colado *et al.* (2010) showed that in performing *two-leg squat jumps*: peak concentric force was significantly greater (26%) when the jumps were performed in water than on land (p=0.002). For concentric RFD, aquatic jumps were higher, although not significantly different from the land jumps. Peak impact force was significantly lower for the aquatic jumps than for land jumps (p<0.001). Impact RFD between land and aquatic jumps were found (p<0.001), with the values for aquatic jumps being statistically lower than the land jumps. The time to reach maximum concentric force was higher for aquatic jumps than for land jumps (p=0.015).

Triplett *et al.* (2009) showed that in performing *single-leg static jumps*, peak concentric force was significantly greater (44.9%) when the jumps were performed in water than on land (p<0.05). For concentric RFD, was significantly higher (30.4%) for the aquatic jumps than for the land jumps (p<0.05). Peak impact force was significantly lower for the aquatic jumps than for land jumps (p<0.05). Impact RFD for aquatic jumps were significantly lower (p<0.05) than the values for land jumps. Landing impact force decreased by 44.8% when jumping in water. Mean impact force of the participants was 2.38 body mass on dry land, whereas it was 1.31 body mass in the aquatic medium. There was a shorter total jump time (p<0.05) for the aquatic jumps, whereas the time required to reach peak concentric force was not significantly different from the land jumps, despite the greater resistance to movement in the aquatic medium.

Triplett *et al.* (2009), Colado *et al*. (2010) and Donoghue *et al.* (2011) showed significant reductions in impact force that could be attributed to the buoyancy force experienced by the body. These lower rates of impact RFD suggest reductions in the stress to the musculoskeletal system (Irmischer *et al.,* 2004). Impact force and impact force development rate are two parameters that indirectly indicate the stress level that the musculoskeletal system receives (Irmischer *et al.,* 2004). Therefore, aquatic jumps could generate less joint stress because impact force RFD can be 80% slower than on dry land (Triplett *et al*., 2009).

Jump intensity can be indirectly expressed through peak concentric force and concentric RFD (Jensen & Ebben, 2007). Triplett *et al.* (2009) and Colado *et al*. (2010) showed that performing jumps in an aquatic medium was a way of increasing the intensity of the jumps, improving peak concentric force and concentric RFD. This was most likely due to the increased resistance to the movements, created by the drag force (Colado, Tella & Llop, 2006) which usually occurs in any movement in the aquatic medium and especially with quick movements such as jumps. They have a positive relationship with the speed of movement, especially when performed at maximal efforts (Colado, Tella & Triplett, 2008; Colado, Tella, & Triplett, 2009). Because an increase in the RFD could contribute to enhanced performance in jumping activities (Kyröläinen *et al.,* 2005), APT could serve as an alternate training method for improving performance. A high concentric RFD combined with a short overall movement time is desirable in a team sport, for example, because this could result in more efficient movements (Triplett *et al*., 2009).

Water provides an ideal environment for carrying out jumps, as the variables associated with the exercise intensity are boosted, while those related to the impact force are reduced, which could be less harmful (Triplett *et al*., 2009; Colado *et al*., 2010). Closed chain kinetic exercises such as aquatic jump exercises result in greater force production and RFD in the same amount of time with less impact and thus offer a viable alternative to traditional land-based jump exercises (Colado *et al*., 2010). The benefit of APT was that it is an exercise mode that could be performed without compromising speed of movement whilst reducing the potential for joint injury (Triplett *et al.,* 2009), because of the resistive and buoyant properties of water (Miller *et al.,* 2007). APT programmes could be used as an alternative or as a complement to traditional LPT programmes, with similar enhancement in performance outcomes and a reduced potential for muscle soreness and possibly muscle injury (Robinson *et al*., 2004). In the sporting performance field, aquatic jumps could be used to improve overall physical capacity in periods when the workload is more important than focused training (Colado *et al.*, 2010).

Future studies are needed to analyze the kinetics and the kinematics of consecutive aquatic jumps as well as jumps with an eccentric phase, which are more like jumps performed for sport training (Triplett *et al*., 2009). Repeated aquatic jumps could be used for developing rebound explosive muscle endurance with one or both legs, and appear to be considerably safer than LPT (Siff, 2003).

9. Summary

Plyometric programmes conducted in water appear to have similar positive effects on performance variables when compared with LPT. Buoyancy of water reduces the mass of the participant, for faster total jump times and theoretical reduced ground contact time. Fluid resistance produces a greater concentric contraction of the SSC. APT has produced better leg power performances than LPT although not significantly different for power tests of the Maragria-Kalamen and peak power derived from VJ. APT and LPT have also shown similar results in VJ performance and peak leg power derived from the running anaerobic running test (RAST). Optimal pool depth for APT is still a fundamental factor for increasing muscle power using APT. APT can improve leg strength by the imposed training effect of additional muscle activation to overcome the increased resistance of movement through the water. Both APT and LPT have produced similar leg strength enhancements for concentric and eccentric knee extensor/flexors, although APT has shown larger improvements than LPT in peak ankle dorsiflexion torque. APT may be an effective alternative approach to enhancing agility: an appropriate APT prescription can produce similar improvements in 10-, 36.5-, 40-, and 60-m sprint performances. APT would not show better dynamic balance performances than LPT due to insufficient proprioception stimulation. APT does provide comparable training gains to LPT, with less reported muscle soreness and pain sensitivity. Finally, there has not been any reported research establishing the effect of an APT intervention or comparatively with LPT upon horizontal explosive performances.

G. Plyometric programme development and intervention

1. Introduction

Gambetta (2007) 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, 1998). 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). An effective PT programme must accomplish specific goals through the manipulation of these factors: mode, intensity, frequency, duration, recovery, and progression (Chu, 1998; Potash & Chu, 2008).

The only reported recommendations for implementing an aquatic plyometric programme were from Miller *et al.* (2001). 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 within water.

2. Age considerations

Although plyometrics have commonly been viewed as only appropriate for conditioning elite adult athletes, prepubescent, children and adolescents may also benefit from training with plyometric and plyometric-like exercises (Potash & Chu, 2008). Youth sports involve plyometric movements and training for these sports should also involve plyometric activities. Literature does not have long-term data looking at the effects of plyometric activities on human articular cartilage and long bone growth (Voight & Tippett, 2004). Research demonstrates that plyometric training (PT) results in power and strength gains in adolescent athletes (Myer *et al.*, 2006; Faigenbaum *et al.*, 2007), and that PT may in fact contribute to increased bone mineral content in young females (Witzke & Snow, 2000). An appropriately designed PT programme could better prepare young athletes for the demands of sport practice and competition by enhancing neuromuscular control and performance. As with adults, recovery between workouts must be adequate to prevent overtraining. Optimal amount of recovery should vary based on the intensity of the training programme and the participant's skills, abilities, and tolerance as well as on the same time of year (e.g. off-season, pre-season, or in-season) (Potash & Chu, 2008).

3. Mode

The modes of plyometric training (PT) are determined by the body region or major muscle group(s) involved in a specific code-of-sport. Sport-specific movement patterns and activities can involve both the upper and lower body. There are three types of modes of plyometric exercise:

Lower-body plyometrics

Lower body plyometrics are appropriate for virtually any athlete and any sport. Lower body PT allows the participant the ability to produce more force in a shorter amount of time, thereby allowing a higher jump. Dependant upon the requirements of the sport, a participant must be able to produce quick and/ or repeated powerful movements and changes in direction in all planes: horizontal, vertical, and lateral (Potash & Chu, 2008). Table 2.1 describes these different types of lower body drills.

Upper-body plyometrics

Rapid, powerful upper body movements are required for several sports and activities (Potash & Chu, 2008). Plyometric drills for the upper body are not used as extensively as the lower body, but they are nevertheless essential to athletes who require upper body power (Wilk *et al.,* 1993; Newton *et al.,* 1997). Stretch shortening exercises for the throwing athlete provide advanced strengthening exercises that are more aggressive and at higher exercise levels (higher demands on shoulder musculature) than those provided by a simple isotonic dumbbell exercise programme. These programmes can only be utilized once the participant has performed a strengthening programme for an extended period of time (Wilk *et al.,* 1993). Plyometrics for the upper body include, amongst other, medicine ball throws, catches, and several types of push-ups (Potash & Chu, 2008).

Trunk plyometrics

The trunk plays an equally important role in athletic movements. In addition to controlling posture, the trunk serves as the vital link for the transference of forces from the lower body to the upper body. This forces transfer is a common occurrence and necessary in throwing and racquet sports (Voight *et al.,* 1995). Exercises for the trunk can also be performed “plyometrically”, as it is difficult to perform true plyometric drills to utilize the stretch shortening cycle directly target the trunk musculature (Potash & Chu, 2008). Use of medicine balls has offered new dimensions to trunk plyometrics, for explosive power development in both flexion and rotation, safely and effectively (Boyle, 2004).

Table 2.1 The different types of lower-body plyometric drills (Potash & Chu, 2008)

Type of Jump	Rationale
Jumps in Place	These drills involve jumping and landing in the same spot. Jumps in place emphasize the vertical component of jumping. They are usually performed repeatedly without rest between jumps
Standing Jumps	Standing jumps emphasize either the horizontal or vertical components. These drills are at maximal effort with sufficient recovery between repetitions.
Multiple hops and jumps	These drills involve repeated movements and may be viewed as a combination of jumps in place and standing jumps.
Bounds	These drills use exaggerated movements with greater horizontal speed than other drills.
Box Drills	By using a box these drills increase the intensity of multiple hops and jumps. The box may be used to be jumped on to, or jumped off from.
Depth Jumps	Using the athlete's gravity, depth jumps increase exercise intensity. The athlete assumes a position on a box, steps off, lands, and immediately jumps vertically, horizontally, or to another box.

4. Intensity, frequency, and duration

Intensity is the effort involved performing a given task (Chu, 1998), and also the amount of stress placed on involved muscles, connective tissues, and joints and is primarily controlled by the type of plyometric exercise performed (Potash & Chu, 2008). Plyometrics range from simple tasks to highly complex and stressful exercises (Chu, 1998). Low intensity exercises that are long response in nature (more than 10-repetitions), place high demands on the anaerobic glycolysis energy system. High intensity exercises are short response in nature (less than 10-repetitions), place high demands on the ATP-CP energy system (Piper & Erdmann, 1998; Radcliffe &

Farentinos, 1999). Intensity of plyometric exercises can be increased by adding light weights, by raising the platform height for depth jumps, or simply aiming to cover a further distance in longitudinal jumps, and also progressing to single-leg activities (Chu, 1998; Chmielewski *et al.,* 2006). Horizontal body movements are less stressful than vertical movements, depending upon the participant's technical proficiency and body mass. The heavier the participant, the greater the training demand placed on the participant (Voight & Tippett, 2004). Intensity of upper extremity plyometric exercises can be increased by using heavier resistance, moving the body or ball through greater distances, using higher speeds, and finally progressing from double-arm to single-arm activities (Chmielewski *et al.,* 2006). In general, as intensity increases, volume should decrease. Consideration must be given to choosing the right drills for the sport during a specific training cycle (e.g., off-season, pre-season, or in-season) (Potash & Chu, 2008). When performing high intensity exercises, proper technique is the primary objective. Volume-based parameters must be modified if technique deteriorates (Piper & Erdmann, 1998).

Plyometric volume is the total work performed during a single training session, expressed as the number of repetitions and sets (Chu, 1998; Potash & Chu, 2008). Lower body plyometric volume is normally given as the number of foot contacts (each time a foot, or feet together, contact the surface) per workout, but can be expressed as distance covered with bounding (Chu, 1998). Recommended volume of foot contacts in any one-session will vary inversely with the intensity of the exercise (Voight & Tippett, 2004). In a review of plyometric literature, Coetzee (2007) summarised that plyometric volume can amount to between one and 10 exercises, and range between two and 10 sets. Suggested lower body plyometric volumes vary for participants of different levels of experience. Suggested plyometric volume guidelines are indicated by foot contacts per session: beginners (no experience) 80- to 100-; intermediate participants (some experience) 100- to 120- and advanced participants (considerable experience) 120- to 140-foot contacts (Coetzee, 2007; Potash & Chu, 2008). Upper body plyometric volumes can be expressed as the number of throws or catches per training session (Potash & Chu, 2008).

Frequency is the number of plyometric training sessions per week and typically ranges between two to four times a week (Coetzee, 2007), depending on the sport and time of the year (Potash & Chu, 2008). Duration of the PT programmes vary between three and 12-weeks (Coetzee, 2007). Generally, 48- to 72-hours of rest is recommended for recovery between plyometric training sessions (Chu, 1998). Intensity plays a major role in determining the frequency of training (Voight & Tippett, 2004). If an adequate recovery period does not occur, muscle fatigue will result in the participant being unable to respond optimally to the exercise stimuli (ground contact, distance, height) with maximal quality efforts (Chu, 1998; Voight & Tippett, 2004).

Recovery is defined as the rest time between repetitions, sets, or sessions of plyometric exercise (Chmielewski *et al.,* 2006). Recovery is the key variable determining whether plyometrics will develop power or muscular endurance. Recovery between exercises will vary from one athlete to another depending on skill and fitness level (Piper & Erdmann, 1998). Work-rest ratio for a plyometric exercise depends on the intensity of the exercise and the energy system used. In general, the higher the intensity, the longer the recovery time required if the goal is to stress the ATP-PC energy system. If muscle endurance is a goal, short rest periods can be employed (Piper & Erdmann, 1998). For power training, a longer recovery of 45- to 60-seconds between sets of multiple of events, allow for maximum recovery between efforts (Chu, 1998). A work-rest ratio of 1:5 to 1:10 is recommended to ensure enough rest for proper execution of the exercise (Chu, 1998; Coetzee, 2007). Shorter recovery periods of 10-15 seconds between sets do not allow for maximum recovery of muscular endurance, since PT is an anaerobic activity (Chu, 1998). For example, when performing a maximum-effort drop vertical jump, athletes may rest for 5- to 10-seconds in between repetitions. In rehabilitation settings, where low-intensity plyometric exercises are often used, smaller work-rest ratios (e.g., 1:1 or 1:2) have been used (Voight & Tippett, 2004). Allowing proper recovery time ensures that sufficient muscle force is available for the optimal performance of plyometric exercise (Chmielewski *et al.,* 2006).

Potash and Chu (2008) advised that plyometrics is a form of resistance training and therefore must follow the principles of progressive overload, and must follow the systematic increase in training frequency, volume and intensity in various combinations. The sport and training phase will determine the training schedule and method of progressive overload. Generally, as intensity increases, volume decreases. The PT programme's intensity should progress from low to moderate volumes of low-intensity, to low to moderate volumes of moderate intensity, to low to moderate volumes of moderate to high intensity.

As in any programme, plyometric exercise should be preceded with a general warm-up, dynamic stretching, and a specific warm-up. The specific warm-up should consist of low-intensity, dynamic movements (Potash & Chu, 2008).Table 2.2 describes these different types of lower body plyometric warm-up drills.

Table2.2 Lower-body plyometric warm-up drills (Potash & Chu, 2008)

Type of Jump	**Explanation**
Marching	Mimics running movements Improves proper lower body movements for running.
Jogging	Prepares for impact and high-intensity plyometric drills. E.g. toe jogging, straight-leg jogging, butt-kicking.
Skipping	Skipping is an exaggerated form of reciprocal upper and lower extremity movements.
Footwork	Footwork drills that target change of direction.
Lunging	This drill is based upon the forward lunge, and may also be multi-directional.

5. Training consideration for aquatic-based plyometric training

According to Miller *et al.* (2001) several recommendations must be addressed before beginning any aquatic plyometric programme.

It is recommended that all participants wore a bathing suit that conformed to the body in order to minimize drag and facilitate a quick rebound from a stretched position. Wearing oversized shorts or T-shirts creates more resistance and slows the movement of jumping or bounding drills, thus reducing preload of the muscle. Participants should be encouraged to wear aquatic shoes with non-slip soles. Aquatic shoes help to ensure proper foot contact, increasing the efficiency of the plyometric drill and decreasing the likelihood of slipping that may result in injury. It is recommended that athletes receive proper instruction on land regarding the plyometric drills before entering the water. It is very difficult to demonstrate jumping over or around obstacles that are submerged 60- to 90-cm. A dry-run performance before the athletes enter the water can be extremely beneficial for successful completion of the plyometric drills. Finally, when performing group work in succession (e.g., single-leg bounding or multiple-cone hops), athletes should maintain adequate distance between each other to avoid creating a current. A strong current will enable following athletes to be pulled across the water with minimal physical exertion, thereby decreasing the training effect. The water level should be kept around waist height for all athletes. Water too deep creates an increase in resistance while performing the plyometric movement(s) and may affect the participant's ability to maintain proper body control and coordination. Water too deep (above the waist) may also decrease the stretch-shortening cycle reaction time. Deep water jumping can cause increases in arm swing drag when propelling a submerged arm in the water. In addition, there is a possibility that the participants will be totally submerged when performing jumping activities in water too deep. Avoid activities greater than 180º rotation in the water. The water resistance slows the rotating speed, and athletes have difficulty performing these activities.

H. Rugby union football

1. Introduction

Rugby union requires many different components of fitness such as aerobic and anaerobic fitness, speed, agility, power, flexibility, and sport-specific skills (Duthie, Pyne & Hooper, 2003). Rugby is a contact sport in which players are subjected to severe internal and external forces. In order to withstand these forces and maintain repeated work efforts to be sustained for a 60-80 minutes game (match duration dependent on age-category in adolescent rugby), players have to be well-conditioned (Marshall, 2005).

2. Physical attributes and positional differences in rugby union

Rugby union players require a diverse range of physical attributes. Distinct physique will naturally orientate a player towards a particular position over others. This makes rugby an atypical sport when compared with a number of other team sports, for example, where homogeneity of physique and physical performance attributes are more common (Quarrie *et al.* 1996). Backs tend to be leaner, shorter, faster, more aerobically fit relative to body mass and more explosive than their forward counterparts. Forwards produce better absolute results when measured for strength and aerobic endurance, but when expressed relative to body mass (kg) the results favour the backs (Duthie *et al.*, 2003).

Forwards are typically heavier, taller, and have a greater proportion of body fat than backs. These characteristics are changing in the modern game, with forwards developing greater total mass and higher muscularity. The forwards demonstrate superior absolute aerobic and anaerobic power, and muscular strength. Results favour the backs when body mass is taken into account (Duthie *et al.*, 2003). Quarrie *et al.* (1996) and Nicholas (1997) outlined the positional group's broad physical requirements, skills and tasks. The front row position demands strength and power in the scrums. The second rowers have a larger body mass, optimal strength is essential, and added power is a distinct advantage. The loose forwards require optimal strength and power, as their position requires them to defend as well as retain and turn over possession. Strength is essential for the halfback as he is constantly in among his own and opposition forwards in physical situations and must have good acceleration, thus the development of speed strength is of major importance. The inside backs require speed strength and power due to the high intensity of contact with the opposition in defence and attack, whereas outside backs require speed strength in attacking situations and for cover defending.

2.1 Speed

Speed and acceleration are essential requirements, as players are often required to accelerate to make a position nearby or sprint over an extended distance. Backs achieve similar sprint times to track sprinters over distances of 15- and 35- metres (m) (Dowson, Nevill & Lakomy*,* 1998). With the assistance of time motion analyses using global positioning satellite tracking devices, Hartwig, Naughton and Searl (2011) found in adolescent rugby union players (aged between 14- and 18-years) mean sprint distance during a match was 13.5 ± 5-m. More specifically, the mean sprint distances for forwards was 12.3 ± 5.1-m, and backs were 13.6 ± 4.8-m during match conditions. While running at high or maximal speeds, players usually cover distances ranging from seven to 47-m (Hartwig *et al.,* 2011). Running often involves changing direction, acting as a support player, making or breaking a tackle, or hitting a ruck. This also includes backward and lateral movements, such as retreating to avoid the offside line, shadowing an attacker, or evading opponents during a line-out (Luger & Pook, 2004).

2.2 Agility

Rugby is a multidirectional sport, where players have to generate speed from varying positions and change directions quickly without decreasing speed (Luger & Pook, 2004). Rugby relies heavily on acceleration: the capacity to rapidly reach a high speed from various starting positions, supported by agility. Agility is seen as the ability to change direction and decelerate quickly (Baker & Nance, 1999; Luger & Pook, 2004). Agility is required for close quarter reactive movements involved in evading tacklers and being in the optimal position to make a tackle when defending (Gamble, 2004).

2.3 Muscular strength and power

Rugby players need a higher degree of power in the execution of tackles, in acceleration from a static position and during rucking as well as mauling and scrumming when forceful play can take place (Duthie *et al.,* 2003; Marshall, 2005). Line-out jumping, breaking through tackles and fast as well as effective changes in running direction (agility) when attacking will also require players to develop their muscle output optimally (Lugar & Pook, 2004). Maximal strength and explosive power are major programme goals for rugby union (Gamble, 2004). Muscle strength is required during the contact situations in rugby. According to Duthie *et al.* (2003) forwards should possess greater strength than backs, and backs should possess more speed than forwards. Upper body strength has been shown to be important in all playing positions, with the forwards tending to have greater upper-body strength, and the backs greater upper-body power (Meir *et al.,* 2001).

In a review of rugby union physiology, Duthie *et al.* (2003) mentioned that rugby demands a high anaerobic capacity during sustained and repeated intense efforts. Work periods in the intermittent team game activity are primarily anaerobic in nature, although the aerobic system is utilised during rest periods to replenish energy stores. During cycle ergometry and treadmill sprint testing, forwards were able to produce higher absolute peak and mean power outputs across a range (7-40 seconds) compared with backs. In a typical rugby match, 95% of activities last less than 30-seconds, and rest periods are generally greater than the preceding work effort. Players who have the capabilities to produce high anaerobic power outputs also tend to have the greatest fatigue of moderate (30-seconds) duration.

Based upon qualitative assessment of the physical work involved in rugby, the predominant biomechanical action is the simultaneous triple extension of hips, knees, and ankles, often transmitting force through the shoulders as the point of contact during collisions with other players. Triple extension characterizes the high-force activities involved in contesting and retaining possession in open play and the high-power (high force/fast movement speed) dynamic actions associated with jumping, running and tackling (Gamble, 2004). Triple extension also occurs during the acceleration phase of sprinting and help players to develop the rapid force required for initiating movement and changing direction (Luger & Pook, 2004). Heavy load strength training and explosive power drills, particularly explosive lifting, medicine ball and plyometric drills, enhance strength and power for this triple-extension movement (Gamble, 2004; Luger & Pook, 2004). Players with high levels of strength and explosive power are also more likely to have high levels of speed and agility (Luger & Pook, 2004).

CHAPTER THREE

METHODOLOGY

A. Introduction

In this chapter, the methods of research will be discussed. The research design of the study and the utilized participant population will be explained. Finally the testing protocol implemented to substantiate the aims, objectives, and research questions will be explained

B. Study design

In this experimental outcome study, amateur high school rugby union players completed a series of tests before and after a plyometric exercise intervention of 14-plyometric training (PT) sessions, on land and in waist-deep water. The intervention was performed during concurrent summer sport as a pre-season component for rugby union. The pre-test battery was performed a week prior to the first week of the seven-week intervention, and post-testing was completed a week after the cessation of the seven-week intervention study.

C. Participants

A group of 52-male rugby union players, between the ages of 15- and 19-years, from a single high school in the Cape Town southern suburbs, volunteered to participate. The research population included athletes who were engaged in power-related high school sports. An appointment was made with the volunteer rugby players and the protocol was explained. The players had the opportunity to ask questions about the study and test procedures. Participants were given a study information form (Appendix E), a parent or guardian informed consent form (Appendix D), and a participant health screening form (Appendix G) for the parents or guardians to complete. Participants were then asked to read and sign an informed consent form (Appendix F), after parental consent was given to participate in the study.

Permission was granted by the Western Cape Education Department (WCED) and the headmaster of the South African College School to use the high school pupils as participants for research purposes (Appendix A). Upon approval from the Western Cape Education Department (Reference number: 20090710-0070) (Appendix B), ethical clearance was granted by the Stellenbosch University Ethical Subcommittee A (Reference number: 220/ 2009) (Appendix C).

All the rugby players had to meet the following inclusion and exclusion criteria:

1. Inclusion criteria

a) Adolescent male volunteers between the ages of 15- to 19- years
b) Apparently healthy according to the American College of Sports Medicine's (ACSM) guidelines and without musculo-skeletal, metabolic, cardiovascular/ respiratory, haemotological or endocrine disorders
c) All participants had to be participating in a summer school sport of cricket, athletics, swimming or water polo
d) All participants had to maintain all sporting commitments during the study, and adhere to making at least 12- of the 14-study training sessions over the seven week intervention period
e) All participants had to be able to swim and be confident in an aquatic environment

2. Exclusion criteria

a) Any participant who has had a musculoskeletal injury in the last six-months or a leg length discrepancy (≥3cm)

The 52- volunteer rugby players were randomly divided into three groups: 18 in the aquatic PT-group, 17 in the land PT-group, and 17- rugby players forming the control-group. The control-group had to continue with normal summer school sport during the study period, and was allowed to maintain pre-season gymnasium training. They were not permitted to engage in any type of plyometric or explosive-power-based athletic-type strength training lifts. The incentive for the players to complete the programme was that they would receive all test results *pro bono.*

D. Experimental overview and procedure

All participants completed the pre-testing at the first contact session a week prior to beginning the intervention. All kinanthropometric measurements and field-based tests were completed by both the experimental groups and control-group.

The kinanthropometric measurements included standing height and body mass. One laboratory test namely was used to measure lower body leg power. Field-based testing consisted of further lower body power testing, agility, and sprint speed. The lower body power battery included repeated countermovement jumps, sergeant vertical jump test, and standing broad jump test. The agility test was an Illinois agility test. Sprint speed was measured over the distances of 10- and 40- metres.

After the intervention the players had to repeat all the tests. The testing was completed in the indoor gymnasium of South African College School. Sprint speed was performed upon a grass field to sport-specificity.

All tests (pre-and post-intervention) were done at approximately at the same time of the day, to limit the effect of circadian variations in the test results. Participants were instructed to sleep for at least eight hours sleep the night before scheduled testing. The participants were not allowed to take part in any strenuous physical activity within the 24-hours prior to the scheduled testing. The participants were instructed to follow their usual diets during the intervention.

Testing and prescribed exercises (plyometric training) were done at the South African College School, under the supervision of the researcher and qualified trainer. The researcher is a registered biokineticist and certified strength and conditioning specialist (CSCS) from the National Strength and Conditioning Association (NSCA), and was trained in all aspects of laboratory exercise testing.

E. Test and measurements

1. Kinanthropometry

Standing height: Standing height was measured with a stadiometer (SECA® 206, Hamburg, Germany) according to the method of Ellis *et al.* (2000). Standing height was utilized to determine the maximal distance between the ground and the participant's vertex. The stadiometer was placed in a perpendicular position to the floor, the participant stood erect and barefoot with heels (in contact of each other), buttocks, upper back and the rear of the head in contact with the vertical section of the stadiometer. The upper limbs were pendent and the head was held in the Frankfurt horizontal plane. Before the measurement was taken, the participant was instructed to inhale deeply and stretch upwards to the fullest extent, ensuring that the participant's heels did not rise and the stadiometer branch did make firm contact with the head. Stature was recorded to the nearest centimetre (cm).

Body mass: Body mass was reported using a flat, electronic scale (SECA® 813, Hamburg, Germany) according to the method of Ellis *et al.* (2000).. Participants were assessed wearing loose-fitting, short-sleeved shirts and shorts. They stood barefoot on the scale. Measurements were recorded to the nearest gram (g).

2. Repeated countermovement jumps

Body weight repeated countermovement jumps (CMJ) were used to evaluate functional capacity of the lower body using a Fitro-Dyne (Fitronic, Bratislava, Slovakia). A Fitrodyne is a relatively inexpensive, portable device that attaches to conventional resistance-training equipment and measures the speed of movement, from which muscle power is calculated. It is regarded as a reliable measure of concentric muscle power for jump squats (r=0.97) (Jennings *et al.*, 2005). The Fitrodyne was attached to a belt securely around the participant's waist. Participants were required to complete a single test of 20- continuous, repetitions of body weight vertical jumps at maximal effort. To avoid immeasurable work output, horizontal and lateral displacements had to be minimized, and the participant's hands were required to be kept on the hips throughout the jump (Bosco *et al.,* 1983). Prior to a single effort of repeated jumps, participants were to perform to two to three jumps to familiarize themselves with the repeated CMJ technique. Participants were asked to minimize the amount of time during ground contact/ amortization for each jump. For each completed repetition during the test, peak power was recorded in watts (w) and peak velocity was recorded in metres per second ($m.s^{-1}$). For statistical purposes, in respect of each set of peak power or peak velocity scores, an average, minimum, maximum, and anaerobic fatigue indexes were calculated.

The use of the above values for the Fitrodyne repeated CMJs were adapted from the running anaerobic sprint test (RAST). The RAST was originally adapted from the Wingate Anaerobic test (WAnT) to assess the anaerobic power and capacities for running sports; measuring the peak power, average power, and fatigue index variables. For the WAnT, participants are required to complete 30-seconds of supermaximal exercise on either an arm-crank or leg-cycle ergometry (Bar-O, 1987; Zajac, Jarzabek & Waskiewicz 1999). WAnT assumes that peak power output represents the energy-generating capacity of the high energy phosphates, while the average power reflects glycolytic capacity (Inbar & Bar-O, 1986).As a WAnT-derived test, the participants were required to complete 20-repeated jumps (without an arm swing) which were estimated to take 30-seconds, same as the peak test period of the WAnT cycle test (Ferreira, 2010).

RAST was first investigated by Zachargoiannis *et al.* (2004), who verified significant correlations between the RAST and the WAnT for peak and average power variables (r=0.82 and r=0.75 respectively). RAST could be used to measure the anaerobic capacity and power. Zagatto *et al.* (2009) also established that the RAST had a significant correlation with the WAnT: peak power r=0.46; mean power r=0.53; fatigue index r=0.63.

The repeated jumps test included an anaerobic fatigue index which established the percentage decline in power output during the test. Fatigue index represents the total capacity to produce ATP via the immediate and short-term energy systems. (McAradle *et al*., 2001). Fatigue index is also mentioned in literature as an anaerobic glycolytic capacity predictor (Bar-O, 1987). It measures the amount of fatigue from a single bout of exercise (Hoffman, Epstein, Einbinder & Weinstein, 2000). The lower the percentage of the fatigue index is, the better the condition of the participant, in terms of fatigue and recovery (Shiran *et al.,* 2008). The fatigue index was calculated, as ([peak power- minimum power/ peak power] x 100) (Zagatto *et al.,* 2009).

3. Sergeant vertical jump test

Lower body, vertical explosive power was measured by means of the Sergeant vertical jump test according to the method of Ellis *et al.* (2000). The vertical jump is regarded as a reliable (r=0.93) and an objective test (r=0.78) to determine the peak anaerobic power output of participants (Johnson & Nelson, 1979). Participants were instructed to stand with the dominant arm's shoulder and dominant leg's foot against the wall. The participants chalked their fingertips, elevated a straightened arm from the shoulder, and stretched closest to the board, leaving a mark at the height of full stretch, indicating the measured reach mark. From a stationary position to whatever countermovement depth was preferred; the participant took off from two feet with no preliminary steps or shuffling. Participants used an arm swing and jumped as high as possible, leaving a chalk mark on the measuring board with the inner hand. This distance was then recorded as maximum jump height. The difference between the reach and maximum jump height was then calculated and recorded to the nearest cm. The participants performed two trials with a 30s rest period between each trial. The better of the two trials were recorded for the purpose of data analysis.

4. Standing broad jump

Lower body, horizontal explosive power was measured by means of a standing broad jump (SBJ) according to the method of Logan, Fornasiero, Abernethy and Lynch (2000). The SBJ is regarded as a reliable (r=0.963) and an objective test (r=0.607) to determine the peak anaerobic power output of participants (Johnson & Nelson, 1979). The test emphasizes powerful knee and hip extension from a starting posture marked by deep knee flexion (Logan *et al.*, 2000). This starting posture is common in rugby union, indicative of pre-engaged scrumming and defensive body positions. The participant stood with feet comfortably apart, behind the line. Arm swing was allowed to increase the sport specificity of the test. Participants had to jump maximally and were allowed to perform a countermovement prior to take-off. The measured jump distance was recorded from the takeoff line to the back of the heels closest to the takeoff line (Harman & Garhammer, 2008) to the nearest cm. Participants were allowed to perform two trials, with 30s rest period between each trial. The better of the two trials was recorded for the purpose of data analysis.

5. Speed

Acceleration and speed was measured by means of a 10- and 40-m sprint. The test-retest reliability for the 10- and 40-m sprint tests were reported as 0.88, and 0.92 respectively (Gabbett, 2002). It was suggested that testing of rugby players should include measurements of acceleration and maximal velocity over an extended distance (~40m) with intervals of 10-m (acceleration) and 30-40-m (maximal velocity split) (Duthie *et al.,* 2003). Times were recorded using dual electronic timing gates (Swift speed light sport-timing systems, New South Wales, Australia) positioned at 10- and 40-m upon a section of a rugby field, cross-wind from a predetermined starting point. On the command, "Go", participants sprinted from a standing start. They were instructed to run as quickly as possible along the 40-m distance. Testing was performed upon a grass surface to maintain specificity of the same playing surface as rugby union. Speed was measured to the nearest 0.01 second, with the fastest value obtained from two trials used as the speed score.

6. Illinois agility test

Agility was measured by means of an Illinois agility run according to the method of Gabbett *et al.* (2002). The Illinois agility test is regarded as a reliable measure of agility (r=0.86) (Gabbett, 2002).The purpose of the Illinois agility test is to test the ability of the player to change direction and control their center of gravity. It also indicates body awareness, body control, and footwork. A deficiency here could indicate a lack of functional core strength and leg strength (Foran, 2001). From a standing start position near the first bottom-corner (Figure. 3.1), and on the command, "Go", participants sprinted 10- m, turned, and returned to the starting line. After returning to the starting line, they swerved in and out of four markers, completing two 10-m sprints to finish the agility course. A measurement was recorded from both the left and right hand side of the Illinois agility test. Times were recorded using dual beam electronic timing gates (Swift speed light sport timing systems, New South Wales, Australia). The better of two trials was recorded to the nearest 0.01 second (s).

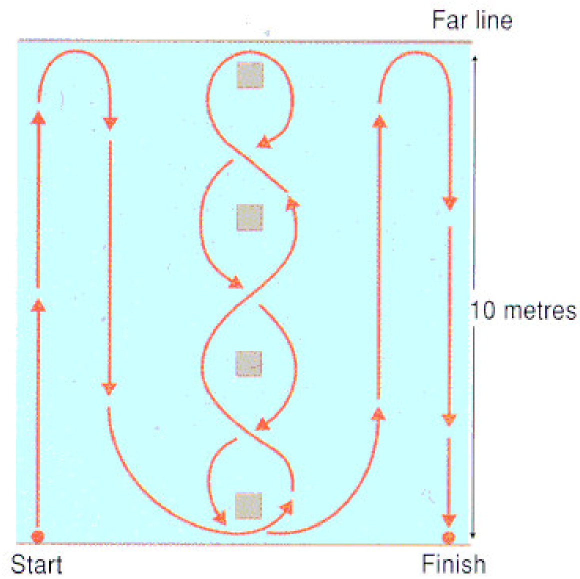


Figure 3.1: The Illinois agility test (Foran, 2001).

F. Intervention

The PT programme (Appendix H) consisted of 14-training sessions, 2-training sessions per week, over seven-weeks. Recommendations from Piper and Erdmann (1998); Miller *et al.,* (2001; 2007); Martel *et al*., (2005); Potash and Chu (2008) were used in the plyometric intervention prescription and periodization, over the seven-week period (See Appendix I for photos from the intervention). Participants had to complete at least 12 of the 14 sessions without missing more than two sessions consecutively. Participants rested 48 hours between sessions, and worked with a 1: 5 – 1: 10 work to rest ratio.

The intervention consisted of three parts per training session: four rugby-specific plyometric (core) exercises, continuous, maximal bodyweight squat jumps and depth jumps of 40-cm. The exercise intensity progressed over the 14-sessions. Training volume was determined by increasing the amount of repetitions per week of completing the given plyometric exercise. Rugby-specific plyometric exercises were each completed over a distance of 20.5-m, and were divided into three levels of difficulty (low, medium, hard) to define intensity. The second part of the intervention was continuous, maximal CMJ for duration of time, ranging from 10-to-30s, for three to four repetitions. The duration of CMJ increased biweekly for progression. The third component was 40-cm depth jumps. Boxes used during the box drills and depths jumps were made of galvanized steel, with a rubber landing area and rubber stoppers for feet to prevent any slipping upon the ceramic tile pool surfaces. The aquatic plyometric group completed the plyometric intervention in a 113-cm deep pool (Figure 3.2). The land-based plyometric group completed the plyometric intervention upon grass fields (Figure 3.3a and Figure 3.3 b).

Figure 3.2: The aquatic-based plyometric intervention group

Figure 3.3: The land-based plyometric intervention group

APT participants in the present study were advised upon incorrect clothing and training considerations prior to completing the PT intervention in water. Participants were not allowed to wear tee-shirts to minimize drag. Whilst performing the bounding and repeated plyometric exercises, participants were spaced between each other, not only for ensured recovery between repetitions but to minimize a current forming and decreasing the training effect. During the repeated countermovement jumps, participants were evenly space away from each other in the swimming pool, to minimize the effects of wave drag and subsequent turbulence.

Both experimental groups were allowed to maintain their existing summer sport of cricket, athletics, swimming or water polo, and pre-season rugby union gymnasium training. The permission given from school's headmaster to perform the intervention was that it had to be performed after the participant's school commitments of education, culture and sport. The participant's summer sport commitment consisted of a single sport, comprised of two training sessions in the week of 90-minutes in duration, and then a match fixture upon the Saturday morning. Upon an overview of the experimental group's summer sport commitments, the aquatic or land-based interventions were placed upon either a Monday-Wednesday or Tuesday-Thursday to allow the participants to perform the plyometric intervention upon their off-days between summer sport practices. Participants were instructed not to participate in weight training upon PT days for the duration of the study, even in the morning of PT.

Since both groups had little or no experience in PT, the intervention was systematically progressed per week to ensure that the players maintained correct exercise execution with good technique, and maintained balance with proper landing technique. A proper landing technique was defined as landing with shoulders over the knees, and proper flexion in the hip, knees, and ankles. Correct landing was emphasised to prevent injuries and ensure effective training. Land-based plyometric group participants were asked to wear correct footwear, with a non-slip sole. During the entire plyometric intervention, safety and correct technique were strongly advised, and were corrected during the training sessions. Each PT session began with a five minute jog, dynamic stretching for the lower limbs and trunk, and plyometric specific warm-up exercises such as side-to-side shuffles, body weight squatting exercises and high-knee shuttle runs. Each session was concluded with ten minutes of static stretching for the lower limbs and lower back.

G. Control-group

The control-group did not participate in any of the PT sessions, but were entitled to maintain their existing summer sport and pre-season gymnasium training. They were not permitted to engage in any other type of plyometric or explosive-power based athletic type strength training lifts. The control-group followed the same testing procedures as the experimental group.

The researcher was involved in the participant's pre-season rugby union gymnasium exercise prescription and periodization, which did not include any explosive or plyometric exercises.

H. Statistical analysis

Descriptive data are expressed as means ± standard deviation (SD), unless otherwise specified. The effects of the intervention programme were assessed using statistical data processing package (Excel, Microsoft Office 2003®, United States of America) with single-factorial ANOVA analysis for mean change between the three different groups. Bonferroni post hoc analysis was completed, with a t-test between groups for statistical significant difference for an all performance variables. In all analyses the level of statistical significance was set at $p<0.05$. Effect sizes (ES) were calculated for pre and post-test results in each group as well as for differences between the experimental and control-group to determine practical significance for all values which showed statistical significance. Effect size (ES) (expressed as Cohen's D-value) can be interpreted as follows: an ES of more or less 0.75 was large, an ES of more or less 0.4 was medium and an ES of more or less 0.15 was small practical significance (Thalheimer & Cook, 2002).

CHAPTER FOUR

RESULTS

A. Introduction

The aim of the study was to compare the effectiveness of an aquatic and land-based plyometric programme upon selected, sport-specific performance variables in adolescent male, rugby union players. To this end, players were evaluated on a single laboratory test, and a number of field-based tests.

B. Participant characteristics

Participants were randomly divided into two experimental groups and a control-group. There were no statistically significant differences with regards to their age, height, and body mass (Table 4.1) at baseline testing. There were also no significant differences in height or body mass of the participants after the intervention.

Table 4.1 Personal characteristics of the aquatic and land experimental and control groups during baseline testing ($p > 0.05$).

	Water Group		**Land Group**		**Control**	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
n	18		17		17	
Age (years)	16.33 ± 0.84	15 - 18	16.23 ± 0.75	15 – 17	16.41 ± 0.93	15 - 18
Height (cm)	1.75 ± 0.04	169 - 188	1.76 ± 0.08	165 – 191	1.77 ± 0.07	166 - 192
Body mass (kg)	74.92 ± 14.54	59.7 - 126.4	74.66 ± 11.22	60.7 - 95.5	78.56 ± 10.06	57.1 - 94.3

C. Explosive power

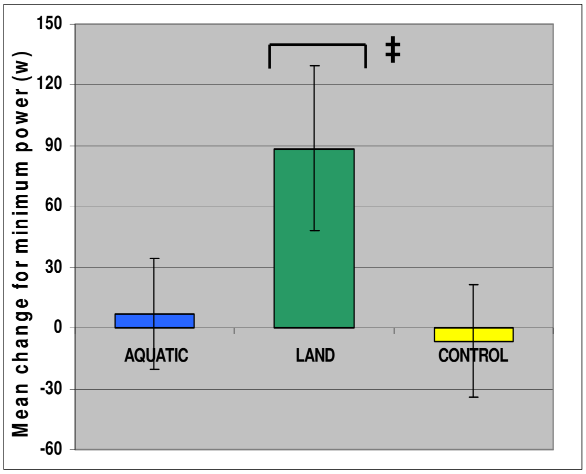
1. Fitrodyne repeated countermovement jumps

1.1 Peak power

Table 4.2 Descriptive statistics, range and significance of the pre- and post-test as well as group result differences for the Fitrodyne repeated countermovement jumps, peak power measurements (p>0.05).

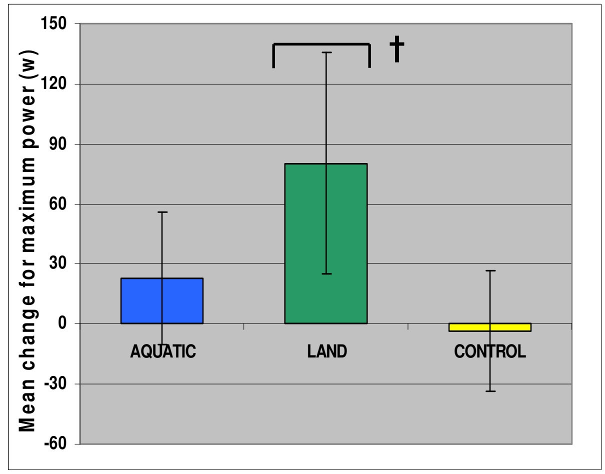
Measurements		**Pre-test**		**Post-test**	
		Mean ±SD	Range	Mean ±SD	Range
Minimum (watts)	Water (n=18)	1440.8 ± 220.1	1146 - 2138	1454.2 ± 278.6	1100 - 2349
	Land (n=17)	1470.5 ± 216.6	1137 - 1864	1572 ± 259.3‡** ªª nn	1162 - 2224
	Control (n=17)	1552.8 ± 170.7	1118 - 1913	1534.7 ± 171.8	1258 - 1872
Maximum (watts)	Water (n=18)	1845.4 ± 294	1325 - 2744	1874.9 ± 384.3	1329 - 3127
	Land (n=17)	1823.4 ± 276.5	1382 - 2404	1922.2 ± 315.8†*ªªnn	1527 - 2574
	Control (n=17)	1936.6 ± 204.9	1392 - 2347	1929.6 ± 222.1	1540 - 2398
Average (watts)	Water (n=18)	1647.2 ± 269.8	1240.4 - 1248.5	1669.7 ± 314.2ª	1276.3 - 2167.7
	Land (n=17)	1646.3 ± 250.6	1276.3 - 2167.7	1744.2 ± 274.2‡*ªªnn	1344.6 - 2367.2
	Control (n=17)	1739.4 ±177.7	1270.1 - 2060.9	1719.7 ± 181.4	1378.1 - 2105.1
Fatigue Index (%)	Water (n=18)	21.8 ± 3.6	13.5 - 25.2	22.2 ± 3.5	14.9 - 25.2
	Land (n=17)	19.2 ± 3.7	10.9 - 24.6	18.2 ± 4.6*ªn	11.5 - 25.1
	Control (n=17)	19.7 ± 4.1	10.2 - 25.4	20.4 ± 3.4	15.7 - 25.5

% = percentage
† Pre- and post-test values within group are significantly different (p≤0.05)
‡ Pre- and post-test values within group are significantly different (p≤0.01)
* Small effect size: pre- to post-test (ES: 0.15)
** Medium effect size: pre- to post-test (ES: 0.40)
ª Small effect size: control vs. experimental group (ES: 0.15)
ªª Medium effect size: control vs. experimental group (ES: 0.40)
n Small effect size: water group vs. land group (ES: 0.15)
nn Medium effect size: water group vs. land group (ES: 0.40)



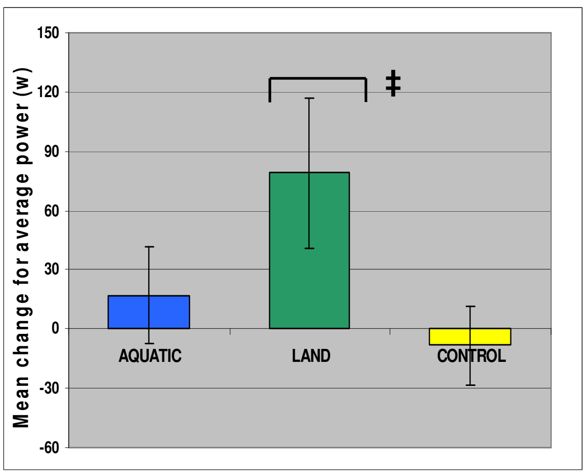
‡ Pre- to post-testing (p≤0.01)

(a)



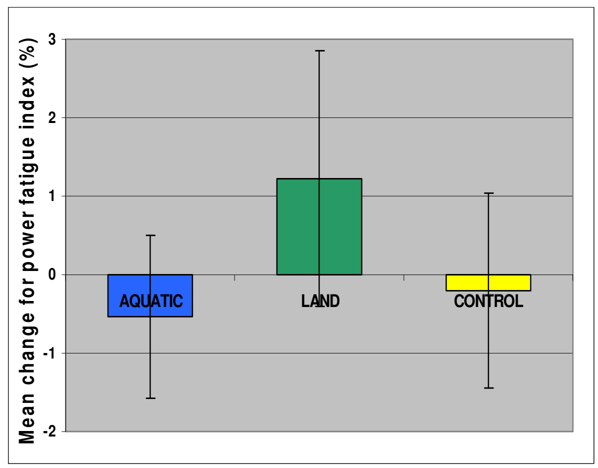
† Pre- to post-testing (p≤0.05)

(b)



‡ Pre- to post-testing (p≤0.01)

(c)



(d)

Figure 4.1 The effect of the intervention program upon the repeated countermovement jump's concentric peak power measurements: (a) minimum, (b) maximum, (c) average, (d) fatigue index.

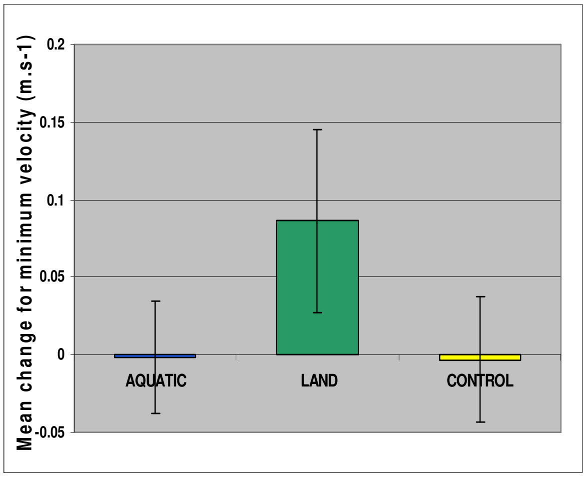
The results for the Fitrodyne repeated countermovement jumps, peak power measurements are presented in Table 4.2 and Figure 4.1. The land plyometric group was the only group that attained statistically significant ($p \leq 0.05$) increases pre- to post-testing in the minimum (6.9%; effect size [ES]: 0.44), maximum (5.42%; ES: 0.34), and average (5.94%; ES: 0.39) peak power values. Although no statistically significant differences were found between groups, the land plyometric group attained practically significant higher values than the aquatic plyometric group for minimum (ES: 0.63), maximum (ES: 0.37) and average (ES: 0.52) peak power values. The land plyometric group also obtained moderate practical significance compared with the control-group for the minimum (ES: 0.67), maximum (ES: 0.46), and average (ES: 0.73) peak power measurements. The control-group reported no improvements in peak leg. The land group was the only group to improve peak power fatigue index, pre- to post-testing by 5.59%, with small practical significance (ES: 0.26), as well as small practical significance (ES: 0.32) compared with the aquatic plyometric group.

1.2 Peak velocity

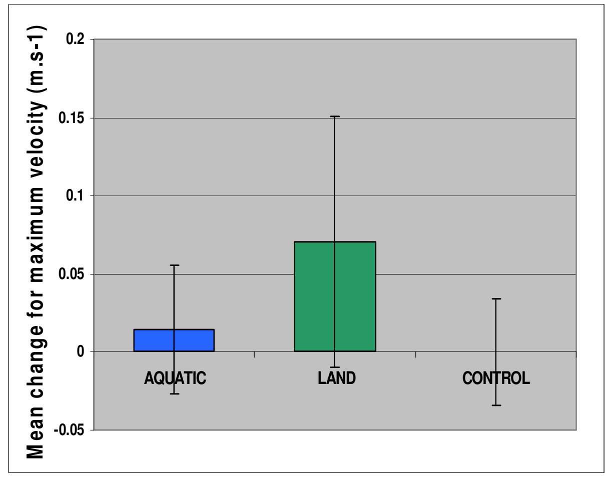
Table 4.3 Descriptive statistics, range and significance of the pre- and post-test as well as group result differences for the Fitrodyne repeated countermovement jumps, peak velocity measurements (p>0.05).

Measurements		**Pre-test**		**Post-test**	
		Mean ±SD	Range	Mean ±SD	Range
Minimum ($m.s^{-1}$)	Water (n=18)	1.98 ± 0.14	1.64 - 2.29	1.97 ± 0.17	1.75- 2.38
	Land (n=17)	2.02 ± 0.18	1.81 - 2.62	2.1 ± 0.16** $^{aa\ nn}$	1.82 - 2.38
	Control (n=17)	2.02 ± 0.16	1.71 - 2.22	2.01 ± 0.18	1.66 - 2.27
Maximum ($m.s^{-1}$)	Water (n=18)	2.53 ± 0.18	2.19 - 2.78	2.54 ± 0.2	2.15 - 2.92
	Land (n=17)	2.5 ± 0.19	2.2 - 3.04	2.57 ± 0.21* $^{a\ n}$	2.24 - 3.01
	Control (n=17)	2.52 ± 0.17	2.20 - 2.8	2.52 ± 0.18	2.19 - 2.86
Average ($m.s^{-1}$)	Water (n=18)	2.26 ± 0.16	1.87 - 2.53	2.26 ± 0.2	1.94 - 2.66
	Land (n=17)	2.25 ± 0.17	2.03 - 2.77	2.33 ± 0.18** $^{aa\ n}$	2.06 - 2.78
	Control (n=17)	2.26 ± 0.16	1.99 - 2.54	2.255 ± 0.2	1.91 - 2.59
Fatigue Index (%)	Water (n=18)	21.75 ± 3.63	13.53 - 25.18	22.22 ± 3.47	15 - 25.17
	Land (n=17)	19.23 ± 3.72	10.93 - 24.61	18.08 ± 4.57* $^{a\ n}$	11.42 - 25.09
	Control (n=17)	19.73 ± 4.13	10.20 - 25.35	20.38 ± 3.38	15.76 - 25.49

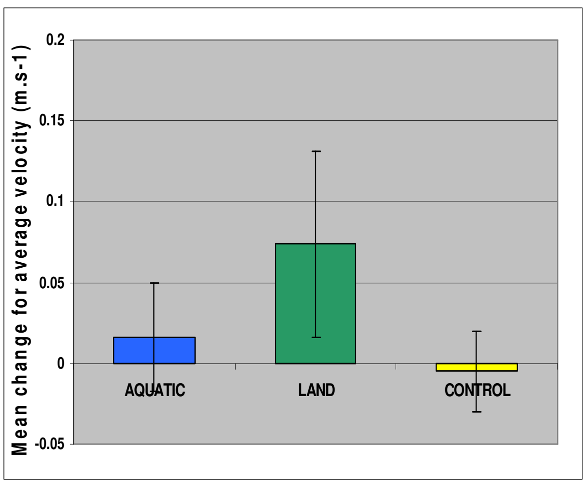
$m.s^{-1}$ = metres per second
% = percentage
* Small effect size: pre- to post-test (ES: 0.15)
** Medium effect size: pre- to post-test (ES: 0.40)
^{a} Small effect size: control vs. experimental group (ES: 0.15)
^{aa} Medium effect size: control vs. experimental group (ES: 0.40)
^{n} Small effect size: water group vs. land group (ES: 0.15)
^{nn} Medium effect size: water group vs. land group (ES: 0.40)



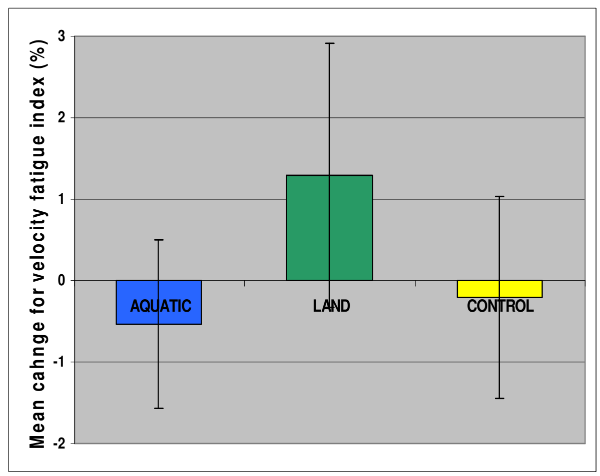
(a)



(b)



(c)



(d)

Figure 4.2 The effect of the intervention program upon the repeated countermovement jump's concentric peak velocity values: (a) minimum, (b) maximum, (c) average, (d) fatigue index

As table 4.3 indicates, no statistically significant changes occurred pre- to post-testing or between the groups. In Figure 4.2, the land plyometric group displayed the greatest improvements in peak velocity measurements than both the aquatic plyometric and control-group, in pre- to post-testing changes. These changes in pre- to post-testing scores indicated the land plyometric group having small practical significance in maximum peak velocity values (ES: 0.36; 2.87%), and medium practical significance for the minimum (ES: 0.49; 4.17%) and average peak velocity values (ES: 0.45;

3.49%). The effect of the intervention showed no improvement for the aquatic plyometric group in the minimum velocity and fatigue index scores, and little improvement in the maximum (0.33%) and average peak velocity scores (0.75%). Control-group exhibited decreased performances in the peak velocity measurements. The land plyometric group attained practically significant higher values than the aquatic plyometric group for the minimum (ES: 0.52), maximum (ES: 0.22) and average (ES: 0.31) peak velocity values.

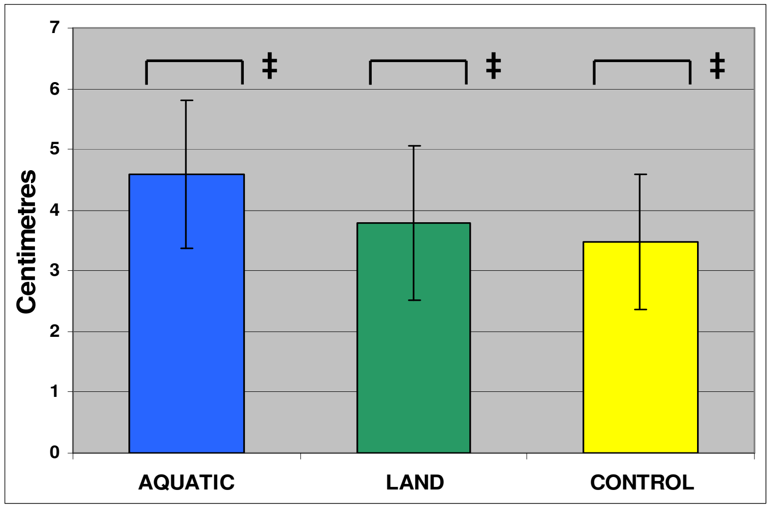
The land group was the only group to decrease peak velocity fatigue rates, pre- to post-testing by 5.98%, with small practical significance (ES: 0.29), as well as small practical significance (ES: 0.34) when compared with the aquatic plyometric group.

2. Sergeant vertical jump

Table 4.4 Descriptive statistics, range and significance of the pre- and post-test as well as group result differences for the Sergeant Vertical jump (p>0.05)

Measurements		**Pre-test**		**Post-test**	
		Mean ±SD	Range	Mean ±SD	Range
VJ	Water (n=18)	49.91 ± 8.14	36.5 - 61	53.85 ± 8.73‡** ª	42 - 75
Difference	Land (n=17)	49.67 ± 6.84	36 - 62	53.18 ± 5.25‡**	42 - 63.5
(cm)	Control (n=17)	48.23 ± 6.61	33 - 58	51.46 ± 8.19‡**	37.5 - 63

VJ= vertical jump
cm= centimetres
‡ Pre- and post-test values within group are significantly different (p≤0.01)
** Medium effect size: pre- to post-test (ES: 0.40)
ª Small effect size: control vs. experimental group (ES: 0.15)



‡ Pre- to post-testing (p≤0.01)

Figure 4.3 The effect of the intervention program upon sergeant vertical jump.

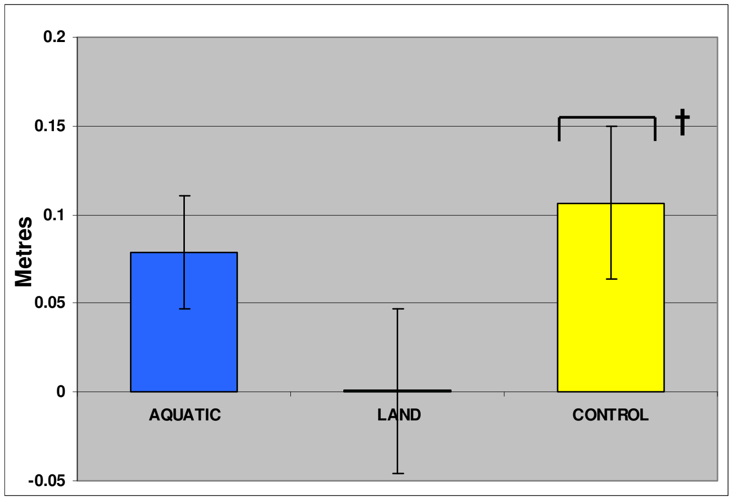
Table 4.4 listing the Sergeant vertical jump performances, all group improved with statistical (p ≤0.01) and medium practical significance, pre- to post-testing. No statistical differences were found between the groups. Figure 4.3 indicates the aquatic plyometric group displayed the greatest performance in jump height, pre- to post-testing by 7.88%, whereas the land plyometric and control-group improved their scores by 7.06% and 6.69%, respectively. The aquatic group also revealed small practical significance (ES: 0.26) when compared with the control-group.

3. Standing broad jump

Table 4.5 Descriptive statistics, range and significance of the pre- and post-test as well as group result differences for the standing broad jump (p>0.05).

Measurements		**Pre-test**		**Post-test**	
		Mean ±SD	Range	Mean ±SD	Range
Broad	Water (n=18)	2.140 ± 0.26	1.68 - 2.62	2.21 ± 0.245*ª nn	1.75 - 2.57
Jump	Land (n=17)	2.116 ± 0.16	1.8 - 2.36	2.11 ± 0.168	1.8 - 2.37
(m)	Control (n=17)	2.010 ± 0.24	1.67 - 2.49	2.11 ± 0.217†**	1.85 - 2.57

m= metres
† Pre- and post-test values within group are significantly different (p≤0.05)
* Small effect size: pre- to post-test (ES: 0.15)
** Medium effect size: pre- to post-test (ES: 0.40)
ª Small effect size: control vs. experimental group (ES: 0.15)
nn Medium effect size: water group vs. land group (ES: 0.40)



† Pre- to post-testing (p≤0.05)

Figure 4.4 The effect of the intervention program on the standing broad jump.

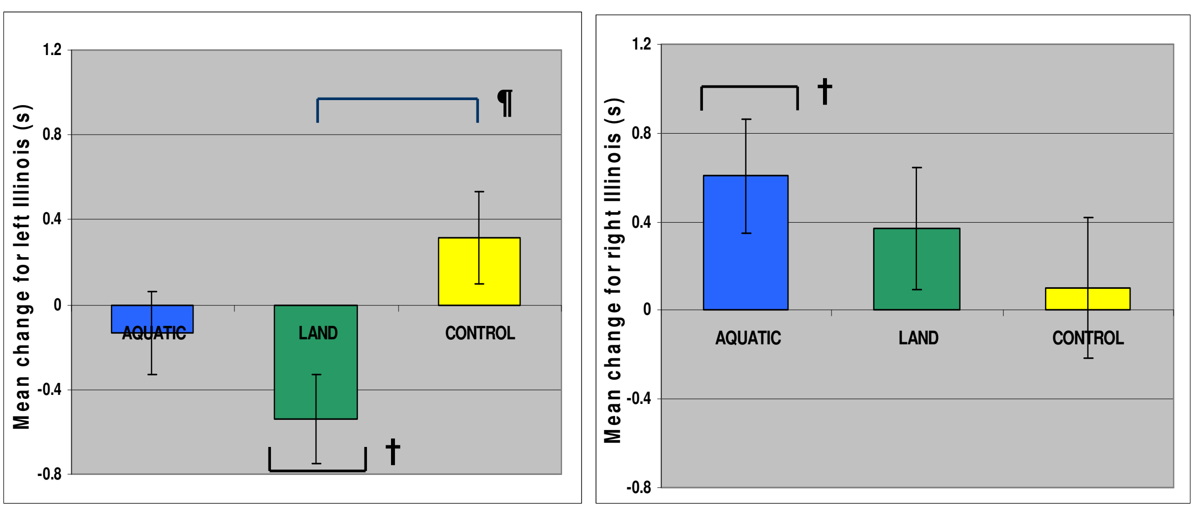
As Table 4.5 indicates, only the control and aquatic plyometric group improved horizontal explosives performances, pre- to post-testing by 5% and 3.6% respectively. There were no inter-group differences present. In Figure 4.4, the control-group exhibited a significant improvement ($p \leq 0.05$; ES: 0.45), pre- to post-testing. Whereas the aquatic plyometric group showed a positive trend in their scores ($p=0.051$). The aquatic plyometric group showed medium practical significance (ES: 0.47) compared with the land group.

D. Agility

Table 4.6 Descriptive statistics, range and significance of the pre- and post-test as well as group result differences for the Illinois agility test (p>0.05).

Measurements		Pre-test		Post-test	
		Mean ±SD	Range	Mean ±SD	Range
Illinois:	Water (n=18)	16.58 ± 0.88	15.62 - 18.45	16.73 ± 0.87 ^{nn}	15.45 - 18.08
Left (s)	Land (n=17)	16.42 ± 0.77	14.68 - 17.63	16.97 ± 0.76†	15.83 - 18.55
	Control (n=17)	17.04 ± 1.03	15.41 - 18.81	16.87 ± 0.70¶* ^{aaa}	15.60 - 18.01
Illinois:	Water (n=18)	17.01 ± 1.15	15.07 - 19.18	16.50 ± 0.89†** ^{aan}	15.37 - 17.92
Right (s)	Land (n=17)	16.91 ± 1.18	15.68 - 20.21	16.60 ± 0.63* ^{a}	15.21 - 17.61
	Control (n=17)	16.94 ± 0.95	15.51 - 18.01	16.90 ± 0.89	15.60 - 18.66

s= seconds
† Pre- and post-test values within group are significantly different (p≤0.05)
¶ Statistically significant difference between control group and land group (p≤0.05)
* Small effect size: pre- to post-test (ES: 0.15)
** Medium effect size: pre- to post-test (ES: 0.40)
^{a} Small effect size: control vs. experimental group (ES: 0.15)
^{aa} Medium effect size: control vs. experimental group (ES: 0.40)
^{aaa} Large effect size: control vs. experimental group (ES: 0.75)
^{n} Small effect size: water group vs. land group (ES: 0.15)
^{nn} Medium effect size: water group vs. land group (ES: 0.40)



† Pre- to post-testing (p≤0.05)
¶ Difference between control and land (p≤0.05)

(a)

† Pre- to post-testing (p≤0.05)

(b)

Figure 4.5 The effect of the intervention program on the Illinois agility test: (a) left, and (b) right.

Table 4.6 lists the Illinois agility test results. In Figure 4.5 (a) for Left Illinois agility test, no group experienced a statistically significant decrease in agility time, pre- to post-testing. Although the control-group decreased their agility time by 1.02% with small practical significance (ES: 0.2). The land plyometric group experienced statistically significant increases in agility times ($p \leq 0.05$), pre to post-testing. The independent *t*-tests results of the Left agility test showed statistically significant values when the control-group was compared with the land plyometric group. The aquatic plyometric group displayed medium practical significance (ES: 0.52) when compared with the land plyometric group.

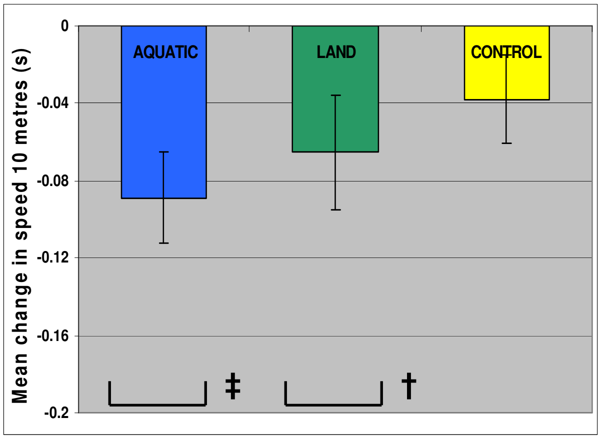
Figure 4.5 (b) displays that all groups decreased their agility time for the Right Illinois agility test. The aquatic plyometric group was the only group to reflect statistical and practical significance values in pre to post-testing (3.01%; ES: 0.51). As for the Left Illinois agility test, the aquatic plyometric group displayed small practical significance (ES: 0.26) when compared with the land plyometric group.

E. Speed

Table 4.7 Descriptive statistics, range and significance of the pre- and post-test as well as group result differences for the sprint speed ($p > 0.05$).

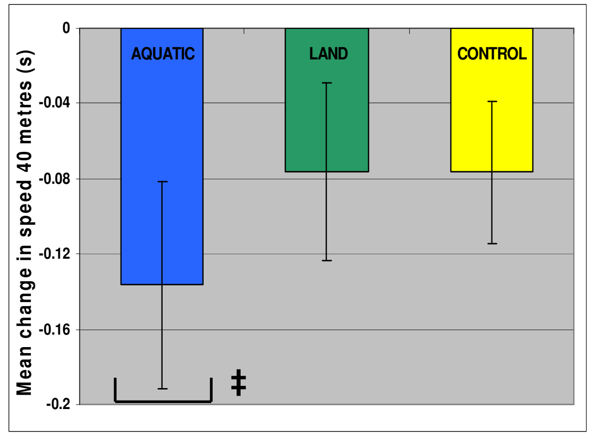
Measurements		**Pre-test**		**Post-test**	
		Mean ±SD	Range	Mean ±SD	Range
Speed:	Water (n=18)	1.81 ± 0.10	1.67 - 2.03	1.90 ± 0.11 ‡	1.75-2.21
10m (s)	Land (n=17)	1.81 ± 0.12	1.61 - 2.09	1.88 ± 0.11 † [n]	1.70-2.10
	Control (n=17)	1.82 ± 0.10	1.69 -1.98	1.87 ± 0.08	1.77-2.06
Speed:	Water (n=18)	5.610 ± 0.35	5.16 - 6.28	5.75 ± 0.36 ‡	5.35-6.75
40m (s)	Land (n=17)	5.611 ± 0.31	4.99 - 6.11	5.68 ± 0.29 [n]	5.23-6.17
	Control (n=17)	5.618 ± 0.31	5.17 - 6.24	5.72 ± 0.32	5.26-6.33

s= seconds
† Pre- and post-test values within group are significantly different ($p \leq 0.05$)
‡ Pre- and post-test values within group are significantly different ($p \leq 0.01$)
[n] Small effect size: land group vs. water group (ES: 0.15)



† Pre- to post-testing (p≤0.05)
‡ Pre- to post-testing (p≤0.01)

(a)



‡ Pre- to post-testing (p≤0.01

(b)

Figure 4.6 The effect of the intervention program upon sprint speed: (a) 10-metres, and (b) 40-metres.

As Table 4.7 indicates, no groups showed improvements in speed for both the 10- and 40- metre speed tests. In Figure 4.6 (a), for the 10-metre speed test, both the aquatic and land plyometric group displayed statistically significant slower speed times, pre- to post-testing. Although the land plyometric group showed a small practical significance (ES: 0.17) compared with aquatic group. Figure 4.6 (b) demonstrated the aquatic plyometric group attaining statistically slower performances for the 40-metre speed test. The land plyometric group produced a small practical significance (ES: 0.33) compared with aquatic group plyometric group.

F. Summary

Peak leg power (indirect) was significantly improved only by the land plyometric group. All groups significantly improved vertical jump performances, which the aquatic plyometric group showed the greatest enhancement due to the intervention. Although the aquatic plyometric group displayed a positive trend in the standing broad jump, the control group demonstrated the greatest increase in horizontal jump performance.

Agility performances for both the Left and Right Illinois agility test were marginally enhanced by the control-group. But the aquatic plyometric group was the only group to reflect a statistically significant improvement in the Right agility times.

Although there were no improvements for speed performances, the land plyometric group reflected small practical significance for both the 10- and 40-metre speed test when compared with aquatic plyometric group.

CHAPTER FIVE

DISCUSSION

A. Introduction

In this chapter, the conceptual conclusions attained from the study shall be discussed. In culmination of this experimental intervention study, conventional research instruments were applied to compare the performance enhancement of a plyometric training programme within an aquatic- or upon a land-based training environment. The adolescent, rugby union participants opened a new field of investigation into this previously un-investigated population group. This comparative study between two plyometric training groups created a new understanding of existing issues of previously published literature on aquatic plyometric training. The findings of this study will be discussed around the research questions stated in Chapter One.

B. Research questions

The following research questions have been addressed in this study:

1. **What are the effects of a seven-week land-based compared to an aquatic-based plyometric training programme upon adolescent rugby union players' leg power?**

Fitrodyne repeated countermovement jumps: peak concentric power

The land-based plyometric training (LPT) group was the only group to present with statistically significant improvement in peak concentric power (indirect), pre- to post-testing for the repeated countermovement jumps (CMJ). The aquatic-based plyometric training (APT) group negligibly increased peak power scores. The control-group did not show any improvements in leg power for the repeated CMJ. LPT appears to be a more effective training stimulus for the stretch-shortening cycle (SSC) than APT or participants maintaining an extra-curricular, summer sport. PT could improve concentric and stretch-shortening cycle SSC jump performances through changes in mechanical properties of the muscle-tendon complex (Kubo *et al.*, 2007). The LPT-group also performed their intervention upon an identical surface which pre- to post-testing of the repeated CMJ occurred. LPT also would have become increasingly tolerant of the training intensities of PT upon land. Therefore, training surface specificity at these similar training intensities could have caused the trained effect in indirect peak power for the LPT-group.

Fatouros *et al.* (2000) attained similar findings upon measuring average leg muscle endurance by means of repeated jumps, to calculate jumping mechanical power in untrained men. The 12-week intervention compared the effects of combination training (plyometric training [PT] and weight training [WT]), and PT upon VJ height, jumping mechanical power, and flight time, with a control-group. Participants executed maximal, repeated vertical jumps for 15-seconds to calculate average power output and flight time. Combination training group exhibited a significantly better performance than the PT- and the WT-groups in VJ height, jumping mechanical power, and flight time. PT-and WT-groups each increased flight time and decreased ground time significantly, although it was their combination that reflected greatest gains in these two-parameters. Fatouros *et al.,* (2000) showed that combination training decreased ground time or the amortization phase between jumps. This adaptation possibly occurred because of a better utilization of stored elastic energy, resulting in a higher jump and increased flight time (and thus reduced ground time). Therefore, the combination of PT and WT appeared to have a greater potential in enhancing VJ performance than PT alone (Markovic & Mikulic, 2010; Sáez-Sáez De Villarreal *et al.,* 2010).

Fitrodyne repeated countermovement jumps: peak concentric velocity

The LPT-group was the only group to show statistically significant improvement in peak concentric velocity (indirect), pre- to post-testing or repeated CMJ. Same as the peak power finding, the APT negligibly improved concentric velocity scores, whereas the control-group did not show improvement. Fatouros *et al.,* 2000 found that LPT could decrease ground time or shorten the amortization phase between jumps. In accordance with the velocity specificity principle of training, decreased ground contact times could elicit an increased ability to generate explosive ground-reaction forces during PT (Thomas *et al*., 2009), at increased speeds of movement or execution during PT (Makaruk & Sacewicz, 2010).

The non-significant findings of the APT-group in the present study, of peak concentric velocity and power for repeated CMJ are similar to the results of Miller *et al.* (2007). Miller *et al.* (2007) also found slight changes in average force and power measured upon a force plate for squat jumps (SJ), CMJ, 15-cm depth jumps (DJ), and VJ height measured separately, in a comparative six-week study of waist and chest-deep APT with a control. The untrained male and female adult participants, presented with slight changes in force and power production in the chest-deep group and only slight, non-significant differences in the VJ-height in the waist-deep group. Participants were previously inactive, untrained and it was suggested that the APT-intervention intensity and training total might have been too low. Miller *et al*. (2007) concluded that optimal depth for performing APT to enhance power and force production was still inconclusive, yet APT showed similar benefits as LPT. Optimal pool depth for APT has yet to be validated. This still appears as a fundamental factor when training to increase muscle power (Miller *et al*., 2002; Stemm & Jacobson, 2007).

The physical properties of water have to be considered for effective training utilizing APT. Buoyancy of water reduces the body mass, stretch reflex and amount of eccentric loading experienced by the participant during APT. The water's drag force facilitates the concentric muscular component of the plyometric jump. Decreased amounts of force applied (load) experienced during landing in APT due to buoyancy, aids a more rapid transition from eccentric to concentric activity may occur and theoretically shortening the amortization phase of a plyometric task. LPT experiences heavier loads (no buoyancy effect) at lower velocities and a longer amortization phase, improving strength but not power (Behm & Sage, 1993; Miller *et al.,* 2002; Robinson *et al*., 2004; Colado *et al.,* 2010). In accordance with speed-specificity of resistance training, a lower load and (theoretical) faster amortization training stimulus would be expected to produce improvements in muscle-power output at higher velocities (Behm & Sage, 1993; Colado *et al.,* 2010). This concept explains why APT has shown improvements in muscle-power output and supports the premise that APT might be useful in increasing power performances (Miller *et al.,* 2002).

Triplett *et al.* (2009) and Colado *et al.* (2010) both have shown that double-legged and single-leg static jumps could have quicker, total jump times in water, with a higher concentric rate of force development (RFD), but with slower time-to-peak concentric force than LPT. Colado *et al.* (2010) performed a similar study as Triplett *et al.* (2009) upon the same group of elite handball, adolescent female participants, except a year apart. Squat or static jumps are purely concentric in nature due to the lack of a rapid countermovement prior to the jump. Static jumps would benefit faster jump times for APT and higher RFD due to buoyancy, although the drag and viscosity of the water will reduce the time-to-peak concentric force.

Donoghue *et al.* (2011) further explored the kinetics of both slow and fast SSC exercises (with countermovement) comparatively, on land and in water. Their study presented a better reflection regarding the kinetics of comparing APT and LPT exercises. Plyometric exercises of varying intensity levels were tested: ankle hops, countermovement jumps (CMJ), tuck jumps, a single-leg vertical jump (VJ) and a 30-cm depth jumps (DJ). Compared to the equivalent jumps performed on land, RFD was significantly reduced (33%-62%) in water for ankle hops, tuck jumps, and the CMJ. DJ showed a reduction in RFD, but not significantly. Single-leg VJ showed an improvement in RFD (26%) over land jumps, as previously found by Triplett *et al*. (2009). The study by Donoghue *et al*. (2011) showed reductions in peak ground reaction forces, impulse, and RFD in the APT exercises. These reductions were subject to substantial individual variation, possibly attributed to: water depth, participant height, body composition and landing techniques.

The three abovementioned studies performed kinetic analyses of plyometric exercises by means of single-effort analysis. Future studies are needed to analyze the kinetics and the kinematics of consecutive aquatic jumps, as well as jumps with an eccentric phase, which are more like jumps performed for sport training (Triplett *et al*., 2009).

Fitrodyne peak power and velocity fatigue index

The land experimental group was the only group to exhibit a positive change in fatigue rate, although not statistically significantly. The reason for the LPT improvement may have been due to training upon the same surface as been tested upon for the Fitrodyne repeated jumps. For the fatigue index, the group that attains the greatest score for indirect, peak power and velocity will theoretically have lower rates of fatigue due its calculation. The maximum score for peak power or velocity was the denominator in the calculation, giving a lower quotient and a lower rate of fatigue.

APT was theoretically expected to show a higher rate in fatigue index, due to the water environment possessing was 12- times more resistant than air. Exercise performed in water required higher energy expenditure than the same exercise performed on land. Energy cost for water running is four times greater than the energy cost for running the same distance on land. A participant not only has to perform the activity or exercise, but must maintain a level of buoyancy and overcome the resistive forces of the water (Thein & Brody, 1998; Hoogenboom & Lomax, 2004).

Shiran *et al.* (2008) also attained non-significant changes in fatigue index percentages in their five-week comparative APT- and LPT-study on professional male wrestlers. Anaerobic power was assessed by means of a running anaerobic sprint test (RAST) with a fatigue index. Results indicated both experimental groups provided similar, yet non-significant, improvements in peak and mean power, without any meaningful difference between the training environments. For Shiran *et al.* (2008), both of the experimental groups' fatigue index percentages increased non-significantly, pre- and post-testing; suggesting that both experimental groups' state of recovery did not improve after the intervention.

Sergeant vertical jump test

In the Sergeant vertical jump test, all three groups improved explosive, vertical leg power significantly pre- to post-testing. The APT-group showed the greatest improvement in VJ performance. The control-group was requested to maintain their usual compulsory summer, extra-curricular sport. Findings from this study would suggest that there is a strong enough trend that an adolescent participating in a summer, extra-curricular school sport could adequately develop a participant's vertical explosive power. It appears that the three training modalities were sufficient to impose a training stimulus for vertical explosive leg power, upon the adolescent male participants.

Findings of the present study are in agreement with the LPT and APT comparative studies of Robinson *et al.* (2004) and Gulick *et al.* (2007) for VJ. Robinson *et al.* (2004) compared the effect of eight weeks APT versus LPT on VJ in healthy women. It should be mentioned that Robinson *et al.* (2004) did not have a control-group. The study found large increases in VJ performance in both APT- and LPT- experimental groups of similar magnitude, without any significant differences between them. Gulick *et al.* (2007) compared the effects of APT versus LPT in male and female untrained, university students upon peak power calculated from VJ height. No significant differences were found among the two experimental groups and control for VJ estimated power, after the six week intervention. All groups showed improvement in muscle power. Only the APT-group showed a significant increase in muscle power, pretraining to mid-intervention testing at three-weeks. Although no significant differences were found between the groups, APT-group showed the greatest improvement in VJ estimated power test.

Standing broad jump

In the standing broad jump performances, only the control-group in the present study showed a statistically significant increase in horizontal jump distance, pre- to post-testing. LPT did not show any improvement. There has been no reported research establishing the effect of an APT-intervention or comparatively with LPT, upon horizontal explosive performances. The APT-group showed a positive trend (p=0.051) in the standing broad jump, pre- to post-testing. This improvement for APT could be attributed to increased resistance of water. In conjunction with the previous findings of the VJ, adolescent males can enhance vertical and horizontal explosive performances by simply undertaking a summer, extra-curricular sport. These findings suggest that a summer sport within a school system could offer valuable preparation for power-based winter sports, such as rugby union and hockey.

Short-term LPT of six-weeks can significantly improve horizontal explosive performances in trained and untrained participants, using sport-specific PT exercises (Adam *et al.*, 1992; Markovic *et al.*, 2007b); combination training of weight training (WT) and PT (Faigenbaum *et al.*, 2007) and with real-time feedback after PT performances to help maintain training targets and intensity thresholds (Randell *et al.*, 2011). Theoretically, the horizontal jump performances in water should have been greater due to the added resistance from the viscosity of water, inducing a larger training effect in linear movements (Miller *et al.,* 2002; Martel *et al.*, 2005).

During the intervention, both experimental groups performed progressive PT that trained linear explosives performances. There was great disparity in the test results between groups especially with the LPT showing no improvements and control showing the enhancement in performance. This disparity could be explained possibly by the test battery being too intensive performing all tests in a single-sitting. In pre-testing and post-testing all subjects were tested in a circuit: all explosive leg power tests including agility, with speed being performed last with all participants present. Local fatigue experienced by the participants could have been a major limiting factor for the participant's performance.

2. **What are the effects of a seven-week land-based compared to an aquatic-based plyometric training programme upon adolescent rugby union players' agility?**

Left Illinois agility test

For the left Illinois agility test, there were no significant pre-to-post differences. Only the control-group improved their performances, pre- to post-testing, although not statistically significant.

Previous studies have found positive, significant findings for both LPT and comparative APT and LPT studies upon the traditional (left) Illinois agility test. Miller *et al.* (2006) found that LPT significantly improved Illinois agility times pre- to post-testing, and being significantly faster than its control-group in a six-week intervention upon untrained male and female adult participants. The control-group maintained their pre-testing agility times. In an unpublished study, Jones (2008) compared the effects of aquatic- and land-based plyometric training upon agility and static balance in female athletes, in a six-week intervention. ATP-group was significantly faster than the LPT-group in the Illinois agility run.

Right Illinois agility test

All three groups had faster times for the Right-Illinois agility test, pre- to post-testing. The APT-group was the only group to exhibit statistically significantly improvement in agility times, pre- to post-testing. The hypothetical reasons from literature why APT can improve agility times are due to the physical properties of water. Viscosity and cohesion of water increases this resistance, providing an important training stimulus for agility within an aquatic environment (Miller *et al.*, 2001; Gulick *et al.,* 2007). Also, the collective effect of speed specificity, repetitive jump training with the shorter amortization phase, could too result in improved agility (Behm and Sage, 1993; Gulick *et al.,* 2007).

There is high variability with the Illinois agility test results for adolescent male participants. Comparatively, both the left and right Illinois agility test should theoretically reflect similar trends in results. Unfortunately, the participants were involved in concurrent, extra-curricular school sport, and further compounded by a multitude of uncontrollable factors that could have caused of such varied results between the left and right Illinois agility test (Kidd, 2011). The difference in results between the Left- and Right- Illinois agility could be due to the small sample size of the study, fatigue sustained from the intensive testing battery or leg dominance. The participants may have been right-leg dominant and performed more work upon the right leg and thus could explain the enhanced results of the Right-Illinois agility test.

The Illinois agility test is traditionally performed from the left side only. For this study, the Illinois agility test was performed from the right-hand side too. There is no reported research of the Illinois agility being tested from both sides. Rugby is a multidirectional sport, where players have to generate speed from varying positions and change directions quickly without decreasing speed (Luger & Pook, 2004). The ability to accelerate from a starting position and perform complex ballistic movements comprising of both concentric and SSC explosive movements are essential for attacking and defensive facets of the game (Rimmer & Sleivert, 2000; Luger & Pook, 2004; Markovic & Mikulic, 2010).

3. **What are the effects of a seven-week land-based compared to an aquatic-based plyometric training programme upon adolescent rugby union players' speed?**

There were no positive changes for both experimental groups and control for the 10- and 40- metre (m) sprint speed performances, pre- to post-testing. All groups demonstrated slower times for both test distances. Both the APT and LPT had significantly slower times for the 10-m, and APT showed a significantly slower time for the 40-m. The poor performances in sprint speed for all groups were attributed to: testing fatigue, motivation, and a softer post-testing surface for the speed tests.

For both pre-testing and post-testing, speed was tested after the leg power test battery and agility tests. A major methodological flaw in this study was the post-testing for the speed test. Post-testing was performed upon a softer, more compliant (less stiff) surface of grass nearer to the cricket pitch than the original pre-testing site on the outer field. The original site was unavailable due to the grass field being irrigated. Sprint testing upon softer surfaces presents alterations in running kinetics, which do not favour faster time performances.

During running, as the foot contacts the ground, joint motion at the ankle, knee, and even the hip lowers the body centre of mass, representing absorption of energy and compression of the conceptual leg spring (Bishop *et al.,* 2006). During energy generation, the runner's limb extends, representing recoil of the spring (Blazevich, 2004; Bishop *et al.*, 2006). Overall centre of mass lowering and leg shortening is greater on stiffer surfaces while the ground reaction force remains constant. Thus, the leg spring is less compliant when running on softer surfaces (Blazevich, 2004). Potential for the amount of stretch reflex and eccentric loading of the leg musculature is decreased. Due to the less stiff surface, the propulsive and explosive capability of the sprinting participant is decreased. Performing the test upon a softer surface, sprint times will inevitably be slower.

Previous plyometric studies have exhibited significant sprint performance findings due to a PT intervention. Rimmer and Sleivert (2000) in an eight-week study, compared plyometric and sprint training for optimal 10-and 40-m sprint times enhancement. The plyometric group showed a statistically significant decrease in time over the 10-m and 40-m. These improvements were not significantly different from the sprint group. Both the sprint and control-group showed no improvements in sprint times.

In LPT-studies, no improvements in sprint performance have also been found. Thomas *et al.* (2009) compared the effect of either depth jumps or CMJ plyometric jumps in a six week intervention upon trained adolescent soccer players. Post-training analysis showed both groups experienced no change in 20-m sprint speed performance, or statistically significant differences between experimental groups. These finding were due to the PT not being performed at sprint-specific velocities of muscle action or movement. In accordance with the velocity specificity principle of training, ground contact times were not short enough to elicit an increased ability to generate the explosive ground-reaction forces as experienced during sprinting. In retrospect, Thomas *et al.* (2009) reported this lag in amortization phase and speed of movement could have been rectified by using specific verbal cueing instructions for the participants during the intervention. Makaruk and Sacewicz (2010) showed that irrespective of the level of jumping ability of the participants, maximal leg power output was significantly improved using specific verbal cueing instructions during PT. These verbal instructions emphasised improving the speed of execution and minimizing ground contact during PT.

In comparative APT and LPT literature, APT has shown to be as effective as or better than LPT in sprinting and running performances. Shiran *et al.* (2008) found no improvements in 5-m sprint times in the APT- and LPT-groups. 10- and 20-m times showed improvement for both experimental groups. 10-m sprint times were non-significantly faster for the both APT- and LPT-groups. LPT showed the only significant improvement in the 20-m sprint time, pre- to-post-testing. Robinson *et al.* (2004) found both the APT and LPT significantly improved in 40-m sprint velocity performances, pre- to post-testing. Both experimental groups reported similar improvements in 40-m velocity. Arazi and Asadi (2011) also found both APT- and LPT-groups significantly faster in 36.5- and 60-m sprint times, pre-to post testing.

C. Training considerations of aquatic- and land-based plyometric training

For any exercise prescription, focus should be to improve the functional or sport-specific movements with exercises that approximate the demands of the desired activity (speed, agility, strength power, endurance) (Dutton, 2008). Specificity of exercise prescription means that exercise and training prescription must be designed to meet the demands of the participant's sport. When loads are applied, they should be specific to the desired effect. The adaptations that the body makes to exercise loads (training effect) are to a large degree specific to the structures and functions that are loaded (Magee, Zachazewski & Quillen, 2007). In summary, this is called the principle of specific adaptation to imposed demand (SAID).

Training adaptations that occur from performing either LPT or APT are a result of the physical properties specific to each training environment imposed upon the exercising participant. LPT utilizes body weight and gravity to eccentrically load the muscles. Elastic properties of the musculotendinous unit serve as store houses of potential energy. Stretch reflex provides a defence mechanism to protect against sudden, forceful muscular stretches (Martel *et al.*, 2005). Combination of the stretch reflex response and a maximal voluntary muscle contraction can be very effective at enhancing upper and lower-extremity power, strength, and SSC muscle function in healthy individuals (Potash & Chu, 2008; Markovic & Mikulic, 2010). The intense nature of plyometrics with eccentric contraction loading can result in damage to the muscle and/ or connective tissue that can subsequently lead to muscle soreness (Jamurtas *et al.,* 2000; Harrison & Gaffney, 2004; Drinkwater, Lane, & Cannon, 2009). PT periodization that results in too closely grouped PT sessions, or excessive durations of high-volume PT could result primarily in peripheral fatigue that will substantially impair force and rate of force development (Drinkwater *et al.*, 2009). PT is appropriate for virtually any sport if properly applied in the context of the sport. Therefore, 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 of these three goals (Gambetta, 2007).

APT employs the resistive and buoyant properties of water (Miller *et al.,* 2007). Stretch reflex and the amount of eccentric loading are reduced in water by the effects of buoyancy. The viscosity of the water provides greater than normal resistance (Martel *et al.*, 2005). Buoyancy of water facilitates the concentric muscular component and theoretically decreases the amortization phase of APT. A participant performing APT will land with lower load, but will have a faster transition time. The shorter the amortization phase, the more successful the plyometric task is at improving power (Behm & Sage, 1993; Miller *et al.,* 2002).

Closed chain kinetic exercises such as aquatic jump exercises may result in greater force production and RFD in the same amount of time with less impact and thus could offer a viable alternative to traditional land-based jump exercises (Colado *et al.*, 2010). These decreases in impact due to the buoyancy could potentially reduce the amount of reported muscle soreness (DOMS), and reduce the risk of possible muscle or joint injury (Miller *et al.* 2002; Robinson *et al.,* 2004; Triplett *et al.,* 2009).

Triplett *et al.* (2009), Colado *et al*. (2010) and Donoghue *et al.* (2011) showed significant reductions in impact force that could be attributed to the buoyancy force experienced by the body. Peak impact forces (ground reaction forces [GRF]) were significantly reduced (33%-54%) for all APT exercises tested (ankle hops; tuck jumps; CMJ; single-leg VJ; DJ) (Donoghue *et al.,* 2011). This was consistent with previous research that found reductions of 45% and 59% in peak GRF during single- and double-leg squat jumps in water at the level of the xiphoid process (Triplett *et al*., 2009; Colado *et al.,* 2010). GRF of plyometric exercises performed on land varied from 4.32 to 6.77 bodyweight (BW), whereas aquatic values varied from 1.99 to 4.05 BW (Donoghue *et al.,* 2011).

Within a periodization programme for team sport, APT could be used to improve overall physical capacity in periods when the workload is more important than focused training; APT is a way of increasing the intensity of the plyometric jumps (Colado *et al.*, 2010). Since the intensity of jumps can be expressed by peak concentric force and concentric RFD (Jensen & Ebben, 2007). Both Triplett *et al.* (2009) and Colado *et al.* (2010) exhibited in comparative APT and LPT kinetic studies that performing jumps in water showed higher peak concentric force and concentric RFD values than LPT. This was likely due to the increased resistance to the movements, created by the drag force (Colado, Tella & Llop, 2006), which occurs for any movement in an aquatic medium and especially with quick movements such as jumps performed at maximal efforts (Colado *et al.,* 2008, 2009). A high concentric RFD combined with a short overall movement time is something desirable in a team sport, for example, because this could result in more efficient movements (Triplett *et al*., 2009). Because an increase in the RFD could contribute to enhanced performance in jumping activities (Kyröläinen *et al.,* 2005), APT could serve as an alternate training method for improving performance. Future studies are still needed to analyze the kinetics and the kinematics of consecutive aquatic jumps with an eccentric phase, which are more like jumps performed for sport training (Triplett, *et al*., 2009).

Muscle contraction type is a key consideration when performing exercise in water, especially when increasing resistance is based upon viscosity. Exercises performed against the water's resistance almost always elicit concentric contractions, and lacks eccentric muscle actions. Although, eccentric muscle actions during lower body exercise movements could be achieved if the water was shallow enough to minimize buoyancy (Thein & Brody, 1998).

In the context of the present study, the use of fluid resistance as means of resistance whilst performing APT, generally there is reduced eccentric muscle actions of the lower body musculature during these movements due to buoyancy. Without sufficient eccentric resistance, the lower body muscle groups will act for the most part concentrically. While performing the primary exercise movement of the triple-extension during APT, the antagonist muscle group acts concentrically while returning to starting position of jump. Performing LPT involves alternating concentric and eccentric actions, whereas APT generally involves only alternate concentric actions of antagonist muscle groups; each muscle group rests while the antagonist works. The lack of eccentric muscle action with APT means such exercise probably does not provide a functional SSC and optimal training for many sport movements that involve eccentric muscle actions (e.g., running, jumping, and throwing) (Harman, 2008).

D. Conclusion

Aquatic-based plyometric training could provide similar and even better performance in vertical jump and agility than land-based plyometric training, in an adolescent male population. Land-based plyometric training could provide greater improvement in peak power and velocity in this population. The positive findings of the control-group for VJ and standing broad jump are promising for power-based sport preparation and conditioning, as vertical and horizontal explosive power forms the basis of fundamental sport-specific movements (Adam *et* al, 1992; Potteiger *et al.*, 1999; Markovic *et al.*, 2007b). Therefore, the present study adds validation for maintaining a compulsory, summer sport in the current school system to ensure *basic* preparation of adolescent males for power-based sports in the winter. Competitive participation in summer and winter sports at higher levels requires participants to partake in additional training at much higher intensities and volumes. At higher levels of team participation, participants do require to be involved in additional: weight training and sport-specific conditioning that includes plyometric training.

Aquatic-plyometric training could be a safer plyometric modality for inexperienced participants that have not performed plyometrics previously nor completed weight training prior to plyometric training. APT could provide technique and posture accommodation within an immersed environment. The buoyancy of water makes APT a useful modality for heavier athletes to still complete plyometric training with decreased risk of injury. APT offers biokineticists, coaches and sport scientists a safer pre-season and in-season lower limb power training modality that could bring about an increase in intensity safely within a microcycle or mesocycle of an athlete’s periodization, without DOMS normally associated with PT, according to Robinson *et* *al.* (2004), Jensen & Ebben (2007) and Triplett *et al.* (2009). Although, if a participant has completed an extensive weight training program within a monitored periodization and motivated to perform, LPT may be a physiologically more correct training modality for explosive-power enhancement in conjunction with sport-specific training.

LPT might be a functionally superior training modality for athletes, although water plyometrics has similar performance benefits without the DOMS typically associated with plyometric training. The reduced eccentric muscular action of training in an aquatic environment is not conducive to the sport specific demands of most sports where repeated cycles of SSC can occur. Thus, APT should not completely replace LPT, as the APT might not adequately develop the specific neuromuscular patterns or functional needs of explosive sports.

Plyometrics is rarely used in sports as a single training modality, and should not be considered an end to itself. It should rather be incorporated into a multi-component physical conditioning programme that includes strength, speed, aerobic, flexibility, proper nutrition, and sport-specific training for skill enhancement and coordination (Voight & Tippett, 2004; Potash & Chu, 2008; Markovic & Mikulic, 2010).

E. Limitations

1. The current study's sample was too small consisting of 17- participants per group. A group of 30-participants would be advisable to eradicate trends in results but attain statistical significance.

2. Concurrent in-season summer sport (cricket, water polo, athletics) and pre-season winter sport (rugby) training posed a major time management issue with regard to planning and maintaining consistent training sessions for the intervention. Intervention had to be scheduled after compulsory sport in the afternoons, as per recommendations from the headmaster's permission to perform the study.

3. All of the tests were performed on one day. There were complaints from the participants of lower limb local fatigue from performing three power tests, as well as agility and speed assessments.

4. The present study was seven weeks in duration as suggested in the study by Luebbers *et al.* (2003). The seven-week intervention could have been too long for a male adolescent population. The LPT-group needed a lot of motivation between weeks five and seven. A six-week intervention might have been sufficient for maintaining morale and motivation of the participants for successful and productive training sessions. A retention period of three-weeks after the intervention has been completed, could elicit greater improvements in power, speed and agility.

5. Post-testing for the sprint test was performed upon a different site, due to unforeseen circumstances on the day of testing. The section of grass used for post-testing, closer to the cricket pitch, was softer than the original testing site upon the outer field. Same testing surface must be adhered to for post-testing purposes. If an intervention is being performed within a school, communicate with the school grounds' man to verify a mutual time for utilizing the same test surface or facilities.

F. Recommendations for future research

1. Comparative depths of immersion for aquatic-plyometric training upon vertical jump, standing broad jump, countermovement jump and squat jump performances, versus land-based plyometric training.

2. The effect of aquatic-plyometric training at different immersion depths upon closed kinetic chain, lower limb strength.

3. Efficacy of aquatic-plyometric training upon lateral movement based agility tests.

4. Compilation of standardized aquatic-plyometric training exercise prescription guidelines.

5. SSC timing (particularly amortization timing) during repeated jumps in water with force plate and motion analysis at: knee-deep, anterior superior spines (ASIS), xiphirsternum (XIPH), and at the seventh cervical vertebra (C7) level, versus land-based plyometric training.

6. Validation of the Fitrodyne 20-repetition repeated countermovement jumps protocol to the RAST and Wingate cycle test.

7. Validation and correlation of the Fitrodyne 15-second duration repeated countermovement jumps protocol to the RAST and Wingate cycle test.

8. Future studies are needed to analyze the kinetics and the kinematics of consecutive aquatic jumps as well as jumps with an eccentric phase, which are more like jumps performed for sport training (Triplett *et al*., 2009).

G. Practical applications of the study

Based upon the results from this study, practical considerations of the study will be summarized:

- Land plyometric training could be a superior training modality than aquatic-plyometric training, for optimally utilizing the SSC muscle function for correct preparation of athletes for explosive power.
- Aquatic-plyometric training could be used for participants who have never completed plyometrics before. The buoyancy and accommodation of water should assist the participant to learn correct technique earlier in a submaximal intensity. Heavier athletes can utilize the buoyancy forces to perform plyometrics without experiencing excessive impact forces.

- Aquatic plyometric training can be completed within an in-season periodization without DOMS, especially when a workload increase is necessary within a microcycle or mesocycle.
- Summer school sport is still a fundamental, yet general training modality, which forms the basic components of vertical and horizontal explosiveness for power-based sport conditioning.

REFERENCES

1. ADAMS, K.; O'SHEA, J.P.; O'SHEA, K.L. & CLIMSTEIN, M. (1992). The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *Journal of Applied Sport Science Research*, 6 (1): 36–41.

2. 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.

3. BAKER, D. & NANCE, S. (1999). 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.

4. BALCIUNAS, M.; STONKUS, S.; ABRANTES, C. & SAMPAIO, 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.

5. Bar-O, O. (1987). The Wingate anaerobic test: an update on methodology, reliability and validity. *Sports Medicine*, (4): 381-394.

6. BEHM, D.G. & SALE, D.G. (1993). Velocity specificity of resistance training. *Sports Medicine*, 15 (6): 374-388.

7. 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

8. BLAZEVICH, A.J. (2004). The influence of running surface properties on lower limb injury in human athletes. In: SOULSBY, E.J.L. & WADE, J.F. (Ed.)

9. 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.

9. 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.

10. BOYLE, M. (2004). *Functional training for sport*. Champaign, Illinois: Human Kinetics.

11. 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.

12. CHU, D.A. (1998). *Jumping into Plyometrics* (2nd ed.). Champaign, Illinois: Human Kinetics.

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

14. 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.

15. 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.

16. 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.

17. 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.

18. 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.

19. 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.

20. DOWSON, M.N.; NEVILL, M.E.; LAKOMY, H.K.A. (1998). Modelling the relationship between isokinetic muscle strength and sprint running performance. *Journal of Sports Science,* (16): 257-265.

21. 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.

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

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

24. 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.

25. FAIGENBAUM, A.D.; MCFARLAND, J.E.; KEIPER, F.B.; TEVLIN, W.; RATAMESS, N.A.; KANG, J. & HOFFMAN, J.R. (2007). Effects of a short-term plyometric and resistance training program on fitness performance in boys age 12 to 15 years. *Journal of Sports Science and Medicine*, (6): 519-525.

26. 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.

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

28. 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.

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

30. 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.

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

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

33. 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.

34. GEHRI, D.J.; RICHARD, M.D.; KLEINER, D.M. & KIRKENDALL, D.T. (1998). A comparison of plyometric training techniques for improving vertical jump and energy. *Journal of Strength and Conditioning Research,* 12(2): 85-89.

35. GRANTHAM, N. (2002). Plyometrics 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.

36. 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.

37. 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.

38. 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.

39. 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.

40. 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.

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

42. HARRISON, R.A.; HILMAN, M. & BULSTRODE, S. (1992). Loading of the lower limb when walking partially immersed: implications for clinical practice. *Physiotherapy,* (78): 164.

43. 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.

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

45. 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.

46. 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.

47. 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.

48. HUTCHINSON, M. R.; TREMAIN, L.; CHRISTIANSEN, J. & BEITZEL, J. (1998). Improving leaping ability in elite rhythmic gymnasts. *Medicine & Science in Sports & Exercise*, 30 (10): 1543-1547.

49. 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.

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

51. 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.

52. 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.

53. 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.

54. 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.

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

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

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

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

59. 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.

60. 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.

61. 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.

62. 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.

63. 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.

64. 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.

65. 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.

66. LUGER, D. & POOK, P. (2004). *Complete conditioning for rugby.* Champaign, Illinois: Human Kinetics.

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

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

69. 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.

70. 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.

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

72. 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.*

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

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

75. 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.

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

77. 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.

78. 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.

79. 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.

80. 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.

81. 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.

82. 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.

83. 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.

84. 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.

85. 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.

86. 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.

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

88. 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.

89. 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.

90. PIPER, T.J., & ERDMANN, L.D. (1998). A 4 step plyometric program. *Strength and Conditioning Journal,* 20(6): 72-73.

91. 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.

92. 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.

93. POTASH, D.H., AND 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.

94. 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.

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

96. 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.

97. RADCLIFFE, J.C. & FARENTINOS, R.C. (1999). *High-powered plyometrics*. Champaign, IL: Human Kinetics

98. 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.

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

100. ROBINSON, L.E.; DEVOR, S.T.; MERRICK, M.A. & BUCKWORTH, J. (2004). The effects of land versus aquatic plyometrics on power, torque, velocity, and muscle soreness in women. *Journal of Strength and Conditioning Research*, 18(1): 84-91.

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

102. 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.

103. 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

104. 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.

105. 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.

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

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

108. 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.*

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

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

111. THALHEIMER, W., & COOK, S. (2002). How to calculate effect sizes from published research articles: A simplified methodology. Hyperlink [http://work-learning.com /effect _sizes.htm]. Retrieved November 31, 2002

112. THEIN, J.M. & BRODY, L.T. (1998). Aquatic-based rehabilitation and training for the elite athlete. *Journal of Orthopaedic & Sports Physical Therapy*, (27): 32–41.

113. 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.

114. 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.

115. 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.

116. TURNER, A.M.; OWINGS, M. & SCHWANE, J.A. (2003). Improvement in running economy after 6 weeks of plyometric training. *Journal of Strength and Conditioning Research,* 17(1): 60–67.

117. 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

118. 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.

119. VOIGHT, M.L.; DRAOVITCH, P. & TIPPETT, S. Plyometrics. (1995). In: *Eccentric Muscle Training in Sports and Orthopaedics.* M. (2nd ed.). (61-88). New York, USA: Churchill Livingstone.

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

121. 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.*

122. 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.

123. 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.

124. 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.

125. 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.

126. 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.

127. 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.

128. 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.

APPENDIX A

HEADMASTER CLEARANCE TO CONDUCT RESEARCH

SPECTEMUR AGENDO
1829

South African College High School

Newlands Avenue, Newlands 7700
Private Bag, Newlands 7725

Secretary: 021 689 4164/5/6, Fax: 021 685 2669
Email: highschool@sacollege.org.za
Website: www.sacollege.org.za

2009.07.22

TO WHOM IT MAY CONCERN

I, Kenneth Ball, headmaster of the South African College School have given consent to Mr. David Fabricius to utilize high school pupils as subjects for his Masters study, within the first school term, from 18 January to 26 March 2010. The utilization of these scholars will only be allowed once the Western Cape Education Department has given its approval in writing, for scholars to participate in the study. Only after which may the selected scholars attain parental consent to participate in the study after school in time after academic, cultural and sport commitments.

This consent shall be given in good faith under the guidance of Stellenbosch University that the exercise intervention is appropriate and beneficial for performance enhancement within the subject group. Those scholars utilized in the study, are required to be screened and be clear of injury and ill-health, and that all the necessary emergency procedures are in place, in the unlikely event of an emergency.

Yours sincerely

K R BALL
HEADMASTER

Headmaster: K R Ball

APPENDIX B

WESTERN CAPE EDUCATION DEPARTMENT CLEARANCE

Navrae Enquiries *IMibuzo*	**Dr RS Cornelissen**
Telefoon Telephone *IFoni*	*(021) 467-2286*
Faks Fax IFeksi	*(021) 425-7445*
Verwysin Reference ISalathiso	*20090710-0070*

Wes-Kaap Onderwysdepartement

Western Cape Education Department

ISebe leMfundo leNtshona Koloni

Mr. DL Fabricius
20 Derry Street
Vredehoek
CAPE TOWN
8001

Dear Mr DL Fabricius

<u>RESEARCH PROPOSAL: THE EFFECT OF CHEST-AND WAIST-DEEP AQUATIC PLYOMETRIC TRAINING ON POWER, SPEED, AND AGILITY IN ELITE LEVEL ADOLESCENT ATHLETES</u>

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved participant to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **13 January 2010 to 26 March 2010**.
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Dr R. Cornelissen at the contact numbers above quoting the reference number.
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:
    The Director: Research Services
    Western Cape Education Department
    Private Bag X9114
    CAPE TOWN
    8000

We wish you success in your research.

Kind regards.

Signed: Ronald S. Cornelissen
for: **HEAD: EDUCATION**
DATE: 3 August 2009

APPENDIX C

STELLENBOSCH UNIVERSITY ETHICAL COMMITTEE CLEARANCE

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

27 November 2009

Tel.: 021 - 808-4622
Enquiries: Sidney Engelbrecht
Email: sidney@sun.ac.za

Reference No. 220/2009

Mr DL Fabricius
Department of Sport Science
University of Stellenbosch
STELLENBOSCH
7602

Mr DL Fabricius

APPLICATION FOR ETHICAL CLEARANCE

With regards to your application, I would like to inform you that the project, *The effect of the chest- and waist-deep aquatic plyometric training on power, speed and agility in elite level adolescent athletes,* has been approved on condition that:

1. The researcher/s remain within the procedures and protocols indicated in the proposal;
2. The researcher/s stay within the boundaries of applicable national legislation, institutional guidelines, and applicable standards of scientific rigor that are followed within this field of study and that
3. Any substantive changes to this research project should be brought to the attention of the Ethics Committee with a view to obtain ethical clearance for it.

We wish you success with your research activities.

Best regards

MRS. MALÉNE FOUCHÉ
Manager: Research Support

Afdeling Navorsingsontwikkeling • Division of Research Development
Privaat Sak/Private Bag X1 • 7602 Stellenbosch • Suid-Afrika/South Africa
Tel +27 21 808 9111 • Faks/Fax: +27 21 808 4537

APPENDIX D

PARENT INFORMATION SHEET AND INFORMED CONSENT FORM

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot•your knowledge partner

SPORT SCIENCE RESEARCH PARTICIPATION INFORMATION

Dear Madam/ Sir

Your son has been selected to participate in a research study by David Fabricius (Masters Student, Sport Science) from the Sport Science Department at Stellenbosch University. Your son has met the participant criteria to participate in this study. The research project shall be undertaken upon the South African College School (SACS) estate, during the first term of 2010.

Title of the research project: Comparison of aquatic and land plyometric training on power, speed and agility in adolescent rugby union players.

Purpose of the study: To compare the effectiveness of an aquatic-based and a land-based plyometrics training programme upon a male adolescent population, as part of preparatory conditioning for rugby union. And to determine which training condition will have the most significant effect upon leg power, speed, and agility.

Background Information: Plyometrics is a training technique that is used in all types of sports to increase strength and explosiveness. Research has shown that athletes who use plyometric exercises are better able to increase acceleration, vertical jump height, leg strength, joint awareness, and overall proprioception. Aquatic plyometric training also has the potential to provide similar improvements in skeletal muscle function and/or sport-related attributes of explosive training in land-based plyometrics with less delayed-onset muscle soreness.

Benefits: Adolescent athletes with a correctly prescribed intervention shall benefit greatly from plyometric training. The study coincides very well with pre-season for winter sports such as tennis, rugby union and field hockey, where vast amounts of leg power, agility and speed are required to succeed in these sports. The postulated outcome of this study would be the validation that male adolescent athletes can perform high-intensity plyometric exercises in water; it is proposed that APT could provide similar benefits or offered as an alternative approach to performance, rather than land-based plyometrics, but with lower risk of muscle soreness and/or overtraining.

Participant Requirements:
The adolescent athlete must be in excellent health and between the ages of 15 and 19 years, and participating in power related sport such as rugby union, at a national, provincial or high school. Participants will be required to maintain all sporting commitments during the running of the study, and still adhere to making at least 14 of the 16 training sessions over the 7-week study. All individuals must be able to swim and be confident in an aquatic environment. And be available for the two research project testing sessions within the SACS indoor gymnasium complex, prior to the study, and a week after the cessation of the study.

Plyometric training programme: The study shall comprise of three groups: aquatic plyometric training (APT), land-based plyometrics (LPT), and a control-group. All groups will be selected at random. The land-based plyometric group (LPT) shall be completing their intervention upon a grass-surfaced training field. The waist-deep aquatic plyometric group (APT) shall be completing the intervention in an approximately 113 centimetre deep pool. Both plyometric training groups will maintain the same training programme for the course of the whole study. The control-group will asked to maintain their existing, extra-curricular summer sport.

Freedom of Consent: The researcher's intent is to only include participants that freely choose to participate in this study. Thus participation is voluntary and your son is free to withdraw consent at any time. Withdrawal will have absolutely no influence on his future involvement with Stellenbosch University. Your consent to permit your son's participation in this research will be indicated by your signing and dating the attached consent form to this document and your son's consent form; both returned back to the researcher prior to the study starting. Signing the consent form indicates that you have freely given your son's account to participate, and there has no coercion to participate.

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Title of the research project: Comparison of aquatic and land plyometric training on power, speed and agility in adolescent rugby union players.

Your son has been asked to participate in a research study conducted by David Fabricius (Masters Student, Sport Science) from the Sport Science Department at Stellenbosch University. We seek your consent for him to participate in this research study. The results from your son's involvement in this study shall contribute to my Master of Sport Science thesis. He was selected as a possible participant in this study because he participates in power related sport such as rugby union and, is between the ages of 15 to 19 years.

1. PURPOSE OF THE STUDY
To compare the effectiveness of an aquatic-based and a land-based plyometrics training programme upon a male adolescent population, as part of preparatory conditioning for rugby union. And to determine which training condition will have the most significant effect upon sport-specific performance variables such as: leg power, speed, and agility.

2. PROCEDURES
Your son's participation in this study is voluntary; we would ask you to acknowledge:

(A.) You have read the participant information sheet, and the researcher has carefully explained to him all the procedures involved, as stated on the participant information sheet
(B.) Your son is responsible to completing three testing sessions for anthropometrical assessments, sports-specific functional testing, and questionnaires
(C.) You are aware that the total duration of the study is seven weeks, comprising of the whole first school term
(D.) You are aware that the anthropometrical assessments include body mass, stature, and body mass index
E.) You are aware that the sports-specific functional tests include four lower body power tests, sprint speed test, and an agility test
(F.) You are aware that with your son's participation in the study, he will have to complete a minimum of 12 of the 14, bi-weekly plyometric training sessions over the seven week intervention and not miss two consecutive training in the same week
(G.) Your son will have to take the responsibility to be and stay highly motivated during the testing programme
(H.) You are aware that if your son is selected to be apart of the control-group, he will not take part in any of the study's plyometric training, and will required to maintain his usual extra-curricular sport
(I.) You aware of the risks involved in this study and understood that the researcher/ test observers and/ or Stellenbosch University may not be held responsible for any injuries/ problems that might occur to your son during any of the tests or intervention in this project
(J.) I will receive a copy of the study participant information sheet and informed consent form for my own records

(K.) I understand that this research project has been approved by Stellenbosch University's Ethics Subcommittee A.

3. POTENTIAL RISKS AND DISCOMFORTS

The procedures used in this research project involve no serious risks to the participants. The researcher will do all within his power to reduce possible risks. If the participant falls in a health risk category, he would be excluded from the study. Due to the fact that participants will be performing physical tests, they might experience discomfort. The participants may stop at any time they feel that they can not continue the activity.

The participant will be advised to contact the principal researcher/ sport physician in case they experience any problems. However, if for some reason, they are not able to contact the researcher or physician then they are advised to contact their family practitioner or go to the Emergency Department of nearest hospital; Kingsbury or Claremont Hospitals in the Cape Town Southern suburbs. The researcher(s) are competent and experienced in sport testing and will not expose research participants to unnecessary risks or discomfort. Health and safety procedures are in place to deal with emergencies that may arise during the tests.

There will be a biokineticist (David Fabricius; contact number 083 315 7702) on site for the duration of all the tests and training. A medical doctor (Schwellnus, Derman, Swart; contact number: (021) 659 5644) and physiotherapists (Calligeris and Diale Physiotherapists; contact number: (021) 659 5684) are approximately 1.2 kilometres away from the testing venue, at the Sport Science Institute of South Africa, Newlands Cape Town.

4. POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

Plyometric exercise is a high-intensity, high-velocity resistance exercise designed to increase muscular power and coordination. Plyometrics have been found to significantly improve vertical jump, strength, reaction time, and speed. Research has shown that athletes who use plyometric exercises are better able to increase acceleration, vertical-jump height, leg strength, joint awareness, and overall proprioception. Adolescent athletes with a correctly prescribed intervention shall benefit greatly from plyometric training. The study coincides very well with pre-season for winter sports such as tennis, rugby union and field hockey, where vast amounts of leg power, agility and speed are required to succeed in these sports. Aquatic plyometric training also has the potential to provide similar improvements in skeletal muscle function and/or sport-related attributes of explosive training in land-based plyometrics with less delayed-onset muscle soreness.

5. PAYMENT FOR PARTICIPATION

As a participant your son will not receive any financial reimbursement or payment to participate in the study and there will be no costs involved for his participation in this project.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with your son will remain confidential, but that the results will be published in research journals. You understand that no material that could identify you or your son will be used in any reports of this study.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to allow your son to be in this study or not. If you would allow your son to volunteer in this study, he may withdraw, or you may withdraw your son at any time without consequences of any kind, without giving a reason and, there will no repercussions whatsoever at school and/ or within the boarding establishment. And in no way will affect his future involvement with Stellenbosch University. Your son and you may also refuse to answer any questions you don't WAnT to answer and still remain in the study. The investigator or medical doctor may withdraw your son from this project if deemed necessary for medical purposes.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact:

Main Researcher

David Fabricius (Masters of Sport Science student, Sport Science)

Phone: 0833157702; email: 15949362@sun.ac.za

Study Leader

Dr. Ranel Venter (Senior Lecturer: Department of Sport Science)

Phone: 021 808 4721; email: rev@sun.ac.za

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue your child's participation without penalty. You are not waiving any legal claims, rights or remedies because of his participation in this research study. If you have questions regarding his rights as a research participant, contact Ms. Maryke Hunter-Husselman at (021) 808 46 23 at the Unit for Research Development.

SIGNATURE OF GUARDIAN OR LEGAL REPRESENTATIVE

The information above was received to me/ the guardian/ legal representative by David Fabricius in English and I am/the guardian/ legal representative is in command of this language. I/the parent/the guardian was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent that the participant/participant may participate in this study. I have been given a copy of this form.

____

Name of Participant/Participant

____

Name of Legal Representative (if applicable)

____ ______________

Signature of Participant/Participant or Legal Representative *Date*

APPENDIX E

PARTICIPANT INFORMATION SHEET

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot·your knowledge partner

Sport Science Research Participation Information

Title of the research project:
"Comparison of aquatic and land plyometric training on power, speed and agility in adolescent rugby union players"

Researcher and Contact Address
David Fabricius (Masters of Sport Science student, Sport Science)
Phone: 0833157702; email: 15949362@sun.ac.za
Dr. R. Venter (Study Leader: Department of Sport Science)
Phone: 021 808 4721; email: rev@sun.ac.za

Background Information:

Plyometrics is a training technique that is used in all types of sports to increase strength and explosiveness. Research has shown that athletes who use plyometric exercises are better able to increase acceleration, vertical jump height, leg strength, joint awareness, and overall proprioception. Aquatic plyometric training also has the potential to provide similar improvements in skeletal muscle function and/or sport-related attributes of explosive training in land-based plyometrics with less delayed-onset muscle soreness.

Project Objectives:

To compare the effectiveness of an aquatic-based and a land-based plyometrics training programme upon a male adolescent population, as part of preparatory conditioning for rugby union. And to determine which training condition will have the most significant effect upon leg power, speed, and agility.

Participant Requirements:

To be included in this study you need to be in excellent health and between 15 and 19 years, without a history of musculo-skeletal, metabolic, cardiovascular or endocrine disorders, who participates in extra-curricular rugby union sport will allowed to volunteer to participate in the study. Participants will be required to maintain all sporting commitments during the running of the study, and still adhere to making at least 14 of the 16 training sessions over the seven week study. All individuals must be able to swim and be confident in an aquatic environment.

Payment for Participation:

As a participant you will not receive any financial reimbursement or payment to participate in the study and there will be no costs involved for your participation in this project.

Benefits: Plyometric exercise is a high-intensity, high-velocity resistance exercise designed to increase muscular power and coordination. Plyometrics have been found to significantly improve vertical jump, strength, reaction time, and speed. Research has shown that athletes who use plyometric exercises are better able to increase acceleration, vertical jump height, leg strength, joint awareness, and overall proprioception. Adolescent athletes with a correctly prescribed intervention shall benefit greatly from plyometric training. The study coincides very well with pre-season for winter sports such as tennis, rugby union and field hockey, where vast amounts of leg power, agility and speed are required to succeed in these sports. The postulated outcome of this study would be the validation that male adolescent athletes can perform high-intensity plyometric exercises in water; it is proposed that APT could provide similar benefits or offered as an alternative approach to performance, rather than land-based plyometrics, but with lower risk of muscle soreness and/or overtraining.

Participants completing the study will receive a report summarizing the main findings of this study and will be invited to a presentation of the completed study.

Research Procedures:

The research project is to be undertaken by the Stellenbosch University's Sport Science Department, to be completed at the South African College School (SACS) estate.

TESTING: All testing procedures shall be done within the SACS indoor gymnasium complex, which you shall visit on two separate occasions. During these visits, the following tests will be done:
First Visit: Is the baseline testing and familiarization with the apparatus and procedures. You would of have to bring back the consent form at was given to you last year for your parents/ guardians to have signed, to allow to participate in the study. Your height and weight will be taken. You will run an agility test, complete four lower body power jump tests consecutively, and then finally complete a forty metre sprint. None of these tests are invasive. This session may take between 60-90minutes
Second Visit: The second testing will commence at the end of the seven week plyometric training programme. The third visit will occur after a two week recovery period within the last week of the first term. The following tests shall be performed: body mass, the agility run, three consecutive jump tests, and then the forty metre sprint.

PLYOMETRIC TRAINING PROGRAMME: The study shall comprise of three groups: aquatic plyometric training (APT), land-based plyometrics (LPT), and a control-group. All groups will be selected at random. The land-based plyometric group (LPT) shall be completing their intervention upon a grass-surfaced training field. The waist-deep aquatic plyometric group (APT) shall be completing the intervention in an approximately 113 centimetre deep pool. Both plyometric training groups will maintain the same training programme for the course of the whole study. The control group will asked to maintain their existing, extra-curricular summer sport.

Potential Risks:

The procedures used in this research project involve no serious risks to the participants. The researcher will do all within his power to reduce possible risks. If the participant falls in a health risk category, he would be excluded from the study. There is a possibility that the participant may experience one or more symptoms during either: the 40-metre sprint, Standing long jump, Illinois Agility test, Sergeant Jump Test, and Fitrodyne Jump repeated jumps test. The symptoms include light-headedness, dizziness, fainting, chest, jaw, neck or back pain or pressure, severe shortness of breath, wheezing, coughing or difficulty breathing, nausea, cramps or severe pain or muscle ache and fatigue, since these tests due exert the body. Due to the fact that participants will be performing physical tests, they might experience discomfort. The participants may stop at any time they feel that they can not continue the activity.

The participant will be advised to contact the principal researcher/ sport physician in case they experience any problems. However, if for some reason, they are not able to contact the researcher or physician then they are advised to contact their family practitioner or go to the Emergency Department of nearest hospital; Kingsbury or Claremont Hospitals in the Cape Town Southern suburbs. The researcher(s) are competent and experienced in sport testing and will not expose research participants to unnecessary risks or discomfort. Health and safety procedures are in place to deal with emergencies that may arise during the tests.

There will be a biokineticist (David Fabricius; contact number 083 315 7702) on site for the duration of all the tests and training. A medical doctor (Schwellnus, Derman, Swart; contact number: (021) 659 5644) and physiotherapists (Calligeris and Diale Physiotherapists; contact number: (021) 659 5684) are approximately 1.2 kilometres away from the testing venue, at the Sport Science Institute of South Africa, Newlands Cape Town.

Rights of Research Participants:

You can choose whether to be in this study or not. You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms. Maryke Hunter-Husselman at (021) 808 46 23 at the Unit for Research Development.

Freedom of Consent:

The researcher's intent is to only include participants that freely choose to participate in this study. Thus participation is voluntary and you are free to withdraw consent at any time. Withdrawal will have absolutely no repercussions whatsoever at school and/ or within the boarding establishment. And in no way will affect your future involvement with Stellenbosch University. Your consent to participate in this research will be indicated by your parents' / guardian's signing and dating the consent form. Signing the consent form indicates that you have freely given your account to participate, and there has no coercion to participate.

Confidentiality:

All data collected for this research will be treated with absolute confidently. All questions and data sheets will be numerically coded and no names will be included in the data collection or analysis. This means that reported results will not include any names by any means.

Data & Results:

Recorded data will be securely retained for a period of six years at the Sport Science Department. No one except the researcher and project supervisor will be able to access this raw data. Please take note that overall data may be published in a peer review scientific journal.

Identification of Investigators:

If you have any questions or concerns about the research, please feel free to contact the principle researcher Mr. David Fabricius (021 462 6236, 083 315 7702 or 15949362@sun.ac.za) or the project supervisor, Dr. R. Venter (021 808 4721 or rev@sun.ac.za) at any time if you feel a topic has not been explained to your complete satisfaction.

APPENDIX F

STUDY PARTICIPANT INFORMED CONSENT FORM

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Title of the research project: Comparison of aquatic and land plyometric training on power, speed and agility in adolescent rugby union players

You are asked to participate in a research study conducted by David Fabricius (Masters Student, Sport Science) from the Sport Science Department at Stellenbosch University. The results from your involvement in this study shall contribute to my Master of Sport Science thesis. You were selected as a possible participant in this study because you participate in a power related sport such as rugby union and, are between the ages of 15 to 19 years.

10. PURPOSE OF THE STUDY

To compare the effectiveness of an aquatic-based and a land-based plyometrics training programme upon a male adolescent population, as part of preparatory conditioning for rugby union. And to determine which training condition will have the most significant effect upon sport-specific performance variables such as: leg power, speed, and agility.

11. PROCEDURES

Upon your selection to participate in this study, we would ask you to acknowledge:

(A.) You have read the participant information sheet, and the researcher has carefully explained to me all the procedures involved, as stated on the participant information sheet
(B.) You will take responsibility to complete the two testing sessions for anthropometrical assessments, sports-specific functional testing, and questionnaires
(C.) You are aware that the total duration of the study is seven weeks, comprising of the whole first school term.
(D.) You are aware that the anthropometrical assessments include body mass, stature, and body mass index
(E.) You are aware that the sports-specific functional tests include three lower body power tests, sprint speed test, and an agility test
(F.) You are aware that you will have to complete a minimum of 12 of the 14, bi-weekly plyometric training sessions over the seven week intervention and not miss two consecutive training in the same week
(G.) You take the responsibility to be and stay highly motivated during the testing programme
(H.) You are aware that if you are selected to be apart of the control-group, you will not take part in any of the study's plyometric training, and will required to maintain your usual extra-curricular sport.
(I.) You aware of the risks involved in this study and understood that the researcher/ test observers and/ or Stellenbosch University may not be held responsible for any injuries/ problems that might occur during any of the tests or intervention in this project
(J.) I will receive a copy of the participant information sheet and informed consent form for my own records
(K.) I understand that this research project has been approved by Stellenbosch University's Ethics Subcommittee A.

12. POTENTIAL RISKS AND DISCOMFORTS

The procedures used in this research project involve no serious risks to the participants. The researcher will do all within his power to reduce possible risks. If the participant falls in a health risk category, he would be excluded from the study. There is a possibility that the participant may experience one or more symptoms during either: the 40-metre sprint, Standing long jump, Illinois Agility test, Sergeant Jump Test, and Fitrodyne repeated jumps test. The symptoms include light-headedness, dizziness, fainting, chest, jaw, neck or back pain or pressure, severe shortness of breath, wheezing, coughing or difficulty breathing, nausea, cramps or severe pain or muscle ache and fatigue, since these tests due exert the body. Due to the fact that participants will be performing physical tests, they might experience discomfort. The participants may stop at any time they feel that they can not continue the activity.

The participant will be advised to contact the principal researcher/ sport physician in case they experience any problems. However, if for some reason, they are not able to contact the researcher or physician then they are advised to contact their family practitioner or go to the Emergency Department of nearest hospital; Kingsbury or Claremont Hospitals in the Cape Town Southern suburbs. The researcher(s) are competent and experienced in sport testing and will not expose research participants to unnecessary risks or discomfort. Health and safety procedures are in place to deal with emergencies that may arise during the tests.

There will be a biokineticist (David Fabricius; contact number 083 315 7702) on site for the duration of all the tests and training. A medical doctor (Schwellnus, Derman, Swart; contact number: (021) 659 5644) and physiotherapists (Calligeris and Diale Physiotherapists; contact number: (021) 659 5684) are approximately 1.2 kilometres away from the testing venue, at the Sport Science Institute of South Africa, Newlands Cape Town.

13. POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

Plyometric exercise is a high-intensity, high-velocity resistance exercise designed to increase muscular power and coordination. Plyometrics have been found to significantly improve vertical jump, strength, reaction time, and speed. Research has shown that athletes who use plyometric exercises are better able to increase acceleration, vertical-jump height, leg strength, joint awareness, and overall proprioception. Adolescent athletes with a correctly prescribed intervention shall benefit greatly from plyometric training. The study coincides very well with pre-season for winter sports such as tennis, rugby union and field hockey, where vast amounts of leg power, agility and speed are required to succeed in these sports. Aquatic plyometric training also has the potential to provide similar improvements in skeletal muscle function and/or sport-related attributes of explosive training in land-based plyometrics with less delayed-onset muscle soreness.

14. PAYMENT FOR PARTICIPATION

As a participant you will not receive any financial reimbursement or payment to participate in the study and there will be no costs involved for your participation in this project.

15. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential, but that the results will be published in research journals. You understand that no material that could identify you will be used in any reports of this study.

16. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind, without giving a reason and, there will no repercussions whatsoever at school and/ or within the boarding establishment. And in no way will affect your future involvement with Stellenbosch University. You may also refuse to answer any questions you don't WAnT to answer and still remain in the study. The investigator or medical doctor may withdraw you from this project if deemed necessary for medical purposes.

17. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact:

Main Researcher
David Fabricius (Masters of Sport Science student, Sport Science)
Phone: 0833157702; email: 15949362@sun.ac.za
Study Leader
Dr. Ranel Venter (Senior Lecturer: Department of Sport Science)
Phone: 021 808 4721; email: rev@sun.ac.za

18. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms. Maryke Hunter-Husselman at (021) 808 46 23 at the Unit for Research Development.

SIGNATURE OF RESEARCH PARTICIPANT

The information above was described to me/ the participant by David Fabricius in English and I am in command of this language. I/the participant was given the opportunity to ask questions and these questions were answered to MY satisfaction.

I hereby consent to participate in this study. I have been given a copy of this form.

____
Name of Participant/Participant

______________________________________ ______________
Signature of Participant/Participant *Date*

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to __________________ [*name of the participant].* He was encouraged and given ample time to ask me any questions. This conversation was conducted in English and no translator was used.

______________________________________ ______________

Signature of Investigator ***Date***

APPENDIX G

RESEARCH PARTICIPANT HEALTH SCREENING FORM

HEALTH HISTORY SECTION IS ADAPTED FROM THE STANDARDIZED PHYSCIAL ACTIVITY READINESS PAR-Q & YOU QUESTIONNAIRE (AMERICAN COLLEGE OF SOPRTS MEDICINE, 2006)

Sport Science Department
Coetzenburg
Stellenbosch
7600

Telephone **021 808 49 15**
Facsimile **021 808 48 17**

Stellenbosch University

Sport Science Research Participant Health Screening Form

Researchers and Contact Address
David Fabricius (MSc student, Sport Science)
Phone: 083 315 7702 or 021 462 62 36; email: 15949362@sun.ac.za
Dr. R Venter (Promoter; Department of Sport Science)
Phone: 021 808 49 15
Prof. Derman/ Prof. Schwellnus and Dr. Swart (Medical Doctors, Medical Practice, Sport Science Institute of South Africa)
Phone: 021 659 56 44
Research Project Correspondence: aquaresearchproject@gmail.com

TEST ADMINISTRATOR ____________________

HEALTH HISTORY

Please complete the following questions

Contact number of general physician/ doctor	
Has your doctor ever said that you may not do any physical activity?	No ☐ Yes ☐
Do you feel pain in your chest when you do physical exercise?	No ☐ Yes ☐
Do you smoke?	No ☐ Yes ☐
Have you had any chest pains in the past month?	No ☐ Yes ☐
Do you lose your balance because of dizziness?	No ☐ Yes ☐
Do you experience the loss of consciousness?	No ☐ Yes ☐
	No ☐ Yes ☐
If yes, please specify:	
Are you using any medication?	No ☐ Yes ☐
If yes, please specify: ***Name and indicate if chronic***	

Do you know of any reason why you should not do this study?		No ☐ Yes ☐
Do you suffer from any of the following conditions? Please specify if necessary.		
Musculo-skeletal problems	No ☐ Yes ☐	
Metabolic- and endocrine disorders	No ☐ Yes ☐	
Immune deficiencies	No ☐ Yes ☐	
Cardiorespiratory disorders	No ☐ Yes ☐	
Cardiovascular disorders	No ☐ Yes ☐	
Haematological disorders	No ☐ Yes ☐	

If you said yes to one or more questions, the researcher will contact you to refer you a doctor or your family general practitioner. If your health status changes during the study, please inform the principle investigator.

Participation to this study in voluntary and you may withdraw from the study at anytime.

Please do not hesitate to ask any questions. You can contact the principle researcher, David Fabricius:

E-mail: aquaresearchproject@gmail.com
Cellular phone: 083 315 7702
Fax: 021 808 48 17

Thank you for your co-operation.

Yours Sincerely

David Fabricius

I, ____ (Name of participant/ participant) have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

The information above was described to me/ the participant by David Fabricius in English and I am/the participant is in command of this language. I/the parent/the guardian was given the opportunity to ask questions and these questions were answered to his satisfaction.

____
Signature of Participant

____________________________________ ____________________________________

Name of Parent/ Legal Representative **Signature of Parent/Legal Representative**

____________________________________ ____________________________________
Signature of Researcher **Date**

APPENDIX H

PLYOMETRIC INTERVENTION PROGRAMME

Week 1

Warm-up:

- Jogging for 3 min at 50% pace around field or pool
- Dynamic stretches (high-knee jogging, skipping, bodyweight squats)

Rest between sets: 60 seconds (1:5; work: rest)

Rest between repetitions: 30 seconds

Rest between repetitions for depth jumps: 5-10 seconds

Session 1

Exercise	Intensity	Sets	Reps	Duration	Distance
Ankle hops	Low	2	1		20.5m
Skipping	Low	2	1		20.5m
Power skipping	Low	2	1		20.5m
Tuck jumps	Medium	2	1		20.5m
Repeated countermovement jumps	Medium	3		10s	
Depth jumps (Into landing only)	Low	2	3		

Session 2

Exercise	Intensity	Sets	Reps	Duration	Distance
Ankle hops	Low	2	1		20.5m
Skipping	Low	2	1		20.5m
Power skipping	Low	2	1		20.5m
Tuck jumps	Medium	2	1		20.5m
Repeated countermovement jumps	Medium	3		10s	
Depth jumps (Into landing only)	Low	2	3		

Week 2

Warm-up:

- Jogging for 3 min at 50% pace around field or pool
- Dynamic stretches (high-knee jogging, skipping, bodyweight squats)

Rest between sets: 60 seconds (1:5; work: rest)

Rest between repetitions: 30 seconds

Rest between repetitions for depth jumps: 5-10 seconds

Session 1

Exercise	**Intensity**	**Sets**	**Reps**	**Duration**	**Distance**
Ankle hops	Low	3	1		20.5m
Skipping	Low	3	1		20.5m
Power skipping	Low	3	1		20.5m
Tuck jumps	Medium	3	1		20.5m
Repeated countermovement jumps	Medium	3		10s	
Depth jumps (Into landing only)	Low	3	3		

Session 2

Exercise	**Intensity**	**Sets**	**Reps**	**Duration**	**Distance**
Ankle hops	Low	3	1		20.5m
Skipping	Low	3	1		20.5m
Power skipping	Low	3	1		20.5m
Tuck jumps	Medium	3	1		20.5m
Repeated countermovement jumps	Medium	3		10s	
Depth jumps (Into landing only)	Low	3	3		

Week 3

Warm-up:

- Jogging for 3 min at 50% pace around field or pool

- Dynamic stretches (high-knee jogging, skipping, bodyweight squats)

Rest between sets: 60 seconds (1:5; work: rest)

Rest between repetitions: 30 seconds

Rest between repetitions for depth jumps: 5-10 seconds

Session 1

Exercise	Intensity	Sets	Reps	Duration	Distance
Single-leg ankle hops	Low	3 (6)	1		20.5m
Side-to-side ankle hops	Low	3		15s	
Tuck jump	Medium	3	1		20.5m
Repeated long jump	Medium	3	1		20.5m
Repeated countermovement jumps	Medium	4		10s	
Depth Jumps	Medium	3	3		

Session 2

Exercise	Intensity	Sets	Reps	Duration	Distance
Single-leg ankle hops	Low	3 (6)	1		20.5m
Side-to-side ankle hops	Low	3		15s	
Tuck jump	Medium	3	1		20.5m
Repeated long jump	Medium	3	1		20.5m
Repeated countermovement jumps	Medium	4		10s	
Depth Jumps	Medium	3	3		

Week 4

Warm-up:

- Jogging for 3 min at 50% pace around field or pool
- Dynamic stretches (high-knee jogging, skipping, bodyweight squats)

Rest between sets: 60 seconds (1:5; work: rest)

Rest between repetitions: 30 seconds

Rest between repetitions for depth jumps: 5-10 seconds

Session 1

Exercise	Intensity	Sets	Reps	Duration	Distance
Single-leg ankle hops (L/R)	Low	4 (8)	1		20.5m
Side-to-side ankle hops	Low	4		15s	
Tuck jump	Medium	4	1		20.5m
Repeated long jumps	Medium	4	1		20.5m
Repeated countermovement jumps	Medium	4		20s	
Depth Jumps	Medium	3	3		

Session 2

Exercise	Intensity	Sets	Reps	Duration	Distance
Single-leg ankle hops (L/R)	Low	4 (8)	1		20.5m
Side-to-side ankle hops	Low	4		15s	
Tuck jump	Medium	4	1		20.5m
Repeated long jump	Medium	4	1		20.5m
Repeated countermovement jumps	Medium	4		20s	
Depth Jumps	Medium	3	3		

Week 5

Warm-up:

- Jogging for 3 min at 50% pace around field or pool
- Dynamic stretches (high-knee jogging, skipping, bodyweight squats)

Rest between sets: 60 seconds (1:5; work: rest)

Rest between repetitions: 30 seconds

Rest between repetitions for depth jumps: 5-10 seconds

Session 1

Exercise	Intensity	Sets	Reps	Duration	Distance
Zigzag hops	Low	4	1		20.5m
Single-leg side-to-side ankle hops(L/R)	Medium	4 (8)		10s	
Repeated vertical jump	Medium	4	1		20.5m
Repeated long jumps	Medium	4	1		20.5m
Repeated countermovement jumps	Medium	4		20s	
Depth Jumps	Medium	4	3		

Session 2

Exercise	Intensity	Sets	Reps	Duration	Distance
Zigzag hops	Low	4	1		20.5m
Single-leg side-to-side ankle hops(L/R)	Medium	4 (8)	1	10s	
Repeated vertical jump	Medium	4	1		20.5m
Repeated long jumps	Medium	4	1		20.5m
Repeated countermovement jumps	Medium	4		20s	
Depth Jumps	Medium	4	3		

Week 6

Warm-up:

- Jogging for 3 min at 50% pace around field or pool
- Dynamic stretches (high-knee jogging, skipping, bodyweight squats)

Rest between sets: 60 seconds (1:5; work: rest)

Rest between repetitions: 30 seconds

Rest between repetitions for depth jumps: 5-10 seconds

Session 1

Exercise	Intensity	Sets	Reps	Duration	Distance
Zigzag hops	Low	5	1		20.5m
Single-leg side-to-side ankle hops(L/R)	Medium	5 (10)		10s	
Repeated vertical jump	Medium	5	1		20.5m
Repeated long jumps	Medium	5	1		20.5m
Repeated countermovement jumps	Medium	4		30s	
Depth Jumps	Medium	5	3		

Session 2

Exercise	Intensity	Sets	Reps	Duration	Distance
Zigzag hops	Low	5	1		20.5m
Single-leg side-to-side ankle hops(L/R)	Medium	5 (10)		10s	
Repeated vertical jump	Medium	5	1		20.5m
Repeated long jumps	Medium	5	1		20.5m
Repeated countermovement jumps	Medium	4		30s	
Depth Jumps	Medium	5	3		

Week 7

Warm-up:

- Jogging for 3 min at 50% pace around field or pool
- Dynamic stretches (high-knee jogging, skipping, bodyweight squats)

Rest between sets: 60 seconds (1:5; work: rest)

Rest between repetitions: 30 seconds

Rest between repetitions for depth jumps: 5-10 seconds

Session 1

Exercise	Intensity	Sets	Reps	Duration	Distance
Power skipping	Low	5	1		20.5m
Zigzag hops	Medium	5	1		20.5m
Repeated vertical jump	Medium	5	1		20.5m
Front box jumps (3)	High	5	3		
Repeated countermovement jumps	Medium	4		30s	
Depth Jumps	Medium	5	3		

Session 2

Exercise	Intensity	Sets	Reps	Duration	Distance
Power skipping	Low	5	1		20.5m
Zigzag hops	Medium	5	1		20.5m
Repeated vertical jump	Medium	5	1		20.5m
Front box jumps (3)	High	5	3		
Repeated countermovement jumps	Medium	4		30s	
Depth Jumps	Medium	5	3		