

CHAPTER 2



2

LITERATURE REVIEW: Effects of different plyometric training programs on the physical motor ability and anthropometric components of subjects

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1. INTRODUCTION

The change of “Rugby Union” from an amateur to a professional sporting code in 1995 placed much more emphasis on the financial rewards that players and the coaching staff could obtain when winning matches (Duthie *et al.*, 2003:974-975; Quarrie & Hopkins., 2007:895). Therefore, the ability to become faster, stronger and more explosive in a shorter period of time became a high priority for players, coaches and conditioning coaches. Players who are faster, stronger and more explosive will be able to break through tackles, accelerate fast from a static position and change running direction fast and effectively during attacks (Luger & Pook, 2004). This need for better power related abilities led to the introduction of jump training, resisted jump training and complex power training methods into the training regimens of rugby players (Comyns *et al.*, 2007:59; Bevan *et al.*, 2009:1780). However, the broad spectrum of components that rugby players need to develop to compete successfully in rugby matches has forced rugby coaches and other conditioning experts to focus on combined rugby-conditioning programs which make use of a wide range of training methods rather than simplistic conditioning programs which only focus on one training modality at a time (Corcoran & Bird, 2009:66).

In 1975 Fred Wilt started to use the term plyometrics to describe the jump and power related training methods that athletes use (Chu, 1998:1). The term plyometrics was derived from two Latin words namely “plyo” and “metrics” which could directly be translated to mean a

“measurable increase” (Chu, 1998:1). Plyometrics can be described as any exercise that utilises the stretch reflex of the muscles to produce a forceful reaction (Shah, 2012:116). These exercises are aimed at linking sheer muscle strength and movement speed in order to produce muscle power (Adams *et al.*, 1992:36; Australian Rugby Union, 2004:69; Chatzinikolaou *et al.*, 2010:1389). The physiological principles of plyometric training can be explained by making use of two models: The mechanical model states that mechanical, elastic potential energy is stored in tendons and muscles due to a rapid stretch that occurs during the eccentric muscle action and is released during the concentric muscle action to contribute to total force production (Van den Heuvel Yang *et al.*, 2012:412). The neurophysiological model involves the stimulation of the stretch reflex and stretch-shortening cycle through a rapid and forceful eccentric muscle action to facilitate a maximal increase in muscle recruitment over a minimal amount of time during a concentric muscle contraction (Van den Heuvel Yang *et al.*, 2012:412). Three phases can be distinguished during plyometric actions, namely an eccentric/stretching or loading phase; an amortization phase which refers to the delay between the concentric and eccentric phases and a concentric phase (Potach & Chu, 2008:414-417). Therefore, for plyometrics to be effective there needs to be a muscle contraction that is invoked by a rapid eccentric movement, followed by a short amortization phase, which ends with an explosive concentric movement (Kubo *et al.*, 2007:1801; Arazi *et al.*, 2012b:23). Most exercises involve a muscular contraction that starts off rapidly, but decelerates suddenly before the end of the movement. However, plyometric exercises are characterized by the lack of a “decelerative” phase and are open-ended movements into free space (Chu, 1998:5; Shah, 2012:116).

Plyometric training methods include, amongst others, variations of bounding, leaping, skipping, hopping and jumping drills; medicine ball throwing exercises as well as weightlifting and resistance exercise variations (Dodd & Alvar, 2007:1177; Cappa & Behm, 2011:1; Shah, 2012:116). The need for conditioning coaches to find training regimens that have a greater neural effect have also forced them to explore other plyometric training variations such as resisted jump training where resistance is added to plyometric jumps as well as complex training methods where plyometric exercises are combined with strength training exercises (Weber *et al.*, 2008:726). Various sporting codes such as basketball, volleyball, handball, cycling and soccer have explored plyometrics as an add-on to their existing training regimens (Ebben *et al.*, 2000; Perez-Gomez *et al.*, 2008; Bal *et al.*, 2011; Bonacci *et al.*, 2011; Arazi *et al.*, 2012a/b). However, notwithstanding the widespread acceptance and use of plyometric training alone and as an added training method to sport specific programs, the possible benefits of these type of program have been questioned by

several researchers (Bruce-Low & Smith, 2007:30; De Villarreal *et al.*, 2010:519; Hill & Leiszler, 2011:1).

It is in view of the uncertainty with regard to the benefits of plyometric programs alone or combined plyometric or combined plyometric and sport specific program, that this literature overview was undertaken. The first aim of this literature overview was to review critically all available and relevant research of the last 14 years (2000-2013) with regard to plyometric related program, the type of program that were used as well as the effects of these program on the physical, motor ability and anthropometric components of study subjects. Secondly, the researchers made an attempt to provide detailed guidelines to prospective researchers and practitioners in the field of Sport Science for the use of different types of plyometric training methods and programs.

2. METHOD OF RESEARCH

All related computer searches were performed using SportDiscus, Medline, Academic Research, Academic Search Premier and Masterfile databases. Furthermore, Google Scholar internet search engine was also used to trace the available literature. The searches were narrowed down to only include articles from the past 14 years (2000-2013) and those which made use of adult populations (age: ≥ 18 years) as test subjects. Furthermore, articles that investigated plyometric training programs alone or a combination with other conditioning techniques or in combination with sport specific programs were used. Key words used in the searches included, but were not limited to, the following: plyometrics, plyometric training, explosive power, combined program, complex training, resistance training, resisted jump training.

In the subsequent section the types of plyometric training programs that are cited in the literature are named and discussed in order to provide the reader with background information concerning the methodology of the different types of programs.

3. TYPES OF PLYOMETRIC TRAINING PROGRAMS

3.1 Land-based plyometric training programs

3.1.1 Complex plyometric training program

Complex training program are conducted by first performing a resistance exercise which is then followed by the execution of a matched plyometric exercise (Jensen & Ebben, 2003:345; Ingle *et*

al., 2006:988; Bevan *et al.*, 2009:1780). For example, squats will be followed by squat jumps or rear foot elevated one legged squats will be followed by lunge jumps.

3.1.2 Resistive jump training program

Resistive jump training can be described as the use of a wide range of resistive loads (for example resistance bands) while performing a plyometric exercise which requires the body's musculature to move against an opposing force (Fleck & Kraemer, 2004:3; Faigenbaum & Myer, 2010:56). The use of the VertiMax apparatus (VertiMax Inc, 2013) as a resistive jump training apparatus to obtain improvements in explosive power and speed over longer periods of time is being widely proclaimed through the internet (VertiMax Inc, 2013). The resistance band-setup of the VertiMax allows practitioners to change the resistance or load that subjects jump against. According to the VertiMax web site (VertiMax Inc, 2013), the purpose of this apparatus is to maximize leg power and arm swing velocity in relation to the athlete's balance control so that a higher vertical lift can be obtained during jumping exercises.

3.1.3 Resistance jump training program

Resistance jump training can be defined as jumps that are performed with an extra weight that can take the form of a barbell or dumbbells. Researchers differentiate between low speed/high force training which is described as training at relative high intensities of 80% of the 1 repetition maximum (RM) or high speed/high power training which is described as training at relative low intensities and high speeds (Harris *et al.*, 2000:14). According to Harris *et al.* (2000:14), low speed/high force training will lead to maximal strength gains, whereas high speed/high power training will result in superior power output gains.

3.1.4 Complex weight lifting resistance training program

The main objective of Olympic lifts is to initiate force through a maximal effort against a maximum resistance (Chu, 1998:87). Athletes commonly use Olympic lifts to develop both explosive power and functional strength due to the fact that these exercises are executed at high speeds over a bigger range of motion than other exercises (Sandler, 2005:102). Examples of exercises that are used under this category are: Power cleans, snatches as well as clean and jerks, just to name a few.

3.1.5 Body weight jumping plyometric training program

Practitioners use different types of plyometric exercises to stimulate the slow and fast stretch shortening cycle (SSC). For example vertical jumps and box jumps are used to stimulate the slow, SSC whereas bounding, hurdle hops and depth jumps are used to stimulate the fast SSC (Jensen *et al.*, 2008:199).

3.2 Aquatic-based plyometric training programs

Researchers have highlighted the potential risks of land-based plyometric training programs as a conditioning technique and stated that aquatic-based plyometric training program may provide a safer and more effective alternative for athletes who need to develop their muscle power optimally (Robinson *et al.* 2004:84; Arazi *et al.* 2012a:2). According to Ploeg *et al.* (2012:40), less pressure is put on the musculoskeletal system due to a decrease in impact forces during the execution of aquatic-based plyometric training programs which reduces injury risk. As the name suggests, aquatic-based plyometric training programs are always performed in water and make use of water's unique properties such as surface, profile and wave drag as well as the high viscosity of this medium to perform plyometric related exercises (Robinson *et al.*, 2004:84).

4. EFFECTS OF DIFFERENT PLYOMETRIC TRAINING PROGRAMS ON THE PHYSICAL, MOTOR ABILITY AND ANTHROPOMETRIC COMPONENTS OF SUBJECTS

In view that the main focus of this review was to review critically all available and relevant research of the last 14 years (2000-2013) with regard to plyometric related program, the type of programs that were used as well as the effects of these program on the physical, motor ability and anthropometric components of study subjects, the researcher decided to review the relevant literature under the following categories: the effects of using a plyometric training program alone or the effects of using a combined plyometric training program. Fifty articles (see Table 1 and 2) which investigated the effects of plyometric training programs alone (29 articles) or combined plyometric training program (21 articles) were identified. The results and conclusions of these articles will form the basis of the following discussion.

4.1 Effects of plyometric training programs alone on the physical, motor ability and anthropometric components of subjects

Table 1 presents information with regard to articles that investigated the effects of plyometric training programs alone on the physical, motor ability and anthropometric components of subjects.

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Rimmer and Sleivert (2000) Effects of a plyometrics intervention program on sprint performance	26 males 24 ± 4	To determine the effects of: • Plyometric training group (PT): sprint-specific plyometric exercises of 2-8 sets and 5-10 reps with 3 min rest between sets • Sprint training group (ST): 2-8 maximal effort sprints over 25-55 m with a 3-4 min recovery period between each effort • Control group (CG): no plyometric and sprint training • Preceded by a warm-up of 10 min running and 5 min leg stretching on 10 and 40m sprint performance.	8 weeks PT and ST: 2 x per week except week 4 1 x per week
Miller <i>et al.</i> (2002) Comparisons of land-based and aquatic-based plyometric programs during an 8-week training period	21 females and 19 males 22.2 ± 3.9	To determine the effects of: • Aquatic-plyometric training group (APT): side to side ankle hops, standing jump and reach, front cone jumps, double leg hops, lateral cone hops, tuck jumps with knees up, lateral jump over barrier and single leg with low-high training intensity (80-120 foot contacts) • Land-plyometric training group (LPT): side to side ankle hops, standing jump and reach, front cone jumps, double leg hops, lateral cone hops, tuck jumps with knees up, lateral jump over barrier and single leg with low-high training intensity (80-120 foot contacts) • CG: no training on vertical jump power, Margaria-Kalamen muscle power output test, ankle and knee isokinetic peak torque, range of motion and muscle soreness in sedentary and recreational active individuals.	8 weeks APT: 2 x per week LPT: 2 x per week

Values presented as PT = Plyometric training; ST = Sprint training; CG = Control group; APT = Aquatic plyometric training; LPT = Land plyometric training

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Robinson <i>et al.</i> (2004) The effects of land versus aquatic plyometrics on power, torque, velocity and muscle soreness in women	32 females 20.2 ± 0.3	To determine the effects of: APT group: 3-5 sets of 10-20 reps of 10 drills involving a series of bounds, hops and jumps which lasted 65 min and carefully progressed over an 8 week training period: sets and reps were increased after two weeks and again after 5 weeks. Training was conducted in a pool LPT group: 3-5 sets of 10-20 reps of 10 drills involving a series of bounds, hops and jumps which lasted 65 min and carefully progressed over an 8 week training period: sets and reps were increased after two weeks and again after 5 weeks. Training was conducted in a gymnasium - a 5 min warm-up preceded each session on peak power output (Sargent vertical jump test), peak torque (isokinetic strength test), peak velocity (40 m sprint), and bone density, muscle soreness and pain sensitivity (subjective and objective self-report muscle soreness scale and algometre of the rectus femoris, biceps femoris and gastrocnemius) and also anthropometric measurements (height and leg length) in physically active women.	8 weeks APT: 3 x per week LPT: 3 x per week
Baker and Newton (2005) Acute effect on power output of alternating an agonist and antagonist muscle exercise during complex training	9 males 18.8 ± 0.8	To determine the effects of: Experimental group (EG): 5 reps bench press throws with 40kg and prone bench pulls at 50% of 1RM bench press CG: no intervention exercises - Preceded by a warm-up of 5 reps bench press (60kg) and bench press throws (20kg) on power output during bench press throws in the agonist muscle exercise in college rugby league players.	1 day

Values presented as APT = Aquatic plyometric training; LPT = Land plyometric training; EG = Experimental group; CG = Control group

Table 1: Studies regarding the effects of plyometric training program alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Clark <i>et al.</i> (2006) The acute effects of a single set of contrast preloading on a loaded counter movement jump training session	9 males 17.3 ± 2.2	To determine the effects of: • Jump squat training group: 6 reps loaded countermovement jumps (LCMJs) with 40kg which was followed 4 min later with 4 sets x 6 reps LCMJ with 20kg. Rest of 3 min between sets was allowed • CG: 6 reps LCMJ with 20kg, which was followed 4 min later with 4 sets x 6 reps LCMJ with 20kg. Rest of 3 min between sets was allowed • Preceded by a 5 min warm-up of light intensity ladder and hurdle drills on the vertical jump height, peak power output and mean power output.	2 weeks 2 sessions
Miller <i>et al.</i> (2006) The effects of a 6 week plyometric training program on agility	19 females and 9 males 24.2 ± 4.8	To determine the effects of: • PT group: 2-5 sets of 6-15 reps ranging between 90-140 foot contacts: side to side ankle hops, standing jump and reach, front cone jumps, standing long jump, lateral jump over barrier, double leg hops, lateral cone hops, diagonal cone hops, standing long jump with lateral sprint, single leg bounding, single leg lateral jumps, cone hops with 180° turn, hexagon drill and cone hops with change of direction sprints from a low to high training intensity • CG: no plyometric exercises on agility using the T-test and Illinois Agility Run test and power output during a force plate test (ground contact time while hopping) in subjects.	6 weeks PT: 2 x per week

Values presented as CG = Control group; PT = Plyometric training

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Reyment <i>et al.</i> (2006) Effects of a four week plyometric training program on measurements of power in male collegiate hockey players	17 males 20.9 ± 1.9	To determine the effects of: PT: warm up which consisted of 2-4 sets of 10 yard low intensity dynamic exercises which lasted 15 minutes in total that preceded plyometric drills; followed by a 4-week (low, medium, high) training intensity one-legged and two legged multi directional jumps: during week 1-4 players performed 40 reps skate jumps, 2 sets of 10 reps squats, squat jumps, split squat jumps super sets and 4 sets of 20 sec Russian box jumps (week 1 and 2); 3-4 sets of 30 sec slide boards; 2 sets of 10-14 sec box jumps, 2 sets of 10-15 sec line jumps and 5sets of 20 sec Russian box jumps (week 3 and 4). A 10 min general cool down concluded the training session on the 3 site skinfold test, height and weight, 40 yard dash, vertical jump test height of the left, right and both foot jumps and anaerobic power values using the Wingate bike testing protocol of male hockey players.	4 weeks PT: 2 x per week Hockey training: did not alter hockey training routine throughout the 4 weeks
Wilcox <i>et al.</i> (2006) Acute explosive-force movements enhance bench-press performance in athletic men	12 males 22.3 ± 2.5	To determine the effects of: Session 1: performing a series of 1RM attempts with increasing loads until the 1RM is reached Session 2: performing 2 medicine-ball chest passes (3-5kg) 30 sec before each 1RM attempt Session 3: performing 2 plyometric push-ups 30 sec before each 1RM attempt - Preceded by a warm-up consisting of 5 min low intensity cycling and 3 upper body static stretches on bench-press 1RM strength in athletic men.	3 weeks

Values presented as PT = Plyometric training; RM = Repetition maximum

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Kubo <i>et al.</i> (2007) Effects of plyometric and weight training on muscle-tendon complex and jump performance	10 males 22 ± 2	To determine the effect of: - PT group performed on one side and WT group on the other side in the same session. The leg of the PT protocol were executed first and the WT leg thereafter PT group: 10 reps x 5 sets hopping and drop jump exercises with a between-set rest interval of 30 sec, which consisted of unilateral plantar flexion at 40% of the 1RM WT group: 10 reps x 5 sets hopping and drop jump exercises lifting and lowering the load at an constant velocity, taking 1 sec for the concentric action and 3 sec for the eccentric action with a rest interval of 60 sec, which consisted of unilateral plantar flexion at 80% of the 1RM on the mechanical properties of the muscle-tendon complex, muscle activities and performance during jumping.	12 weeks PT: 4 x per week WT: 4 x per week
Markovic <i>et al.</i> (2007) Effects of sprint and plyometric training on muscle function and athletic performance	93 males 20.1 ± 1.1	To determine the effects of: ST group: 3-4 sets of 3 reps sprints with rest intervals of 3 min and 1 min between sets and repetitions, respectively for 10 weeks PT group: 4-10 sets of 10 reps hurdle jumps (40-60 cm) with 3 min rest intervals between sets for 10 weeks CG: no training on maximal isometric squat strength, squat and countermovement jump height, power drop jump performance and 3 athletic performance tests including the standing long jump, 20m sprint and 20 yard shuttle run test in physical education students.	10 weeks ST: 3 x per week PT: 3 x per week

Values presented as PT = Plyometric training; WT = Weight training; RM = Repetition maximum; ST = Sprint training; PT = Plyometric training; CG = Control group

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Stemm and Jacobson (2007) Comparison of land and aquatic-based plyometric training on vertical jump performance	21 males 24 ± 2.5	To determine the effects of: - a 5 min warm-up on a stationary bicycle and a 5 min stretching session which preceded each training routine APT group: 3 sets of 15 squat jumps, side hops and knee tuck jumps separated by 1 min rest LPT group: 3 sets of 15 squat jumps, side hops and knee tuck jumps separated by 1 min rest CG: no training on maximum vertical jump height using the vertec vertical jump test in physically active college age men.	6 weeks APT: 2 x per week LPT: 2 x per week
McClenton <i>et al.</i> (2008) The effect of short-term vertimax versus depth jump training on vertical performance	20 males and 11 females 21.6 ± 2.08	To determine the effect of: Vertimax training group (VTG): 1-2 sets x 4-8 reps of quarter quick jumps, squat jumps with increased resistance and contrast jumps that consisted of multiple squat jumps with no resistance (totalling 139 jumps) Depth jump training group (DJG): 2-4 sets x 4-10 reps of depth jumps of which the jump height increased by 10 cm weekly to a maximum height of 100 cm (totalling 137 jumps) CG: no training on vertical jump height in recreational trained volunteers.	6 weeks VTG, DJG and CG: 2 x per week

Values presented as APT = Aquatic plyometric training; LPT = Land plyometric training; CG = Control group; VTG = Vertimax training; DJG = Depth jump training

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Shiran <i>et al.</i> (2008) The effect of aquatic and land plyometric training on physical performance and muscular enzymes in male wrestlers	21 male wrestlers 20.3 ± 3.6	To determine the effects of: - a 15 min warm-up preceded each training session and each session closed with 5 min stretches for cool-down APT group: depth jumps, star jumps, rocket jumps and squat jumps that were done with an gradual increment starting in week 1-2: 80% training intensity, week 3-5: 85% training intensity, week 6-8: 90% training intensity, week 9-11: 95% training intensity, week 12-14: 100% training intensity and week 15-16: 105% training intensity. Exercises were done in sets of 30 reps with 30-45 sec rest between sets and 2 min rest between each jump and lasted for 55 min LPT group: depth jumps, star jumps, rocket jumps and squat jumps that were done with an gradual increment starting in week 1-2: 80% training intensity, week 3-5: 85% training intensity, week 6-8: 90% training intensity, week 9-11: 95% training intensity, week 12-14: 100% training intensity and week 15-16: 105% training intensity. Exercises were done in sets of 30 reps with 30-45 sec rest between sets and 2 min rest between each jump and lasted for 55 min CG: no plyometric training but continued with their normal training on power (RAST test), speed (5, 10, 20m test), maximum strength (back squat), agility and fatigue index($FI = \frac{\text{Maximum power} - \text{Minimum power}}{\text{Total time elapsed in 6 reps}}$) in male wrestlers.	16 sessions APT: 3 x per week LPT: 3 x per week

Values presented as APT = Aquatic plyometric training; LPT = Land plyometric training; CG = Control group; RAST = Running-based anaerobic sprint test

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Drinkwater <i>et al.</i> (2009) Effect of an acute bout of plyometric exercise on neuromuscular fatigue and recovery in recreational athletes	10 males 21.6 ± 1.3	To determine the effects of: PT session: alternate single-leg bounds, jumps over cones, alternate leg power skips, lateral hopping with 2 jumps in each direction over cones and depth jumps (totalling 212 ground contacts) followed by a 30 sec rest between each set of bounds and skips; 20 sec between each set of box jumps and side jumps and 15 sec between each set of depth jumps on the right knee extensors (evoked twitch properties, maximal isometric torque and voluntary activation) using a KIN-COM in recreational athletes.	1 day
Thomas <i>et al.</i> (2009) The effect of two plyometric training techniques on muscular power and agility in youth soccer players	12 males 17.3 ± 0.4	To determine the effects of: DJG group: sessions included 80-120 foot contacts of drop jumps performed from a height of 40cm Countermovement drop jumps group (CMDJ): totalling 80-120 foot contacts of counter movement drop jumps per session on vertical jump height, 20 m sprint speed and 505 agility in soccer players.	6 weeks DJG: 2 x per week CMDJ: 2 x per week Both DJG and CMDJ group performed soccer training 2-4 x per week and played a match 1 x per week

Values presented as PT = Plyometric session; DJG = Depth jump training; CMDJ = Countermovement drop jump

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Chatzinikolaou <i>et al.</i> (2010) Time course of changes in performance and inflammatory responses after acute plyometric exercise	24 males 25.5 ± 1.9	To determine the effects of: PT group: 5 sets x 10 reps hurdle jumps totalling 50 jumps and 5 sets x 10 reps drop jumps totalling 50 jumps with a 2 and 5 min rest between sets and exercises, respectively CG: no training on the anthropometric profile and maximal oxygen consumption (body mass and standing height, body fat and $\text{VO}_{2\text{ max}}$), vertical jump height assessment (countermovement jumps), assessment of leg strength (knee extensor peak torque using a Cybex 6000), blood sampling and biochemical assays (delayed onset of muscle soreness, knee range of motion, creatine kinase and blood lactate dehydrogenase activities, white blood cell count, C reactive protein, uric acid, cortisol, testosterone, IL-6 and IL-1b concentrations) in healthy men.	5 days

Values presented as PT = Plyometric training; CG = Control group

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Ploeg <i>et al.</i> (2010) The effects of high volume aquatic plyometric training on vertical jump, muscle power and torque	16 males and 23 females 22.1 ± 2.9	To determine the effects of: • LPT group 1: week 1: 2 sets x 15 reps side to side ankle hops and standing jump and reach and 6 sets x 5 reps front cone hops; week 2: 2 sets x 15 reps side to side ankle hops and standing long jump, 6 sets x 5 reps lateral jumps over barrier and 10 sets x 3 reps double leg hops; week 3: 2 sets x 12 reps side to side ankle hops, standing long jumps and lateral cone hops, 6 sets x 4 reps lateral jumps over barrier, 8 sets x 4 reps double leg hops; week 4: 2 sets x 12 reps single leg bounding, 3 sets x 10 reps standing long jumps and lateral cone jumps, 8 sets x 4 reps lateral jumps over barrier and 4 sets x 6 reps tuck jumps with knees up; week 5: 2 sets x 10 reps single leg bounding and jump to box, 6 sets x 3 reps double leg hops, 2 sets x 12 reps lateral cone hops, 6 sets x 5 reps tuck jumps with knees up, 3 sets x 10 reps lateral jumps over barrier; week 6: 2 sets x 10 reps jump to box, lateral cone hops and single leg lateral jumps, 4 sets x 5 reps depth jumps to prescribed height, 6 sets x 3 reps double leg hops, 4 sets x 5 reps tuck jumps with knees up. The training volume were 90-120 foot contacts and training intensity (low-high) varied from week 1-6 and LPT 1 sessions were performed on a hardwood gym floor • APT group 1: same as above but session performed in a 106.7 cm depth pool • APT group 2: doubled the same protocol as performed by APT 1 • CG: no plyometric training on vertical jump height (using the Vertec device measuring height and potential jumping ability), muscular peak power and torque value of the dominant kicking knee (KinCom isokinetic dynamometre) in healthy adult participants.	6 weeks LPT 1: 2 x per week APT 1: 2 x per week APT 2: 2 x per week

Values presented as LPT = Land plyometric training; APT = Aquatic plyometric training; CG = Control group

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Chelly <i>et al.</i> (2010) Effects of in-season short-term plyometric training program on leg power, jump and sprint performance of soccer players	23 males 19 ± 0.7	To determine the effects of: PT group: a twice weekly light resistance training program for both the upper and the lower limbs, supplemented with a specific plyometric program consisted of week 1: 5 sets, week 2: 7 sets, week 3:10 sets and week 4: 5 sets x 10 reps of hurdle jumps and week 5-8: 4 sets x 10 reps of drop jumps CG: a standard training sessions which included 90 min skill development activities at various intensities; offensive and defensive tactics and 30 min of continuous play with no plyometric training - Preceded by a 15 min warm-up on peak power output, jump force, jump height and lower limb muscle volume in junior soccer players.	8 weeks PT: 2 x per week

Values presented as PT = Plyometric training; CG = Control group

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Arazi and Asadi (2011) The effect of aquatic and land plyometric training on strength, sprint, and balance in young basketball players	18 male basketball players 18.81 ± 1.46	To determine the effects of: LPT group: 15-25 reps of 3 sets ankle jumps, 8-12 reps of 3 sets speed marching, 8-12 reps of 3 sets squat jumps and 8-12 reps of 3 sets skipping drills performed on a 3 cm mat. Subjects also continued with their routine basketball training APT group: 15-25 reps of 3 sets ankle jumps, 8-12 reps of 3 sets speed marching, 8-12 reps of 3 sets squat jumps and 8-12 reps of 3 sets skipping drills performed in a swimming pool. Subjects also continued with their routine basketball training CG: no plyometric training but players continued their routine basketball training - preceded by a warm-up consisting of a 5 min jog and 5 min stretching as well as ballistic movements. The sessions were concluded with a 5 min stretching routine on 1RM leg press, 36.5 m and 60 m sprints and dynamic balance using the 5m timed up and go test in young male basketball players.	8 weeks LPT and APT training: 3 x per week (Saturday, Monday and Wednesday) with 48 hours recovery between sessions

Values presented as LPT = Land plyometric training; APT = Aquatic plyometric training; CG = Control group; 1RM = Repetition maximum

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Bal <i>et al.</i> (2011) Effects of a short term plyometric training program on agility in young basketball players	30 males 18 ± 24	To determine the effects of: EG: 2-5 sets x 4-12 reps side to side ankle hops, standing jump and reach, front cone hops, standing long jumps, lateral jumps over barriers, double leg hops, lateral cone hops, diagonal cone hops, standing long jump with lateral sprint, single leg bounding, lateral single leg jumps, cone hops with 180° turn, hexagon drill, cone hops with change of direction with foot contacts ranging between 80-110 per session CG: no training on T-test and Illinois Agility Run test agility in inter-college basketball players.	6 weeks EG: 2 x per week
Bonacci <i>et al.</i> (2011) Plyometric training as an intervention to correct altered neuromotor control during running after cycling in triathletes: A preliminary randomised controlled trial	11 males and 4 females 21.6 ± 5.2	To determine the effects of: PT group: 1-6 sets of 6-20 reps countermovement jumps, knee lifts, ankle jumps, back extensions, squats, hamstring curls, alternate leg bounds, skip for height, single-leg ankle jumps, continuous hurdle jumps and scissor jumps for height CG: no plyometric training on lower limb EMG neuromotor control and running economy during running and after cycling in triathletes.	8 weeks PT: 3 x 30 min per week

Values presented as EG = Experimental group; CG = Control group; PT = Plyometric training

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Cappa and Behm (2011) Training specificity of hurdle versus countermovement jump training	13 males 22.3 ± 2.2	To determine the effects of: Session 1: performing 1 maximal CMJ and after a 1 min rest period another CMJ on a force platform Session 2: performing 4 jumps over 50 cm hurdles with a force platform positioned after the second hurdle, after which 2 trails of randomized bilateral (100, 120, 140 and 160% of CMJ height) and unilateral (70, 80, and 90% of CMJ height) jumps with 1 min rest between jumps were performed on vertical ground reaction force, contact time and rate of force development in provincial rugby players.	4 days
Dal Pupo <i>et al.</i> (2011) Kinetic parametres as determinants of vertical jump performance	24 males 12 athletes and 12 volleyball players 21.2 ± 3.3	To determine the effects of: Session: 3 CMJ were performed followed 2 min later by the squat jumps (SJ) - a warm-up which included stretches followed by 5-6 CMJ and SJ at 1 min intervals were executed before the data collection to ensure the protocol was standardized on jump performance, peak velocity, absolute and relative maximum force, rate of force development and time to reach maximum force in sprint runners and volleyball players.	1 day

Values presented as SJ = Squat jump; CMJ = Countermovement jump

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Kamalakkannan <i>et al.</i> (2011) The effect of aquatic plyometric training with and without resistance on selected physical fitness variables among volleyball players	36 players 18-20 years	To determine the effects of: • APT group: 2-8 sets x 4-12 reps of single leg jumps, double leg jumps, alternative leg jumps and side hop jumps • APT with weight jacket group: 2-8 sets x 4-12 reps of single leg jumps, double leg jumps, alternative leg jumps and side hop jumps while wearing a weight jacket • CG: no training on 50 m sprint speed, Coopers' endurance test and explosive power using the vertical jump test in volleyball players.	12 weeks APT: 3 x per week APT with weight jacket: 3 x per week

Values presented as APT = Aquatic plyometric training; CG = Control group; CG = Control group

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Arazi <i>et al.</i> (2012a) Comparative effect of land- and aquatic-based plyometric training on jumping ability and agility of young basketball players	18 male basketball players 18.81 ± 1.46	To determine the effects of: • APT group: 15-25 reps of 3 sets ankle jumps, 8-12 reps of 3 sets speed marching, 8-12 reps of 3 sets squat jumps and 8-12 reps of 3 sets skipping drills with 1 min rest between sets performed in a 130 cm deep swimming pool. Subjects also continued with their routine basketball training • LPT group: 15-25 reps of 3 sets ankle jumps, 8-12 reps of 3 sets speed marching, 8-12 reps of 3 sets squat jumps and 8-12 reps of 3 sets skipping drills with 1 min rest between sets performed on a 3 cm mat. Subjects also continued their routine basketball training • CG: no plyometric training but a regular conditioning program for basketball were followed • Preceded by a warm-up consisting of a 5 min jog and 5 min stretching as well as ballistic movements. The sessions were concluded with a 5 min static stretching routine on explosive leg power (vertical jump test and standing broad jump) and agility (T-Test and Illinois agility run test) in semi-professional male basketball players.	8 weeks PT: 3 x per week with a 48 hours recovery period

Values presented as APT = Aquatic plyometric training; LPT = Land plyometric training; CG = Control group; PT = Plyometric training

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Arazi <i>et al.</i> (2012b) Cardiovascular and blood lactate responses to acute plyometric exercise in female volleyball and handball players	8 volleyball and 10 handball female players 21.83 ± 1.76	To determine the effects of: Session 1: a familiarization session during which subjects' age, body height, body weight and sport experience were measured Session 2 (two days after familiarization session): a 10 min warm-up and the performance of 5 sets x 10 reps box jumps and 5 sets x 10 reps depth jumps with 2-3 min rest between sets on muscle soreness (measured immediately before plyometric exercise directly after as well as 24, 48 and 72 h after exercise), perceived exertion (directly after exercise), cardiovascular responses: blood pressure and heart rate (assessed after the final jump of each set) and blood lactate concentrations (before exercise and 3 min after exercise) in female volleyball and handball players.	1 week
Macaluso <i>et al.</i> (2012) Preferential type II muscle fiber damage from plyometric exercise	8 males 22 ± 1	To determine the effects of: PT: 10 sets x 10 SJs with 1 min rest between sets - Preceded by a warm-up consisting of 5 min backward and forward running followed by 5 min of general stretches for the leg muscles and 10 sets x 10 reps maximal squat jumps with a 60 sec recovery time between sets on skeletal muscle structural and ultra-structural changes in healthy sedentary males.	3 days

Values presented as PT = Plyometric training group; SJ = Squat jump

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Singh and Singh (2012) Effects of progressive depth jumping on vertical jump performance	80 males 18-22 years	To determine the effects of: • Vertical depth jump training (VD): 6 sets x 10 reps of VD with a 15 sec rest-walk between reps and 220 m slow jogging between sets • Horizontal depth jump training (HD): 6 sets x 10 reps of HD with a 15 sec rest-walk between reps and 220 m slow jogging between sets • Combination of group 1 & 2 (CD): 6 sets x 10 reps of CD with a 15 sec rest-walk between reps and 220 m slow jogging between sets • CG: no training on depth jump execution and performance from a dropping height of 18 inches in male athletes.	10 weeks VD: 2 x per week HD: 2 x per week CD: 2 x per week

Values presented as VD = Vertical depth jump training; HD = Horizontal depth jump training; CD = Combination of control group 1 & 2; CG = Control group

Table 1: Studies regarding the effects of plyometric training programs alone on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Chen <i>et al.</i> (2013) The acute effect of drop jump protocols with different volumes and recovery time on countermovement jump performance	10 male volleyball players 20.9 ± 1.6	To determine the effects of: • Day 1: the determination of drop jump (DJ) height and familiarization procedure • DJ1: 3 CMJs (pre-test) which were followed 2 min later with 1 set of 5 reps, and after 3 recovery times (2 min, 6 min and 12 min) with another 3 reps CMJs with 30 sec rest between jumps • DJ2: 3 CMJs (pre-test), which were followed 2 min later with 2 sets of 5 reps with 1 min rest between sets after which the same procedure as above was repeated • Day 2: randomly assigned to DJ1 or DJ2 • Day 3: groups performed the opposite training regime • Day 1 and 2 were preceded by a warm up consisting of 5 min cycling and 5 min stretching of the lower extremities on maximum ground reaction force and countermovement height.	3 days Volleyball training: 5 x per week

Values presented as DJ = Drop jump; CMJ = Countermovement jump

4.1.1 Aquatic- versus land-based plyometric program alone

Seven articles could be found that made comparisons between the effects of land- (LPT) and aquatic-based plyometric program (APT) on various physical and motor ability components of subjects (Miller *et al.*, 2002; Robinson *et al.*, 2004; Stemm & Jacobson, 2007; Shiran *et al.*, 2008; Ploeg *et al.*, 2010; Arazi & Asadi, 2011; Arazi *et al.*, 2012a). The majority of these studies showed that LPT and APT delivered similar results with regard to increases in muscle power, force, isokinetic peak torque (pre to post-test isokinetic knee-flexion and ankle-dorsi-flexion peak torques (APT and LPT)); plantar-flexion (APT), ankle plantar flexion (APT) and ankle dorsi-flexion range of motion (LPT) as well as vertical jumping height among recreationally active adults (Miller *et al.*, 2002:276; Robinson *et al.*, 2004:87; Stemm & Jacobson, 2007:569; Ploeg *et al.*, 2010:44; Arazi *et al.*, 2012a:6). In contrast one study found that the onset of muscle soreness and pain sensitivity increased significantly ($p < 0.05$) more at the same post-training time in the LPT group compared to the APT group (Robinson *et al.*, 2004:87). Participation in the last-mentioned plyometric training program also led to significant ($p < 0.05$) negative changes in perceived muscle soreness at 48 hours and 96 hours after the exercise. Significant pre-post-training speed improvements ($p < 0.05$) were also observed for 20 m, 36.5 m and 60 m as well as for improvements in leg strength (1.5-2 x body weight back squat and 1RM leg press) in both LPT and APT groups (Shiran *et al.*, 2008:458; Arazi *et al.*, 2011:105).

4.1.2 Lower body plyometric training program/exercises alone

Fourteen studies investigated the effects of a lower plyometric training program/exercises on several physical and motor ability components of subjects (Miller *et al.*, 2006; Reymont *et al.*, 2006; Drinkwater *et al.*, 2009; Thomas *et al.*, 2009; Chelly *et al.*, 2010; Chatzinkolaou *et al.*, 2010; Bonacci *et al.*, 2011; Cappa & Behm, 2011; Dal Pupo *et al.*, 2011; Bal *et al.*, 2011; Arazi *et al.*, 2012b; Macaluso *et al.*, 2012; Singh & Singh, 2012; Chen *et al.*, 2013). In this regard lower body plyometric training programs led to significant pre-post training increases ($p < 0.05$) in the agility T-, 505- and Illinois tests, force plate agility and speed (Miller *et al.*, 2006:462; Thomas *et al.*, 2009:332; Bal *et al.*, 2011:274). Significant pre-post training increases ($p < 0.05$) were also reported for the left foot vertical jump height, Wingate Test anaerobic peak power, anaerobic

relative peak power and power drop percentage by Reymont *et al.* (2006:54). More benefits with regard to physical and motor ability components after participation in a lower body plyometric training program were also found by Chelly *et al.* (2010:2675) who observed significant pre-post training increases ($p < 0.05$) in thigh muscle volume; in absolute peak power (W) and peak power relative to body mass ($\text{W} \cdot \text{kg}^{-1}$) during a force velocity cycle ergometre test; in squat jump and CMJ height as well as in average jumping power (W) and for 5 and 40 m running velocities.

A study on the acute effects of uni- and bilateral hurdle jumps at different percentages of the CMJ height concluded that the contact time of bilateral hurdle jumps at 160% of the CMJ height were significant longer ($p < 0.05$) than hurdle jumps done at 100, 120 and 140% of the CMJ height (Cappa & Behm, 2011:4). They also indicated that the contact times during bilateral hurdle jumps were significant ($p < 0.05$) different from those of unilateral jumps and CMJs (Cappa & Behm, 2011:4). Another acute related study compared the effects of CMJ and squat jumps on different measures of subsequent CMJ and squat jumps in sprint runners and volleyball players (Dal Pupo *et al.*, 2011:45). The sprint runners obtained significant ($p < 0.05$) higher heights, power, maximal force and peak velocity values during both the plyometric jumps compared to the volleyball players (Dal Pupo *et al.*, 2011:45). Singh and Singh (2012:1918) compared vertical to horizontal depth jump training and found that the vertical jump training group's results improved significantly ($p < 0.05$) more with regard to jump height compared to the horizontal jump training group. Lastly, the execution of a CMJ on subsequent CMJs at different post-test intervals led to a significant ($p < 0.001$) improvement in CMJ height over time (2, 6 and 12 min) (Chen *et al.*, 2013:157).

Bonacci *et al.* (2011:18) investigated the more long-term effects (8 weeks) of a lower body plyometric training program in triathletes and found that the presence of altered neuromotor control due to cycling before running in triathlon can be corrected by adding plyometric exercises to regular endurance training.

However, in contrast to the reported positive results of plyometric training significant decrements ($p < 0.05$) were noticed immediately after a lower body plyometric training program (5 specific exercises) in maximal voluntary contraction total torque, and muscle fibre twitch, rate of muscle fibre twitch torque development and the rate of muscle relaxation (Drinkwater *et al.*, 2009:1184) as well as for vertical jump height (Thomas *et al.*, 2009:334).

Research with regard to muscle related changes after participation in a lower body plyometric training program showed that significant increases ($p < 0.05$) occurred in creatine kinase, lactate dehydrogenase, C-reactive protein and uric acid activity as well as in lactate responses; cortisol, free testosterone and IL-6 concentrations as well as in delayed onset of muscle soreness post-exercise (Chatzinikolaou *et al.*, 2010:1394). Plasma creatine kinase activity also increased significantly ($p < 0.05$) due to acute land based plyometric exercises in a study by Macaluso *et al.* (2012:416). They also found that perceived muscle soreness increased significantly ($p < 0.05$) after plyometric exercises (Macaluso *et al.*, 2012:416). An acute related study by Arazi *et al.* (2012b:25) did not only investigate possible changes in muscle related parameters but also in central factors due to lower body plyometric training exercises in volleyball and handball players. Both groups showed significant increases ($p < 0.05$) during the plyometric exercises in heart rates, blood lactate concentrations and the rate pressure product ($RPP = \text{systolic blood pressure value} \times \text{heart rate}$) compared to the pre-plyometric exercise period. Furthermore, systolic blood pressure increased significantly ($p < 0.05$) from pre- to post-plyometric exercises in both groups (Arazi *et al.*, 2012b:25). During all the sets of box jumps the handball players experienced significant increases ($p < 0.05$) in diastolic blood pressure compared to the volleyball players who only showed significant increases ($p < 0.05$) in box jumps during set 3 (Arazi *et al.*, 2012b:25). However, for depth jumps the same measurement only showed significant increases ($p < 0.05$) during the third and fifth set in handball players compared to the volleyball players who showed significant increases ($p < 0.05$) during set 2.

4.1.3 Resistance plyometric training alone

Only one article could be traced which investigated the effects of resistance plyometric training exercises alone on subsequent plyometric exercise performance (Baker & Newton, 2005). The researchers reported a significant 4.7% increase in post-test bench press throws peak power as a result of the intervention strategy which included heavy antagonist muscle bench pulls with a 40 kg resistance (Baker & Newton, 2005:203).

4.1.4 Resistance plyometric training with increased weight *versus* resistance plyometric training with the same weight

Clark *et al.* (2006) compared the effects of resistance plyometric training with decreased weight *versus* resistance plyometric training with the same weight. A significant ($p < 0.05$) difference was experienced in the increased weight group for peak vertical displacement compared to the same weight group in the sets performed after the preloading intervention. Furthermore, the increased weight group jumped significantly ($p < 0.05$) higher (8.6%) during the third set in comparison with the same weight group (Clark *et al.*, 2006:164). Lastly, peak power output resulted in a significant effect ($p < 0.05$) in the increased weight group during the second and third sets and during the final 50 millisecond interval of the concentric movement performed after the preloading exercise (Clark *et al.*, 2006:164).

4.1.5 Plyometric training *versus* a sprint training program alone

Two articles compared the effects of a plyometric *versus* a sprint training program alone (Rimmer & Sleivert, 2000; Markovic *et al.*, 2007). Markovic *et al.* (2007:546) also included a control group (CG) in their study who did not participate in any training program. A significant ($p = 0.002$) pre-post training improvement in isometric squat strength was reported for the sprint group (SG) (Markovic *et al.*, 2007:546). Squat jump (SJ) and CMJ height as well as drop jump performance and standing long jump distance revealed significant ($p < 0.001$) pre-post plyometric training increases for both groups (sprint and plyometric group (PG) (Markovic *et al.*, 2007:546). These improvements were also significantly ($p < 0.001$) higher for the two last-mentioned groups compared to the CG (Markovic *et al.*, 2007:546). Furthermore, only the SG experienced

significant ($p < 0.001$) improvements in 20 m sprint test time, 20 yard shuttle run test distance and in the mean concentric power output during execution of the squat jump (SJ) and CMJ (Markovic *et al.*, 2007:546). These improvements were also significantly ($p = 0.02$) greater in the SG than in the CG (Markovic *et al.*, 2007:546). Overall the two identified studies also reported significant ($p < 0.03$) pre-post training decreases in sprint time over 40 m and split times for both the 0-10 m and 20-30 m intervals (Markovic *et al.*, 2007:546; Rimmer & Sleivert, 2000:298).

4.1.6 Plyometric training versus a resistive plyometric training program alone

Only one study compared the possible effects of plyometric *versus* resistive plyometric and no training (McClenton *et al.*, 2008). They concluded that only normal plyometric training led to significant improvements ($p < 0.05$) in vertical jump height when the three (plyometric training, resistive plyometric training and control) groups were compared (McClenton *et al.*, 2008:323).

4.1.7 Aquatic plyometric versus aquatic plyometric with weight training program alone

Kamalakkannan *et al.* (2011:207) investigated the effects of an aquatic plyometric *versus* an aquatic plyometric with weight training program. The study concluded that the aquatic plyometric training with weight group had shown more significant ($p < 0.05$) improvements in 50 m speed, Coopers' test endurance and explosive power as assessed by the vertical jump test compared to both the aquatic plyometric and control groups.

4.1.8 Plyometric training versus a non-plyometric training program alone

In a study by Wilcox *et al.* (2006), comparisons were made between the effects of performing two types of explosive upper body exercises before the execution of a 1RM bench press and the effects of not performing these exercises before execution of the 1RM exercise. The authors concluded that 1RM bench press strength was significantly greater after performing post-activation potentiation plyometric push-ups or medicine-ball chest passes compared to a protocol where these exercises were not performed beforehand (Wilcox *et al.*, 2006:265).

4.1.9 Resistance plyometric versus plyometric training alone

Only one study was found which investigated resistance plyometric *versus* plyometric training alone (Kubo *et al.*, 2007). Both plyometric training (PT) and weight training (WT) groups showed significant ($p < 0.05$) pre-post training improvements in muscle volumes and maximal voluntary isometric strength of the plantar flexor muscles, plantar flexor muscle activation assessed by superimposing electrical stimuli, increased squat jump (SJ) height, average electromyographic activity of the plantar flexors during the SJ, CMJ and drop jumps (DJ). Joint stiffness did, however, increase during PT ($p = 0.047$) but stayed unchanged during WT ($p = 0.191$) (Kubo *et al.*, 2007:1806). Comparisons between groups showed that significant ($p < 0.05$) better pre-post training improvements for reduced time to peak torque, maximal tendon elongation and elastic energy storage; angular velocities for the concentric phase of SJ; jumping height during the CMJ and relative SJ, CMJ and DJ heights in the PT than the WT group. The WT group displayed a significant ($p < 0.05$) higher average Achilles tendon stiffness value compared to the PT group.

4.2 Effects of combined plyometric training program on the physical, motor ability and anthropometric components of subjects

Table 2 presents information with regard to the articles that investigated the effects of combined plyometric training programs on the physical, motor ability and anthropometric components of subjects.

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Ebben <i>et al.</i> (2000) Electromyographic and kinetic analysis of complex training variables	10 males 19.9 ± 1.4	To determine the effects of: • Group 1 (Medicine Ball Power Drop only training group): 1 set of 5 reps maximal medicine ball power drops with 30% of bench press 1RM. The testing procedure was preceded by a 3 min warm-up consisting of anaerobic activity, 10 clockwise and counter clockwise small arm circles, 10 clockwise and counter clockwise large arm circles and shoulder stretching, a activity-specific warm-up of 1 set of 5 reps at 50% RM, 1 set of 3 reps at 80% RM bench presses, 10 Reps of the medicine ball power drops were then performed after a 5 min rest. The session ended with a low intensity aerobic activity cool-down • Group 2 (Bench press and Medicine ball power drop exercises training group): 1 set of 5 reps lying supine bench press exercise with a weight that was determined during execution of the previous tests. Subjects received a 5 min rest after the bench press after which they performed 1 set of 5 reps medicine ball power drop. The warm-up and activity-specific warm-up were done in the same manner as group 1. The session concluded with a 3 min low intensity aerobic activity cool-down on the mean electromyography of the pectoralis major and long head of the triceps muscle as well as vertical ground reaction force in NCAA Division 1 basketball players.	1 day 1 session

Values presented as RM = Repetition maximum

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Fatouros <i>et al.</i> (2000) Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength	41 males 20.7 ± 1.96	To determine the effects of: • Group 1 (PT): squat, depth and box jumps, jump over cones and bench, repeated triple jumps, single or double-leg hops, as well as alternate leg bounds • Group 2 (WT): 12 weeks of training of which the first 8 weeks consisted of: barbell squats, leg presses, leg curls and standing calf raises and the last 4 weeks of: barbell jump squats, cleans, snatches, push presses as well as core exercises. Throughout the 12 weeks front and side lunges, step-ups, sitting calf raises and deadlifts were performed. • Group 3 (PT plus WT): a weight-training protocol where performed 180 min after the plyometric exercises program • Group 4 (CG): no training on vertical jump height and jumping mechanical power, flight time and leg strength.	12 weeks 3 x week

Values presented as PT = Plyometric training; WT = Weight training; CG = Control group

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Hrysomallis and Kidgell (2001) Effect of heavy dynamic resistive exercises on upper-body power	12 males 22.8 ± 3.0	To determine the effects of: Group 1 (5RM Bench Press and explosive push-ups): a warm-up that consisted of 5 minute of moderate-intensity stationary cycling, 2x 20 sec chest, shoulder and arm static stretches and 8 reps of conventional push-ups. This was followed by 5 reps of bench presses and 3 reps of explosive push-ups with a 3 minute rest period that separated the 5RM bench press and explosive push-ups Group 2 (Explosive push-ups only): same warm up performed as group 1 to ensure consistency followed by 3 explosive push-ups only on the impulse and maximum rate of force development during an explosive push-up.	3 weeks 3 sessions

Values presented as RM = Repetition maximum

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Duthie <i>et al.</i> (2002) The acute effects of heavy loads on jump squat performance: An evaluation of the complex and contrast methods of power development	11 hockey and softball females 23.7 ± 3.2	To determine the effects of: - a warm-up of 4 min cycling and 5 min light stretching of the lower extremities followed by 3 sets of submaximal half squats (60-80%) with a 1 min rest period between sets preceded each testing session Traditional training session (control): light load jump squats were performed before heavy load half squats Conventional training session: half squats were performed after the jump squats Complex training session: completion of all sets of heavy resistance exercises followed by sets of lighter exercises Contrast training session: contrasting heavy squats with light jump squats in an alternating manner on mean jump height, peak power and maximal force during the jump squat.	4 sessions Each session was separated by a minimum of 3 days and a maximum of 5 days
Turner <i>et al.</i> (2003) Improvement in running economy after 6-weeks of plyometric training	11 females and 10 males 29 ± 7	To determine the effects of: EG: a combination of running and plyometric training (10-30 reps of single and double legged vertical jumps, continuous vertical jumps, split squat jumps and incline jumps) CG: a regular running training program on the economy of running, VO_{2max} and vertical jump height during various jumping tests.	6 weeks Running training: 10 miles for 3 x per week PT: 3 x per week

Values presented as EG = Experimental group; CG = Control group; PT = Plyometric training

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Chimera <i>et al.</i> (2004) Effects of plyometric training on muscle-activation strategies and performance in female athletes	9 females: 7 soccer and 2 field hockey players 18-22 years	To determine the effects of: EG: a combination of strength training, practices, games, tournaments and plyometric training: plyometric training included wall touches, split squat jumps, lateral cone jumps, cone jumps with 180° turns, and drop jumps CG: regularly off-season strength training, practices, games and tournaments on electromyography using six muscles analysed during drop jumps and subsequent vertical jumps, vertical jump height and 40 yard shuttle run sprint speed.	6 weeks Practice: 3 x per week WT: 2 x per week
Fletcher and Hartwell (2004) Effect of an 8 week combined weights and plyometrics training program on golf drive performance	11 males 29 ± 7.4	To determine the effects of: Combined WT and PT group: weight training: performing 3 sets x 6-8 reps bench press, squat, single arm row, lunge, shoulder press, upright row, abdominal crunch, back extension and side bends. Plyometric training: performing 3 sets x 8 reps with a 3 kg medicine ball, seated horizontal twists, standing horizontal twists, standing back extensions as well as golf swings CG: regular golf training on golf drive performance (club head speed and driving distance) of club standard players.	8 weeks WT and PT: 2 x per week

Values presented as EG = Experimental group; CG = Control group; WT = Weight training; PT = Plyometric training

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Brandenburg (2005) The acute effects of prior dynamic resistance exercise using different loads on subsequent upper body explosive performance in resistance-trained men	9 males 25.4 ± 4.0	To determine the effects of: • Session 1: a warm up followed by a series of 3 bench press throws (preconditioning) and a conditioning contraction or control protocol, and then a second series of 3 bench press throws (post-conditioning) concluded the session. The conditioning contraction consisted of 1 set of 5 repetitions bench press using a 100% load of the previously determined 5RM load. Each session was performed 48 hours apart • Session 2: same as above except the conditioning contraction consisted of 1 set of 5 repetitions of bench press using a 75% load of the previously determined 5RM load • Session 3: same as above except the conditioning contraction consisted of 1 set of 5 repetitions of bench press using a 50% load of the previously determined 5RM load • CG: only the 6 bench press throws (pre- and post-conditioning) were done with no conditioning exercises in between on Smith Machine bench press 1RM and 5RM strength, bench press throws explosive upper-body performance and average power (by means of a chronoscopic timing system) in resistance trained men.	2 weeks 6 sessions

Values presented as CG = Control group; RM = Repetition maximum

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Herrero <i>et al.</i> (2005) Electromyostimulation and plyometric training effects on jumping and sprint time	40 males 19–22 years	To determine the effects of: • Electromyostimulation group (EMS): electromyostimulation training of the knee extensor muscles • PT group: Weeks 1 and 2: more horizontal jumps than drop jumps with 90 jumps per session; Weeks 3 and 4: more drop jumps than horizontal jumps with 105 jumps per session • Combined EMS and PT group: a combination of the above-mentioned program: 2 consecutive days of EMS training followed by one rest day and then 2 consecutive days of plyometric training • CG: no training on 20m sprint time, squat and countermovement jump height, maximal voluntary bilateral isometric leg strength and cross sectional area of the thigh.	4 weeks EMS: 4 x per week PT: 2 x per week Combination training: EMS: 2 x per week, PT: 2 x per week

Values presented as EMS = Electromyostimulation; PT = Plyometric training; CG = Control group; CMJ = Countermovement jump

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Comyns <i>et al.</i> (2006) The optimal complex training rest interval for athletes from anaerobic sports	9 males and 9 females 23.5 ± 3.85	To determine the effects of: • Session 1: performing a 1RM CMJ test and single leg-CMJ's familiarization trials • Session 2: an activity-specific warm-up of 2 sets x 3 CMJs followed by 3 pre-squat CMJs, then a 5RM squat of 87% of the 1RM followed by a 30 sec, 2, 4, or 6 min rest period before completing 3 CMJs. 10 Min were given between each complex pair and 2 complex pairs were performed on each test day • Session 3: Same as session 2 • Preceded by 3 min low intensity jogging and static stretches of the quadriceps, hamstrings, gastrocnemius, soleus, gluteals, and hip adductors on ground reaction force and flight time during jump performance in athletes and rugby players.	3 weeks 3 sessions

Values presented as CMJ = Countermovement jump; RM = Repetition maximum

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Dodd and Alvar (2007) Analysis of acute explosive training modalities to improve lower-body power in baseball players	45 males 18-23 years	To determine the effects of: Group 1: a complex training program consisting of 2 sets x 6 reps of 3 heavy resistance training exercises and 3 plyometric exercises Group 2: heavy resistance training (squats, lunges, split squats), 4 sets x 6 reps at 80-90% of 1RM Group 3: high velocity training (box jumps, depth jumps, split squat jumps), 4 sets x 6 reps at 0-30% of 1RM. - Preceded by a 10-15 min dynamic warm-up which included skill-specific movements on 20, 40, and 60-yd sprinting, vertical jump, standing broad jump and T-agility performance in baseball players.	15 weeks Baseball specific conditioning: 3 x per week Complex training, heavy resistance training, high velocity training: 2 x per week
Kilduff <i>et al.</i> (2007) Postactivation potentiation in professional rugby players: Optimal recovery	23 males 24 ± 3.4	To determine the effect of: Day 1: a body mass baseline CMJ followed after a 10 min rest period by the performance of a 3RM squat preload stimulus. The preload stimulus was followed every 4 min up to 20 min with the execution of CMJ Day 2: baseline ballistic bench throws, followed after a 10 min rest period by the performance of a 3RM bench press preload stimulus. The preload stimulus was followed every 4 min up to 20 min with the execution of ballistic bench throws - Preceded by a warm-up consisting of 5 min cycling and dynamic stretches on peak power output during a ballistic bench press throw performed on a smith machine using 40% of predicted 1RM in professional rugby players.	2 days

Values presented as CMJ = Countermovement jump; RM = Repetition maximum

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Deutsch and Lloyd (2008) Effect of order of exercise on performance during a complex training session in rugby players	8 males 20.4 ± 1.7	To determine the effects of: • Day 1: completing questionnaires and executing a familiarization session • Day 2: performing loaded parallel squats (LPS) and a speed test • Day 3: performing CMJ and a speed test • Day 4: <i>Group 1:</i> performing LPS followed by CMJ; <i>Group 2:</i> performing CMJ followed by LPS • Day 5: <i>Group 1:</i> performing CMJ followed by LPS; <i>Group 2:</i> performing LPS followed by CMJ on peak power, jump height and duration of amortization phase in rugby players.	5 days
Perez-Gomez <i>et al.</i> (2008) Effects of weight lifting training combined with plyometric exercises on physical fitness, body composition, and knee extension velocity during kicking in football	37 males Strength training group: 23.4 ± 0.5 Control group: 24.3 ± 0.5	To determine the effect of: • STG: 4-9 sets x 5 reps bi-lateral plyometric exercises (unloaded drop jumps and explosive hurdle jumps) followed by 3-5 sets x 2-12 reps bilateral inclined press, leg extension, half squat and leg curl at 50-90% of 1RM • CG: no training on lower-limb lean mass (dual-energy X-ray absorptiometry), 1RM maximal strength (inclined leg press, leg extension, leg curl and half squat), muscle biopsies, vertical jump performance, Wingate anaerobic test, 30 m running sprint test, anaerobic capacity (300 m running test) and 20 m shuttle run aerobic maximal power in physical education students.	6 weeks STG: 3 x per week

Values presented as LPS = Loaded parallel squats; CMJ = Countermovement jump; STG = Strength training group; RM = Repetition maximum; CG = Control group

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Rhea <i>et al.</i> (2008a) The effectiveness of resisted jump training on the Vertimax in high school athletes	50 females and 14 males 17.4 ± 2.1	To determine the effects of: • Training control group (TCG): 4 sets of back squats, power cleans, standard deadlifts, dumbbell walking lunges and Romanian deadlifts at 75-85% of 1RM as well as running/plyometric training which consisted of 20-40 yard sprints, front and side hurdle jumps, depth jumps, split squat jumps and bounding with 2 min rest between each set and 5 min rest between different exercises • Vertimax training group (VTG): 4 sets of back squats, power cleans, standard deadlifts, dumbbell walking lunges and Romanian deadlifts at 75-85% of 1RM as well as running/plyometric training which consisted of the same exercises as group 1. This group also performed 2-6 sets x 8-10 reps half-squat jumps, quarter-squat jumps 2-6 sets of 5-10 reps and split-squat 1-3 sets of 6-10 reps with 2 min rest between each set and 5 min rest between different exercises on lower body peak power using the powerlizer during the counter-movement vertical jump in high school athletes.	12 weeks Resistance training: 2-3 x week Plyometric, sprint and VTG: 1-2 x week

Values presented as TCG = Training control group; VTG = Vertimax training group; RM = Repetition maximum

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Rhea <i>et al.</i> (2008b) An examination of training on the Vertimax resisted jumping device for improvements in lower body power in highly trained college athletes	26 males and 14 females College age	To determine the effect of: • TCG: 6-10 sets of back squats, power cleans, standard deadlifts, dumbbell walking lunges and Romanian deadlifts at 80-90% of 1RM as well as sprint plyometric training which consisted of 10-15 reps of 20-40 yard sprints, front/side hurdle jumps, depth jumps, split squat jumps, and bounding with 2 min rest between each set and 5 min rest between different exercises • VTG: 6-10 sets of back squats, power cleans, standard deadlifts, dumbbell walking lunges and Romanian deadlifts at 80-90% of 1RM as well as sprint/plyometric training which consisted of the same exercises as group 1. This group also performed an additional 2-4 sets x 5-10 reps half-squat jumps, 2-4 sets x 8-10 reps quarter-squat jumps and 2-4 sets x 5-10 reps split-squat jumps on the Vertimax with 2 min rest between each set and 5 min rest between different exercises on jumping ability and peak power output using the powerlizer during the CMJ test in collegiate athletes.	12 weeks Resistance training: 2-3 x per week Plyometric, sprint and VTG: 1-2 x per week

Values presented as TCG = Training control group; RM = Repetition maximum; VTG = Vertimax training group

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Weber <i>et al.</i> (2008) Acute effects of heavy-load squats on consecutive squat jump performance	12 males 20.3 ± 1.7	To determine the effects of: - a warm-up of 5 min cycling on a cycle ergometre and 10 repetitions of back squats at 50% of their 5RM preceded both testing conditions. A 3 min rest between each set were given to the squat jump condition and 1 week between each testing condition Back squat condition: 7 consecutive squat jumps (pre) followed by 5 reps back squats at 85% of 1RM, followed by another 7 reps of consecutive squat jumps (post) SJ condition: 1 set of 7 consecutive squat jumps (pre) followed by 1 set of 5 reps consecutive squat jumps, followed by another set of 7 reps squat jumps (post) on mean and peak jump height as well as mean and peak ground reaction force of back squat and squat jump conditions in track and field athletes.	1 week

Values presented as RM = Repetition maximum; SJ = Squat jump

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Esformes <i>et al.</i> (2010) Postactivation potentiation following different modes of exercises	13 males 22 ± 3	To determine the effects of: • Plyometric exercise group (PLYO): 1 set of 6 contacts per exercise (alternate speed bounds, right/left speed hops and vertical bounds) totalling 24 foot contacts, with a 15 sec rest interval between each exercise. After another 5 min rest 3 CMJs were performed and after another 10 min the sequence was repeated 3 times • Heavy weight exercise group (SQUAT): 1 set of 3 half squats at their 3RM performed as quickly as possible. After 5 min rest 3 CMJs were performed and after another 10 min the sequence was repeated 3 times • CG: inactivity with no additional warm-up • Both the PLYO and SQUAT performed stabilization strength tests and determined each individuals half squat 3RM before the start of testing, then before each session a standardized warm-up which consisted of a 400 m jog and 4 reps of dynamic drills over 15 m. A condition specific warm-up then followed. PLYO group: 1 set of 6 foot contacts per plyometric exercise (alternate speed bounds, right/left speed hops and vertical bounds) totalling 24 foot contacts, with a 15 sec rest interval between each exercise. SQUAT group: 2 sets of 6-10 half squats at 60 and 85% of their 3 RM with 2 min rest between sets on maximal displacement, peak power, peak vertical force, rate of force development and relative force using the Kisler force platform during the execution of the CMJ.	3 sessions

Values presented as CG = Control group; PLYO = Plyometric exercise group; SQUAT = Heavy weight exercise group; RM = Repetition maximum

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Witmer <i>et al.</i> (2010) The acute effects of back squats on vertical jump performance in men and women	12 males and 12 females 21.1 ± 2.3	To determine the effects of: • Session 1: a 1RM back squat determination • Session 2: Group 1: performing 2 x 10m dynamic lunge walks and 2 x 10 reps dynamic body squats after which 5 reps back squats at 30% of 1RM followed by 4 reps back squats at 50% of 1RM and finally 3 reps back squats at 70% of 1RM with a 2 min rest between each loading set. After the last rep of the back squats a 3 min rest period were given before the performance of 10 CMJ with 3 min rest between jumps. Group 2: performing 2 x 10 m dynamic lunge walks and 2 x 10 reps dynamic body squats after which a 3 min rest period followed. 10 CMJ were then completed with a 3 min rest between jumps • Session 3: Group 1 followed the procedure that group 2 followed during session 2. Group 2 followed the procedure that group 1 followed during session 2 on jump height and vertical stiffness during countermovement vertical jumps.	3 sessions

Values presented as RM = Repetition maximum CMJ = Countermovement jump

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Beneka <i>et al.</i> (2012) Muscle performance following an acute bout of plyometric training combined with low or high intensity weight exercise	30 males 22.8 ± 2.2	To determine the effects of: • Plyometric exercises with high intensity weight exercise: plyometric protocol: 50 jumps over hurdles and 50 drop jumps combined with weight training: 2 sets of 2-3 reps leg presses at 90% of 1RM and 2 sets x 1-2 reps leg extensions at 95% of 1RM with a 2 min rest period between sets and 5 min rest between exercises • Plyometric exercises with low intensity weight exercise: performed same plyometric protocol as above combined with weight training: 4 sets of 8 reps leg presses and 4 sets of 8 reps leg extensions at 60% of 1RM, with 3 min rest between sets and 3 to 5 sec rest between reps • CG: no training • Both training protocols were preceded by a 10 min warm-up of light running and stretching on vertical jump height using a Kistler force platform and knee extensor peak torque was measured using a isokinetic dynamometre in healthy male participants.	4 days

Values presented as RM = Repetition maximum; CG = Control group

Table 2: Studies regarding the effects of combined plyometric training programs on selected physical, motor ability and anthropometric components of subjects

Authors, date and title of publication	Number, gender and age (years) of test subjects	Intervention program	Duration and frequency of intervention
Pienaar and Coetzee (2013) Changes in selected physical, motor performance and anthropometric components of university-level rugby players after one microcycle of a combined rugby conditioning and plyometric training program	40 males 18.94 ± 0.40	To determine the effects of: EG: performing 2 sets of 10 reps of a variety of plyometric exercises with a 30 sec rest between sets combined with 12-16 medium to high intensity (70-85% of 1RM) resistance exercises and a rugby specific field program CG: 12-16 medium to high intensity (70-85% of 1RM) resistance exercises and a rugby specific field program on antropometric components (triceps, subscapular, abdominal, supraspinal, front thigh and calf skinfolds; body stature; body mass; ankle, femur, humerus and wrist breadths; relaxed and contracted upper arm, forearm, thigh and calf girths); upper body explosive power (3 kg medicine ball put test), lower body explosive power (vertical jump test), acceleration and sprint speed (5, 10 and 20 m sprint tests), agility (t-test), anaerobic power and capacity (Wingate Anaerobic test) of university-level rugby players.	4 weeks PT: 3 x per week Field sessions: 1 x per day Resistance training sessions: 3 x per week

Values presented as EG = Experimental group; RM = Repetition maximum; CG = Control group; PT = Plyometric training group

4.2.1 Combined plyometric and resistance training *versus* plyometric training alone

Three articles investigated the effects of a combined plyometric and resistance training *versus* plyometric training program alone (Ebben *et al.*, 2000; Hrysomallis & Kidgell, 2001; Brandenburg, 2005). The researchers reported no significant differences in mean and peak ground forces or mean electromyography (EMG) during a set of medicine ball power drop exercises preceded by a set of high-loaded bench press (Ebben *et al.*, 2000:454). Acute upper body power indicators such as impulse and maximum rate of force development were not significantly augmented when explosive push-ups followed a 5RM bench press (Hrysomallis & Kidgell, 2001:428). Average bench press throw power and potentiation ratio produced by the different complex sets (with bench press at 100%, 75%, 50% of 5RM) were also not significantly differently influenced between combined and non-combined programs (Brandenburg, 2005:430).

4.2.2 Combined resistance and plyometric *versus* resistance or plyometric training alone

Three articles looked at the effects of combined resistance and plyometric *versus* resistance or plyometric training alone (Fatouros *et al.*, 2000; Dodd & Alvar, 2007; Perez-Gomez *et al.*, 2008). Fatouros *et al.* (2000:473) reported significantly ($p < 0.05$) better performances in vertical jump height, jumping mechanical power and flight time for the combined program training group than for the plyometric and weight training groups. Significantly ($p < 0.05$) higher improvements were also noted for leg press and squat leg strength in the combined program training group compared to the plyometric training group but not compared to the resistance training group (Fatouros *et al.*, 2000:473). Combined resistance and plyometric training resulted in a significant enlargement in lower limb lean mass ($p = 0.05$) compared to the control group who did not train (Perez-Gomez *et al.*, 2008:505). They also reported significant improvements ($p < 0.05$) in maximum angular velocity of the knee in step kicks on a stationary ball; CMJ vertical velocity at take-off, height jumped, maximum instantaneous vertical velocity and maximum instantaneous power; 1RM incline leg press, leg extension and half squat strength; kicking performance; VJ and maximum dynamic force compared to the control group (Perez-Gomez *et al.*, 2008:505).

On a microscopic level the combined program led to a significant ($p \leq 0.05$) increase in the amount of myosin-heavy chain (MHC) type IIa muscle fibres and a significant ($p \leq 0.05$) reduction in the amount of MHC type I muscle fibres (Perez-Gomez *et al.*, 2008:505). The study of Dodd and Alvar (2007) revealed that no significant differences between groups were found for any of the measured variables. However, they observed greater percent improvements in pre- to post-combined program vertical jump height; standing broad jump distance; 20-, 40- and 60 yard speed

as well as T-agility changes than in the resistance or plyometric training programs alone (Dodd & Alvar, 2007:1179). Despite pre-post changes no significant differences were observed between groups (Dodd & Alvar, 2007:1179).

4.2.3 Combined electromyostimulation (EMS) and plyometric versus EMS or plyometric training alone

The study by Herrero *et al.* (2005:536) found that a combined EMS and plyometric training program was significantly ($p < 0.05$) more effective in improving squat and countermovement jump height as well as 20 m sprint time than a plyometric training or EMS program alone. However, despite changes in maximal voluntary bilateral isometric leg strength and cross-sectional area of the thigh, no significant differences were observed between the different programs (Herrero *et al.*, 2005:536).

4.2.4 Combined high weight resistance and plyometric training versus combined low weight resistance and plyometric training

A comparison between the effects of a combined high weight and a combined low weight and plyometric training protocol showed that both programs caused significant decreases ($p < 0.001$) in squat jumping height for 24, 72 and 96 hours post-exercise (Beneka *et al.*, 2012:4).

4.2.5 Combined running and plyometric versus running training alone

Turner *et al.* (2003) investigated the combined effects of running and plyometric training *versus* a running program alone. Subjects who did the combined program experienced significant increases ($p < 0.05$) in post-training running economy compared to the running training program alone (Turner *et al.*, 2003:64). No significant differences were reported for CMJ and squat jump post-training efficiency between groups although both groups showed greater efficiencies from pre- to post-training (Turner *et al.*, 2003:64).

4.2.6 Combined resistance, plyometric and golf versus a regular golf training program

Fletcher and Hartwell (2004:61) found significant ($p \leq 0.05$) more pre-post program positive changes in golf club head speed and driving distance for a combined resistance, plyometric and golf *versus* a regular golf training program.

4.2.7 Combined sport specific, resistance and plyometric *versus* combined sport-specific and resistance training

The available studies reported that combined sport specific, resistance and plyometric training programs caused significantly bigger ($p < 0.05$) increases in muscle-activation patterns of the EMG dependant variables (Chimera *et al.*, 2004:27). Furthermore, Pienaar and Coetzee (2013:408) found significantly ($p < 0.05$) bigger increases in femur breadth, wrist breadth, body stature and skeletal mass; 20 m speed; upper body explosive power; agility; peak power, average power, relative peak power, relative average power, total work, relative total work, average power over 5, 10, 15, 20, and 25 seconds and work measurements of the Wingate anaerobic test (Pienaar & Coetzee, 2013:408) in rugby players due to a combined sport specific, resistance and plyometric compared to a combined sport-specific and resistance training program.

4.2.8 Combined resistance and resistive plyometric training *versus* combined resistance and normal plyometric training as a post-activation potentiation strategy

Two studies by Rhea *et al.* (2008a & b) made a comparison between the effects of a combined resistance and resistive plyometric training *versus* a combined resistance and normal plyometric training program. Collectively the search results indicated that CMJ peak power increased significantly ($p < 0.05$) more in the combined resistance and resistive plyometric training group than the combined resistance and normal plyometric training group (Rhea *et al.*, 2008a:733; 2008b:738).

4.2.9 Plyometric training as a post-activation potentiation strategy

Seven studies implemented plyometric training as a post-activation potentiation strategy (Duthie *et al.*, 2002; Comyns *et al.*, 2006; Kilduff *et al.*, 2007; Deutsch & Lloyd, 2008; Weber *et al.*, 2008; Esformes *et al.*, 2010; Witmer *et al.*, 2010). In this regard, Wilcox *et al.* (2006:262) described post-activation potentiation as a phenomenon that leads to an enhancement of neuromuscular function and as a consequence provides an optimal environment for explosive-force production. Duthie *et al.* (2002:534) found that mean jump height, peak power or maximal force did not change significantly between the traditional, complex or contrast training sessions. However, a significant ($p < 0.05$) lower average mean peak power of sets value was revealed for the complex training compared to the traditional training method (Duthie *et al.*, 2002:534). Comparisons between the peak power values of sets during each session, showed that the complex training method led to a significant ($p < 0.05$) lower peak power value during set 1 compared to the traditional training method (Duthie *et al.*, 2002:534). The higher strength group also displayed

significantly ($p < 0.05$) better performance changes than the lower strength group during the contrast training method (Duthie *et al.*, 2002:534). Comyns *et al.* (2006:472) investigated the effects of different rest intervals during complex training on the flight time and peak ground reaction forces of CMJ in athletes of both gender groups. They found a significant reduction ($p < 0.05$) in CMJ flight time in both genders at 30 sec and 6 min intervals after completion of 5RM back squats (Comyns *et al.*, 2006:474). Overall the researchers concluded that it is better to determine each individual's intra-set complex training exercises rest intervals in order to get the most benefit from the training session (Comyns *et al.*, 2006:476).

On the other hand, Kilduff *et al.* (2007:1136) found that upper (bench press throws) and lower body (CMJ) peak power output significantly ($p = 0.05$) decreased when the bench press throws and CMJ were performed 15 sec after the preload stimulus compared to 8 and 12 min after exercise. Deutsch and Lloyd (2008:806) reported a significant ($p < 0.05$) increase in 20 m sprint times (slower) after the performance of CMJs compared to the control measurements (no jumps). A significant ($p < 0.05$) increase in loaded parallel squats peak force when performed after execution of CMJ's was also observed (Deutsch & Lloyd, 2008:806). However, the performance of loaded parallel squats before execution of CMJ's, did not lead to any significant improvement in CMJ height (Deutsch & Lloyd, 2008:806).

Weber *et al.* (2008:727) observed that the execution of five repetitions of squat jumps as well as a five-repetition back squat at 85% of 1RM led to significant ($p < 0.05$) improvements in SJ height as well as peak and mean ground reaction forces of five repetition squat jumps. In contrast the execution of a five-repetition back squat at 85% of 1RM led to significant ($p < 0.05$) improvements in mean ground reaction force of five repetition squat jumps but to significant ($p < 0.05$) decreases in mean and peak jump height (Weber *et al.*, 2008:727). In another study, Esformes *et al.* (2010:1914) indicated a significant ($p = 0.009$) higher CMJ maximal displacement value for the group that performed a 3RM back half squat before execution of the CMJ than the groups who performed plyometric exercises or no activities before execution of the jump (Esformes *et al.*, 2010:1914). Lastly, Witmer *et al.* (2010:208) reported that the performance of 3 repetitions of back squats at 70% of 1RM before the execution of CMJ's every three minutes until 10 jumps were completed, led to no significant changes in CMJ height or vertical stiffness (ratio of the vertical force to the negative displacement of the centre of mass during the propulsive phase of the jump) compared to subjects that did not perform squats beforehand (Witmer *et al.*, 2010:208). They also concluded that practitioners who wish to use complex training methods should try and

individualize the protocols in terms of the post-activation potentiation that is obtained (Witmer *et al.*, 2010:212).

5. GUIDELINES FOR THE IMPLEMENTATION OF SUCCESSFUL PLYOMETRIC TRAINING PROGRAMS

The following discussion is dedicated to the exercise guidelines that need to be followed when either a plyometric training program alone or combined plyometric training program is designed and implemented. The guidelines were selected according to the plyometric training programs that delivered statistical significant results with regard to the pre- to post-training effects. For the purpose of this section, the sum of the averages of the exercise variables that were presented in each of the identified articles was calculated and divided by the number of articles that reported on the relevant exercise variables to obtain a total average score for each exercise variable ($\bar{x}$).

With regard to the plyometric programs alone the durations of intervention periods were between 3 days ($\bar{x} = 2.57$) and 7 weeks ($\bar{x} = 6.95$) (Rimmer & Sleivert, 2000:295; Miller *et al.*, 2002:268; Robinson *et al.*, 2004:84; Baker & Newton, 2005:202; Clark *et al.*, 2006:162; Miller *et al.*, 2006:459; Reymont *et al.*, 2006:44; Wilcox *et al.*, 2006:269; Kubo *et al.*, 2007:1801; Markovic *et al.*, 2007:543; Stemm & Jacobson, 2007:568; McClenton *et al.*, 2008:321; Drinkwater *et al.*, 2009:1181; Thomas *et al.*, 2009:332; Chatzinikolaou *et al.*, 2010:1389; Ploeg *et al.*, 2010:39; Chelly *et al.*, 2010:2670; Arazi & Asadi, 2011:101; Bonacci *et al.*, 2011:15; Cappa & Behm, 2011:1; Dal Dupo *et al.*, 2011:41; Kamalakkannan *et al.*, 2011:205; Bal *et al.*, 2011:271; Arazi *et al.*, 2012a:1; Arazi *et al.*, 2012b:23; Macacuso *et al.*, 2012:414; Singh & Singh, 2012:1915; Chen *et al.*, 2013:154) or in one case authors only referred to the number of sessions that were executed to be 16 sessions (Shiran *et al.*, 2008:458). Training frequency was set at 2 ($\bar{x} = 2.4$) sessions per week (Rimmer & Sleivert, 2000:295; Miller *et al.*, 2002:268; Robinson *et al.*, 2004:84; Clark *et al.*, 2006:162; Miller *et al.*, 2006:459; Reymont *et al.*, 2006:44; Kubo *et al.*, 2007:1801; Markovic *et al.*, 2007:543; Stemm & Jacobson, 2007:568; McClenton *et al.*, 2008:321; Shiran *et al.*, 2008:458; Thomas *et al.*, 2009:332; Ploeg *et al.*, 2010:39; Chelly *et al.*, 2010:2670; Arazi & Asadi, 2011:101; Bonacci *et al.*, 2011:15; Kamalakkannan *et al.*, 2011:205; Bal *et al.*, 2011:271; Arazi *et al.*, 2012a:1; Singh & Singh, 2012:1915) and exercise sets ranged between 3 ($\bar{x} = 3.29$) and 6 ($\bar{x} = 5.75$) sets per exercise (Rimmer & Sleivert, 2000:295; Robinson *et al.*, 2004:84; Clark *et al.*, 2006:162; Miller *et al.*, 2006:459; Reymont *et al.*, 2006:44; Kubo *et al.*, 2007:1801; Markovic *et al.*, 2007:543; Stemm & Jacobson, 2007:568; McClenton *et al.*, 2008:321; Chatzinikolaou *et al.*, 2010:1389; Ploeg *et al.*, 2010:39; Chelly *et al.*, 2010:2670; Arazi & Asadi,

2011:101; Bonacci *et al.*, 2011:15; Kamalakkannan *et al.*, 2011:205; Bal *et al.*, 2011:271; Arazi *et al.*, 2012a:1; Arazi *et al.*, 2012b:23; Macacuso *et al.*, 2012:414; Singh & Singh, 2012:1915; Chen *et al.*, 2013:156). The number of repetitions that were performed per plyometric session varied between 7 ($\bar{x} = 7.12$) and 16 ($\bar{x} = 16.77$) repetitions (Rimmer & Sleivert, 2000:295; Robinson *et al.*, 2004:84; Baker & Newton, 2005:202; Clark *et al.*, 2006:162; Miller *et al.*, 2006:459; Reymont *et al.*, 2006:44; Wilcox *et al.*, 2006:264; Kubo *et al.*, 2007:1801; Markovic *et al.*, 2007:543; Stemm & Jacobson, 2007:568; McClenton *et al.*, 2008:321; Chatzinikolaou *et al.*, 2010:1389; Ploeg *et al.*, 2010:39; Chelly *et al.*, 2010:2670; Arazi & Asadi, 2011:101; Bonacci *et al.*, 2011:15; Cappa & Behm, 2011:1; Dal Dupo *et al.*, 2011:41; Kamalakkannan *et al.*, 2011; Bal *et al.*, 2011:271; Arazi *et al.*, 2012a:1; Arazi *et al.*, 2012b:23; Macacuso *et al.*, 2012:414; Singh & Singh, 2012:1915; Chen *et al.*, 2013:156).

Few articles mentioned the exercise intensity at which the plyometric exercises were performed. The known exercise intensities varied between 60 ($\bar{x} = 60$) and 105% ($\bar{x} = 105$) of the 1RM (Kubo *et al.*, 2007:1801; Shiran *et al.*, 2008:458). Rest periods between sets varied between 90 sec ($\bar{x} = 88.9$ sec) and 3 min ($\bar{x} = 180$ sec) and rest periods between exercises between 1 ($\bar{x} = 54.7$ sec) and 3 min ($\bar{x} = 167$ sec) (Rimmer & Sleivert, 2000:295; Baker & Newton, 2005:202; Clark *et al.*, 2006:162; Miller *et al.*, 2006:459; Wilcox *et al.*, 2007:264; Kubo *et al.*, 2007:1801; Markovic *et al.*, 2007:543; Stemm & Jacobson, 2007:568; McClenton *et al.*, 2008:321; Shiran *et al.*, 2008:458; Drinkwater *et al.*, 2006:264; Thomas *et al.*, 2009:332; Chatzinikolaou *et al.*, 2010:1389; Arazi & Asadi, 2011:101; Cappa & Behm, 2011:1; Dal Dupo *et al.*, 2011:41; Arazi *et al.*, 2012a:1; Arazi *et al.*, 2012b:23; Macacuso *et al.*, 2012:414; Singh & Singh, 2012:1915; Chen *et al.*, 2013:156). Exercise volume is another exercise variable that is not often mentioned in studies. The studies that indicated exercise volume used 87 ($\bar{x} = 86.7$) to 137 ($\bar{x} = 137.286$) foot contacts per session (Miller *et al.*, 2002:268; Miller *et al.*, 2006:459; McClenton *et al.*, 2008:321; Shiran *et al.*, 2008:458; Thomas *et al.*, 2009:332; Chatzinikolaou *et al.*, 2010:1389; Ploeg *et al.*, 2010:39). The amount of exercises done per session was documented to be 11 exercises on average and varied between 2 and 11 exercises (Rimmer & Sleivert, 2000:297; Robinson *et al.*, 2004:85; Miller *et al.*, 2006:460; Reymont *et al.*, 2006:59; Stemm & Jacobson, 2007:569; Shiran *et al.*, 2008:458; Ploeg *et al.*, 2010:42; Arazi & Asadi, 2011:104; Kamalakkannan *et al.*, 2011:206; Bal *et al.*, 2011:273; Arazi *et al.*, 2012a:6). Lastly, warm-ups that most often preceded more successful plyometric sessions consisted of aerobic exercises (jogging, light intensity ladder and hurdle drills, stationary cycling, backward and forward running) of between 5 and 15 min (Rimmer & Sleivert, 2000:296; Reymont *et al.*, 2006:48; Macaluso *et al.*, 2012:415; Chen *et al.*,

2013:156); static stretching exercises for 5 min (Clark *et al.*, 2006:163; Wilcox *et al.*, 2006:263; Stemm & Jacobson, 2007:569) and in some cases also dynamic and ballistic movements of which the duration or number of repetitions was not mentioned (Arazi & Asadi, 2011:104; Arazi *et al.*, 2012a:5; Arazi *et al.*, 2012b:24). Some authors also stated that they made use of a specific warm-up which followed the general warm-up period but did not provide the reader with information regarding the activities that were performed during this period or the duration of activities (Robinson *et al.*, 2004:85; Chelly *et al.*, 2010:2672).

The exercise variables that were chosen for combined plyometric training programs that delivered more significant benefits with regard to physical, motor ability and anthropometric components than non-combined plyometric programs were as follow: Intervention periods ranged between 1 day (Ebben *et al.*, 2000:452) and 7 weeks ($\bar{x} = 6.71$) (Fatouros *et al.*, 2000:472; Hrysomallis & Kidgell, 2001:427; Turner *et al.*, 2002:62; Chimera *et al.*, 2004:24; Fletcher & Hartwell, 2004:60; Brandenburg, 2005:428; Herrero *et al.*, 2005:534; Comyns *et al.*, 2006:473; Dodd & Alvar, 2007:1178; Perez-Gomez *et al.*, 2008:502; Rhea *et al.*, 2008a:732; Rhea *et al.*, 2008b:737; Weber *et al.*, 2008:727; Pienaar & Coetzee, 2013:401) respectively whereas training frequency was most often set at 3 sessions ($\bar{x} = 2.55$) per week (Fatouros *et al.*, 2000:472; Turner *et al.*, 2002:62; Chimera *et al.*, 2004:24; Fletcher & Hartwell, 2004:60; Herrero *et al.*, 2005:534; Dodd & Alvar, 2007:1178; Perez-Gomez *et al.*, 2008:502; Rhea *et al.*, 2008a:732; Rhea *et al.*, 2008b:737; Pienaar & Coetzee, 2013:401).

Exercise sets ranged between 2 ($\bar{x} = 2.25$) and 7 sets per exercise ($\bar{x} = 7.25$) (Ebben *et al.*, 2000:452; Fletcher & Hartwell, 2004:60; Brandenburg, 2005:428; Comyns *et al.*, 2006:473; Dodd & Alvar, 2007:1178; Perez-Gomez *et al.*, 2008:502; Rhea *et al.*, 2008a:732; Rhea *et al.*, 2008b:737; Weber *et al.*, 2008:727; Esformes *et al.*, 2010:1913; Beneka *et al.*, 2012:3; Pienaar & Coetzee, 2013:401) that were performed for 6 ($\bar{x} = 5.67$) to 12 ($\bar{x} = 11.90$) repetitions (Ebben *et al.*, 2000:452; Hrysomallis & Kidgell, 2001:427; Turner *et al.*, 2002:62; Fletcher & Hartwell, 2004:60; Brandenburg, 2005:428; Dodd & Alvar, 2007:1178; Perez-Gomez *et al.*, 2008:502; Rhea *et al.*, 2008a:732; Rhea *et al.*, 2008b:737; Weber *et al.*, 2008:727; Beneka *et al.*, 2012:3; Pienaar & Coetzee, 2013:401). Exercise intensity was set at between 57 ($\bar{x} = 56.83$) and 88% ($\bar{x} = 88.00$) of 1RM (Ebben *et al.*, 2000:452; Brandenburg, 2005:428; Herrero *et al.*, 2005:534; Comyns *et al.*, 2006:473; Dodd & Alvar, 2007:1178; Kilduff *et al.*, 2007:1135; Perez-Gomez *et al.*, 2008:502; Rhea *et al.*, 2008a:732; Rhea *et al.*, 2008b:737; Weber *et al.*, 2008:727; Witmer *et al.*, 2010:207; Pienaar & Coetzee, 2013:401).

Rest periods of 2- ($\bar{x}$ = 128 sec) to 5 min ($\bar{x}$ = 315 sec) were used between sets and 30 sec ($\bar{x}$ = 24 sec) to 3 min ($\bar{x}$ = 153 sec) between exercises (Ebben *et al.*, 2000:452; Fatouros *et al.*, 2000:472; Hrysomallis & Kidgell, 2001:427; Duthie *et al.*, 2002:532; Turner *et al.*, 2002:62; Brandenburg, 2005:428; Herrero *et al.*, 2005:534; Dodd & Alvar, 2007:1178; Kilduff *et al.*, 2007:1135; Esformes *et al.*, 2010:1913; Beneka *et al.*, 2012:3). The articles that mentioned exercise volume, used between 65 to 150 foot contacts per session (Fatouros *et al.*, 2000:473; Turner *et al.*, 2003:62; Fletcher & Hartwell, 2004:60; Perez-Gomez *et al.*, 2008:503; Rhea *et al.*, 2008a:733; Rhea *et al.*, 2008b:737; Esformes *et al.*, 2010:1913; Beneka *et al.*, 2012:3). Lastly, the warm-ups that preceding the combined plyometric sessions consisted of aerobic activities (stationary cycling, jogging) for a period of between 3 and 5 min (Ebben *et al.*, 2000:454); static and dynamic stretching and in some cases also mobility exercises such as push-ups and back squats (Hrysomallis & Kidgell, 2001:427).

6. SHORTCOMINGS WITH REGARD TO THE PLYOMETRIC TRAINING ALONE AND THE COMBINED PLYOMETRIC TRAINING PROGRAMS

The literature review enabled the author to identify certain shortcomings with regard to the content of the available literature and the methodology that was followed by authors of these publications. Each of these shortcomings will be addressed in the next section in order to assist future researchers in this field of study.

6.1 Plyometric training programs only

Firstly, only one study out of a possible twenty nine studies gave an indication of the exercise intensity that was used during execution of the plyometric exercises (Shiran *et al.*, 2008:458). Researchers would only be able to set up scientific plyometric program and determine the progression of exercise variables if they are aware of the exercise intensity guidelines that must be followed (Chu, 1998:28). Secondly, only eight studies (Miller *et al.*, 2002:270; Miller *et al.*, 2006:460; McClenton *et al.*, 2008:323; Shiran *et al.*, 2008:458; Thomas *et al.*, 2009:333; Chatzinikolaou *et al.*, 2010:1391; Ploeg *et al.*, 2010:42; Bal *et al.*, 2011:273) mentioned the number of foot contacts (exercise volume) that was prescribed for each plyometric session. According to Chu (1998:28), foot contact volumes are determined by subjects' experience of plyometric training with beginners that will perform between 100 to 250 foot contacts per session; intermediate subjects between 150 and 300 foot contacts per session and advanced subjects between 150 and 450 foot contacts per session depending on the intensities of the lower body

plyometric exercises. It would, therefore, be important to indicate the exercise volume of a plyometric session or program in order to establish the correctness of the program.

Thirdly, only twelve studies (Rimmer & Slievert, 2000; Robinson *et al.*, 2004; Clark *et al.*, 2006; Reymont *et al.*, 2006; Wilcox *et al.*, 2006; Stemm & Jacobson, 2007; Chelly *et al.*, 2010; Arazi & Asadi, 2011; Arazi *et al.*, 2012a; Arazi *et al.*, 2012b; Macaluso *et al.*, 2012; Chen *et al.*, 2013) showed that a warm-up period preceded the main set of the plyometric sessions or programs. A warm-up will ensure that subjects' establish the necessary motor patterns to perform jumping exercises correctly (Chu, 1998:9). Therefore, the absence of a warm-up period may possibly lead to the incorrect execution of jumping exercises due to the fact that the body and relevant muscles were not prepared for the activities that followed. This is a factor that may threaten the internal validity of a specific study. Fourthly, only ten studies (Robinson *et al.*, 2004; Reymont *et al.*, 2006; Wilcox *et al.*, 2006; Drinkwater *et al.*, 2009; Thomas *et al.*, 2009; Cappa & Behm, 2011; Dal Pupo *et al.*, 2011; Arazi *et al.*, 2012b; Macaluso *et al.*, 2012; Chen *et al.*, 2013) included a control group as part of the study design. Without a control group, who was not subjected to the intervention program, there is no way of knowing if a particular result is due to the specific intervention or due to some or other uncontrolled factor that influenced the study results (Altman, 1999:9). Another shortcoming was the small group sizes that were used in some studies. In this regard eight of the identified studies (Baker & Newton, 2005; Clark *et al.*, 2006; Wilcox *et al.*, 2006; Drinkwater *et al.*, 2009; Thomas *et al.*, 2009; Cappa & Behm, 2011; Macaluso *et al.*, 2012; Chen *et al.*, 2013) made use of only eight subjects to determine the effects of plyometric exercises or a program. Researchers would not be able to detect worthwhile differences between the programs being investigated if the group sizes are too small. For studies to reach statistical significance the appropriate sample size needs to be determined beforehand by means of a power calculation (Thomas *et al.*, 2011:118).

Fifthly, despite the fact that plyometrics was originally developed as a training technique to enhance the speed, power and agility of athletes (Markovic *et al.*, 2007:543; Miller *et al.*, 2006:462), only eighteen of the twenty nine identified studies made use of athletes or sport participants to determine the possible influence of plyometric exercises or programs on different aspects of subjects' physical and motor ability profile (Baker & Newton, 2005; Clark *et al.*, 2006; Reymont *et al.*, 2006; Wilcox *et al.*, 2006; Shiran *et al.*, 2008; Drinkwater *et al.*, 2009; Thomas *et al.*, 2009; Chelly *et al.*, 2010; Arazi & Asadi, 2011; Bal *et al.*, 2011; Bonacci *et al.*, 2011; Cappa & Behm, 2011; Dal Pupo *et al.*, 2011; Kamalakkannan *et al.*, 2011; Arazi *et al.*, 2012a; Arazi *et al.*,

2012b; Singh & Singh, 2012; Chen *et al.*, 2013). However, a further analysis revealed that only five of the sport related studies made use of team sport participants as possible subjects (Wilcox *et al.*, 2006; Shiran *et al.*, 2008; Bonacci *et al.*, 2011; Dal Pupo *et al.*, 2011; Singh & Singh, 2012). In view of this shortcoming, researchers would, therefore, not be able to generalize the research findings of the majority of plyometric related studies to the sport participating population.

Lastly, not all of the plyometric training techniques that are applied by coaches and Sport Scientists have been investigated frequently by researchers to ascertain the benefits that may be derived. For example, only one study could be found that investigated the possible benefits of a resistive plyometric training program alone on subjects (McClenton *et al.*, 2008). More plyometric related studies of this nature are needed to provide proof for the use of different plyometric training techniques to condition athletes of different sports.

6.2 Combined plyometric training programs

Similar to what was found with regard to plyometric training programs alone related studies, only eight combined plyometric training programs related studies (Fatouros *et al.*, 2000; Turner *et al.*, 2003; Fletcher & Hartwell, 2004; Perez-Gomez *et al.*, 2008; Rhea *et al.*, 2008a; Rhea *et al.*, 2008b; Esformes *et al.*, 2010; Beneka *et al.*, 2012) out of a possible twenty two studies mentioned the number of foot contacts that were completed per training sessions. Secondly, only seven studies (Ebben *et al.*, 2000, Hrysomallis & Kidgell, 2001; Duthie *et al.*, 2002; Comyns *et al.*, 2006; Dodd & Alvar, 2007; Kilduff *et al.*, 2007; Weber *et al.*, 2008) provided information with regard to the warm-up routine that preceded the main set of each training session. Furthermore, only nine studies (Ebben *et al.*, 2000; Hrysomallis & Kidgell, 2001; Comyns *et al.*, 2006; Kubo *et al.*, 2007; Rhea *et al.*, 2008a; Rhea *et al.*, 2008b; Witmer *et al.*, 2010; Pienaar & Coetzee, 2013) included and documented the amount of rest between sets and/or repetitions. Plyometric programs will only lead to the development of power if the recommended 1:5 to 1:10 work to rest ratio is followed when compiling and executing these programs (Chu, 1998:30).

Furthermore, ten of the identified studies (Ebben *et al.*, 2000; Hrysomallis & Kidgell, 2001; Duthie *et al.*, 2002; Comyns *et al.*, 2006; Dodd & Alvar, 2007; Kilduff *et al.*, 2007; Kubo *et al.*, 2007; Deutsh & Lloyd, 2008; Weber *et al.*, 2008; Witmer *et al.*, 2010) did not include a control group (which received no treatment) as part of their study design. Without a control group there is no way of knowing if a particular result is due to a variable being tested or to some other factor (Altman, 1999:9). Quite a few studies made use of very small group sizes (≤ 13) for their subject

groups (Ebben *et al.*, 2000; Hrysomallis & Kidgell, 2001; Duthie *et al.*, 2002; Fletcher & Hartwell, 2004; Brandenburg, 2005; Deutsh & Lloyd, 2008; Weber *et al.*, 2008; Esformes *et al.*, 2010). For studies to reach statistical significance the appropriate sample size needs to be determined through a power calculation that is done before commencement of the study (Thomas *et al.*, 2011:118).

Another shortcoming of combined plyometric program related studies, is that only about 40% (nine out a possible twenty one) of identified studies focused on team sport participants as study subjects (Ebben *et al.*, 2000; Duthie *et al.*, 2002; Comyns *et al.*, 2006; Dodd & Alvar, 2007; Kilduff *et al.*, 2007; Deutsch & Lloyd, 2008; Esformes *et al.*, 2010; Witmer *et al.*, 2010; Pienaar & Coetzee, 2013). Furthermore, only one study made use of a combined sport specific and plyometric training program as an intervention to investigate the benefits of executing a combined sport specific and non-plyometric *versus* a combined sport specific and plyometric program for team sport participants (Pienaar & Coetzee, 2013). In view of this shortcoming a need exists to conduct more research on combined sport specific and plyometric training programs and to identify the most effective ways of conditioning team sport participants. Lastly, only two studies have thus far investigated the possible influence of combined resistive plyometric training programs (Rhea *et al.*, 2008a; Rhea *et al.*, 2008b). The effectiveness of using other plyometric training techniques as part of a combined program will only be realized if researchers give more attention to it in research publications.

7. CONCLUSIONS AND RECOMMENDATIONS

Research suggests that plyometric training which was derived from jump and power training regimes was develop in the 1970s to increase the explosive power, speed and agility of athletes. Plyometrics can be described as any exercise during which a muscle contraction is invoked by a rapid eccentric movement, which is followed by a short amortization phase and which ends with an explosive concentric movement. The physiological principles of plyometric training can be explained by making use of two models: the mechanical model which states that mechanical, elastic potential energy is stored and released during the concentric muscle action to contribute to total force production; and the neurophysiological model which refers to the stimulation of the stretch reflex and stretch-shortening cycle to facilitate a maximal increase in muscle recruitment over a minimal amount of time during a concentric muscle contraction.

The need for conditioning coaches to find training regimens that have a greater neural effect have forced them to explore other plyometric training variations such as resisted jump training as well

as complex training methods and to explore the use of plyometrics as an add-on to their existing training regimens. However, notwithstanding the widespread acceptance and use of plyometric training, the possible benefits of these types of programs have been questioned by several researchers. It is in view of this background that the aim of this literature overview was to review critically all available and relevant research of the last 14 years (2000-2013) with regard to plyometric related programs, the type of programs that were used as well as the effects of these programs on the physical, motor ability and anthropometric components of study subjects. Secondly, the researcher made an attempt to provide detailed guidelines to prospective researchers and practitioners in the field of Sport Science for the use of different types of plyometric training methods and programs.

With regard to the possible benefits of plyometric training programs/exercises alone, the literature seem to support the use of this training modality when the aim is to improve significantly ($p < 0.05$) the following physical and motor ability components: joints' range of motion (ankle plantar flexion and dorsi-flexion); speed (over 5 to 60 m); agility (T-test, Illinois and 505); upper (bench press throws) and lower body explosive power (Vertical jump peak and mean power output, height; peak torque and movement velocity during squat; countermovement jump height; power drop jump performance; standing long jump distance; RAST power test); anaerobic peak power (Wingate Anaerobic Test); upper and lower body strength (ankle and knee isokinetic peak torque; 1RM Bench and leg press; maximal isometric squat strength) and cardiovascular endurance (12 Minute Cooper Test). Plyometric exercises or programs' benefits can even be extended to include significant changes ($p < 0.05$) in muscle, peripheral, haematological and central factors, such as: increased thigh muscle volume; increased rate of muscle fibre twitch torque development and rate of muscle relaxation; increased average electromyographic activity, tendon elongation and elastic energy storage during squat jump execution; a decrease in altered neuromotor control; increased creatine kinase, lactate dehydrogenase and lactate activity as well as increased free testosterone concentrations; increased heart rates and the rate pressure product during plyometric exercises as well as increased systolic and diastolic blood pressure during and after plyometric exercises. The plyometric training programs/exercises alone which were more successful in obtaining significant results with regard to the different physical and motor ability components adhered to the following exercise guidelines: the programs' duration was between 3 days and 7 weeks and consisted of 2 plyometric sessions a week. During these sessions, 3 to 6 sets of 7 to 16 repetitions were performed with 90 sec to 3 min rest between sets and 1- and 3 min rest

between 2 to 11 plyometric exercises per session. Foot contacts per session varied between 79 to 137 repetitions and the known exercise intensities ranged between 60 and 105% of the 1RM.

However, the research also showed that in some cases plyometric training programs/exercises alone had a significant ($p < 0.05$) negative effect on several components. For example, perceived muscle soreness and pain sensitivity were significantly ($p < 0.05$) increased for up to 96 hours post-plyometric training for especially land based programs. Together with this, subjects also experienced significant increases ($p < 0.05$) in C-reactive protein and uric acid activity as well as in cortisol and IL-6 concentrations. These increases are all an indication that protein breakdown was increased and that the immune system of the body was under pressure. Furthermore, in some cases the plyometric training programs/exercises alone was not more successful in bringing about significant changes in the following physical and motor ability components when compared with other programs or no training: muscle power (vertical jump test); relative increase in electromyographic activity (plantar flexors); reaction force, contact time and rate of force development of the right and left legs.

The above-mentioned research results further revealed that combined plyometric training programs were more effective in causing significant ($p < 0.05$) positive pre-post training changes in the following variables compared to combined non-plyometric or non-combined programs: lower (CMJ and SJ post-training efficiency, mean jump height, peak power or maximal force, CMJ height) and upper body explosive power (average bench press throw power and potentiation ratio); anaerobic power and work (Wingate Anaerobic Test); speed (over 20-60 yards and 20 m); agility (T-test); lower (1RM leg press and squat, leg extension and half squat, 5RM back squat at 85% of 1RM) and upper body strength (5RM bench press); CMJ flight time, mean and peak ground reaction forces; maximum angular velocity of the knee (in step kicks on a stationary ball); vertical velocity at CMJ take-off; golf driving distance and club head speed; running economy and kicking performance. Significant increases ($p < 0.05$) for the following anthropometric measurements and muscle related variables were also reported when the effects of a combined plyometric training program were compared to that of a combined non-plyometric program: lower limb lean mass; femur and wrist breadth as well as skeletal mass; the amount of myosin-heavy chain (MHC) type IIa muscle fibres and; muscle-activation patterns of the electromyographic dependant variables. The combined plyometric training programs which were more successful in obtaining significant results with regard to the different physical and motor ability components adhered to the following exercise guidelines: the duration of programs was between 1 day and 7

weeks with 3 plyometric sessions that were performed per week. The plyometric sessions consisted of 4 to 9 exercises of which 6 to 12 repetitions were performed for 2 to 7 sets. Rest periods of between 2- and 5 min were used between sets and 30 sec to 5 min between exercises. The exercise volume ranged between 65 to 150 foot contacts per session whereas exercise intensity was set at between 30 and 105% of the 1RM.

However, in some cases the combined plyometric program did cause significant results for the following physical and motor ability components compared to combined non-plyometric programs: mean and peak ground forces and mean electromyographic activity (during medicine ball power drop exercises); power indicators such as impulse and maximum rate of development (5RM bench press preceding explosive push-ups); average bench press throw power and potentiation ratio; countermovement and squat jump post-training efficiency; mean jump height, peak power, maximal force and countermovement jump height.

During the review of plyometric program related research, the following shortcomings were, however, identified: several studies did not give any indication of certain exercise variables (exercise intensity, number of foot contacts, the amount of rest between exercises and sets) that were prescribed for the different types of plyometric related programs; several studies did not include a control group as part of the study design; in a high number of studies a warm-up or familiarization session did not precede the plyometric program/exercises; in many cases the group sizes of study subjects were too small to detect significant differences between program changes; only 33 of the 50 reviewed studies used athletes or sport participants as study subjects and of these only 14 studies included team sport participants as study subjects; and lastly, only a handful of studies have thus far investigated the effectiveness of other types of plyometric training techniques such as resistive plyometric training.

In conclusion, although the literature presently contains a rather large amount of data concerning the effects of various combined and plyometric training programs alone, insufficient data with regard to the possible effects of different types of plyometric techniques on the physical, motor ability and anthropometric profile of especially teams sport participants, exist. There is, therefore, an urgent need for scientists to do high quality studies and to develop effective plyometric related programs for use in especially team sport participants.

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