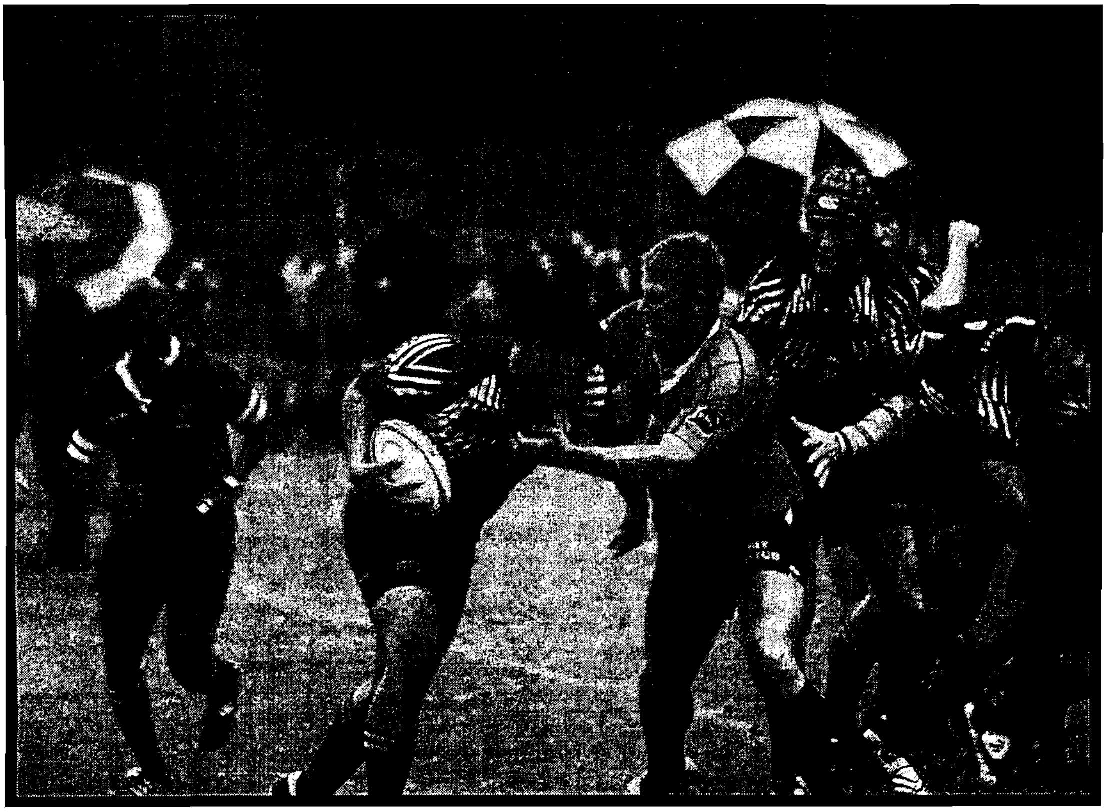
Effect of a combined rugby conditioning and plyometric training program on selected physical and anthropometric components of university-level rugby players

Cindy Pienaar
B.Sc. Honns. (Sport Science)

EFFECT OF A COMBINED RUGBY CONDITIONING AND PLYOMETRIC TRAINING PROGRAM ON SELECTED PHYSICAL AND ANTHROPOMETRIC COMPONENTS OF UNIVERSITY-LEVEL RUGBY PLAYERS



CINDY PIENAAR (12374695)
B.Sc. HONNS. (SPORT SCIENCE)

DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE *MASTER OF SCIENCE* AT THE POTCHEFSTROOM CAMPUS OF THE NORTH-WEST UNIVERSITY

SUPERVISOR: MR BEN COETZEE
MAY 2009

FOREWORD

I would like to take this opportunity to express my sincere appreciation to the following special people for all their assistance, guidance and support during the last couple of years:

To my loving husband, Jaco. Thank you so much for all your love and support and always encouraging me when I needed it most. Thank you for being my best friend and always understanding. I love you with all my heart. Always and forever.

To my parents. Mom and Dad, thank you so much for granting me the opportunity to further my studies. Thank you for always showing an interest in all I set out to do, for always supporting my career and for all your unconditional love. I love you very much.

To my study leader and mentor, Ben Coetzee. Thank you for all the hard work and long hours. I daily continue to learn from you and thank you so much for always being a willing teacher.

To all my other friends and family in Potch, Johannesburg and scattered throughout the world. Some of you have been in my life since forever and so many have come and gone through the years, but at one time or another you all send a prayer and a word of encouragement. Thank you so much. Words can't express how much I appreciate you in my life.

To Mrs Cecilia van der Walt. Thank you for your assistance with the language editing and for seeing to my work in the quickest possible time.

To My Savior, Best Friend and Heavenly Father. Thank you for so many talents and opportunities you bestowed upon me. Thank you so much for blessing me with so many people in my life. I commit myself to being Your hands and feet. You truly are an awesome God!

"Every good gift and every perfect gift is from above, and comes down from the Father of lights, with whom there is no variation or shadow of turning" - James 1:17

DECLARATION

The co-author of the two articles, which form part of this dissertation, Mr. Ben Coetzee (Supervisor), hereby gives permission to the candidate, Mss. Cindy Pienaar to include the two articles as part of a Masters dissertation. The contribution (advisory and supportive) of the co-author was kept within reasonable limits, thereby enabling the candidate to submit this dissertation for examination purposes. This dissertation, therefore, serves as partial fulfillment of the requirements for the Magister Scientiae degree in Sport Science within the School of Biokinetics, Recreation and Sport Science in the Faculty of Health Sciences at the North-West University (Potchefstroom campus).

Mr. Ben Coetzee
Supervisor and co-author

SUMMARY

Plyometrics is a specialized, high-intensity training technique for the improvement of power and performances among athletes primarily participating in dynamic, explosive type of team sports such as rugby league and soccer. In spite of the power requirements of rugby union, no studies to date have attempted to determine the possible benefits of a combined rugby conditioning and plyometric training program on the anthropometric, physical and motor performance components of rugby union players. Seen against this background, the objectives of this study were firstly, to determine the effects of a four-week combined rugby conditioning and plyometric training program on selected physical and motor performance components of university-level rugby players compared to the effects of a rugby conditioning training program alone, and secondly, to determine the comparative effects of these programs on the anthropometric components of university-level rugby players.

Thirty-five (18,94 ± 0,40 years) u/19 rugby players of the North-West University participated in the study. Subjects performed a battery of five physical and motor performance tests, and twenty-six direct and indirect anthropometric measurements were taken prior to and following a four-week combined rugby conditioning and plyometric training program (experimental group) and a non-plyometric training program (control group). Firstly, the descriptive statistics of each test variable were calculated. Next, dependent *t*-tests were performed to reveal the significant changes between pre and post-test results, after which the independent *t*-test values were calculated to determine the significance of pre and post-test changes between the control and experimental group. The level of significance was set at $p \leq 0{,}05$. Lastly, the effect size (ES) values were calculated for all of the pre and post-test results that obtained statistically significant results.

With regard to the physical and motor performance components, the dependent *t*-test results revealed that the control group's upper body explosive power decreased significantly from pre to post-testing. The experimental group showed significant increases in speed over 20 m and agility, as well as in the power and work increments of the Wingate Anaerobic Test (WAnT). In spite of these results the independent *t*-test revealed that speed over 20 m, average power output at 20 s and relative work of the WAnT as well as agility were the only components of the experimental group that improved significantly more compared to the control group. Only small values were obtained when the effect sizes were calculated for each of the significant variables.

The anthropometric results indicated that the control group's skeletal mass and femur breadth increased significantly from pre to post-testing. The wrist breadth of the experimental group also increased significantly during the training period. The significant increase in body stature observed among both groups of players was most likely due to body growth and not due to the training program. No statistically or practically significant differences were, however, observed between the anthropometric measurement changes of the two groups of players.

Hence the conclusion drawn from the above-mentioned results is that a four-week combined rugby conditioning and plyometric training program leads to significantly bigger changes in certain physical and motor performance components of university-level rugby players than a non-plyometric rugby conditioning program alone. However, the combined rugby conditioning and plyometric training program had no significant effect on the anthropometric measurements of players compared to a non-plyometric rugby conditioning training program.

OPSOMMING

Pliometrie is 'n gespesialiseerde, hoë-intensiteit oefeningstegniek wat toegepas word ter verbetering van eksplosiewe krag en prestasies van sportlui wat hoofsaaklik aan dinamiese, eksplosiewe, kraggeoriënteerde spansportsoorte, bv. rugby-liga en sokker, deelneem. Ten spyte van die eksplosiewekrag-vereistes van rugby-unie rugbyspelers het geen studie tot hede ondersoek ingestel na die moontlike voordele van 'n gekombineerde rugbykondisionerings- en pliometrie-oefeningsprogram op die antropometriese, fisieke en motoriese veranderlikes van rugby-unie rugbyspelers nie. Gesien teen hierdie agtergrond was die doelwitte van die studie ten eerste om die effek van 'n vier weke lange gekombineerde rugby- en pliometriekondisioneringsoefeningsprogram op die fisieke en motoriese komponente van rugbyspelers op universiteitsvlak te vergelyk met die effek van 'n rugbykondisioneringsoefeningsprogram, en tweedens, om die vergelykende effek van hierdie programme op die antropometriese komponente van rugbyspelers op universiteitsvlak vas te stel.

Vyf en dertig (18,94 ± 0,40 jare) o/19 rugbyspelers van die Noordwes-Universiteit het aan die studie deelgeneem. Die proefpersone het 'n toetsbattery van 5 fisieke en motoriese toetse voltooi en ses en twintig direkte en indirekte antropometriese metings is geneem voor en na 'n vier weke lange gekombineerde rugby-pliometriekondisioneringsprogram (eksperimentele groep) en 'n nie-pliometrieoefeningsprogram (kontrolegroep). Eerstens is die beskrywende statistiek van elke toetsveranderlike bereken. Vervolgens is afhanklike *t*-toetse uitgevoer om die betekenisvolle veranderinge tussen pre- en posttoetsresultate vas te stel, waarna die onafhanklike *t*-toetswaardes bereken is om die betekenisvolheid van pre- en posttoetsveranderinge tussen die kontrole- en eksperimentele groepe vas te stel. Die vlak van betekenisvolheid is vasgestel op $p \leq 0,05$. Laastens is die effekgroottes bereken vir al die pre- en posttoetsresultate wat statisties betekenisvolle resultate opgelewer het.

Met betrekking tot die fisieke en motoriese komponente het die afhanklike *t*-toetsresultate getoon dat die kontrolegroep se bolyf-eksplosiewe krag betekenisvol afgeneem het van pre- na posttoetsing. Die eksperimentele groep het betekenisvolle verhogings in spoed oor 20 m en ratsheid, asook in die eksplosiewekrag- en werksintervalle van die Wingate Anaerobiese Toets

(WAnT) getoon. Ten spyte van hierdie resultate het die onafhanklike *t*-toets daarop gedui dat spoed oor 20 m, gemiddelde eksplosiewe kraguitset by 20 s en relatiewe werksuitset van die WAnT asook ratsheid die enigste komponente van die eksperimentele groep was wat betekenisvol meer verbeter het in vergeleke met die kontrolegroep. Slegs klein waardes is verkry met berekening van die effekgroottes vir elk van die betekenisvolle veranderlikes.

Die antropometriese resultate het aangetoon dat die kontrolegroep se skeletale massa- en femurdeursnee betekenisvol vergroot het van pre- na posttoetsing. Die gewrigsdeursnee van die eksperimentele groep het ook betekenisvol tydens die oefeningsperiode toegeneem. Die betekenisvolle toename in liggaamslengte wat by beide groepe spelers toegeneem het, was moontlik toe te skryf aan liggaamsgroei en nie aan die oefeningsprogram nie. Geen statisties of prakties betekenisvolle verskille het voorgekom met betrekking tot die antropometriese veranderinge in metings tussen die twee groepe spelers nie.

Die gevolgtrekking waartoe geraak word na aanleiding van bogenoemde resultate is dat 'n vier weke lange gekombineerde rugby-pliometriekondisioneringsprogram tot betekenisvolle groter veranderinge in sommige fisieke en motoriese komponente rugbyspelers op universiteitsvlak lei vergeleke met 'n nie-pliometrierugbykondisioneringsprogram. Daarteenoor het die gekombineerde rugby-pliometriekondisioneringsoefeningsprogram vergeleke met die nie-pliometrierugbykondisioneringsprogram 'n nie-betekenisvolle effek gehad op die antropometriese metings van die spelers.

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LIST OF ABBREVIATIONS

ATT	Agility T-Test
BD	Body Density
cm	centimetre
ES	Effect Size
EMS	Electromyostimulation
g/cm^3	gram per cubic centimetre
J	Joules
kg	Kilogram
MBPT	Medicine Ball Put Test
mm	millimetre
n	Number of subjects in each subgroup
s	Seconds
SD	Standard deviation
SEC	Series elastic component
SF	Skinfold
SUM6SF	Sum of the 6 Skinfolds
VJT	Vertical Jump Test
VO_2	oxygen uptake
VO_2max	maximal oxygen uptake
WAnT	Wingate Anaerobic Test
W	Watts

CHAPTER 1

1 PROBLEM STATEMENT AND PURPOSES OF THE STUDY

1. PROBLEM STATEMENT

Plyometric training is becoming a staple in the training regimens of all levels of athletes and coaches (Kutz, 2003:10). Twenty years ago plyometric training was something mysterious that only a few daring athletes and unconventional coaches applied (Kutz, 2003:10). In recent years, plyometric training has evolved into a widely accepted and exceptionally effective tool to improve power and agility (Kutz, 2003:10). The number of studies done in the field of plyometrics has increased nearly four-fold in the past 5 years. This increase in research outputs pertaining to plyometric training shows that it is an important field of research and an area that warrants further research. In view of this, a definition and description of plyometric training, as well as the results of several studies pertaining to the benefits of plyometric training and combined plyometric training programs will be highlighted in the subsequent section.

Plyometrics is defined as being rapid powerful movements preceded by preloading countermovements that create stretch-shortening cycles which cause an increase in muscle power (Kisner, 1996:2). Additionally, authors (Kraemer, 2003:1; Kutz, 2003:10; Potach & Chu, 2008:414) have also described plyometrics as activities that enable a muscle to reach maximal force in the shortest possible time. Plyometrics is primarily described as "jump training" (Keteyian, 2004) or a specialised, high-intensity training technique that is used to develop power (Quinn, 2001). The afore-mentioned descriptions, together with several research findings, show that plyometric training can be used to improve the power and performances of athletes that primarily participate in dynamic, explosive sports codes (Stemm & Jacobson, 2007:568; Rimmer & Sleivert, 2000:297; Chu, 1998:1) such as football, basketball, baseball, volleyball and various track and field events (Potach & Chu, 2008:414; Luebbers *et al.*, 2003:704; Hoffman, 2002:144; Rimmer & Sleivert, 2000:295; Chu, 1998:2).

In recent times the majority of plyometric-related research has rather focused on the positive benefits of combined plyometric programs than on plyometric training programs alone. Researchers have, for example, investigated combined programs where plyometrics was used along with other modalities such as resistance, electromyostimulation, flexibility and sport specific training (Salonikidis & Zafeiridis, 2008:188; Herrero *et al.*, 2006:536; Rahimi & Bephur, 2005:85; Boerio *et al.*, 2003:10). In this regard several researchers demonstrated that combined plyometric and sport specific conditioning programs were significantly more beneficial for the improvement of single side-step reaction time, sport specific jumping ability as measured by reduction in foot contact time, speed and explosive power output among tennis players and tumbling athletes (Salonikidis & Zafeiridis, 2008:188; Boerio *et al.*, 2003:10). Similarly, combined plyometric and resistance training programs were significantly more effective in increasing 1RM upper and lower body strength (Mangine *et al.*, 2008:136; Harris *et al.*, 2000:18), vertical jumping height, jumping mechanical power, flight time and 50-yard sprint time (Mangine *et al.*, 2008:136; Rahimi & Bephur, 2005:85; Fatouros *et al.*, 2000:473) than resistance and plyometric training programs alone among male subjects. Furthermore, Swanik *et al.* (2002:585) noted that significant neuromuscular benefits, namely improved kinesthesia, time to peak torque, amortization time and torque decrement of the shoulder muscles can be attained by participation in a combined plyometric, resistance, sport specific and functional training program. No studies could be found in which the possible benefits of a combined plyometric program on anthropometric measurements had been investigated.

The important findings of the above-mentioned studies seem to indicate that a sport such as rugby would also benefit from a combined plyometric training program. Rugby is a game of power due to the fact that power is required in the execution of tackles, explosive acceleration, scrummaging and forceful play during rucking and mauling (Duthie *et al.*, 2003:980). In terms of playing position, power is required by the forward players to win the ball in the line outs and to retain the ball in rucks and mauls (Kelton, 1999:2). The back line players must be able to accelerate over short distances and to make and break tackles (Kelton, 1999:2). In spite of considerable variation in the fitness demands of each playing position, it is clear that all rugby players need a degree of speed, strength and power (Jenkins & Reaburn, 2000:327; Siff, 1986:3). This contention is confirmed by Webb and Lander (1984:44) who hold the opinion that in general, rugby requires speed, flexibility, endurance (muscular and cardiovascular), agility and strength. Given that plyometric training may significantly improve speed, endurance, strength and power, applying this type of training method among rugby players can be recommended.

Not withstanding the widespread acceptance and use of plyometric training in the conditioning of athletes, the purported benefits plyometric training have on sport performance have come into question in several research publications (Swanik *et al.,* 2002:585; Lathrop *et al.,* 2001:17; Heiderscheit *et al.,* 1996:132). In this regard Heiderscheit *et al.* (1996:132), for example, showed that plyometric training does not have any significant positive effect on isokinetic concentric/eccentric shoulder internal rotator power, kinesthetic test values or functional parameters of a throwing test. Moreover, a more recent study of Swanik *et al.* (2002:585) supports the rationale that plyometric training may not be the most effective training method to enhance torque development, particularly in highly trained athletes. Furthermore, Lathrop *et al.* (2001:17) found that a combined running-plyometric program does not cause significantly better improvements in running economy, VO_2-max, support time, braking time and braking change in velocity as well as 3 200 m running time compared to a running program only. Other combined plyometric programs also did not yield significantly better results for the combined plyometric program group when compared with the weight training group (Ronnestad *et al.*, 2008:775; Moore *et al.*, 2005:796; Rahimi & Bephur, 2005:86).

Considering the paucity of data examining the benefits of plyometric training, the following research questions are posed: Firstly, what are the effects of a four-week combined rugby conditioning and plyometric training program on selected physical and motor performance components of university-level rugby players compared to the effects of a rugby conditioning program alone? Secondly, what are the effects of a four-week combined rugby conditioning and plyometric training program compared to a rugby conditioning program alone, on the anthropometric components of university-level rugby players? Answers to these questions should provide coaches, sport scientists and other sport-related professionals with information regarding the effectiveness of combined plyometric training programs during a rugby season.

2. OBJECTIVES

The objectives of this study are:

- To determine the effects of a four-week combined rugby conditioning and plyometric training program on selected physical and motor performance components of university-level rugby players compared to the effects of a rugby conditioning program alone; and
- To determine the effect of a four-week combined rugby conditioning and plyometric training program compared to a rugby conditioning program alone, on the anthropometric measurements of university-level rugby players.

3. HYPOTHESES

The study is based on the following hypotheses:

- A four-week combined rugby conditioning and plyometric training program will lead to significantly better changes in selected speed, agility and anaerobic power output values among university-level rugby players than a rugby conditioning program alone.
- A four-week combined rugby conditioning and plyometric training program would have a significantly bigger effect on the body size, lean body, muscle, fat and skeletal mass and somatotype of subjects, compared to a rugby conditioning program alone.

4. STRUCTURE OF THE DISSERTATION

The dissertation is submitted in article format as approved by the Senate of the North-West University and is structured as follows:

Chapter 1: Problem statement, objectives and hypotheses of the study. A bibliography is provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 2: Literature overview: The effects of combined sport specific and plyometric training on a variety of physical and motor ability components. A bibliography is provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 3: Article 1 – Changes in selected physical and motor performance components of university-level rugby players after a four-week combined rugby conditioning and plyometric training program. The article will be presented for possible publication in the Journal of Strength and Conditioning Research. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables will be included within the text so as to make the article easier to read and understand.

Chapter 4: Article 2 – The effects of a four-week combined rugby conditioning and plyometric training program on the anthropometric components of university-level rugby players. The article will be presented for possible publication in the Journal of Strength and Conditioning Research. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not given as guidelines of the journal, tables will be included within the text so as to make the article easier to read and understand.

Chapter 5: Summary, conclusions and recommendations.

Appendix: The demographic, general information questionnaires, informed consent forms, physical and motor ability data collection forms as well as the instructions for authors and an example of a published article from the Journal of Strength and Conditioning Research are attached as addendums.

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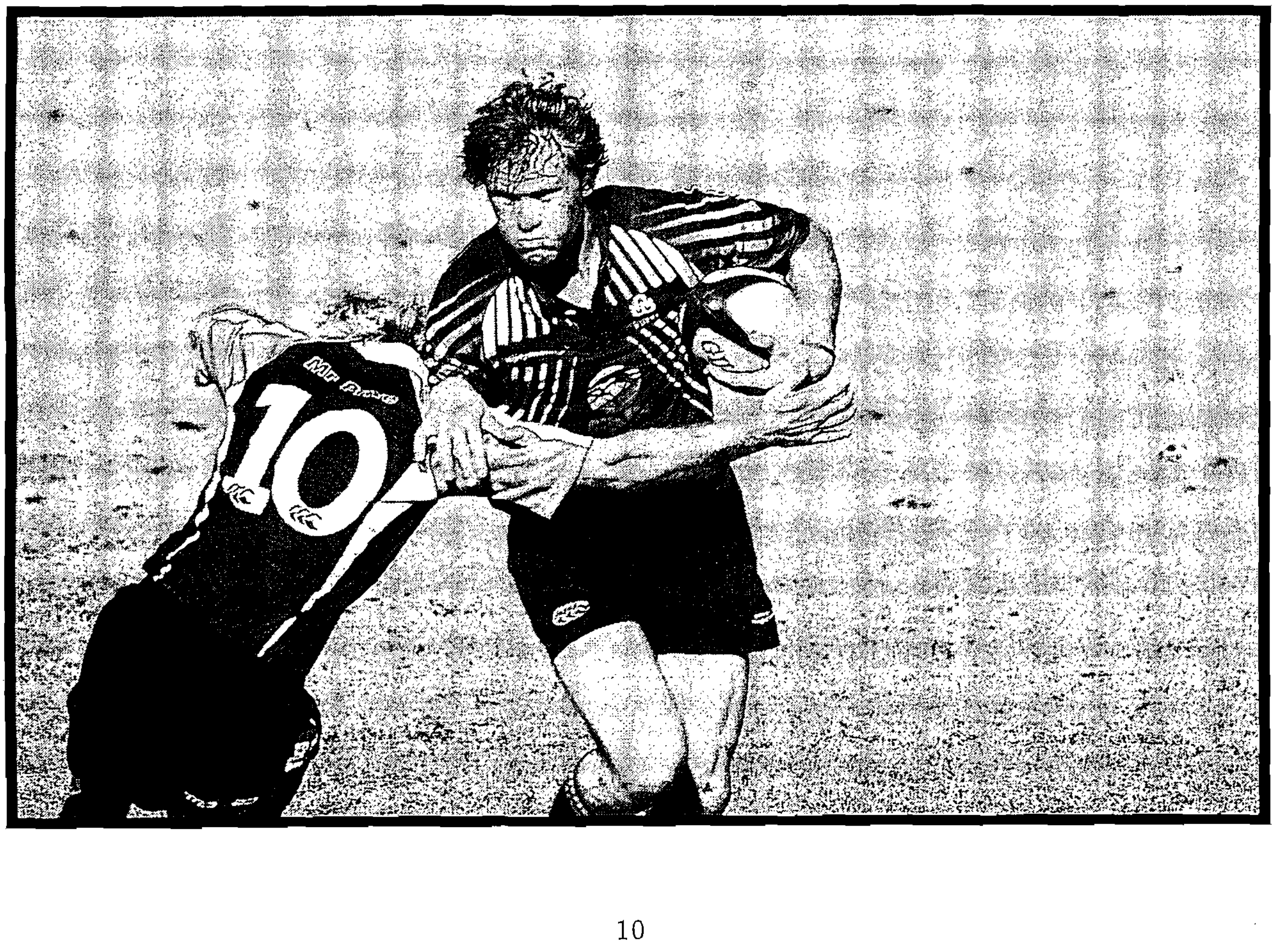
CHAPTER 2



2

LITERATURE OVERVIEW: EFFECTS OF COMBINED SPORT SPECIFIC AND PLYOMETRIC TRAINING PROGRAMS ON A VARIETY OF PHYSICAL AND MOTOR PERFORMANCE COMPONENTS

1. INTRODUCTION

Plyometrics is a high-intensity training technique which is a popular training tool among the sporting fraternity as a method to increase speed (Markovic *et al.*, 2007:543), power (Radcliffe & Farentinos, 1999:1) and agility (Miller *et al.*, 2006:462) of athletes from various types of sports such as football, basketball, baseball, volleyball and various track and field events (Potach & Chu, 2008:414; Luebbers *et al.*, 2003:704; Rimmer & Sleivert, 2000:295; Chu, 1998:2). Plyometrics as it is known and used today received a great deal of attention in the early 1970s when athletes from the Eastern European countries outperformed other athletes in power dependant events (Stemm & Jacobson, 2007:568; Chu, 1998:1). An interest in their training methods led to the discovery of plyometrics, and coaches and athletes started implementing the training technique in their exercising programs (Chu, 1998:2). What used to be a very.mysterious training method is now widely accepted as an effective tool to enhance athletes' performances (Kutz, 2003:10).

The word *plyometrics* originated from two Greek words, "plio", meaning "more" and "metric", meaning "to measure" (Dintiman & Ward, 2003:97) or as Chu (1998:1) described it "measurable increase", and was first used in 1975 by an American track and field coach, Fred Wilt (Dintiman & Ward, 2003:97; Chu, 1998:1). A coach of the Soviet Union, Yuri Verkhoshansky was one of the first to use plyometrics as a training technique and since his first publication in 1966, research on plyometrics as a training technique has steadily increased over the years with articles that doubled in number during the late 1990s and 2000s.

The majority of plyometric-related programs only focused on plyometric training programs but more recently, coaches and sport scientists shifted their attention to complex or compound training, which consists of a combination of plyometric and sport specific training programs (Dodd & Alvar, 2007:1177; Ebben, 2002:42). The inclusion of plyometric training in athletes' existing training programs have been investigated on sports codes such as cycling, gymnastics, athletics, baseball and golf, to name but a few (Dodd & Alvar, 2007:1177; Fletcher & Hartwell, 2004:59; Boerio *et al.*, 2003:1; Bastiaans *et al.*, 2001:79; Dean *et al.*, 1998:238). Not withstanding the widespread acceptance and use of plyometrics in athletes' training programs (Dodd & Alvar, 2007:1177, Fletcher & Hartwell, 2004:59; Fatouros *et al.*, 2000:470), the purported benefits of this type of training have come into question in several research publications (Lathrop *et* *al.,* 2001:17; Lyttle *et al.*, 1996:178;). It is in view of these contradictory research findings regarding the benefits of combined plyometric and sport specific training programs that this literature overview was undertaken. Hence the first aim of the study was to critically analyse the available literature of the past 10 years (1999-2008) with regard to the study subject, the nature of the combination program that was used as well as the findings with regard to the effects of these types of programs on a wide variety of physical and motor performance components and secondly, to provide guidelines for the use of combination plyometric programs as a performance-enhancing training technique.

2. METHOD OF RESEARCH

Computer searches were performed using the SportDiscus, Medline, Academic Research, Academic Search Premier and Masterfile databases. The MetaCrawler, Scirus and Google Scholar internet search engines were also used to trace the available literature. The searches were narrowed down to include only articles from the past 10 years (1999–2008) and those which made use of adult populations ($X \geq 18$ years) as test subjects. Furthermore, only articles that investigated the influence of combined plyometric training programs were used. Key words used in the searches included, but were not limited to, the following: plyometrics, plyometric training, explosive power, combined programs.

In the subsequent section the physiological principles of plyometric training are discussed to provide the reader with the background information necessary to interpret the findings of the different research articles.

3. PHYSIOLOGICAL PRINCIPLES OF PLYOMETRIC TRAINING

The physiological principles underlying plyometric training are explained by means of three models which will be discussed briefly in the subsequent section.

3.1 THE MECHANICAL MODEL

In the mechanical model, potential elastic energy is stored due to rapid stretching of a muscle (Potach & Chu 2008:414). Dintiman and Ward (2003:98) dubbed this phase of a plyometric movement, the *loading phase*. The unloading phase takes place when the energy that was stored in the muscle is immediately released in a reaction opposite to the loading phase (Dintiman & Ward, 2003:98). In short, during the stretch, the musculotendinous unit lengthens, which allows the series elastic component (SEC) to store the elastic energy (Radcliffe & Farentinos, 1999:4; Chu, 1998:4). If this eccentric muscle action is immediately followed by a concentric contraction of the same muscle, the stored elastic energy will be released and in so doing, contribute to the total force production (Potach, 2004:426; Radcliffe & Farentinos, 1999:4). The stored elastic energy will, however, dissipate as heat if the eccentric action is not immediately followed by a concentric muscle contraction (Potach & Chu, 2008:414; Chu, 1998:4).

3.3 THE NEUROPHYSIOLOGICAL MODEL

The reflexive action of plyometric exercises is primarily caused by the sensory responses of the muscle spindles (Potach & Chu, 2008:415; Potach, 2004:426). The muscle spindles act as proprioceptors that are responsible for the activation of the stretch reflex in reaction to the rapid lengthening (eccentric phase) of the muscle. After activation of the stretch reflex a signal is sent to the muscle which leads to a fast muscle contraction (Potach & Chu, 2008:415; Radcliffe & Farentinos, 1999:4). The power of the concentric contraction will depend on the rate at which muscle stretching takes place during the eccentric loading phase (Dintiman & Ward, 2003:98).

3.4 THE STRETCH-SHORTENING CYCLE

The stretch-shortening cycle utilises the energy stored during the eccentric loading phase and the stimulation of the muscle spindles to facilitate maximum power production during the concentric phase of movement (Potach & Chu, 2008:415; Stemm & Jacobson, 2007:568; Potach, 2004:429). The stretch-shortening cycle involves three distinctive phases, namely: phase 1 – the eccentric/stretching or loading phase which involves the storage of elastic energy in the SEC; phase 2 – the amortization phase which is the time period during which a delay occurs between the concentric and eccentric phases; phase 3 – the concentric phase during which the stored elastic energy and stimulation of the muscle spindles lead to a forceful contraction of the muscle (Potach & Chu, 2008:416; Potach, 2004:428; Radcliffe & Farentinos,1999:4). Phase 2 of the stretch-shortening cycle is also the most important phase in determining the power output. A too long amortisation phase will lead to a loss in stored elastic energy. The main focus of athletes will therefore be to shorten the amortisation phase so that maximal power production can be increased (Chu, 1998:4).

It is in the light of the afore-mentioned background that the overview follows pertaining to research articles of the past 10 years that have focused on the effect of combined plyometric training programs.

4. DISCUSSION

The main focus of this review was to determine whether a plyometric program should be followed on its own, or incorporated in existing training programs. Furthermore, the researcher also wanted to investigate the effects of a plyometric training program alone, compared to the effects of a combined training program, which includes sport specific, heavy resistance, speed, functional or electromyostimulation conditioning exercises. Twenty-three articles (see Table 1) which investigated the effectiveness of plyometric training alone or in combination with other forms of training were identified. The results and conclusions of these articles will form the basis of the discussion presented in the section below.

4.1 Combined resistance and plyometric versus a plyometric and/or resistance training program

Five studies reported on the effects of a combined resistance and plyometric training program compared to a plyometric and/or resistance training program alone (Mangine *et al.*, 2008; Carter *et al.*, 2007; Rahimi & Bephur, 2005; Fatouros *et al.*, 2000; Harris *et al.*, 2000). In this regard maximal torso. and leg strength as measured by 1RM bench press (Mangine *et al.*, 2008:136), squats (Mangine *et al.*, 2008:136) and leg press (Fatouros *et al.*, 2000:474) respectively, as well as explosive leg power as measured by vertical jump height (Rahimi & Bephur, 2005:85; Fatouros *et al.*, 2000:474), jumping mechanical power, flight-time (Fatouros *et al.*, 2000:474) and average squat jump power (Mangine *et al.*, 2008:136) all showed significantly greater improvements due to a combined resistance and plyometric training program compared to a resistance or plyometric training program alone. Similar improvements were also reported for the 50-yard sprint (Rahimi & Behpur, 2005:86) and the 10-yard shuttle run times (Harris *et al.*, 2000:18) as well as for baseball throwing velocity (Carter *et al.*, 2007:209) when the effects of combined programs were compared with those of non-combined programs.

Table 1: Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Mangine *et al.* (2008) The effects of combined ballistic and heavy resistance training on maximal lower- and upper-body strength in recreationally trained men	17 males 20,7 ± 1,5	To determine the effect of: ➢ **Heavy resistance training**: a heavy resistance training phase 1: 3-4 sets of 6-8 reps at 80-85% of 1RM; phase 2: 4 sets of 4-6 reps at 85-90% of 1RM ➢ **Combination heavy resistance training and ballistic resistance training:** a heavy resistance training phase 1: 3-4 sets of 6-8 reps at 80-85% of 1RM; phase 2: 4 sets of 4-6 reps at 85-90% of 1RM; ballistic training phase 1: 4 sets of 5 reps at 50% of 1RM; phase 2: 5 sets of 3 reps at 60% of 1RM; ballistic training done earlier in the workout followed by resistance training; the ballistic training was completed before commencement of the resistance training on maximal upper and lower body strength as determined by means of the 1RM bench press and squat as well as maximal upper and lower body power as determined by means of ballistic push-ups and jump squats.	8 weeks 3 x per week (2 upper/lower body split routines)
Marques *et al.* (2008) Changes in strength and power performance in elite female professional volleyball players during the in-season: a case study	10 females 25,3 ± 1,3	To determine the effect of: ➢ combination heavy resistance and plyometric training in addition to regular volleyball specific training during the in-season period: 3 sets of 3-6 reps at 50-80% of predetermined 4RM, with 2 min rest intervals between sets and exercises on countermovement jump height (CMJ), overhead medicine ball throw distance, 4RM bench press and squat.	12 weeks Resistance training: 2 x per week, in-season

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Ronnestad *et al.* (2008) Short-term effects of strength and plyometric training on sprint and jump performance in professional soccer players	21 males 21 - 26	To determine the effect of: ➢ **Experimental group 1**: a combined regular soccer and heavy strength training program of half squats and hip flexions: 2 x per week 3 sets at 4-6RM, for the first 2 weeks; weeks 3-5: 4 sets; for the final 2 weeks: 5 sets ➢ **Experimental group 2**: a combined regular soccer training, heavy strength training and plyometric training program. Strength training: same as above; plyometric training: 2 x per week: double-arm single-leg forward jumps, single-arm alternate-leg forward bounces and double leg hurdle jumps: 2-4 sets of 5-10 foot contacts (reps); 1 min rest between sets ➢ **Control group**: combined regular soccer training and core training program; core training: 2 x per week on 1RM half squats, countermovement, and squat jump height, horizontal distance achieved in a 4-bounce test, peak power attained during a loaded barbell squat jump, sprint acceleration and peak sprint velocity during a 40 m sprint time test.	7 weeks Soccer training: 6-8 x per week (90-120 min) Heavy resistance training: 2 x per week Combined plyometric and heavy resistance training: 2 x per week Core training: 2 x per week
Salonikidis and Zafeiridis (2008) The effects of plyometric, tennis-drills, and combined training on reaction, lateral and linear speed, power, and strength in novice tennis players	64 males and females 21 ± 1,3	To determine the effects of: ➢ **Experimental group 1**: plyometric training: single-leg hops (6 x 14m), single-leg hopping on stairs 20-40 cm high (6 x 20 stairs), single-leg "kangaroo" jumps and knee lifting to the chest ➢ **Experimental group 2**: tennis drill training at maximum speed (for full explanation of drills refer to article) ➢ **Experimental group 3**: a combination of plyometric and tennis drill training; 2 exercises from the plyometric program and 2 tennis drills ➢ **Control group**: no training on reaction time, 4m lateral linear sprints, 12 m linear sprints with and without turn, reactivity ball, drop jump (power) and maximal strength on the "slow" side of the player. "Slow" side determined by means of the time it took to complete 4,115 m side steps.	9 weeks Experimental groups: 3 x per week for all

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Carter *et al.* (2007) Effects of high volume upper extremity plyometric training on throwing velocity and functional strength ratios of the shoulder rotators in collegiate baseball players	24 males 19,7 ± 1,3	To determine the effect of: **Experimental group**: a combination of plyometric ((3 sets of 10-20 reps of 6 upper body exercises; 2 x per week) (weeks 1-2: 3 sets of 10 reps; weeks 3-5: 3 sets of 15 reps; weeks 6-8: 3 sets of 20 reps)), strength and conditioning exercises 3 x per week ➢ **Control group**: a regular strength and conditioning training program as well as rotator cuff strengthening exercises done 3 x per week on functional eccentric external rotation-to-concentric internal rotation strength ratio and throwing velocity.	8 weeks
Dodd and Alvar (2007) Analysis of acute explosive power training modalities to improve lower-body power in baseball players	45 males 18 - 23	To determine the effect of: ➢ baseball specific training 3 x per week, 45 min per session in addition to: ➢ **Group 1**: a complex training program consisting of 2 sets of 6 reps of 3 heavy resistance training exercises and 3 plyometric exercises ➢ **Group 2**: heavy resistance training (squats, lunges, split squats), 4 sets of 6 reps at 80-100% of 1RM ➢ **Group 3**: high velocity training (box jumps, depth jumps, split squat jumps), 4 sets of 6 reps at 0-30% of 1RM on 20, 40, and 60-yd sprinting, vertical jump, standing broad jump and T-agility performance.	15 weeks Baseball specific conditioning: 3 x per week Complex training, heavy resistance training, high velocity training: 2 x per week
Mikkola *et al.* (2007) Concurrent endurance and explosive type strength training increases activation and fast force production of leg extensor muscles in endurance athletes	19 males 19 - 28	To determine the effects of: ➢ **Experimental group**: a regular program of endurance training (same as control group) with 27% of training replaced with explosive strength training and strength and speed exercises, 3 x per week consisting of 2-3 sets of 6-12 reps of each exercise ➢ **Control group**: a regular program of endurance training (roller skiing, running and nordic walking) on isometric strength, sport specific force velocity, endurance performance and maximal oxygen uptake (VO_2 max).	8 weeks Endurance training: ± 11 hours per week Explosive training: 3 x per week

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Herrero *et al.* (2006) Electromyostimulation and plyometric training effects on jumping and sprint time	40 males 19 - 22	To determine the effects of: ➢ **Electromyostimulation (EMS) group**: electromyostimulation training of the knee extensor muscles by placing 2 electrodes on the thigh ➢ **Plyometric training group**: horizontal and drop jumps (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 plyometric training group**: a combination of above-mentioned programs: 2 consecutive days of EMS training followed by one rest day and then 2 consecutive days of plyometric training ➢ **Control group**: 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 Plyometric training: 2 x per week Combination training: EMS 2 x per week, plyometrics 2 x per week
Moore *et al.* (2005) Comparison of two twelve weeks of off-season combined training programs on entry level collegiate soccer players' performance	10 females and 5 males 20,2 ± 0,2	To determine the effects of: ➢ **Olympic style lifting**: regular off-season cardiovascular soccer training and traditional resistance training: 3 sets of 6 reps combined with Olympic style lifts: 3 sets of 6 reps of hang clean and Romanian deadlifts ➢ **Plyometric training**: regular off-season cardiovascular soccer training and traditional resistance training: 3 sets of 6 reps combined with various plyometric drills eg. bounds, tuck jump, box jumps, 1-3 sets of 15-30 reps on vertical jump height, 4RM squat and 25 m sprint time and foot speed over 3 testing opportunities during the 12 week period	12 weeks Olympic lifts and plyometric drills: 3 x per week

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Paton and Hopkins (2005) Combining explosive and high-resistance training improves performance in competitive cyclists	18 males 18 - 38	To determine the effects of: ➢ **Experimental group**: replacing a part of the cyclists existing training and competition training with 12 sessions of 3 sets of 20 reps explosive single-leg jumps, alternated with 3 sets of 5 high-resistance cycling sprints of 30 s each ➢ **Control group**: existing training and competition program on mean power output of 1- and 4 km time trials, peak power output, lactate profile and oxygen consumption during an incremental cycle ergometer test.	4–5 weeks Plyometric training: 2-3 x per week
Rahimi and Behpur (2005) The effects of plyometric, weight and plyometric-weight training on anaerobic power and muscular strength	48 males 19,27 ± 1,36	To determine the effects of: ➢ **Plyometric training group:** depth jumps, split squat jumps, rim jumps and box to box depth jumps: 3 sets of 6 reps progressing to 4 sets of 8 reps ➢ **Weight training group:** resistance training: 4 sets of 10 reps at 40% of 1RM, progressing to 4 sets of 6 reps at 100% of 1RM ➢ **Plyometric and weight training group:** a combination of plyometric and weight training with the volume and intensity reduced by 25% ➢ **Control group:** no training on vertical jump height, 50 yd sprint time and 1RM squat.	6 weeks 2 x per week
Chimera *et al.* (2004) Effects of plyometric training on muscle-activation strategies and performance in female athletes	20 females 18 - 22	To determine the effects of : ➢ **Experimental group**: a combined hockey/soccer resistance and plyometric training program (4-5 exercises, 2 sets of 30-70 reps) ➢ **Control group**: a regular hockey/soccer and resistance training program on the surface electromyography (preparatory and reactive activity) of the right leg's thigh muscles during drop jumps, vertical jumps and sprint speed measurements.	6 weeks Plyometric training: 2 x per week Hockey/soccer training: 3 x per week Resistance training: 2 x per week

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Fletcher and Hartwell (2004) Effect of an 8-week combined weights and plyometric training program on golf drive performance	11 males 29 ± 7,4	To determine the effects of: ➢ **Experimental group**: a combination of regular golf training, weight training: 3 sets of 6-8 reps, and plyometric training: 3 sets of 8 reps ➢ **Control group**: regular golf training on club head speed and driving distance.	8 weeks Weight training and plyometrics: 2 x per week
Wilkerson *et al.* (2004) Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program	19 females 17 - 21	To determine the effects of: ➢ **Experimental group**: a 6 weeks preseason conditioning program that included plyometric jump training, flexibility and isotonic strength training ➢ **Control group**: a preseason conditioning program that included flexibility, isotonic strength training and periodic periods of unstructured plyometric jump training on hamstring and quadriceps isokinetic peak torque, impact forces as measured during forward lunging and unilateral step-downs as well as body core displacement during performance of an agility T-drill.	6 weeks
Boerio *et al.* (2003) Effects of four weeks of plyometric training in tumbler athletes power output	6 males and females 18,33 ± 3,09	To determine the effects of: ➢ **Tumbling and plyometrics**: a combined tumbling and plyometric resistance specific training program on jumping performance, contact time on floor and power development.	4 weeks 5 sessions per week of regular tumbling training 3 combined plyometric and weight training session per week (12 sessions)

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Spurrs *et al.* (2003) The effect of plyometric training on distance running performance	17 males 25 ± 4	To determine the effects of: ➢ **Experimental group**: a combined program of normal running (60-80 km per week) and plyometric training: 2-3 sets of 10-15 reps of various bounds and hops both performed in vertical and horizontal directions ➢ **Control group**: normal running training of 60-80 km per week on running economy, VO_2max, lactate threshold, lower leg musculotendinous stiffness, maximal isometric force, rate of force development, counter movement jump height, horizontal distance achieved in a 5-bound test and 3 km time trial performance.	6 weeks Plyometric training: 2 x per week 1-3 and 3 x per week 4-6
Turner *et al.* (2003) Improvement in running economy after 6 weeks of plyometric training	11 females and 10 males 29 ± 7	To determine the effects of: ➢ **Experimental group**: a combination of regular running training and plyometric training: 10-30 reps of single and double legged vertical jumps, continuous vertical jumps, split squat jumps and incline jumps ➢ **Control group**: 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 3 x per week Plyometric training: 3 x per week
Maffiuletti *et al.* (2002) Effect of combined electrostimulation and plyometric training on vertical jump height	20 males 18-26	To determine the effects of: ➢ **Experimental group**: regular volleyball training and a combination of electromyostimulation (EMS) and plyometric training: 5 sets of 10 vertical jumps, 3 min rest between sets ➢ **Control group**: regular volleyball training on vertical jump height performance and MVC (maximal voluntary contraction) of knee extensors and plantar flexors.	4 weeks Volleyball training: 3 x per week EMS and plyometrics: 3 x per week (12 sessions)

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention programme	Duration and frequency of intervention
Swanik *et al.* (2002) The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics	24 females 20 ± 1,10	To determine the effects of: ➢ **Experimental group:** a combination program of swimming (6 x per week), resistance training (3 x per week), functional training (2 x per week) and plyometric training: 3 sets of 15 reps with elastic tubing, trampoline and medicine balls (2 x per week) ➢ **Control group**: a combination program of swimming (6 x per week), resistance training (3 x per week) and functional training (2 x per week) on shoulder proprioception, kinesthesia and isokinetic muscle performance.	6 weeks Plyometric training: 2 x per week
Bastiaans *et al.* (2001) The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists	14 males 24 ± 8 (E) 29 ± 12 (C)	To determine the effects of: ➢ **Experimental group**: 37% of training supplemented with 4 sets of 30 reps explosive, low-weight squats, leg press single leg step ups as well as 2 sets of 30 reps explosive leg pull and abdominal exercises ➢ **Control group**: a regular program of endurance training on maximal workload measured during a 30 s ergometer test as well as power output during a simulated time trial measured on a ergometer.	9 weeks 8.8 hours per week (E) 8.9 hours per week (C)
Fatouros *et al.* (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: ➢ **Plyometric training**: squat, depth, and box jumps, jumps over cones and bench, repeat triple jumps, single- or double-leg hops as well as alternate leg bounds ➢ **Weight training**: a 12 weeks of weight training program: first 8 weeks: barbell squats, leg presses, leg curls and standing calf raises; last 4 weeks: barbell jump squats, cleans, snatches, push presses as well as core exercises; throughout 12 weeks: front and side lunges, step ups, sitting calf raises and deadlifts ➢ **Plyometric plus weight training**: a combination of plyometric and weight training protocols ➢ **Control group**: no training on vertical jump height, flight time, 1RM squat and 1RM leg press.	12 weeks Training: 3 x per week

Table 1 (cont.): Description of studies regarding the effects of combination plyometric training programs on certain physical and motor performance components

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Duration and frequency of intervention
Harris *et al.* (2000) Short-term performance effects of high power, high force or combined weight-training methods	42 males 18 - 20	To determine the effects of: ➢ **Group 1**: high force training that consisted of the following exercises: parallel squat, quarter squat, bench press, push press, crunch, midthigh pull, semi-straight-leg deadlift, and bent over row: 5 sets of 5 reps at 50-80% of 1RM ➢ **Group 2**: high power training that consisted out of the following exercises: dumbbell squat, quarter squat, bench press, push press, crunch, midthigh pull, semi-straight-leg deadlift and bent over row: 5 sets of 5 reps at 20-45% of 1RM ➢ **Group 3**: a combination of high force and high power training exercises on parallel squat, 1/4 squat and midthigh pull 1RM values, countermovement vertical jump height, standing long jump distance, Margaria-Kalamen stair climbing test, 10-yard shuttle run and 30 m sprint time.	9 weeks Training: 4 x per week
Paavolainen *et al.* (1999) Explosive-strength training improves 5-km running time by improving running economy and muscle power	18 males 19 - 29	To determine the effects of: ➢ **Experimental group**: regular endurance and circuit training twice a week that consisted out of specific abdominal and leg exercises with 32% of training replaced with sport-specific explosive strength training: consisting of sprints, jumping exercises with additional weights or barbell on shoulders, leg-press and knee extensor-flexor exercises with low loads but maximal movement velocities ➢ **Control group**: regular endurance and circuit training twice a week that consisted out of specific abdominal and leg exercises with 3% of training replaced with sport-specific explosive strength training: consisting of sprints, jumping exercises with additional weights or barbell on shoulders and leg-press and knee extensor-flexor exercises with low loads but maximal movement velocities on 5 km time trial performance, maximal isometric leg extensor muscle force, VO_2max, lactate threshold, maximal velocity during an anaerobic running test (MART), 20 m sprint time, the maximum distance achieved after 5 forward jumps and running economy.	9 weeks

On the other hand, the above-mentioned researchers also reported insignificant results when the effects of the mentioned programmes were compared. Variables such as 1RM squat (Rahimi & Bephur, 2005:85; Fatouros *et al.*, 2000:474) and leg press (Fatouros *et al.*, 2000:474), ballistic push-up repetitions (Mangine *et al.*, 2008:136), functional isokinetic eccentric external rotation to concentric internal rotation shoulder strength ratio (Carter *et al.*, 2007:209), standing long jump distance (Harris *et al.*, 2000:18), Margaria-Kalamen stair climbing power (Harris *et al.*, 2000:18) and 30 m sprint time (Harris *et al.*, 2000:18), showed no significant results during the program comparisons.

4.2 Combined sport specific and plyometric versus a sport specific training program

Five journal articles that compared the effects of a combined sport specific (tennis, running, cycling) and plyometric with sport specific training programs alone were identified, namely those of Salonikdis and Zafeiridis, (2008), Paton and Hopkins, (2005), Spurrs *et al.*, (2003), Turner *et al.*, (2003) and Bastiaans *et al.*, (2001). In this regard the research results showed that combined sport specific and plyometric training programs led to significantly bigger increases in mean power output of 1 and 4 km cycling time trials (Paton & Hopkins, 2005:827); peak power output and oxygen consumption (VO_2) during an incremental cycling test (Bastiaans *et al.*, 2001:80; Paton & Hopkins, 2005:827); running economy (Turner *et al.*, 2003:61); maximal workload measurements during a 30 s cycle ergometer test (Paton & Hopkins, 2005:827); 3 km running time trail performance (Spurrs *et al.*, 2003:2); counter movement jump height and 5-bound test distance (Spurrs *et al.*, 2003:2) when compared with sport specific training programs alone.

The combined programs were, however, not successful in all cases in bringing about more significant changes compared to the non-combined programs. Reactivity ball reaction time (Salonikdis & Zafeiridis, 2008:184), 4 m lateral linear sprint time (Salonikdis & Zafeiridis, 2008:184), 12 m linear sprints with and without a turn times (Salonikdis & Zafeiridis, 2008:184), drop jump power and maximal strength of the "slow" side leg (leg that obtained the slowest time in 4,115 m side steps) (Salonikdis & Zafeiridis, 2008:184), lower leg isometric strength, maximal oxygen uptake (VO_2max) (Spurrs *et al.*, 2003:2; Turner *et al.*, 2003:61), running economy (Spurrs *et al.*, 2003:2), lactate threshold (Spurrs *et al.*, 2003:2), lower leg musculotendinous stiffness (Spurrs *et* *al.*, 2003:2) and rate of force development (Spurrs *et al.*, 2003:2) were all examples of variables that were not more significantly influenced by the combined compared to the non-combined program.

One study, namely that of Boerio *et al.*, (2003:2) did, however, not make use of a control group in their investigation of combined sport specific and plyometric training programs. A pre-post test design was used with a combined tumbling and plyometric training program that formed the treatment. They concluded that the combined program led to significant improvements in jumping performance, contact time on the floor and power output among tumbler athletes (Boerio *et al.*, 2003:10).

4.3 Combined electromyostimulation (EMS) and plyometric versus an EMS or plyometric training program alone, or no-training

One article (Herrero *et al.*, 2006) subjected the participant's to a combined EMS and plyometric training program and compared the effects of this program to those of EMS and plyometric training programs alone as well as to no training. They succeeded in showing that the combined program was significantly more effective in improving squat and countermovement jump height as well as 20 m sprint time than the other modalities or no training (Herrero *et al.*, 2006:536). However, no significant differences were found with regard to changes in maximal voluntary bilateral isometric leg strength and cross-sectional area of the thigh.

4.4 Combined sport specific, resistance and plyometric versus combined sport specific and resistance or sprint specific training programs

Seven articles subjected participants to combined sport specific, resistance and plyometric training programs and then compared the effects of these programs to those of combined sport specific and resistance training programs or to those of sport specific training programs alone (Marques *et al.*, 2008; Ronnestad *et al.*, 2008; Dodd & Alvar, 2007; Moore *et al.*, 2005; Chimera *et al.*, 2004; Fletcher & Hartwell, 2004; Paavolainen *et al.*, 1999). In most cases the combined program was, however, not more successful in bringing about significant changes in the different physical and motor performance components when compared with the other programs. Significant differences for the pre and post program changes between the experimental (combined programs) and control group (non-combined programs) were, however, reported for the following variables: countermovement jump height (Marques *et al.*, 2008:1150), overhead medicine ball throw distance (Marques *et al.*, 2008:1150), 4RM bench press and squat strength (Marques *et al.*, 2008:1150), co-activation levels of the abductors and adductors (Chimera *et al.*, 2004:25), golf club speed and driving distance (Fletcher & Hartwell, 2004:60) as well as 5 km time trial performance (Dodd & Alvar, 2007:1178; Paavolainen *et al.*, 1999:1528). The variables that did not achieve significant results were the following: 1RM half squat and 4RM squat strength (Ronnestad *et al.*, 2008:776; Moore *et al.*, 2005:791), vertical, countermovement and squat jump height as well as standing broad jump distance (Ronnestad *et al.*, 2008:776; Dodd & Alvar, 2007:1178; Moore *et al.*, 2005:791; Chimera *et al.*, 2004:25), distance achieved in 4 and 5 bounce tests (Ronnestad *et al.*, 2008:776); peak power attained during a loaded barbell squat jump (Ronnestad *et al.*, 2008:776); sprint acceleration, peak sprint velocity during a 40 m sprint test, 20 and 25 m sprint time and foot speed (Ronnestad *et al.*, 2008:776; Moore *et al.*, 2005:791), maximal isometric leg extensor muscle force (Paavolainen *et al.*, 1999:1528); VO_2max (Paavolainen *et al.*, 1999:1528), lactate threshold (Paavolainen *et al.*, 1999:1528), maximal velocity during an anaerobic running test and running economy (Paavolainen *et al.*, 1999:1528).

4.5 Complex combined sport specific, plyometric and other training modalities versus sport specific or combined sport specific, resistance and plyometric or combined sport specific resistance and functional training programs

Only four studies made use of complex training programs where more than three training modalities were used. Wilkerson *et al.* (2004:20) found that a combined pre-season sport specific conditioning training program which included plyometric, flexibility and isotonic strength training exercises was significantly more effective in increasing hamstring isokinetic peak torque than a program that did not include a structured plyometric training program. Swanik *et al.* (2002:582) compared the effects of a combined sport specific conditioning, resistance, functional and plyometric training program to those of a non-plyometric combined program and also reported a significant difference in changes in shoulder proprioception, kinesthesia and isokinetic muscle performance. In another study where the effects of a complex combined plyometric training program were investigated, Mikkola *et al.* (2007:614) studied the combined effects of a sport specific endurance, plyometric and speed training programme compared to a sport specific endurance training program on the isometric strength, explosive power, endurance performance and the VO_2max of cross country skiers. Results showed that the combination training group experienced significantly greater increases in time to peak power achievement and in 30 m double poling speed than the endurance training group. A combined program of EMS, plyometric and sport specific activities delivered significantly better gains in maximal vertical jumping height and maximal voluntary contraction of the knee extensors and plantar flexors when compared with non-combined programs in a study of Maffiuletti *et al.* (2002:1639).

5. GUIDELINES FOR THE IMPLEMENTATION OF SUCCESSFUL PLYOMETRIC TRAINING PROGRAMS

The next part of the discussion will be dedicated to the exercise guidelines that need to be followed when combined plyometric training programs are compiled with the aim to produce maximal results. The combined programs which seem to have the most significant effects on the various physical and motor performance components of participants when compared with non-combined programs are those that adhere to the following exercise guidelines and combined program set-up: combined plyometric and resistance training programs (Mangine *et al.*, 2008; Rahimi & Behpur, 2005; Fatouros *et al.*, 2000) with intervention periods ranging from 6 to 12 weeks and a training frequency of 2 to 3 times per week, consisting of 6 to 9 exercises where 2 sets of 6 to 10 repetitions (reps) were performed at 40–100% of 1RM and sets progressed over time from 2 to 4 sets with rest periods between 30 s and 4 min between sets; combined sport specific and plyometric training programs (Paton & Hopkins, 2005; Spurrs *et al.*, 2003; Turner *et al.*, 2003; Bastiaans *et al.*, 2001) with periods that ranged from 4 to 9 weeks of 2 to 3 sessions of plyometric training per week, consisting of 2 to 4 body weight jumping exercises repeated for 5 to 30 times (reps) with a 2 min rest between sets; a combined electromyostimulation (EMS) and plyometric training program (Herrero *et al.*, 2006) that lasted 4 weeks during which 2 sessions per week, consisting of 90 to 105 reps of jumps, were performed with a 2 to 5 min rest between sets; combined sport specific, resistance and plyometric training programs (Marques *et al.*, 2008; Chimera *et al.*, 2004; Fletcher & Hartwell, 2004) of 6 to 8 weeks with 2 plyometric and resistance training sessions per week that consisted of 3 sets of 8 reps for the resistance training sessions (2 sessions per week) at 50 to 80% of 4RM, and 2 to 3 sets of 8 reps for the high intensity as well as 30 to 70 reps for the low intensity plyometric exercises with a 2 min rest between each exercise and a 30 s rest between sets; complex combined sport specific, plyometric and other modality training programs (Mikkola *et al.*, 2007;

Wilkerson *et al.*, 2004; Maffiuletti *et al.*, 2002; Swanik *et al.*, 2002) performed over a period of 4 to 8 weeks during which plyometric training was done for 2 to 3 times per week and comprised 2 to 3 sets of 6 to 15 reps with a 2 to 3 min rest between sets.

6. SHORTCOMINGS WITH REGARD TO THE MENTIONED COMBINED PLYOMETRIC TRAINING PROGRAMS

The lack of statistically significant results with regard to the different physical and motor performance components that were influenced by the combined plyometric training programs, amongst other things, suggests that certain shortcomings need to be addressed in future studies that focus on the effects of combined plyometric programs. Firstly, eight out of a possible twenty three studies reported made use of untrained or moderately active individuals (Mangine *et al.*, 2008; Salonikidis & Zafeiridis, 2008; Herrero *et al.*, 2006; Moore *et al.*, 2005; Rahimi & Behpur, 2005; Spurrs *et al.*, 2003; Fatouros *et al.*, 2000; Harris *et al.*, 2000), whereas fifteen studies chose professional or well-trained athletes as their test subjects (Marques *et al.*, 2008:1150; Ronnestad *et al.*, 2008:774; Carter *et al.*, 2007:209; Dodd & Alvar, 2007:1178; Mikkola *et al.* 2007:614; Paton & Hopkins, 2005:827; Chimera *et al.*, 2004:25; Fletcher & Hartwell, 2004:60; Wilkerson *et al.*, 2004:18; Boerio *et al.*, 2003:2; Turner *et al.*, 2003:61; Maffiuletti *et al.*, 2002:1639; Swanik *et al.*, 2002:580; Bastiaans *et al.*, 2001:80; Paavolainen *et al.*, 1999:1528). A study sample has to be representative of the population of interest (Thomas & Nelson, 2001:95), else it will not be possible to generalize the results to the specific population of interest. Plyometrics was originally developed as a training technique to enhance the speed, power and agility of athletes (Markovic *et al.*, 2007:543; Radcliffe & Farentinos, 1999:1; Miller *et al.*, 2006:462), and not for use by sedentary or moderately active individuals. The use of the last-mentioned group of people as subjects in plyometric-related studies can therefore be questioned.

Secondly, six of the studies (Mangine *et al.*, 2008; Marques *et al.*, 2008; Dodd & Alvar, 2007; Moore *et al.*, 2005; Boerio *et al.*, 2003; Harris *et al.*, 2000) did not include a control group as part of the study design. The presence of a control group in a study strengthens the inferences that can possibly be drawn from the results of the study (Altman, 1999:9). Furthermore, in only 11 studies (Marques *et al.*, 2008; Carter *et al.*, 2007; Mikkola *et al.*, 2007; Herrero *et al.*, 2006; Moore *et al.*, 2005; Paton & Hopkins, 2005; Rahimi & Behpur, 2005; Wilkerson *et al.*, 2004; Turner *et al.*, 2003;

Maffiuletti *et al.*, 2002; Fatouros *et al.*, 2000) the subjects were familiarized with the testing protocol and exercises before commencement of the official testing and intervention period. Only 10 studies (Ronnestad *et al.*, 2008; Herrero *et al.*, 2006; Paton & Hopkins, 2005; Fletcher & Hartwell, 2004; Wilkerson *et al.*, 2004; Spurrs *et al.*, 2003; Maffiuletti *et al.*, 2002; Swanik *et al.*, 2002; Harris *et al.*, 2000; Paavolainen *et al.*, 1999) subjected participants to a warm-up prior to measurement of the physical and motor performance components or participation in the training programme. The absence of familiarization and warm-up sessions may threaten the internal validity of a specific study due to the fact that factors such as the cognitive learning effect may also have influenced the study results. In these cases the outcome of the study cannot solely be attributed to the treatments (programs) performed during the course of the study, but to other factors that were not eliminated through the specific study design.

There is no consistency in terms of the durations of combined plyometric training programs used by the different studies. The program durations varied between 4 and 15 weeks with the majority (6) (Rahimi & Bephur, 2005; Chimera *et al.*, 2004; Wilkerson *et al.*, 2004; Spurrs *et al.*, 2003; Turner *et al.*, 2003; Swanik *et al.*, 2002) making use of 6-week periods. Research has yet to determine an optimal duration for plyometric-related training programs (Potach & Chu, 2008:421). Research done by Leubbers *et al.* (2003:708) suggests that a plyometric training program for as short a period as 4 weeks may lead to neuromuscular adaptations. The subjects in their study did, however, receive a 4-week recovery period after completion of the 4-week plyometric program (Leubbers *et al.*, 2003:709). The significant changes in the different explosive power measurements only occurred after the recovery period, which led them to conclude that a 7-week plyometric program is more effective in bringing about neuromuscular changes compared to a 4-week program (Leubbers *et al.*, 2003:705). Almost all the researchers that implemented 6-week plyometric programs concluded that significant changes in either the central or peripheral neural structures or functions were experienced due to the plyometric program. Only 2 of the last-mentioned studies did, however, directly measure the mechanics that were involved in bringing about significant plyometric-related changes (Swanik *et al.*, 2002; Chimera *et al.*, 2004). In this regard Swanik *et al.* (2002:583) showed that plyometric training resulted in significant improvements in proprioception, kinesthesia and amortization time, while Chimera *et al.* (2004:27) found that significant earlier pre-activation and an increase in the force amplitude of the adductor muscle group occurred due to the plyometric training program. In view of the last-mentioned results, it would therefore be advisable to rather make use of 6-week durations when the aim of research is to investigate the effects of plyometric-related programs on the physical and motor performance components of subjects.

Another shortcoming was the use of very small group sizes in some of the studies. Boerio *et al.* (2003:2) only made use of 6 test subjects, whereas Marques *et al.* (2008:1150) used 10 test subjects, compared to Fletcher and Hartwell (2004:60) as well as Turner *et al.* (2003:61) who included 11 participants as test subjects. The last-mentioned studies contained group sizes that were too small to have a good chance of detecting worthwhile differences between the programs being investigated. To ensure a high chance of detecting statistically significant results when program comparisons are made, it would be advisable to perform a power calculation before commencement of the study so as to determine the appropriate sample size (Thomas & Nelson, 2001:108).

Lastly, researchers of several of the listed studies fail to give a detailed description of all the methodology and exercise variables necessary for readers to make valid conclusions and to apply the plyometric-related programs in real training regimens. In this regard, 10 studies (Moore *et al.*, 2005:793; Fletcher & Hartwell, 2004:60; Wilkerson *et al.*, 2004:62; Spurrs *et al.*, 2003:2; Turner *et al.*, 2003:62; Swanik *et al.*, 2002:580; Bastiaans *et al.*, 2001:80; Fatouros *et al.*, 2000:471; Harris *et al.*, 2000:17; Paavolainen *et al.*, 1999:1528) made no mention of the rest periods used between sets and repetitions. Furthermore, only 7 studies (Ronnestad *et al.*, 2008:774; Salonikidis & Zafeiridis, 2008:184; Herrero *et al.*, 2006:534; Rahimi & Behpur, 2005:85; Turner *et al.*, 2003:62; Fatouros *et al.*, 2000:473; Harris *et al.*, 2000:17) gave detailed descriptions of the exercises and the exercise programs that were performed in combination with other training modalities. Mangine *et al.* (2008:134), Ronnestad *et al.* (2008:776), Carter *et al.* (2007:210) and Rahimi and Behpur (2005:85) were the only researchers who provided the reader with information regarding the progression in exercise variables followed during the intervention period.

7. CONCLUSIONS AND RECOMMENDATIONS

From the above-mentioned it is clear that plyometrics is a high-intensity training technique used among the sporting fraternity to increase speed, power and agility in various types of sports. The physiological principles that underlie plyometric training are explained by the Mechanical, Neurophysiological and Stretch-shortening cycle models. Until recently most studies only focused on plyometric training programs, but during the past few years, coaches and sport scientists have shifted their attention to complex or combined plyometric programs consisting of a combination of plyometric and other training programs.

Overall the literature supports the use of combined plyometric above that of non-combined plyometric training programs when the aim is to significantly improve upper and lower body strength as well as explosive power; golf club speed and driving distance; 10–50 yard sprinting times; cycling peak power output; aerobic capacity, running economy as well as improvement in 1-5 km time trials; co-activation of the abductor and adductor muscle groups; isokinetic peak torque of the hamstring and maximal voluntary contraction of both the knee extensor and plantar flexor muscles as well as proprioception and kinesthesia of the shoulder muscles. However, the combined plyometric training programs were not successful in all cases in bringing about more significant changes compared to the non-combined programs. Physical and motor performance components that did not obtain significant results were: upper as well as lower body strength and explosive power; lower leg isometric strength and musculotendinous stiffness; functional isokinetic eccentric to concentric internal shoulder rotation strength ratio; rate of force development; cross-sectional area of the thigh; 4 to 40 m sprinting times when turns or no turns were used; sprint acceleration; foot speed and reactivity ball reaction time; aerobic capacity; lactate threshold and running economy.

The combined plyometric programs which were more successful in obtaining significant results with regard to the different physical and motor performance components, when compared with the non-combined programs, adhered to the following exercise guidelines and program set-up: a 4 to 12-week duration during which 2 to 3 sessions of plyometric training consisting of 2 to 9 exercises, were performed. Subjects usually performed 2 to 3 sets of 5 to 100 repetitions and rested 30 s to 5 min between the different sets. Loaded exercises were performed at an intensity of between 40 and 100% of the 1RM.

Certain shortcomings/limitations were, however, identified during the literature review of the combined plyometric training program-related studies reported in articles which include the following: the use of untrained or moderately active individuals instead of professional or well-trained athletes; the absence of a control group or absence of familiarization and/or warm-up sessions prior to measurement of the different components or participation in the program; the combined plyometric program durations were too short to induce significant neuromuscular changes; some studies contained group sizes that were too small for detecting significant differences between program changes and in several cases researchers failed to give detailed descriptions of all the methodology and exercise variables necessary for making valid conclusions.

Nevertheless, the identified findings highlight the importance, usefulness and effectiveness of combined plyometric training programs to significantly improve certain physical and motor performance components among athletes of different sports codes. However, good quality studies that are comprehensively detailed and use study designs that are specific to intervention studies are required in this research domain.

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CHAPTER 3

3

CHANGES IN SELECTED PHYSICAL AND MOTOR PERFORMANCE COMPONENTS AFTER A FOUR-WEEK COMBINED RUGBY CONDITIONING AND PLYOMETRIC TRAINING PROGRAM

TITLE: CHANGES IN SELECTED PHYSICAL AND MOTOR PERFORMANCE COMPONENTS OF UNIVERSITY-LEVEL RUGBY PLAYERS AFTER A FOUR-WEEK COMBINED RUGBY CONDITIONING AND PLYOMETRIC TRAINING PROGRAM

RUNNING HEAD: PHYSICAL AND MOTOR PERFORMANCE COMPONENT CHANGES DUE TO A COMBINED PROGRAM

LABORATORY: INSTITUTE FOR SPORT SCIENCE AND DEVELOPMENT, FNB PUK HIGH PERFORMANCE INSTITUTE OF SPORT, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH-AFRICA

AUTHORS: CINDY PIENAAR AND BEN COETZEE

DEPARTMENT: SCHOOL OF BIOKINETICS, RECREATION AND SPORT SCIENCE, FACULTY OF HEALTH SCIENCES, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH AFRICA

CORRESPONDING AUTHOR:

CINDY PIENAAR
SCHOOL OF BIOKINETICS, RECREATION AND SPORT SCIENCE
INTERNAL BOX 494
FACULTY OF HEALTH SCIENCES NORTH-WEST UNIVERSITY
POTCHEFSTROOM CAMPUS
POTCHEFSTROOM
2520
SOUTH AFRICA

PHONE: +27 18 299 4284
FAX: +27 18 299 4622
E-MAIL: cindy.pienaar@nwu.ac.za

CHANGES IN SELECTED PHYSICAL AND MOTOR PERFORMANCE COMPONENTS OF UNIVERSITY-LEVEL RUGBY PLAYERS AFTER A FOUR-WEEK COMBINED RUGBY CONDITIONING AND PLYOMETRIC TRAINING PROGRAM

CINDY PIENAAR AND BEN COETZEE

School of Biokinetics, Recreation and Sport Science, North-West University, Potchefstroom, South Africa

ABSTRACT

The purpose of this study was to determine the effects of a 4-week combined rugby conditioning-plyometric compared to a non-plyometric rugby conditioning program on selected physical and motor performance components of university-level rugby players. A pre-post test, randomized group design was used in this study. Thirty-five (18.94 ± 0.40 years) u/19 rugby players of the North-West University (South Africa), who were randomly assigned to either a control or experimental group, performed a battery of 5 physical and motor performance tests before and after a 4-week combined rugby conditioning-plyometric (experimental group) and a non-plyometric rugby conditioning program (control group). The dependent *t*-test results showed that the control group's upper body explosive power decreased significantly from pre to post-testing. The experimental group showed significant increases in speed over 20 m, agility as well as in the power and work measurements of the WAnT. In spite of these results the independent *t*-test revealed that speed over 20 m, average power output at 20 s, relative work of the WAnT and agility were the only components of the experimental group that improved significantly more than the control group. A 4-week combined rugby conditioning-plyometric program therefore leads to significantly bigger changes in selected physical and motor performance components of university-level rugby players than a non-plyometric rugby conditioning program alone.

KEY WORDS explosive power, agility, speed, WAnT, rugby union

INTRODUCTION

Plyometrics is a specialized, high-intensity training technique that enables an athlete's muscles to deliver as much strength as possible in the shortest period of time for power development to take place (6,9,31). Based on this, it is apparent why plyometric training is regarded as a useful training tool for athletes who participate in dynamic, explosive types of sports (33). Research also seems to indicate that team sports such as soccer, baseball, basketball and volleyball (5,23,34,36) will benefit from plyometric training. Despite the power requirements of rugby union, no studies to date have made an attempt to determine the possible benefits of a combined rugby conditioning and plyometric training program on the physical and motor performance components of rugby union players.

Rugby players need a higher degree of power in the execution of tackles, in acceleration from a static position and during rucking as well as mauling when scrumming and forceful play take place (11). Line-out jumping, breaking through tackles and fast as well as effective changes in running direction (agility) when attacking will also require from players to develop their muscle power output optimally (20).

Despite reports that plyometric training does have a significant positive effect on the physical and motor performance components such as agility, speed, the explosive and anaerobic power output of team players, few researchers have investigated the effects of a combined sport specific and plyometric training program on the different components of team players. Dodd and Alvar (10) reported greater increases in the vertical jump performance of baseball players when combining heavy resistance and plyometric training programs, over 12 weeks, than when doing either only heavy resistance training or plyometric training alone. Marques et al. (23) found that combining regular volleyball training with plyometric training led to increased performances in maximal strength as well as in medicine ball throw and counter movement jump tests. Similar findings were reported by Martel et al. (24) who found that combining plyometric training with a traditional volleyball training program led to significantly bigger increases in vertical jump height compared to volleyball training alone. In contrast to the previously mentioned studies, Ronnestad et al. (34) implemented a 7-week plyometric program in addition to regular soccer and resistance training and found no additional benefits by including plyometric training.

Despite the availability of ample literature that demonstrates the positive effect of plyometric training on performance (7,9), it is still not clear whether combined sport specific conditioning and plyometric training programs should be implemented and whether the benefits could be extended to team sports such as rugby union. Literature also does not seem to give a clear indication of the time period over which a plyometric program must be followed in order to gain significant benefits. The plyometric program durations vary between 4 (4) and 12 weeks (13) with one study that showed improvements after just 3 weeks of training (26).

The purpose of the present study therefore was to investigate the effects of a four-week combined rugby conditioning and plyometric training program on selected physical and motor performance components of university-level rugby players compared to the effects of a rugby conditioning program alone. This study was the first to explore the effects of a combined rugby conditioning and plyometric training program on rugby players' physical and motor performance components. The results from this study may possibly provide coaches and other sport professionals with information and guidelines that will enable them to plan and set up more effective combined sport specific conditioning programs.

METHODS

Experimental Approach to the Problem

The specific hypothesis under scrutiny was that a rugby conditioning program, combined with plyometric training will lead to significantly bigger changes in speed, agility and anaerobic power output values among university-level rugby players than a rugby conditioning program alone. Therefore a pre-post-test, randomized design was used for this study and subjects were subjected to a series of physical and motor performance tests after which the experimental group completed a 4-week plyometric program in addition to their regular rugby conditioning program. The control group continued with their normal rugby conditioning program. After completion of the 4-week plyometric training program, the physical and motor performance tests were repeated.

Subjects

Forty u/19 rugby players (18.94 ± 0.40 years) of the North-West University (Potchefstroom Campus - South Africa) were randomly selected to participate in the study and ethical approval was granted by the North-West University's Ethics Committee (number: 06M02). Participants completed an informed consent form and a general information questionnaire regarding their exercising habits, injury incidence and competing level and were randomly assigned to either a control (*n* = 20) or experimental (*n* = 20) group. Only sixteen participants in the control group and nineteen participants in the experimental group executed all the tests, which meant that five subjects were excluded from the study. One subject in each of the groups also did not complete the Agility T-Test, but was still included in the study due to the fact that they completed all the other tests. Once they had completed the last-mentioned forms the test battery was explained to the players.

TABLE 1. Subject characteristics*

Parameters	Control group ($n = 16$)	Experimental group ($n = 19$)
Body stature before program (cm)	179.81 ± 7.88	183.38 ± 7.94
Body stature after program (cm)	180.34 ± 8.23	183.76 ±8.10
Body mass before program (kg)	82.58 ± 10.74	89.96 ± 13.49
Body mass after program (kg)	82.91 ± 10.72	90.05 ± 13.47

* Values are mean ± *SD*.

Training

All subjects were already participating in a rugby conditioning program and had to continue with this program through the duration of the study. The program consisted of field sessions once a day and resistance training sessions three times a week. The experimental group also had to participate in plyometric training sessions three times a week, for a 4-week period, over and above their normal rugby training. Subjects completed 2 sets of 10 repetitions with a 30 second rest period between sets. These guidelines were followed throughout the 4-week training period. The plyometric exercises executed are presented in Table 2. All control group subjects were requested to refrain from any plyometric training.

Testing Procedures

The players underwent four days of testing, namely two pre and two post-test days respectively. On the first pre-test day subjects completed the questionnaire, together with the informed consent form after which an intensive dynamic, rugby specific warm-up was performed for more or less 15 minutes. Finally, a test battery that consisted of the 3 kg medicine ball put, vertical jump, acceleration and speed as well as the Wingate Anaerobic tests were performed. After a period of 48 hours the next testing session followed on the exact same time of day so as to minimize the effects of circadian variations in the different test results. Again a warm-up was performed before the completion of the Agility T-Test. All experimental group subjects were then subjected to four weeks of plyometric training which was performed in conjunction with their normal rugby training program. The control group only continued with their normal rugby conditioning program for the four-week period. Following the four-week period the players were again tested at the exact same time of day (post-test day) and same day of the week as the pre-test day to minimize the effect of circadian variations in the test results. Subjects were instructed to sleep at least 8 hours during the evening and morning prior to the different testing sessions. They were also instructed to abstain from ingesting any drugs or participating in strenuous physical activity that may influence the physical or motor performance components of the players for at least 48 hours before the scheduled tests. Subjects also had to maintain the same diet during the week of testing and arrive at the testing sessions in a fully rested and hydrated state.

TABLE 2: Four-week long plyometric training program

Week	Day	Plyometric exercises
1	1	Power skip, Squat jump, Double-leg tuck jump, Chest pass, Step and throw, and Two-arm put.
	2	Pike jump, Standing long jump, Standing jump over barrier, Prone back extension, Single arm put, and
	3	Front cone hops, Side-to-side push-off, Split squat jumps, Medicine ball V-sit, Rocky full twist, and Me
2	1	Double leg zigzag hop, Cycled split squat jumps, Lateral jump over barrier, Partner straddle sit passes,
	2	Barrier hops, Standing long jump with sprint, Cone hops with change of direction, Pullover throws, Kne
	3	Lateral step-up, Alternate push-off, Side jumps and sprint, Seated Russian twists, Plyometric bench pres
3	1	Front box jump, Lateral box jump, Side-to-side box shuffle, Hammer throw, Medicine ball sit up, and T
	2	Depth jump, Depth jump to second box, Three-point stance with single leg hurdle hop, Standing side to Medicine ball push-ups with a partner.
	3	Pyramiding box hops, Depth jump with 180° turn, Depth jump with standing long jump, Russian twist push-up.
4	1	Multiple box-to-box jump, Depth jump with 360° turn, Depth jump over barrier, Hip rolls, Over the hea depth jump.
	2	30-, 60-, 90-second box drill, Depth jump with reach, Single-leg depth jump with barrier hop, Forwar and Quarter-eagle chest pass.
	3	Depth jump with lateral movement, Depth jump with pass catching, Depth jump with blocking bag, Me pass with jump-and-reach.

Performance tests

Explosive power tests. Upper body explosive power was measured by means of the seated 3 kg Medicine Ball Put Test (3 kg MBPT) according to the method of Ball (1). The seated medicine ball put test is regarded as an objective (*r* = 0.99) (20), valid (*r* = 0.77 – 0.90) (15,19) and reliable test (*r* = 0.77 – 0.99) (14) to assess the muscular power of the arms and shoulder girdle (1). Subjects were instructed to sit up straight with the upper-back area against a wall and the legs extended straight to the front. Subjects were not allowed to move the upper back from the wall during the put action with a view to eliminate the use of momentum. Subjects were instructed to place the palms of their hands on the sides of the ball in a manner as to prevent cocking of the wrists. When ready, the subjects drew the ball back against the chest and forcefully pushed it forwards and upwards. The arc of the ball was controlled by a ring that was positioned 2 m in front of the subject at a height that controlled the angle of release to be approximately 45°. Subjects were given two practice trials, followed by three maximal efforts with a rest period of 30 s between each effort. The best distance of the three maximal efforts were recorded to the nearest centimetre.

Lower body explosive power was measured by means of the Vertical Jump Test (VJT) according to the method of Ellis et al. (12). The VJT is regarded as an objective (*r* = 0.90) and valid test (*r* = 0.93) to determine the peak anaerobic power output of subjects (35). Subjects were instructed to stand against a wall to which a measuring stick was attached, with the dominant arm's shoulder and the dominant leg's foot against the wall. By keeping the heels on the floor, the subjects were requested to reach upwards as high as possible. An arm swing and counter movement was allowed after which the players had to jump as high as possible and touch the measuring stick at the highest possible point. This distance was then recorded as the highest jumping distance. The difference between the reaching and jumping distance was then calculated and recorded to the nearest 1 cm. The subjects performed a minimum of two trials with a 30 s rest period between each trial. The better of the two trials were recorded for the purpose of data analysis. Power values were derived from the formula of Foster et al. (14): Power (W) = 21.67 x body mass (kg) x vertical displacement $(\mathrm{m})^{0.5}$.

Acceleration and speed. The acceleration and running speed of the players were determined by means of a 5, 10 and 20 m maximal sprinting effort. The sprint over a specified distance is seen as an objective, reliable and valid test to determine the acceleration and speed of subjects (16). Ellis et al. (12) reported that players rarely run further than 20 m in a straight line during a game, and this is the reason for a 20 m sprint test. Intermediate beam electronic timing gates (Brower Timing Systems, Utah, USA) were set at 0, 5, 10 and 20 m intervals on a section of the rugby field. The subjects were instructed to start when ready from a standing position with the front foot on the starting-line, so as to eliminate the possible influence of reaction time. Subjects were also instructed to wear their rugby boots during testing. The subjects were requested to sprint as fast as possible through the finishing-line, making sure not to slow down before the finishing-line. Split times (at 5 and 10 m) and final time (20 m) for three trials, with a 2-minute rest period between each, were recorded to the nearest 0.01 s. The best times for 5, 10 and 20 m were used in the final analysis.

Agility T-Test (ATT). Players' agility was evaluated by using the ATT according to the method of VanHeest et al. (42). The T-test was also performed on the rugby field and subjects were again instructed to perform the test in their rugby boots. The subjects were instructed to sprint from a standing starting position to a cone 9 m away, followed by a side-shuffle left to a cone 4.5 m away. After touching the cone the subjects side-shuffled to the cone 9 m away and then side-shuffled back to the middle cone. The test was concluded by back-pedalling to the starting-line. The test score was recorded as the best time of two trials, to the nearest 0.01 s. A 2-minute rest period was allowed between each trial. Subjects were disqualified if they failed to touch the base of any cone, crossed the one foot in front of the other or failed to face forward for the entire test.

Wingate Anaerobic Test (WAnT). The WAnT was implemented to evaluate the anaerobic power and capacity of the players. The WAnT is considered an objective (r = 0.84-0.88) and valid (r = 0.94-0.98) test to determine the anaerobic power and capacity of subjects (18). The test was conducted as per the method described by Inbar et al. (18). The WAnT consisted of a 30-second period during which the subjects were instructed to pedal maximally on a Monark 834 bicycle ergometer (Monark Exercise AB, Varberg, Sweden), at a resistance of 0.1 g/kg body mass for the duration of the period. The players prepared for the test with a five-minute standardized sub-maximal warm-up. The test began with a pedal frequency of about 60 rpm and a low braking force to facilitate the control of pedal cadence. When the players were able to maintain a constant pedal cadence, a countdown started and the full braking force was applied to signal the start of the test. The feet were stabilized to the pedals with stirrups. The players were instructed to sprint maximally from the start of the test and were requested not to pace themselves through the testing period. The peak power, relative peak power, average power, relative average power, total work, relative total work and fatigue rate of each subject were then calculated from the test.

Statistical Analysis

The Statistical Consultation Services of the North-West University determined the statistical methods and procedures for the analyses of the research data. The Statistical Data Processing package (37) which is available on the North-West University network, was used to process the data. The descriptive statistics (averages, standard deviations, minimum and maximum values) of each test variable were firstly calculated. Next, dependent *t*-tests were done to reveal the significant changes between the pre and post-test results and independent *t*-tests were then done to determine the significance of pre and post-test changes between the control and experimental groups. In all analyses the level of significance was set at $p \leq 0.05$. Lastly, effect sizes (ES) were calculated for pre and post-test results in each group as well as for differences between the experimental and control groups to determine practical significance for all the values which showed statistical significance. Effect sizes (ES) (expressed as Cohen's D-value) can be interpreted as follows: an ES of more or less 0.8 is large, an ES of more or less 0.5 is moderate and an ES of more or less 0.2 is small (39).

RESULTS

Explosive power measurements

The results for the explosive power measurements are presented in Table 3. The control group obtained a statistically ($p \leq 0.01$) and practically significant (ES $\geq$ 0.8) lower medicine ball put test result from pre to post-testing. No other explosive power measurement displayed any significance in terms of the changes that took place.

TABLE 3. Descriptive statistics, range and significance of the pre and post-test as well as group result differences for the explosive power measurements

Measurements	Control group ($n = 16$)		Experimental group ($n = 19$)	
	Pre	Post	Pre	Post
3 kg MBPT (m)	4.78 ± 0.36	4.41 ± 0.42 * §	4.64 ± 0.44	4.63 ± 0.49
Range	3.97 – 5.31	3.75 – 5.54	4.00 – 5.68	3.70 – 5.98
VJT (cm)	50.63 ± 6.8	51.56 ± 6.22	50.84 ± 6.59	51.84 ± 7.49
Range	41.00 – 69.00	40.00 – 63.00	43.00 – 67.00	43.00 – 70.00
VJT (W)	1 268.5 ± 169.06	1 286.65 ± 175.52	1 386.63 ± 214.65	1 401.10 ± 223.65
Range	981.27 – 1 539.21	978.84 – 1 610.73	956.16 – 1 728.04	978.22 – 1 777.47

Data are mean ± *SD*
* Pre and post-values within group are significantly different ($p \leq 0.01$).
§ Large effect size control group (ES ≥ 0.8).

Speed and agility measurements

As Table 4 indicates, the experimental group experienced statistically significant decreases in speed over 20 m and ATT times during the training period. Cohen's effects size revealed a small (ES ~ 0.2) and medium practical significance (ES ~ 0.5) for the named measurements. The independent *t*-test results of the last-mentioned variables also showed statistically as well as medium and large practically significant values respectively when the control group was compared with the experimental group.

TABLE 4. Descriptive statistics, range and significance of the pre and post-test as well as group result differences for the speed and agility measurements .

Measurements	Control group ($n = 16$)		Experimental group ($n = 19$)	
	Pre	Post	Pre	Post
Speed 5m (s)	1.14 ± 0.17	1.14 ± 0.18	1.22 ± 0.16	1.14 ± 0.1
Range	0.98 – 1.58	0.80 – 1.45	1.04 – 1.59	1.00 – 1.31
Speed 10m (s)	1.90 ± 0.19	1.90 ± 0.16	1.98 ± 0.18	1.92 ± 0.12
Range	1.70 – 2.40	1.60 – 2.25	1.77 – 2.43	1.78 – 2.19
Speed 20m (s)	3.22 ± 0.24	3.26 ± 0.19	3.34 ± 0.25	3.25 ± 0.16 † ‡ ¶ ∫
Range	2.94 – 3.80	2.90 – 3.65	3.03 – 3.91	3.01 – 3.66
ATT	10.28 ± 0.57*	10.35 ± 0.5*	10.72 ± 0.49**	10.42 ± 0.54** † ‡ ¶¶ ∫∫
Range	9.45 – 11.23*	9.80 – 11.39*	10.04 – 11.57**	9.56 – 11.38**

Data are mean ± *SD*; * $n = 15$; ** $n = 18$
† Pre and post-values within group are significantly different ($p \leq 0.05$).
‡ Changes in pre- and post-training values within the control vs. experimental group are significant ($p \leq 0.05$).
¶ Small effect size (ES ~ 0.2)
¶¶ Medium/Moderate effect size (ES ~ 0.5).
∫ Medium effect size: control *vs*. experimental group (ES ~ 0.5).
∫∫ Large effect size: control *vs*. experimental group (ES ≥ 0.8).

WAnT measurements

Table 5 lists the WAnT results. A significant training effect ($p \leq 0.05$) was seen in the experimental group for peak power, average power, relative peak power, relative average power, total work, relative total work and average power over 5, 10, 15, 20 and 25 s. None of the variables which displayed statistically significant changes, obtained large practically significant values. The change in average power at 20 s was significantly better for the experimental group than for the control group. Again, only a medium effect size value was obtained when this change was analyzed.

TABLE 5. Descriptive statistics, range and significance of the pre and post-test as well as group result dif

Measurements	Control group ($n = 16$)		E
	Pre	Post	Pre
Peak power (W)	1 129.62 ± 234.46	1 134.21 ± 160.38	1 097.35 ±
Range	828.18 – 1 635.54	863.80 – 1 396.11	760.20 – 1
Average power (W)	760.51 ± 92.51	782.57 ± 94.21	763.71 ± 1
Range	575.29 – 897.91	619.74 – 994.78	515.87 – 1
Relative peak power (W/kg)	13.83 ± 2.94	13.82 ± 2.05	12.32 ±
Range	8.53 – 19.92	8.92 – 17.64	8.61 – 1
Average relative power (W/kg)	9.30 ± 1.27	9.54 ± 0.94	8.49 ± 1
Range	6.26 – 11.82	6.93 – 10.94	5.61 – 1
Total work (J)	22 815.34 ± 2 775.34	23 476.99 ± 2 826.43	22 911.30 ±
Range	17 258.70 – 26 937.30	18 592.20 – 29 843.40	15 476.10 – 3
Relative total work (J/kg)	279.13 ± 37.99	284.95 ± 28.00	257.78 ±
Range	187.79 – 354.63	210.70 – 328.32	168.77 – 3
Fatigue ratio (%)	52.71 ± 10.79	51.15 ± 5.68	49.55 ± 1
Range	31.76 – 64.77	42.70 – 64.55	31.76 – 7

TABLE 5 (cont.). Descriptive statistics, range and significance of the pre and post-test as well as group re

Measurements	Control group ($n = 16$)		E
	Pre	Post	Pre
Average W 5 s	1 129.25 ± 233.5	1 134.13 ± 160.46	1 097.32 ±
Range	828.00 – 1 636.00	864.00 – 1 396.00	760.00 – 1
Average W 10 s	818.69 ± 108.64	875.06 ± 106.58	833.42 ± 1
Range	542.00 – 949.00	719.00 – 1 118.00	454.00 – 1
Average W 15 s	773.69 ± 118.38	793.63 ± 102.59	785.42 ± 1
Range	512.00 – 1 029.00	591.00 – 1 007.00	486.00 – 1
Average W 20 s	710.75 ± 107.32	705.31 ± 84.79	693.32 ± 1
Range	524.00 – 938.00	542.00 – 914.00	477.00 – 9
Average W 25 s	601.44 ± 99.01	632.38 ± 87.97	636.11 ± 1
Range	407.00 – 724.00	469.00 – 832.00	447.00 – 8
Average W 30 s	516.31 ± 69.34	551.19 ± 84.31	545.68 ± 1
Range	354.00 – 628.00	410.00 – 701.00	297.00 – 7

Data are mean ± *SD*

* Pre and post-values within group are significantly different ($p \leq 0.01$).

† Pre and post-values within group are significantly different ($p \leq 0.05$).

‡ Changes in pre- and post-training values within the control vs. experimental group are significant ($p \leq 0.05$).

DISCUSSION

The study succeeded in showing that a combined rugby conditioning and plyometric training program of 4 weeks led to significantly bigger changes in certain speed, agility and anaerobic power output values among university-level rugby players than a rugby conditioning program alone. No other studies have been conducted to assess the effects of a combined rugby conditioning and plyometric training program on selected physical and motor performance components, which made it difficult to directly compare the results of this study to similar studies. However, several studies have investigated the effects of combined sport specific and plyometric programs on a wide range of variables. In this regard a study by Wilkerson et al. (43) showed no significant improvements in ATT times after completion of a 6-week combined plyometric and basketball conditioning program by female basketball players. In the present study the combined plyometric and rugby conditioning program resulted in a statistically and practically significant decrease in average ATT times. The group that participated in the combined program also displayed significant pre-post-test, ATT time changes compared to the group that only executed the rugby conditioning program alone. The combined program had a similar effect on the 20 m speed times when the pre-post-test changes of the control and experimental group were compared. Dissimilarly, a 7-week combined plyometric and soccer conditioning program did not lead to significantly lower 40 m sprint times than those of a soccer conditioning program alone in a group of professional soccer players (34).

Although this study design may not explain the reasons underlying the improvements in agility and speed due to the combined plyometric training program in this study, several authors have purposed the following: Plyometric-related programs may promote changes within the neuromuscular system that enhances neuromuscular efficiency. In this regard research evidence suggests that more motor units are stimulated and activated due to plyometric training (25). Furthermore, Swanik et al. (38) concluded that the sensitivity of the muscle spindle system may increase because of a plyometric training program and that this adaptation may lead to enhanced joint proprioception of the participants. Plyometric training also seems to enhance kinesthesia which, together with an enhanced joint proprioception, may increase functional stability (38). The time required for voluntary muscle activation is reduced by plyometric training, which may facilitate faster changes in movement direction and thereby decrease the ATT time (43). This finding was also supported by Hutchinson et al. (17), who presented evidence that a leap training program led to significant improvements ($p < 0.002$) in floor reaction time among rhythmic gymnasts. According to Hutchinson et al. (17), it is also possible that a cognitive, learned effect, rather than a purely motor strengthening effort, is the reason for an increase in the selected physical and motor performance components due to a plyometric training program.

No studies could be found that investigated the effects of a combined sport specific and plyometric training program on the WAnT results of team players. Most of the WAnT-derived variables displayed significant positive changes due to the combined plyometric and rugby conditioning program, except for fatigue ratio and the average power output at 30 s. The finding of Pincivero et al. (29) that those subjects who exert a lower peak power output at the start of the WAnT will develop lower levels of fatigue, may possibly serve as an explanation for the lack of significance in the last-mentioned variables. The experimental group displayed significantly higher relative and absolute peak power output values during post-testing than pre-testing which possibly had a detrimental effect on the fatigue ratios and average power output values at the end of the WAnT. Despite the favourable results, the dependent *t*-test delivered with regard to the effects of a

4-week combined program, the independent *t*-test did not show the same kind of results. The experimental group only achieved significantly better pre and post-test differences than those of the control group in average power output at 20 s. Considering these results, it is possible that the plyometric program had a more pronounced effect on the muscle power endurance than on the peak power output values of the rugby players. The prescribed rest periods of 30 s between sets of plyometric exercises may have resulted in an increase in muscle power endurance instead of muscle peak power due to the fact that the rest periods were too short to allow for the resynthesis of high energy phosphates (8). The anaerobic alactic energy system is usually depleted after 5 to 10 s of high intensity activities and needs at least 3 to 5 minutes for the total resynthesis of the relevant energy sources. (7,8). The high energy phosphates are the major contributors to energy for high intensity plyometric exercises (8). Consequently the short rest periods will result in insufficient high-energy phosphates for the following plyometric exercises and a reliance on the anaerobic lactic system. Naturally, players will therefore decrease their plyometric exercise intensities and focus more on the completion of the prescribed number of repetitions than on the quality of the exercises.

Somewhat unexpected results of this study were that the explosive power tests (3 kg MBPT and VJT) showed no significant changes due to participation in the combined rugby and plyometric conditioning program. Again these results may be related to the short rest periods between the different sets of the plyometric program. The 3 kg MBPT result is, however, consistent with those of Lyttle et al. (21) and Mangine et al. (22), who also did not obtain significant increases in upper body power output values after the completion of an upper body plyometric program. In this regard Bieze (3) states that only elite athletes are able to execute upper body plyometric exercises in such a way that the amortization phase is kept short. Energy that is stored during the eccentric phase of the plyometric exercise will dissipate as heat and will not be used to increase the force of the concentric phase if the amortization phase lasts too long (6,30). What the statement of Bieze (3) therefore suggests is that the young inexperienced university rugby players in this study would not have been able to train the upper body successfully due to their inability to perform the upper body plyometric exercises correctly.

It is interesting to note that the control group that followed the rugby conditioning program experienced a statistically and practically significant decrease in 3 kg MBPT distance. The results show that the rugby conditioning program alone was detrimental for the upper body power development of players. As previously mentioned, the rugby conditioning program primarily consisted of field and resistance training sessions. The primary aim of the field sessions was to increase the players' fitness and to improve their rugby specific skills. Resistance training focused on general conditioning, muscle hypertrophy and strength. What this indicates, is that rugby conditioning programs should include exercises and programs that are specifically aimed at improving explosive power. The fact that the experimental group, that also performed plyometric exercises in their program, maintained their 3 kg MBPT values from pre to post-testing, further accentuates the last-mentioned fact.

The non-significant VJT results after completion of a combined sport specific conditioning and plyometric training program are similar to those of Marques et al. (23), Martel et al. (24), Mihalik et al. (26), Paavolainen et al. (28), Rahimi et al. (32) and Timmons (40) but in contrast to the findings of Bauer et al. (2), Chimera et al. (6), Mangine et al. (22), Moore et al. (27), Ronnestad et al. (34) and Turner et al. (41). The non-significant results with regard to the VJT pre-post-test change was unexpected and can possibly be attributed to the following reasons. Firstly, outliers among the rugby players who completed the combined program could have "pulled" the *t*-test results skew due to the rather small sample size in this study. For example, three players of the experimental group achieved negative results (-5 cm) when the pre and post-test VJT heights were compared. These players also achieved negative results with regard to the VJT power output values with values that ranged between -91.47 and -17.40 W. A further analysis revealed that these players lost 2.3 kg in body weight on average during the intervention period, which had a detrimental effect on their calculated power output values.

Secondly, subjects in this study had already participated in a rugby conditioning program for six months prior to the intervention period. It can therefore be expected that their fitness levels were already high before the start of the intervention period. As a result of this, they would probably not be so sensitive and reactive to a conditioning program compared to untrained subjects. This statement is confirmed by the findings of Turner et al. (41) who attributed the positive results due to a plyometric training period, to the fact that the subjects were untrained. In view of this, it is important to consider the initial fitness levels of the test subjects when planning a study of this kind. Subjects whose initial fitness levels are lower at the start of the study would probably be more sensitive and reactive to a conditioning program than very fit participants.

Another limitation of the current study is a lack of progression in the number of sets and repetitions during the plyometric training period. A continuous adjustment in the last-mentioned exercise variables would probably give rise to more muscle overload and more pronounced changes in the different speed, agility and power measurements.

PRACTICAL APPLICATIONS

If the goal of training is to significantly improve the speed, agility and power of young rugby players, a combined program of sport specific conditioning and plyometric training can be implemented. However, the results of the current study, as well as those of Marques et al. (23), Martel et al. (24), Mihalik et al. (26), Paavolainen et al. (28), and Rahimi et al. (32), indicate that a combined sport specific conditioning and plyometric training program of 4 weeks may not be as effective in increasing all power-related components as a longer combined training program. Therefore, in conclusion, practitioners can apply plyometric training in sport specific programs in an attempt to improve rugby performance by increasing speed, agility and power. Future studies on rugby union should probably rather focus on the possible influence of a combined rugby conditioning and plyometric training program, and the performance outcome of players. Coaches, trainers and sport scientists of rugby union teams can implement plyometric training in their regular training programs and we would suggest a minimum training period longer than 4 weeks.

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CHAPTER 4

4

THE EFFECTS OF A FOUR-WEEK COMBINED PLYOMETRIC PROGRAM ON THE ANTHROPOMETRIC COMPONENTS OF UNIVERSITY-LEVEL RUGBY PLAYERS

TITLE: THE EFFECTS OF A FOUR-WEEK COMBINED RUGBY CONDITIONING AND PLYOMETRIC TRAINING PROGRAM ON THE ANTHROPOMETRIC COMPONENTS OF UNIVERSITY-LEVEL RUGBY PLAYERS.

RUNNING HEAD: EFFECTS OF A COMBINATION PROGRAM ON ANTHROPOMETRIC COMPONENTS

LABORATORY: INSTITUTE FOR SPORT SCIENCE AND DEVELOPMENT, FNB PUK HIGH PERFORMANCE INSTITUTE OF SPORT, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH-AFRICA

AUTHORS: CINDY PIENAAR AND BEN COETZEE

DEPARTMENT: SCHOOL OF BIOKINETICS, RECREATION AND SPORT SCIENCE, FACULTY OF HEALTH SCIENCES, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH AFRICA

CORRESPONDING AUTHOR:

CINDY PIENAAR
SCHOOL OF BIOKINETICS, RECREATION AND SPORT SCIENCE
INTERNAL BOX 494
FACULTY OF HEALTH SCIENCES NORTH-WEST UNIVERSITY
POTCHEFSTROOM CAMPUS
POTCHEFSTROOM
2520
SOUTH AFRICA

PHONE: +27 18 299 4284
FAX: +27 18 299 4622
E-MAIL: cindy.pienaar@nwu.ac.za

THE EFFECTS OF A FOUR-WEEK COMBINED RUGBY CONDITIONING AND PLYOMETRIC TRAINING PROGRAM ON THE ANTHROPOMETRIC COMPONENTS OF UNIVERSITY-LEVEL RUGBY PLAYERS.

CINDY PIENAAR AND BEN COETZEE

School of Biokinetics, Recreation and Sport Science, North-West University, Potchefstroom, South Africa

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ABSTRACT

The purpose of this study was to determine the effects of a 4-week combined rugby conditioning-plyometric compared to a non-plyometric rugby conditioning program on the anthropometric measurements of university-level rugby players. A pre-post-test, randomized group design was used in this study. Players (18.94 ± 0.40 years) were assigned to either a control (*n* = 16) or experimental group (*n* = 19) from the u/19 rugby teams of the North-West University (South Africa). Twenty-six direct and indirect anthropometric measurements were taken before and after a 4-week combined rugby conditioning-plyometric (experimental group) and a non-plyometric program (control group). The dependent *t*-test results showed that the control group's skeletal mass and femur breadth increased significantly from pre to post-testing. The wrist breadth of the experimental group also increased significantly during the training period. In both groups a significant increase in body stature was observed. In spite of these results the independent *t*-test revealed that no significant differences existed between the anthropometric measurement changes of the two groups of players. Only small values were obtained when the effect sizes were calculated for each of the significant variables. A four-week combined rugby conditioning and plyometric training program does not lead to significantly bigger changes in the anthropometric measurements of university-level rugby players than a non-plyometric rugby training program alone.

KEY WORDS plyometrics; rugby; anthropometry; programs; training

INTRODUCTION

Over the years sport professionals and trainers have used various training modalities to influence the physical conditioning of rugby players in such a way that consistent improvements in on-field performances can be attained (12). One of the modalities occasionally used among team sport participants is plyometric training (6,8,27). Plyometric training is an established method of training for the improvement of power and performances among athletes that primarily participate in dynamic, explosive type of team sports (26) such as rugby league, football, volleyball and soccer (10,11,17,20). Notwithstanding the widespread acceptance and use of plyometric training for conditioning team players, it is unclear whether plyometric training will also benefit rugby players' anthropometry in general.

Body size and composition (anthropometry) plays an important role in the performances of rugby players as well as in determining playing position (2,9). In spite of the importance of players' anthropometry, no studies could be traced in which the anthropometric changes of team players due to a plyometric training program have been reported. Despite this observation, studies by Paavolainen et al. (22, 23) and Leubbers et al. (15) found that the body mass values of runners, cross-country skiers and physically active college students respectively increased significantly during a 9-week period of plyometric training. A 1.3% change in lean body mass after 9 weeks of plyometric training among competitive male cyclists (1) seem to suggest that the positive change in body mass due to plyometric training may possibly be attributed to an increase in lean body mass. This conclusion was also supported by Witzke and Snow (34) who presented evidence that a plyometric program of 9 weeks amongst adolescent girls brought about a significant increase in peak bone mass, which may possibly influence an athlete's lean body mass positively. An average increase of 7.3% in type II muscle fibre cross-sectional area which may also benefit a lean body mass related component, namely muscle mass, after 8 weeks of plyometric training, might also explain the increase in lean body mass (25). The results of research by Ronnestad et al. (27), Mikkola et al. (19), Paton and Hopkins (24) and Spurrs et al. (28) on soccer players, endurance athletes, cyclists as well as distance runners did not coincide with the results of the last-mentioned studies. They all concluded that a plyometric program of between 5 and 8 weeks did not appear to offer any significant benefit in terms of body mass increases. Similarly, Leubbers et al. (15) and Potteiger et al. (25) failed to demonstrate that a plyometric training program of between 4 and 8 weeks among physically active males would lead to any significant changes in body fat percentage.

According to literature, both bone mass and muscle fibre cross-sectional area can be improved by making use of load-bearing activities such as jumping (18), running and climbing (14). A bone and muscle mass related body composition characteristic, namely somatotype and especially the mesomorphic component, will probably also be influenced positively due to an increase in bone and muscle mass (3). In this regard, plyometrics will probably benefit these anthropometric variables due to the load-bearing activities it contains. Also, because of the direct relationships between these anthropometric variables and power, which is a requirement for rugby (8,12), certain plyometric-related anthropometric changes would benefit rugby performance in the long run.

Considering the limited availability of research that pertains to the influence of a plyometric and a combined rugby conditioning and plyometric training program on the anthropometric components of rugby players, the purpose of this investigation was to examine the effects of a 4-week combined rugby conditioning and plyometric training program compared to a rugby conditioning program alone, on the anthropometric components of university-level rugby players. This study will be the first to explore the effects of a combined plyometric program on rugby players' anthropometric components. We hypothesized that the combined rugby conditioning and plyometric training program would have a significantly bigger effect on the body size, lean body, muscle, fat and skeletal mass and on the somatotype of subjects, compared to a rugby conditioning program alone. The results from this study may possibly provide coaches and other sport professionals with information and guidelines that will enable them to plan and set up more effective combined sport specific training programs which may also influence the anthropometric components of players.

METHODS

Experimental Approach to the problem

The main focus of this study was to investigate whether a combined rugby conditioning and plyometric training program would lead to significantly bigger changes in anthropometric components than a rugby conditioning program alone. Therefore a pre-post-test, randomized design was used for the study and subjects were randomly assigned to either a control or experimental group. The experimental group completed 4 weeks of a plyometric program in addition to their normal rugby training, while the control group continued with their normal rugby conditioning program. Both groups were subjected to the same testing protocol before and after the 4-week conditioning program.

Subjects

Forty u/19 rugby players (18.94 ± 0.40 years) of the North-West University (Potchefstroom Campus - South Africa) were randomly selected to participate in the study and were randomly assigned to either a control (n = 20) or experimental (n = 20) group. Only sixteen participants in the control group and nineteen participants in the experimental group executed all the tests, which meant that five subjects were excluded from the study. Participants completed an informed consent form and an information questionnaire regarding their exercising habits, injury incidence, playing positions and competing levels. After completion of these documents the test battery was explained to the players. Ethical approval for the study was granted by the North-West University's Ethics Committee (ethical number: 06M02).

Training

All subjects were already participating in a rugby conditioning program and had to continue with this program during the length of the study. This program consisted of field sessions once a day and resistance training sessions three times a week. The experimental group also had to participate in plyometric training sessions three times a week, for a 4-week period over and above their normal rugby training. Subjects completed 2 sets of 10 repetitions with a 30-second rest period between sets. These guidelines were followed throughout the 4-week training period. The plyometric exercises executed are presented in Table 1. All control group subjects were asked to refrain from any plyometric training.

TABLE 1: Plyometric exercises executed during the four-week long plyometric training program

Week	Day	Plyometric exercises
1	1	Power skip, Squat jump, Double-leg tuck jump, Chest pass, Step and throw, and Two-arm put.
	2	Pike jump, Standing long jump, Standing jump over barrier, Prone back extension, Single arm put, and
	3	Front cone hops, Side-to-side push-off, Split squat jumps, Medicine ball V-sit, Rocky full twist, and M
2	1	Double leg zigzag hop, Cycled split squat jumps, Lateral jump over barrier, Partner straddle sit passes,
	2	Barrier hops, Standing long jump with sprint, Cone hops with change of direction, Pullover throws, Kn
	3	Lateral step-up, Alternate push-off, Side jumps and sprint, Russian twists – seated, Plyometric bench p
3	1	Front box jump, Lateral box jump, Side-to-side box shuffle, Hammer throw, Medicine ball sit up, and
	2	Depth jump, Depth jump to second box, Three-point stance with single leg hurdle hop, Standing side and Medicine ball push-ups with a partner.
	3	Pyramiding box hops, Depth jump with 180° turn, Depth jump with standing long jump, Russian t catch push-up.
4	1	Multiple box-to-box jump, Depth jump with 360° turn, Depth jump over barrier, Hip rolls, Over the with depth jump.
	2	30-, 60-, 90-second box drill, Depth jump with reach, Single-leg depth jump with barrier hop, Forwa and Quarter-eagle chest pass.
	3	Depth jump with lateral movement, Depth jump with pass catching, Depth jump with blocking bag, and pass with jump-and-reach.

Testing Procedures

The players were subjected to two days of testing, namely one pre and one post-test day respectively. On the pre-test day subjects completed the questionnaire, together with their informed consent forms after which the anthropometric measurements were taken. All experimental group subjects were then subjected to four weeks of plyometric training which was performed in conjunction with their normal rugby training program. The control group only continued with their normal rugby conditioning program for the four-week period. Following the four-week period the players were again tested at the exact same time of day (post-test day) and same day of the week as the pre-test day to minimize the effect of circadian variations in the test results. Subjects were instructed to sleep at least 8 hours during the evening and morning prior to the different testing sessions. They were also instructed to abstain from ingesting any drugs or participating in strenuous physical activity during the 48 hours prior to the scheduled tests. Subjects were instructed to maintain the same diet during the week of testing and arrive at the testing sessions in a fully rested and hydrated state.

Anthropometric measurements

Body fatness was determined by means of a Harpenden skinfold caliper (Holtain Limited, UK.) with a constant pressure of 10 g/mm^2, to measure subcutaneous adipose tissue, and was calculated through the sum of the following skinfolds (SUM6SF): triceps, subscapular, abdominal, supraspinal, front thigh and calf skinfolds as per the formulas of Withers et al. (33). All measurements were taken at the right side of the body and recorded to the nearest 0.2 mm. Muscle and skeletal mass were calculated according to the formulae of Lee et al. (13) and Martin et al. (as quoted by

Drinkwater & Mazza, (7)). Body stature was recorded to the nearest 0.1 centimetre by means of a stadiometer (Harpenden portable stadiometer, Holtain Limited, UK.) and body mass was recorded to the nearest 0.1 kg with a portable electronic scale (BFW 300 Platform scale, Adam Equipment Co. Ltd., UK.). Ankle, femur, humerus and wrist breadths were measured by making use of a small sliding caliper (Holtain Bicondylar Calipers, Holtain Limited, UK.) and recorded to the nearest 0.1cm. Girth measurements were taken with a flexible steel tape (Lufkin W606PM, Cooper Industries, USA.) and were also recorded to the nearest 0.1 cm. Girth measurements included the relaxed and contracted upper arm, forearm, thigh and calf girths. All measurements were taken by International Society for the Advancement of Kinanthropometry (ISAK) Level 2 accredited anthropometrists.

Statistical Analysis

The Statistical Consultation Services of the North-West University determined the statistical methods and procedures for the analyses of the research data. The Statistical Data Processing package (29) which is available on the North-West University network was used to process the data. The descriptive statistics (averages, standard deviations, minimum and maximum values) of each test variable were firstly calculated. Next dependent *t*-tests were performed to reveal the significant changes between pre and post-test results after which the independent *t*-test values were calculated to determine the significance of pre and post-test changes between the control and experimental group. In all analyses the level of significance was set at $p \leq 0.05$. Lastly, the effect size (ES) value was calculated for each of the pre and post-test results as well as for the pre and post-test differences between the experimental and control group for values that obtained statistically significant results.

Values of more or less 0.8 were interpreted as large, an ES of more or less 0.5 as moderate and an ES of more or less 0.2 as small (30).

RESULTS

Results of the descriptive statistics for the pre and post-test and group result differences (dependent and independent *t*-test results) for the experimental and control group with regard to body fat related measurements are presented in Table 2. No statistical or practical significance was observed for pre to post-test changes in any of the body fat related measurements.

TABLE 2. Descriptive statistics, range and significance for the pre and post-test and group result differences for body fat related measurements.

Measurements	Control group (*n* = 16)		Experimental group (*n* = 19)	
	Pre	Post	Pre	Post
SUM6SF (mm)	66.19 ± 22.20	65.11 ± 21.75	73.64 ± 29.53	72.30 ± 28.42
Range	35.00 – 117.00	31.75 – 105.50	30.50 – 137	36.50 – 138.25
Body fat %	11.11 ± 3.47	10.94 ± 3.39	12.28 ± 4.62	12.07 ± 4.43
Range	6.20 – 19.11	5.71 – 17.20	5.52 – 22.22	6.43 – 22.42
Biceps SF (mm)	4.77 ± 1.97	4.97 ± 2.34	5.24 ± 2.80	5.04 ± 2.91
Range	2.75 – 9.50	3.00 – 11.50	2.50 – 15.00	2.00 – 14.25
Triceps SF (mm)	9.61 ± 3.33	9.41 ± 4.20	10.42 ± 4.08	9.96 ± 3.89
Range	5.50 – 16.50	5.00 – 20.50	4.25 – 18.75	4.50 – 19.25
Subscapular SF (mm)	9.91 ± 2.88	9.59 ± 2.59	11.95 ± 6.24	11.93 ± 6.34
Range	6.50 – 15.00	6.00 – 13.25	5.50 – 29.00	6.00 – 28.50
Abdominal SF (mm)	14.14 ± 5.93	14.14 ± 6.03	16.51 ± 8.00	15.67 ± 7.61
Range	5.75 – 26.00	5.25 – 25.50	6.00 – 32.00	6.50 – 31.75
Supraspinale SF (mm)	8.41 ± 4.01	8.14 ± 3.15	10.14 ± 6.44	9.57 ± 4.87
Range	3.00 – 17.75	3.75 – 16.25	3.50 – 31.00	4.00 – 23.00
Front thigh SF (mm)	14.59 ± 6.57	14.62 ± 5.09	14.70 ± 5.51	14.93 ± 5.38
Range	7.00 – 34.00	6.75 – 26.00	4.50 – 24.50	7.75 – 26.25
Calf SF (mm)	9.53 ± 3.35	9.20 ± 2.97	10.03 ± 3.68	10.24 ± 3.93
Range	4.75 – 16.25	5.00 – 14.50	3.50 – 17.75	4.00 – 18.00

Values presented as mean ± *SD*; range = minimum – maximum; SUM6SF = sum of the 6 skinfolds; SF = Skinfold

Results of the descriptive statistics with regard to the girth measurements are presented in Table 3. No statistical or practical significance was observed in any of the girth measurement changes of the test subjects.

TABLE 3. Descriptive statistics, range and significance for the pre and post-test and group result differences for girth measurements.

Measurements	Control group ($n = 16$)		Experimental group ($n = 19$)	
	Pre	Post	Pre	Post
Relaxed arm girth (cm)	32.64 ± 2.62	32.42 ± 2.64	32.68 ± 3.44	33.22 ± 2.89
Range	28.65 – 36.80	27.90 – 36.50	23.85 – 37.85	29.00 – 37.70
Flexed arm girth (cm)	35.62 ± 2.65	35.70 ± 2.39	36.25 ± 2.39	36.57 ± 2.67
Range	32.00 – 40.00	32.00 – 39.65	31.60 – 39.85	32.55 – 40.30
Forearm girth (cm)	28.97 ± 1.69	28.77 ± 1.36	29.69 ± 1.77	29.51 ± 1.99
Range	25.65 – 31.50	26.50 – 31.00	27.35 – 33.70	26.00 – 34.00
Thigh girth (cm)	56.60 ± 4.10	55.93 ± 4.14	58.23 ± 5.75	57.70 ± 6.08
Range	49.30 – 62.80	49.05 – 62.55	51.20 – 73.80	48.70 – 74.80
Calf girth (cm)	37.79 ± 2.83	37.74 ± 2.66	39.47 ± 3.84	39.47 ± 3.83
Range	34.30 – 44.05	34.80 – 43.50	33.35 – 48.55	33.35 – 48.20

Values presented as mean ± *SD*, range = minimum – maximum

Results of the descriptive statistics with regard to breadth measurements are presented in Table 4. Statistically significant increases were seen for femur breadth among the control group subjects and for wrist breadth among the experimental group subjects. The pre-post-test changes did, however, not obtain high practically significant values.

TABLE 4. Descriptive statistics, range and significance for the pre and post-test and group result differences for breadth measurements.

Measurements	Control group (*n* = 16)		Experimental group (*n* = 19)	
	Pre	Post	Pre	Post
Ankle breadth (cm)	7.44 ± 0.52	7.55 ± 0.43	7.79 ± 0.49	7.86 ± 0.51
Range	6.70 – 8.35	6.85 – 8.25	6.80 – 8.60	6.80 – 8.70
Femur breadth (cm)	9.91 ± 0.53	10.08 ± 0.62 †¶	10.34 ± 0.58	10.48 ± 0.77
Range	9.00 – 10.85	9.00 – 11.05	9.35 – 11.40	9.25 – 11.80
Humerus breadth (cm)	7.17 ± 0.35	7.22 ± 0.50	7.36 ± 0.40	7.38 ± 0.48
Range	6.40 – 7.80	6.30 – 7.85	6.55 – 7.90	6.35 – 7.95
Wrist breadth (cm)	5.80 ± 0.38	5.91 ± 0.35	7.79 ± 0.49	7.86 ± 0.51 †¶
Range	5.20 – 6.65	5.30 – 6.50	6.80 – 8.60	6.80 – 8.70

Values presented as mean ± *SD*, range = minimum - maximum
† Pre and post values within group are significantly different ($p \leq 0.05$).
¶ Small effect size (ES ~ 0.2).

Results of the descriptive statistics for the pre and post-test as well as group result differences (dependent and independent *t*-test results) of the experimental and control group for body stature, body mass, muscle and fat percentage are presented in Table 5. Body stature showed a significant increase ($p \leq 0.05$) from pre to post-testing for both the control and experimental groups, whereas skeletal mass showed a significant increase ($p \leq 0.05$) for only the control group. Again, none of the last-mentioned measurements showed high practically significant changes.

TABLE 5. Descriptive statistics, range and significance for the pre and post-test and group result differences for body stature, body mass, muscle and skeletal mass measurements.

Measurements	Control group ($n = 16$)		Experimental group ($n = 19$)	
	Pre	Post	Pre	Post
Body stature (cm)	179.81 ± 7.88	180.33 ± 8.2 †¶	183.38 ± 7.94	183.76 ± 8.10 †¶
Range	166.40 – 199.30	166.70 – 199.10	166.40 – 199.80	166.90 – 202.00
Body mass (kg)	82.58 ± 10.74	82.91 ± 10.72	89.96 ± 13.49	90.05 ± 13.47
Range	62.20 – 98.50	63.20 – 98.60	62.40 – 115.10	62.60 – 116.00
Muscle mass(kg)	28.34 ± 2.35	28.4 ± 2.4	30.16 ± 3.18	30.14 ± 3.22
Range	24.38 – 32.4	24.55 – 32.88	24.58 – 36.72	23.80 – 37.13
Muscle mass %	34.59 ± 2.09	34.47 ± 2.04	33.79 ± 2.28	33.71 ± 2.09
Range	31.64 – 39.20	32.04 – 38.85	29.68 – 39.40	30.49 – 38.03
Skeletal mass (kg)	9.97 ± 1.34	10.30 ± 1.46 †¶	10.95 ± 1.30	11.22 ± 1.50
Range	7.52 – 12.51	7.72 – 12.73	8.48 – 13.00	8.16 – 13.21
Skeletal mass %	12.14 ± 1.26	12.46 ± 1.23	12.28 ± 1.18	12.56 ± 1.42
Range	10.18 – 14.70	10.74 – 14.88	10.29 – 14.79	9.97 – 14.90

Values presented as mean ± *SD*, range = minimum - maximum
† Pre and Post-values within group are significantly different ($p \leq 0.05$).
¶ Small effect size (ES ~ 0.2).

Results of the descriptive statistics for somatotype are presented in Table 6. No statistically or practically significant changes were observed in any of the somatotype related values for the different groups or between groups.

TABLE 6. Descriptive statistics, range and significance for the pre and post-test and group result differences for somatotype.

Measurements	Control group ($n = 16$)		Experimental group ($n = 19$)	
	Pre	Post	Pre	Post
Mesomorphy	6.20 ± 1.18	6.33 ± 1.15	5.82 ± 1.49	5.93 ± 1.56
Range	4.27 – 8.33	4.45 – 8.54	3.32 – 8.14	3.15 – 8.64
Endomorphy	2.63 ± 0.91	2.54 ± 0.97	2.97 ± 1.52	2.88 ± 1.38
Range	1.36 – 4.22	1.31 – 4.88	1.26 – 6.78	1.31 – 6.27
Ectomorphy	1.73 ± 1.07	1.77 ± 1.11	1.71 ± 1.15	1.75 ± 1.15
Range	0.08 – 3.75	0.05 – 3.74	0.10 – 3.52	0.10 – 3.71

Values presented as mean ± *SD*, range = minimum – maximum

DISCUSSION

To our knowledge this is the first study to investigate the possible effects of a rugby conditioning and a combined rugby conditioning and plyometric training program on the anthropometric components of rugby players. The results of the present study indicated that both type of conditioning programs had a significantly positive effect on the body stature of the rugby players. It was also found that the wrist breadth measurements of the players increased significantly due to the combined rugby conditioning and plyometric training program. Finally, the study results revealed that femur breadth and skeletal mass was significantly increased by participation in a four-week long rugby conditioning program. None of the anthropometric components did, however, display a significantly bigger change due to the combined rugby conditioning and plyometric training program, compared to a rugby conditioning program alone.

The significant increase in body stature after completion of the training programs is most likely due to the growth in body stature among the young group of male rugby players. The average age of the players in this study was 18.94 ± 0.4 years and according to Wilmore et al. (32), some boys do not reach their mature stature until their early 20's. This would suggest that body stature was not influenced by the training programs but rather by the growth factor. Additionally, a statistically significant ($p \leq 0.05$) increase in average wrist breadth was detected for the experimental group. Upper-body plyometric exercises such as the single-clap push-up, medicine ball grab and power drops as well as the upper body resistance exercises executed in the rugby conditioning program may have facilitated bone growth in the load-bearing site. The control group also experienced a significant increase in femur breadth and skeletal mass in spite of the fact that they did not participate in the plyometric program. Again, the increase in femur breadth and skeletal mass can probably be attributed to the load-bearing resistance and on-field rugby specific training exercises the players performed. These results are similar to those of Nelson and Bouxsein (21) who found a significant increase in breadth measurements of the area that was subjected to a load-bearing activity among females who participated in racquet sports. However, a study of Dean et al. (5) showed that athletes who achieve lower pre-training values will normally experience the largest gains in terms of the variables measured. This may account for the significant changes experienced by the control group who displayed lower pre-training values compared to the experimental group in the majority of the variables.

The above-mentioned results would suggest that only the minority of anthropometric components were significantly affected by either the combined rugby conditioning and plyometric training program or the rugby conditioning program alone that the players followed during the 4 week period. The hypothesis that a 4-week combined rugby conditioning and plyometric training program will have a significantly bigger effect on the body size, lean body, muscle, fat and skeletal mass as well as somatotype of subjects, compared to a rugby conditioning program alone, is therefore rejected. Several researchers have made similar observations for a variety of sport events. For example, a study on cross-country skiers by Mikkola et al. (19) failed to show any training-induced hypertrophic adaptations as determined by means of the calf and thigh circumferences when a part of the 8-week training period was replaced with plyometric training. The same researchers also did not observe any significant changes in body weight or fat percentage due to the change in the training program. Similarly, runners and cyclists did not show significant changes after a 5-week and 4 to 5-week combined running and plyometric as well as a combined cycling and plyometric program respectively (24,28). The findings of the present study are, however, not consistent with those of Leubers et al. (15) and Bastiaans et al. (1) who found an increase in body mass and lean body mass after completion of a 4 and 9-week sport specific and plyometric training program respectively.

The non-significant results of this study can possibly be attributed to a number of factors. Firstly, the high individual variability in the different pre and post-measurements might have influenced the *t*-test results. For instance: the individual skeletal mass pre-post-test differences for the experimental group varied between -0.493 (minimum) and 1.656 (maximum) with a standard deviation of 0.587; the values of muscle mass differences varied between -0.406 (minimum) and 0.582 (maximum) with a standard deviation of 0.301 for the control group and between -0.461 (minimum) and 1.490 (maximum) with a standard deviation of 0.766 for the experimental group. The values for fat percentage differences varied between -2.388 (minimum) and 4.227 (maximum) with a standard deviation of 1.818 for the control group and between -4.126 (minimum) and 6.618 (maximum) with a standard deviation of 2.409 for the experimental group. The variability of all these values could have influenced the *t*-test results negatively.

Secondly, another factor that could explain the lack of significance in the results could be the fitness levels of the rugby players who participated in the study. Players in this study had already been subjected to a general rugby conditioning program for six months prior to this intervention. It might therefore be expected that their fitness levels were already high due to participation in the rugby conditioning program. In this regard Paton and Hopkins (24) failed to prove any significant increases in the performance of competitive cyclists after the inclusion of plyometric training into their existing cycling training program. Notably, the authors attributed the outcome of their research to the fact that the cyclists were already in the competitive cycle of their training period and had already attained a high fitness level. Athletes who have already attained a certain fitness level will probably not be so sensitive and reactive to conditioning programs when compared with untrained subjects. The conclusion of Turner et al.'s (31) study, namely that the significant improvement in running economy due to a 6-week plyometric training period was due to the inexperience and the untrained state of the subjects, confirm the last-mentioned statement.

Thirdly, research seems to suggest that a 4-week training period may only lead to neural adaptations and not to morphological changes. Hence it is conceivable that a longer training period would have been more beneficial in a study in which changes in the anthropometric make-up of players was the aim. However, there is no agreement between different researchers concerning this aspect (1,15,19,28).

In view of the fact that several researchers adjusted the number of sets and repetitions of the plyometric program on a weekly basis in their studies (4,16,31), this may also be something to consider. Continuous changes in the exercise variables are sure to enhance the level of overload and the resulting morphological changes.

PRACTICAL APPLICATIONS

This study was the first to report on the effects of a combined rugby conditioning and plyometric training program on the anthropometric components of university-level rugby players. Although not significant in altering the overall anthropometric profile of the rugby players, the significant results in some of the measurements do indicate that certain anthropometric components might be positively influenced by a combined sport specific and plyometric training program. The subjects in this study were young and they already displayed a high fitness level before commencement of this study. The authors anticipate that the beneficial effects of a combined plyometric conditioning program on the anthropometric components would be greater with more experienced subjects who have not yet obtained a certain level of fitness. In this regard, future studies need to be designed to test the possible effects of combined sport specific and plyometric training programs on other team sport participants' anthropometric make-up.

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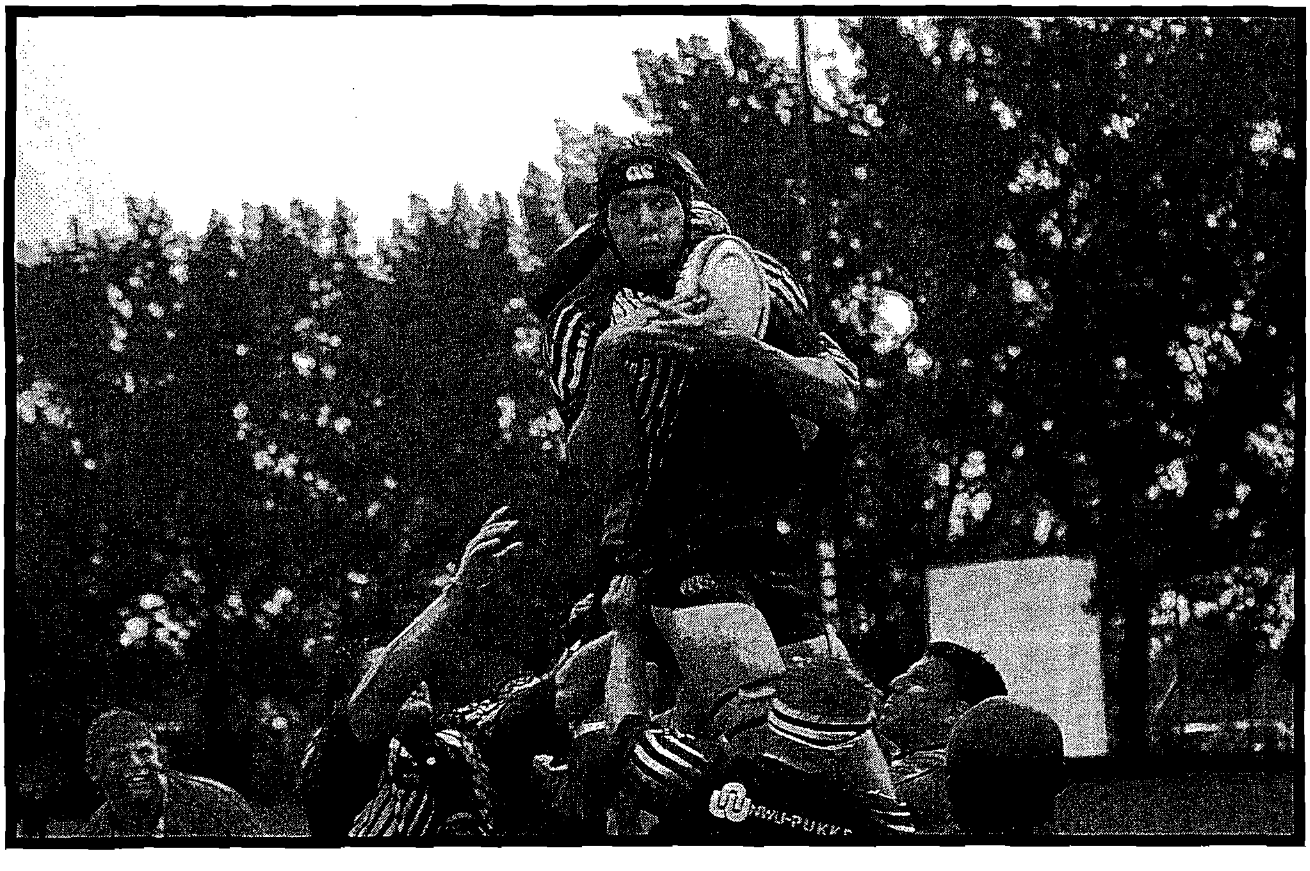
CHAPTER 5



5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1. SUMMARY
2. CONCLUSIONS
3. RECOMMENDATIONS

1. SUMMARY

The purpose of this study was firstly to determine the effects of a four-week combined rugby conditioning and plyometric training program on the physical and motor performance components of university-level rugby players compared to the effects of a rugby conditioning program alone. Secondly, to determine the effects of a four-week combined rugby conditioning and plyometric training program compared to a rugby conditioning program alone, on the anthropometric measurements of university-level rugby players. Chapter 1 provided a brief summary of the problem that underlies the research questions of the study and the research questions itself, the objectives and hypotheses of the study as well as the structure of the dissertation.

Chapter 2 consisted of a literature overview titled "The effects of combined sport specific and plyometric training programs on a variety of physical and motor performance components". The purposes of this review were firstly, to critically analyse the available literature of the past 10 years (1999-2008) with regard to the study subject, the nature of the combination programs used as well as the findings with regard to the effects of these types of programs on a wide variety of physical and motor performance components and secondly, to provide guidelines for the use of combination plyometric programs as performance enhancing training techniques. Twenty-three articles were identified from the available literature of the past 10 years which reported on the investigation into the effectiveness of plyometric training programs in combination with various other training techniques such as resistance, sport specific, speed and functional training as well as electromyostimulation.

Overall the literature supports the use of combined plyometric above that of non-combined plyometric training programs when the aim is to significantly improve upper and lower body strength as well as explosive power; golf club speed and driving distance; 10–50 yards sprinting times; cycling peak power output; aerobic capacity, running economy as well as 1-5 km time trial performances; co-activation of the abductor and adductor muscle groups; isokinetic peak torque of the hamstring and maximal voluntary contraction of both the knee extensor and plantar flexor muscles as well as proprioception and kinesthesia of the shoulder muscles. However, the combined plyometric training programs were not in all cases successful in bringing about more significant changes compared to the non-combined programs. Physical and motor performance components that did not obtain significant results were: upper as well as lower body strength and explosive power; lower leg isometric strength and musculotendinous stiffness; functional isokinetic eccentric to concentric internal shoulder rotation strength ratio; rate of force development; cross-sectional area of the thigh; 4 to 40 m sprinting times when turns or no turns were used; sprint acceleration; foot speed and reactivity ball reaction time; aerobic capacity; lactate threshold and running economy.

The combined programs that served as the best performance enhancing training techniques adhered to the following exercise guidelines and program set-up: a 4 to 12-week duration during which 2 to 3 sessions of plyometric training, consisting of 2 to 9 exercises, were performed. Subjects usually performed 2 to 3 sets of 5 to 100 repetitions and rested for 30 s to 5 min between the different sets. Loaded exercises were performed at an intensity of between 40 and 100% of the 1RM.

Certain shortcomings were, however, identified during the literature review of the combined plyometric training program-related articles which include the following: the use of untrained or moderately active individuals instead of professional or well-trained athletes; the absence of a control group or the absence of familiarization and/or warm-up sessions prior to measurement of the different components or participation in the program; the combined plyometric program durations were too short to induce significant neuromuscular changes; some studies contained group sizes that were too small for detecting significant differences between program changes and in several cases researchers failed to give detailed descriptions of all the methodology and exercise variables necessary to make valid conclusions. Nevertheless, the identified findings highlighted the importance, usefulness and effectiveness of combined plyometric training programs to significantly improve certain physical and motor performance components among athletes of different sports. However, good quality studies that are comprehensively detailed and use study designs that are specific to intervention studies are required in this research domain.

Chapter 3 consisted of the first article titled "Changes in selected physical and motor performance components of university-level rugby players after a four-week combined rugby conditioning and plyometric training program". The purpose of this article was to determine the effects of a four-week combined rugby conditioning and plyometric training program on selected physical and motor performance components of university-level rugby players compared to the effects of a rugby conditioning program alone. The study succeeded in showing that a combined rugby conditioning and plyometric training program of four-weeks led to significantly bigger changes in selected speed, agility and anaerobic power output values among university-level rugby players than a rugby conditioning program alone. The experimental group experienced statistically significant ($p \leq 0,05$) decreases in speed over 20 m and Agility T-Test (ATT) times during the training period. Cohen's effect size revealed a small (ES ~ 0.2) and medium practical significance (ES ~ 0.5) for the mentioned measurements. The independent *t*-test results of these variables also showed statistical as well as medium and large practically significant values respectively when the control group was compared with the experimental group. The change in average power at 20 s as well as relative work for the Wingate Anaerobic Test (WAnT) was significantly better ($p \leq 0,05$) for the experimental group than for the control group. The combined rugby conditioning and plyometric training program did not prove to have a significant influence on the explosive power results of the Vertical Jump Test (VJT) and Medicine Ball Put Test (MBPT). The control group, that followed the rugby conditioning program alone did, however, experience a statistically significant decrease in 3 kg MBPT distance. The rugby conditioning program alone was therefore detrimental to the upper body power development of rugby players. In conclusion, the results of this study seem to suggest that a combined program of sport-specific and plyometric training can be implemented successfully if the goal of training is to significantly improve selected speed, agility and power output values of young rugby players. However, the results of the study also indicated that a combined sport-specific conditioning and plyometric training program of four weeks may not be as effective in increasing all power-related components as a longer combined training program.

The second article, titled "The effects of a four-week combined rugby conditioning and plyometric training program on the anthropometric components of university-level rugby players" was presented in Chapter 4. The purpose of this article was to determine the effects of a four-week combined rugby conditioning and plyometric training program compared to a rugby conditioning program alone, on the anthropometric measurements of university-level rugby players. Statistically significant ($p \leq 0{,}05$) increases were seen for femur breadth among the control group and for wrist breadth among the experimental group. The pre-post-test changes did, however, not show high practically significant values. Body stature showed a significant increase ($p \leq 0{,}05$) from pre to post-testing for both the control and experimental groups, whereas skeletal mass showed a significant increase ($p \leq 0{,}05$) for only the control group. None of the last-mentioned measurements showed high practically significant changes. The significant increase in body stature after completion of the training programs was most likely due to the growth in body stature among the young group of male rugby players and not due to the programs itself. The results would suggest that only the minority of anthropometric measurements were significantly affected by the two types of programs the players executed during the four-week period. However, although not significant in altering the overall anthropometric profile of the rugby players, the significant results in some of the measurements do indicate that certain anthropometric components might be positively influenced by a combined sport specific and plyometric training program.

Both articles were included and compiled in accordance with the guidelines of The Journal of Strength and Conditioning Research to which it will be submitted for publication. Each consisted of an introduction and the experimental approach of the specific studies. The research methods (subjects, procedures and data analyses) were also described together with the results and discussion of each of the studies followed by the practical applications.

2. CONCLUSIONS

The conclusions drawn from this research are presented in accordance with the set hypotheses (Chapter 1):

Hypothesis 1: *A four-week combined rugby conditioning and plyometric training program will lead to significantly better changes in selected speed, agility and anaerobic power output values among university-level rugby players than a rugby conditioning program alone.*

Hypothesis 1 is accepted, based on the results that speed over 20 m and ATT times as well as average power output at 20 s and relative work of the WAnT showed significantly better changes after a four-week rugby conditioning program, combined with plyometric training, compared to a rugby conditioning program alone. As expected, the combined program did, however, not lead to significantly better changes in some of the measurements compared to the rugby conditioning program alone. These were: 3 kg MBPT distance, VJT height and power output, speed over 5 and 10 m, average power over 30 s and fatigue ratio of the (WAnT). What this indicates is that the combined sport-specific conditioning and plyometric training program of this study may not have been effective in increasing all the speed, agility and power output measurements of the rugby players and that certain changes in the exercise variables and program duration need to be considered.

Hypothesis 2: *A four-week combined rugby conditioning and plyometric training program would have a significantly bigger effect on the body size, lean body, muscle, fat and skeletal mass and somatotype of subjects, compared to a rugby conditioning program alone.*

Hypothesis 2 is rejected due to the conclusion that none of the components displayed a significantly bigger change due to the combined rugby conditioning and plyometric training program, compared to a rugby conditioning program alone. A four-week combined training program may therefore only lead to neural adaptations and not to morphological changes. Certain adjustments to the exercise variables and program duration may possibly lead to more pronounced increases in the different anthropometric components.

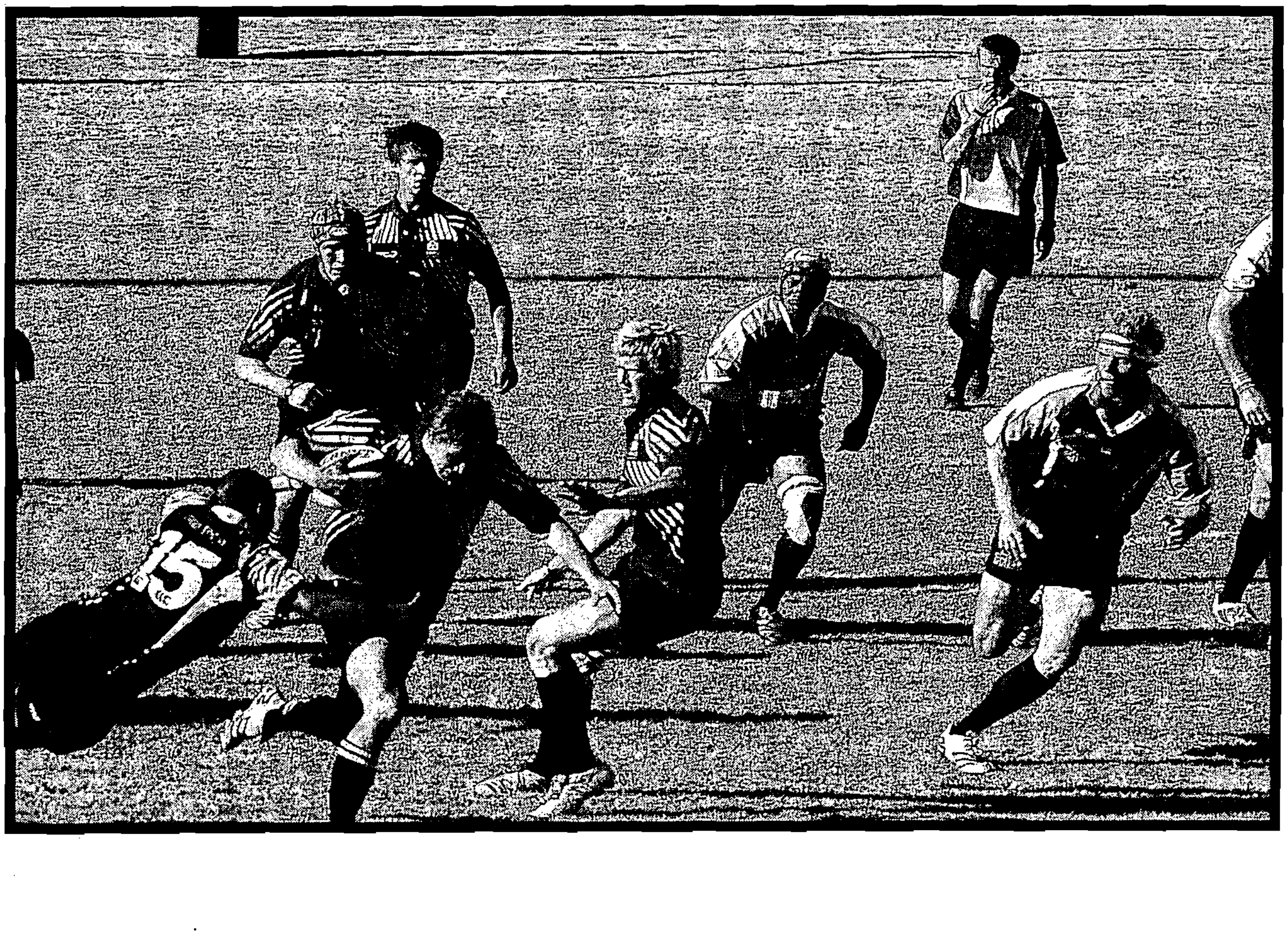
3. RECOMMENDATIONS

The study provides support for the use of combined sport specific and plyometric training programs in the conditioning of young rugby players. It was, however, also observed that not all the selected physical, motor ability and anthropometric components were significantly influenced by the combined rugby conditioning and plyometric training program. These findings suggest that certain shortcomings must be considered when interpreting the results of this study.

- Firstly, outliers among the rugby players who had completed the combined program could have "pulled" the *t*-test results skew due to the rather small sample size in this study. A larger sample size would therefore be advisable.
- Secondly, the high initial fitness levels of the rugby players in this study may have influenced their responsiveness to the combined program negatively. In view of this, it is important to consider the initial fitness levels of the test subjects when planning a study of this nature. Subjects whose initial fitness levels are lower at the start of the study would probably be more sensitive and reactive to a conditioning program than very fit participants.
- Thirdly, the different exercise variables (number of sets and repetitions) of the plyometric training program were not adjusted over time to ensure continuous muscle overload and training adaptations. A study in which the exercise variables are adjusted on a weekly basis according to the subjects' response to the program would probably lead to much more training adaptations than was the case in this study.
- Fourthly, research seems to suggest that a four-week training period may be of insufficient duration to bring about any morphological changes. Hence it is conceivable that a longer training period would have been more beneficial in a study in which changes in the anthropometric make-up of players, amongst other things, was the aim.
- Fifthly, only data of players who are distributed over a small geographic area in South-Africa were utilized. For generalization purposes it would therefore be advisable to include players who are spread over a larger geographic area.
- Lastly, the players in this study fell in the age group 18,1 to 19,5 years. The fact that they were still very young and susceptible to growth changes did influence the anthropometric results (body stature) and may have influenced the pre and post-test changes in physical and motor performance components as well. It can therefore be recommended that researchers rather make use of older test subjects who have already reached full maturity when conducting studies of this nature.

In spite of the shortcomings of the study, it provides a basis for further research in the area of combined sport-specific and plyometric training programs due to the fact that no other studies could be found in which the link between improvements in the physical, motor ability and anthropometric components of rugby players and their participation in a combined rugby conditioning and plyometric training program have been investigated.

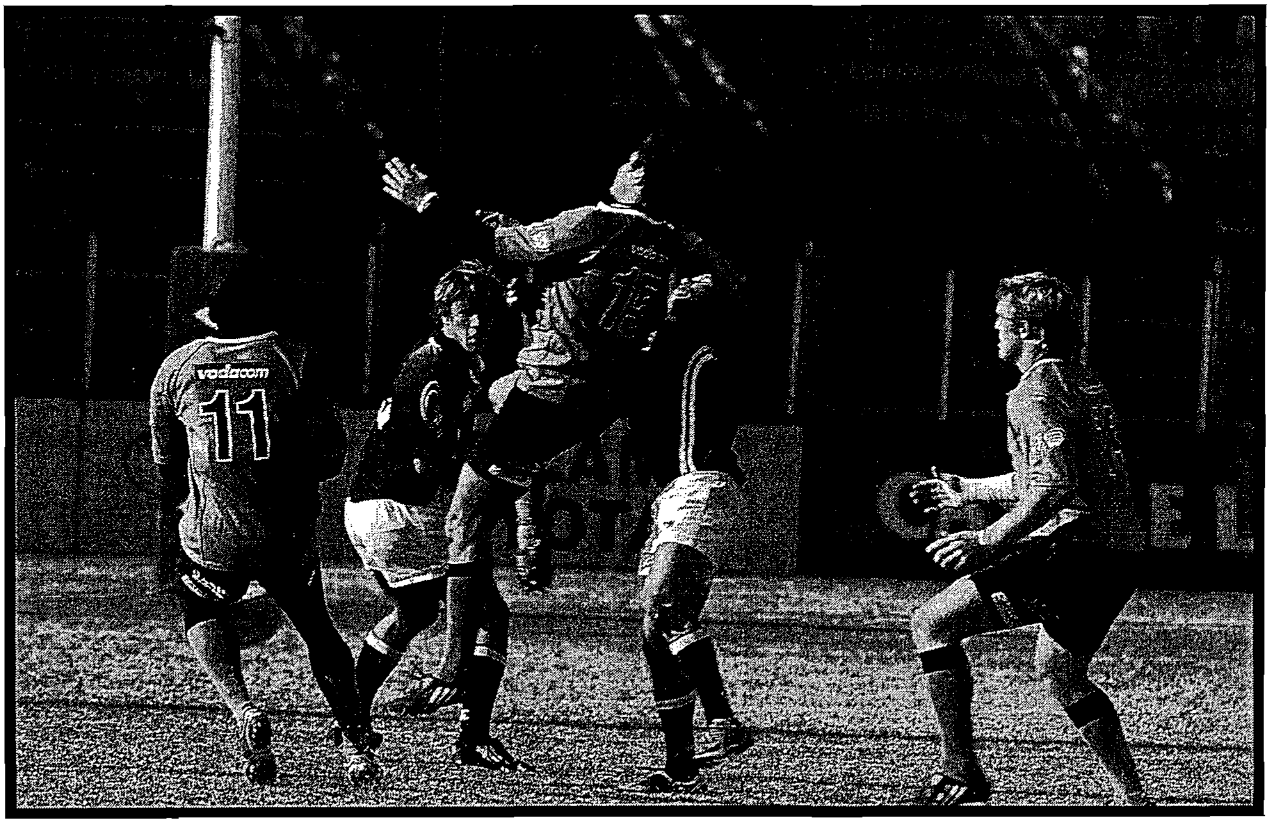
APPENDIX



APPENDIX A, B AND C

APPENDIX A

GENERAL INFORMATION QUESTIONNAIRE, INFORMED CONSENT FORMS AND ANTHROPOMETRIC, PHYSICAL AND MOTOR ABILITY DATA COLLECTION FORMS FOR RUGBY PLAYERS



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POTCHEFSTROOMKAMPUS

1 GENERAL INFORMATION

Please write clearly!

1. GEOGRAPHICAL INFORMATION

1.1 Surname:	**Initials**	**First Name**

1.2 Gender (cross out the one that is applicable):

Male	Female

1.3 Age:

Years:	Months:

1.4 Birth date:

Year:	Month:	Day:

1.5 Job description (cross out the one that is applicable):

Student	Part-time employment	*Full-time employment	*Major sponsorship

* *Please specify if you marked any of these two options:*

1.6 Permanent residential address in South Africa:

1.7 Permanent postal address in South Africa:

1.8 Phone numbers:

Home:	Work:
Fax:	Cell:
E-mail:	

1.9 Ethnic group

White	Coloured	Black	Indian

In the next few question cross out the answers that are applicable to you!!

2. INFORMATION REGARDING TRAINING HABITS

2.1 Years you've been playing cricket - since you started to specialise in cricket.

1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	10-11 years	12 or more

2.2 Frequency of training - how many days per week do you normally train?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.3 Frequency of training - how many days per week do you normally do weight training?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.4 Frequency of training - how many days per week do you normally have net sessions?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.5 Frequency of training - how many days per week do you normally have fielding sessions?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.6 How many hours per day do you normally train?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.7 How many hours per day do you normally spend on weight training?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.8 How many hours per day do you normally spend on training in the nets?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.9 How many hours per day do you normally spend on fielding?

Not Applicable	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours

2.10 How do you think does your coaching compare with those of international cricketers?

Does not compare well at all	Does not compare well	In some aspects the same	Very well

2.11 Do you spend any time on psychological preparation for cricket and competitions?

Never	*Sometimes	*Often	*Always

*** Please specify the type of psychological preparation you do if you marked any of these three options:**

3. MEDICAL INFORMATION

3.1 Please describe any past or current musculoskeletal conditions you have incurred (i.e., muscle pulls, sprains, fractures, surgery, back pain, or any general discomfort):

Head/Neck:

Shoulder/Clavicle:

Arm/Elbow/Wrist/Hand:

Back:

Hip/Pelvis:

Thigh/Knee:

Lower leg/Ankle/Foot:

3.2 Please list any medication being taken currently and/or taken during the last year:

3.3 List any other illness or disorder that a physician has told you of:

4. COMPETITION DATA

4.1 What is your current position in the team? Please give the name and number of the position.

Name:
Number

4.2 In which other position have you played in the last year? Please give the name and number of that position.

Name:
Number:
Name:
Number

4.3 For which team do you currently play rugby?

____

4.4 For which team/s did you play during the last year?

____

____

____

____

4.5 What is the highest level of rugby that you have ever competed in?

Team	Highest achievement obtained	Date

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Informed consent form
PART 1

1. School/Institute:
- School for BRS and Institute for Sport Science and Development (ISSD)

2. Title of project/trial:
- Effect of a combined rugby conditioning and plyometric training program on selected physical and anthropometric components of university-level rugby players.

3. Full names, surname and qualifications of project leader:
- Ben Coetzee, B.Sc, B.Sc Hons. and M.Sc

4. Rank/position of project leader:
(Professor, Lecturer, research scientist etc.)
- Lecturer and Programme Leader of Sports Science in the School for Biokinetics, Recreation and Sports Science (School for BRS)

5. Full names, surname and qualifications of supervisor of the project:
(Complete only if not the same person named in 4.)
- Not applicable

6. Name and address of supervising medical officer *(if applicable)*:
- Not applicable

7. Aim of this project
The aims of this study are:
- To determine the effect of a combined rugby conditioning and plyometric training program on certain physical components of university-level rugby players.
- To determine the effect of a combined rugby conditioning and plyometric training program on certain anthropometric measurements of university-level rugby players.

8. Explanation of the nature of all procedures, including identification of new procedures:
8.1 Research design
The design of the study is a pre-post test, randomized group design. Information will be obtained by means of a questionnaire and a test battery. The objectives of the study will be explained to the players, after which they will all complete an informed consent form.

8.2 Test subjects

The subjects will consist of two groups of rugby players. Fourty u/19 rugby players of the North-West University in Potchefstroom will be randomly selected. The thirty players will again be randomly divided into two groups of twenty players each. One group will form the experimental group and the other group the control group. A pre-test will be done, after which the experimental group will complete 4-weeks of a plyometric training programme in addition to their regular rugby conditioning. The control group will be asked to refrain from any plyometric training and will only take part in their regular rugby conditioning programme. After the intervention period of 4-weeks a post-test will be done for both groups.

8.3 Procedures

a. Demographic and general information questionnaire

The players' demographic and personal information (age and gender) will be collected by means of a demographic and general information questionnaire. The players' exercising habits, injury incidence and competing level will also be determined by means of this questionnaire. Anthropometric data will be collected by means of a few body measurements. The physical and motor performance data will be collected through a test battery.

b. Anthropometric variables

The following anthropometric variables will be determined according to the methods of Norton *et al.* (1996). Body composition, fat mass, muscle mass and skeletal mass will be analyzed in this section. Body fatness will be determined through the sum of the following skinfolds (SUM6SF): triceps, subscapular, abdominal, supraspinale, front thigh and calf skinfolds and according to the formulas of Whithers *et al.* (1987:198). Muscle and skeletal mass will be calculated according to the formulas of Lee *et al.* (2000:796) and Martin *et al.* (as quoted by Drinkwater & Mazza, 1994:103). The following anthropometric variables will be measured under the section of muscle and skeletal mass: body stature, body mass, relaxed arm, thigh and calf girth, triceps, thigh and calf skinfold as well as ankle, femur, humerus and wrist breadths.

c. Physical and motor performance components

The following laboratory tests will be conducted:

i) Explosive power tests
- ➠ Medicine Ball Put (sitting on the floor) Test according to the method of Ball (1991a:331).
- ➠ Vertical Jump Test (VJT) according to the method of Ellis et al. (1998:28).

ii) Twenty metre acceleration and speed test according to the method of Ellis *et al.* (2000:130).

iii) The Agility T-Test (ATT) will be performed according to the method described by VanHeest *et al.* (2002:225).

iv) The Wingate Anaerobic Test (WanT) will be conducted according to the method of Inbar *et al.* (1996:9).

d. Testing methodology

The players will undergo four days of testing, namely two pre and two post-test days respectively. On the first pre-test day subjects will complete the questionnaire, together with the informed consent form after which the anthropometric, explosive power, speed and anaerobic capacity test will follow. On the second day of testing the subjects will perform the agility and strength tests. The experimental group will then be subjected to four weeks of plyometric training that will be performed in conjunction with their normal rugby training. The control group will only follow their normal rugby training during the same time period. Following the

four weeks period each of the groups will again be subjected to the above mentioned tests at the exact same time of day and same day of the week as been tested before.

The plyometric sessions will take place three times a week and will consist of six exercises per session. The list of exercises as well as rest periods that will be followed during the plyometric sessions are presented in Table 1.

9. Description of the nature of discomfort or hazards of probable permanent consequences for the subjects which may be associated with the project:

(Including possible side-effects of and interactions between drugs or radio-active isotopes which

may be used.)

⌦ Subjects may experience episodes of transient light-headedness, fainting, abnormal blood pressure, chest discomfort and nausea.

10. Precautions taken to protect the subjects:

⌦ Only subjects that do not experience injuries and the time of testing will participate in the study. A warm-up and familiarization period will precede each of the testing sessions.

11. Description of the benefits which may be expected from this project:

⌦ Results of this project may provide coaches, sport scientists and other sport related professionals with direction concerning the use and influence of a scientific based plyometric training program on different sport related components.

12. Alternative procedures which may be beneficial to the subjects:

(Complete only if applicable.)

⌦ Not applicable.

Signature: Date: 17/08/2005

Project leader

Table 1: Four week long plyometric training programme

Week	Day	Plyometric exercises	Sets / repetitions	Rest period between sets
1	1	Power skip	2 × 10	30 sec
		Chest pass	2 × 10	30 sec
		Squat jump	2 × 10	30 sec
		Step and throw	2 × 10	30 sec
		Double-leg tuck jump	2 × 10	30 sec
		Two arm put	2 × 10	30 sec
	2	Pike jump	2 × 10	30 sec
		Prone back extension	2 × 10	30 sec
		Standing long jump	2 × 10	30 sec
		Single arm put	2 × 10	30 sec
		Standing jump over barrier	2 × 10	30 sec
		Supine leg lift	2 × 10	30 sec
	3	Front cone hops	2 × 10	30 sec
		Medicine ball V-sit	2 × 10	30 sec
		Side-to-side push-off	2 × 10	30 sec
		Rocky full twist	2 × 10	30 sec
		Split squat jumps	2 × 10	30 sec
		Medicine ball crossover push-ups	2 x 10	30 sec
2	1	Double leg zigzag hop	2 × 10	30 sec
		Partner straddle sit passes	2 × 10	30 sec
		Cycled split squat jumps	2 × 10	30 sec
		Seated solo twist	2 × 10	30 sec
		Lateral jump over barrier	2 × 10	30 sec
		Single-clap push-up	2 x 10	30 sec
	2	Barrier hops	2 × 10	30 sec
		Pullover throws	2 × 10	30 sec
		Standing long jump with sprint	2 × 10	30 sec
		Kneeling side throw	2 × 10	30 sec
		Cone hops with change of directions	2 × 10	30 sec
		Bench press throws	2 × 10	30 sec
	3	Lateral step-up	2 × 10	30 sec
		Russian twists – seated	2 × 10	30 sec
		Alternate push-off	2 × 10	30 sec
		Plyometric bench press throws	2 × 10	30 sec
		Side jumps and sprint	2 × 10	30 sec
		Push-up with weights	2 × 10	30 sec

Table 1: Four week long plyometric training programme (cont.)

Week	Day	Plyometric exercises	Sets / repetitions	Rest period between sets
3	1	Front box jump	2 × 10	30 sec
		Hammer throw	2 × 10	30 sec
		Lateral box jump	2 × 10	30 sec
		Medicine ball sit up	2 × 10	30 sec
		Side-to-side box shuffle	2 × 10	30 sec
		Two ball medicine ball push-up	2 x 10	30 sec
	2	Depth jump	2 × 10	30 sec
		Standing side to side pass	2 × 10	30 sec
		Depth jump to second box	2 × 10	30 sec
		Medicina ball sit up and twist	2 × 10	30 sec
		Three-point stance with single leg hurdle hop	2 × 10	30 sec
		Medicine ball push-ups with a partner	2 × 10	30 sec
	3	Pyramiding box hops	2 × 10	30 sec
		Russian twisit walking	2 × 10	30 sec
		Depth jump with 180 degree turn	2 × 10	30 sec
		Depth push-up	2 × 10	30 sec
		Depth jump with standing long jump	2 × 10	30 sec
		Drop and catch push-up	2 × 10	30 sec
4	1	Multiple box-to-box jump	2 × 10	30 sec
		Hip rolls	2 × 10	30 sec
		Depth jump with 360 degree turn	2 × 10	30 sec
		Over the head backward throw	2 × 10	30 sec
		Depth jump over barrier	2 × 10	30 sec
		Incline push-up and depth jump	2 × 10	30 sec
	2	30-, 60-, 90-second box drill	2 × 10	30 sec
		Forward through the legs	2 × 10	30 sec
		Depth jump with reach	2 × 10	30 sec
		Lateral shuffle and pass	2 × 10	30 sec
		Single-leg depth jump with barrier hop	2 × 10	30 sec
		Quarter-eagle chest pass	2 × 10	30 sec
	3	Depth jump with lateral movement	2 × 10	30 sec
		Medicine ball grab	2 × 10	30 sec
		Depth jump with pass catching	2 × 10	30 sec
		Power drops	2 × 10	30 sec
		Depth jump with blocking bag	2 × 10	30 sec
		Catch and pass with jump-and-reach	2 × 10	30 sec

(Potach & Chu, 2000; Chu, 1998; Dintiman *et al.*, 1998; Radcliff & Farentinos, 1985; Gambetta & Odgers, 1991.)

PART 2

To the subject signing the consent as in part 3 of this document:

You are invited to participate in a research project as described in paragraph 2 of Part 1 of this document. It is important that you read/listen to and understand the following general principles, which apply to all participants in our research project:

1. Participation in this project is voluntary.
2. It is possible that you personally will not derive any benefit from participation in this project, although the knowledge obtained from the results may be beneficial to other people.
3. You will be free to withdraw from the project at any stage without having to explain the reasons for your withdrawal. However, we would like to request that you would rather not withdraw without a thorough consideration of your decision, since it may have an effect on the statistical reliability of the results of the project.
4. The nature of the project, possible risk factors, factors which may cause discomfort, the expected benefits to the subjects and the known and the most probable permanent consequences which may follow from your participation in this project, are discussed in Part 1 of this document.
5. We encourage you to ask questions at any stage about the project and procedures to the project leader or the personnel, who will readily give more information. They will discuss all procedures with you.
6. If you are a minor, we need the written approval of your parent or guardian before you may participate.
7. We require that you indemnify the University from any liability due to detrimental effects of treatment by University staff or students or other subjects to yourself or anybody else. We also require indemnity from liability of the University regarding any treatment to yourself or another person due to participation in this project, as explained in Part 1. Lastly it is required to abandon any claim against the University regarding treatment of yourself or another person due to participation in this project as described in Part 1.
8. If you are married, it is required that your spouse abandon any claims that he/she could have against the University regarding treatment or death of yourself due to the project explained in Part 1.

PART 3

Consent

Title of the project:

⌦ Changes in strength, power and certain physical as well as anthropometric components of university-level rugby players after four weeks of plyometric training

I, the undersigned .... (full names) read/listened to the information on the project in PART 1 and PART 2 of this document and I declare that I understand the information. I had the opportunity to discuss aspects of the project with the project leader and I declare that I participate in the project as a volunteer. I hereby give my consent to be a subject in this project

I indemnify the University, also any employee or student of the University, of any liability against myself, which may arise during the course of the project.

I will not submit any claims against the University regarding personal detrimental effects due to the project, due to negligence by the University, its employees or students, or any other subjects.

(Signature of the subject)

Signed at .... on ....

Witnesses

1. ....

2. ....

Signed at .... on ....

For non-therapeutic experimenting with subjects under the age of 21 years the written approval of a parent or guardian is required.

I, ... (full names) parent or guardian of the subject named above, hereby give my permission that he/she may participate in this project and I also indemnify the University and any employee or student of the University, against any liability which may arise during the course of the project.

Signature: .... Date: ....

Relationship: ....

ISSD·ISWO
Institute for Sport Science and Development
Instituut vir Sportwetenskap en -ontwikkeling

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
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POTCHEFSTROOMKAMPUS

Rugby Protocol

Name and Surname	
Age	
Position	

Measurement	**Trial 1**	**Trial 2**	**Average**
Body mass (kg)			
Stature (cm)			
Skinfolds	**Trial 1**	**Trial 2**	**Average**
Biceps (mm)			
Triceps (mm)			
Subscapular(mm)			
Supra-spinal (mm)			
Abdominal(mm)			
Thigh (mm)			
Medial calf (mm)			
Diameter	**Trial 1**	**Trial 2**	**Average**
Humerus (cm)			
Wrist (cm)			
Femur (cm)			
Ankle (cm)			
Girths	**Trial 1**	**Trial 2**	**Average**
Relaxed upper arm (cm)			
Contracted upper arm (cm)			
Forearm (cm)			
Thigh (cm)			
Calf girth (cm)			

Measurement			
Reach height (cm)	A		
Measurement	Trial 1	Trial 2	Highest
A-B (cm)			
Vertical jump (cm)			
Measurement	Value		
Explosive power calculation (W)			
Measurement	Trial 1	Trial 2	Highest
Medicine ball put (m)			
Speed	Trial 1	Trial 2	Lowest
5m-speed (sec)			
10m-speed (sec)			
20m –speed (sec)			
Agility	Trial 1	Trial 2	Lowest
Agility T-test (sec)			

Wingate Anaerobic Test	Trial
Peak watts (W)	
Peak watts/kg (W/kg)	
Fatigue ratio	
Total work (joules/kg/body mass)	
Total work (joules)	
Average watts (W)	
Average watts/kg/body mass (W/kg)	
Average watts at 5 seconds (W)	
Average watts at 10 seconds (W)	
Average watts at 15 seconds (W)	
Average watts at 20 seconds (W)	
Average watts at 25 seconds (W)	
Average watts at 30 seconds (W)	

APPENDIX B SUBMISSION GUIDELINES FOR AUTHORS

The Journal of Strength and Conditioning Research™

THE OFFICIAL RESEARCH JOURNAL OF THE NATIONAL STRENGTH AND CONDITIONING ASSOCIATION

Manuscript Submission Guidelines

Authors should submit the original file in one of the following formats: Microsoft® Word® (.doc, .rtf, .txt), Corel® WordPerfect® (.wpd, .rtf, .txt), or Adobe® Acrobat® (.pdf).

You must submit the cover letter, copyright release, and manuscript separately to separate identifying information from the manuscript.

Manuscript must match JSCR formatting, including terminology use and units.

Please attempt to keep all figures and tables in a single file (instead of submitted as separate attachments). We prefer that each diagram be pasted into a PowerPoint presentation. Ensure all figures are labeled and referenced in the manuscript.

IRB approval must be mentioned.

If you use Microsoft Word, save in the .doc format.

Cover Letter: A cover letter must accompany the manuscript and state the following: "This manuscript contains material that is original and not previously published in text or on the Internet, nor is it being considered elsewhere until a decision is made as to its acceptability by the *JSCR* Editorial Review Board." Please include the corresponding author's full contact information, including address, email, and phone number.

Compliance with NIH and Other Research Funding Agency Accessibility Requirements: A number of research funding agencies now require or request authors to submit the post-print (the article after peer review and acceptance but not the final published article) to a repository that is accessible online by all without charge. As a service to our authors, LWW will identify to the National Library of Medicine (NLM) articles that require deposit and will transmit the post-print of an article based on research funded in whole or in part by the National Institutes of Health, Wellcome Trust, Howard Hughes Medical Institute, or other funding agencies to PubMed Central. The revised Copyright Transfer Agreement provides the mechanism.

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IRB: The NSCA and the Editorial Board of the *JSCR* have endorsed the American College of Sports Medicine's policies with regards to animal and human experimentation. Their guidelines can be found online at http://www.editorialmanager.com/msse/. Please read these policies carefully. Each manuscript must show that they have had Institutional Board approval for their research and appropriate consent has been obtained pursuant to law. All manuscripts must have this clearly stated in the methods section of the paper or the manuscript will not be considered for publication.

Authorship: All authors should be aware of the publication and be able to defend the paper and its findings and should have signed off on the final version that is submitted. For additional details related to authorship, see "Uniform Requirements for Manuscripts Submitted to Biomedical Journals" at http://www.icmje.org/.

Formatting and Units: All manuscripts must be double-spaced with an additional space between paragraphs on 8½ x11-inch paper. The paper should include a minimum of 1-inch margins and page numbers in the upper right corner next to the running head. Please use a font of at least 12. Authors must use terminology based upon the International System of Units (SI). A full list of SI units can be accessed online at http://physics.nist.gov/. Manuscript identification numbers (e.g., R-12034) will be assigned to each manuscript, and should be placed on all revised manuscripts and used along with the manuscript title for all communications with the Editorial Office. Any revision should have the revision number placed after the manuscript number, (e.g., R-12034, Revision 1).

Language Use: Again the *JSCR* endorses the same policies as the American College of Sports Medicine in that the language is English for the publication. "Authors who speak English as a second language are encouraged to seek the assistance of a colleague experienced in writing for English language journals. Authors are encouraged to use nonsexist language as defined in the American Psychologist 30:682-684, 1975, and to be sensitive to the semantic description of persons with chronic diseases and disabilities, as outlined in an editorial in *Medicine & Science in Sports & Exercise®*, 23(11), 1991. As a general rule, only standardized abbreviations and symbols should be used. If unfamiliar abbreviations are employed, they should be defined when they first appear in the text. Authors should follow Webster's Tenth Collegiate Dictionary for spelling, compounding, and division of words. Trademark names should be capitalized and the spelling verified. Chemical or generic names should precede the trade name or abbreviation of a drug the first time it is used in the text."

Manuscript Format Guidelines

1. Title Page

The title page should include the manuscript title, brief running head, laboratory(s) where the research was conducted, authors' full name(s) spelled out with middle initials, department(s), institution(s), full mailing address of corresponding author including telephone and fax numbers, and email address, and disclosure of funding received for this work from any of the following organizations: National Institutes of Health (NIH); Welcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).

2. Blind Title Page

A second title page should be included that contains only the manuscript title. This will be used for reviewer copies.

3. ABSTRACT and Key Words

On a separate sheet of paper, the manuscript must have an abstract with a limit of 275 words followed by 3 – 6 key words not used in the title. The abstract should have sentences (no headings) related to the purpose of the study, brief methods, results, conclusions and practical applications. Do not end with statements such as "will be discussed."

4. Text

The text must contain the following sections with titles in ALL CAPS in this exact order:

A. INTRODUCTION

This section is a careful development of the hypotheses of the study leading to the purpose of the investigation. Limit information that is "chapter like" in nature as this is not an exhaustive review of the topic. Focus the studies lending support to your hypothesis(es) and giving the proper context to the problem being studied. In most cases use no subheadings in this section and try to limit it to 4 – 6 concisely written paragraphs.

B. METHODS

Within the METHODS section, the following subheadings are required in the following order: "Experimental Approach to the Problem," where the author(s) show how their study design will be able to test the hypotheses developed in the introduction and give some basic rationales for the choices made for the independent and dependent variables used in the study; "Subjects," where the authors include the Institutional Review Board or Ethics Committee approval of their project and appropriate informed consent has been gained. All subject characteristics that are not dependent variables of the study should be included in this section and not in the RESULTS; "Procedures," in this section the methods used are presented with the concept of "replication of the study" kept in mind. After reading this section another investigator should be able to replicate your study. Under this subheading you can add others but please limit their use to that which makes the methods clear and in order of the investigation (e.g., Biochemical Assays or EMG Analyses); "Statistical Analyses," here is where you clearly state your statistical approach to the analysis of the data set(s). It is important that you include your alpha level for significance (e.g., $P < 0.05$). Please place your statistical power in the manuscript for the n size used and reliability of the dependent measures with intra-class correlations (ICC Rs). Additional subheadings can be used but should be limited

C. RESULTS

Present the results of your study in this section. Put the most important findings in Figure or Table format and less important findings in the text. Do not include data that is not part of the experimental design or that has been published before. Place descriptive data about subjects in the METHODS section under the subheading of Subjects. Make sure that you cite each Figure and Table, and in space between paragraphs indicate roughly where you want each Figure or Table to appear (e.g., Table 1 about here)

D. DISCUSSION

Discuss the meaning of the results of your study in this section. Relate them to the literature that currently exists and make sure that you bring the paper to completion with each of your hypotheses. Limit obvious statements like, "more research is needed."

E. PRACTICAL APPLICATIONS

In this section, tell the "coach" or practitioner how your data can be applied and used. It is the distinctive characteristic of the *JSCR* and supports the mission of "Bridging the Gap" for the NSCA between the laboratory and the field practitioner. This section of the paper should speak directly to this audience and not to the exercise or sport scientist.

5. References

All references must be alphabetized by surname of first author and numbered. References are cited in the text by numbers [e.g., (4,9)]. All references listed must be cited in the manuscript and referred to by number therein. For original investigations, please limit the number of references to fewer than 40 or explain why more are necessary. The Editorial Office reserves the right to ask authors to reduce the number of references in the manuscript. Please check references carefully for accuracy. Changes to references at the proof stage, especially changes affecting the numerical order in which they appear, will result in author revision fees. Below are several examples of references:

Journal Article
Hartung, GH, Blanco, RJ, Lally, DA, and Krock, LP. Estimation of aerobic capacity from submaximal cycle ergometry in women. *Med Sci Sports Exerc* 27: 452-457, 1995.

Book
Lohman, TG. Advances in Body Composition Assessment. Champaign, IL: Human Kinetics, 1992.

Chapter in an edited book
Yahara, ML. The shoulder. In: Clinical Orthopedic Physical Therapy. Richardson, JK and

Iglarsh, ZA, eds. Philadelphia: Saunders, 1994. pp. 159-199.

Software
Howard, A. Moments [software]. University of Queensland, 1992.

Proceedings
Viru, A, Viru, M, Harris, R, Oopik, V, Nurmekivi, A, Medijainen, L, and Timpmann, S. Performance capacity in middle-distance runners after enrichment of diet by creatine and creatine action on protein synthesis rate. In: Proceedings of the 2nd Maccabiah-Wingate International Congress of Sport and Coaching Sciences. Tenenbaum, G and Raz-Liebermann, T, eds. Netanya, Israel, Wingate Institute, 1993. pp. 22 - 30.

Dissertation/Thesis
Bartholmew, SA. Plyometric and vertical jump training. Master's thesis, University of North Carolina, Chapel Hill, 1985.

6. Acknowledgements

In this section you can place the information related to Identification of funding sources; Current contact information of corresponding author; and gratitude to other people involved with the conduct of the experiment. In this part of the paper the conflict of interest information must be included. Authors are required to state in the acknowledgments all funding sources, and the names of companies, manufacturers, or outside organizations providing technical or equipment support. In particular, authors should: 1) Disclose professional relationships with companies or manufacturers who will benefit from the results of the present study, and 2) State that the results of the present study do not constitute endorsement of the product by the authors or the NSCA. Failure to disclose such information could result in the rejection of the submitted manuscript.

7. Figures

First, create a page entitled "Figure Legends" in which each of the figure legends are listed. Include this page in your manuscript document. Next, place each of the figures in a PowerPoint presentation if possible. All figures should be labeled and each figure must be referenced in the manuscript. All figures should be professional in appearance. They should also be viable for size reductions to fit manuscript space allocations. One set of figures should accompany each manuscript. Use only clearly delineated symbols and bars.

Electronic photographs copied and pasted into Word and PowerPoint will not be accepted. Images should be scanned at a minimum of 300 pixels per inch (ppi). Line art should be scanned at 1200 ppi. Please indicate the file format of the graphics. We accept TIFF or EPS format for both Macintosh and PC platforms. We also accept image files in the following Native Application File Formats:

Adobe Photoshop (.psd)
Adobe Acrobat (.pdf) (use Press setting under Job Option)
Illustrator (.ai)
Macromedia FreeHand (.fh)
Corel Draw (.cdr)
Canvas (.cvs)
PowerPoint (.ppt)
Word (.doc)
Excel (.xls)

InDesign (.id)
PageMaker (.pmd)
QuarkXPress (.qxd)

If you will be using a digital camera to capture images for print production, you must use the highest resolution setting option with the least amount of compression. Digital camera manufacturers use many different terms and file formats when capturing high-resolution images, so please refer to your camera's manual for more information.

Please also attempt to format tables into the PowerPoint presentation and include a title. If necessary, tables can be added to the end of the manuscript, but must be double-spaced and include a brief title. Provide generous spacing within tables and use as few line rules as possible. When tables are necessary, the information should not duplicate data in the text. All figures and tables must include standard deviations or standard errors.

Author Fees

JSCR does not charge authors a manuscript submission fee or page charges. However, once a manuscript is accepted for publication and sent in for typesetting, it is expected to be in its final form. If excessive revisions (more than 5) are made at the proof stage, the corresponding author will be billed $3.75 per revision. In addition, the following charges will apply to figure revisions: $25.00 per Halftone (B&W) Figure Remake, $19.00 per Line Art (B&W) Figure Remake, and $150.00 per Color Figure Remake. Please note that the most common cause for excessive revisions is the renumbering of references. If one change to a single reference causes other references to be renumbered, it affects both the reference section and each citation for those references in the text. Each one of these changes is counted as an author revision so please check your references carefully.

Manuscript Format Checklist

Approval by Institutional Review Board
Manuscript contains the following sections (in order)
Title Page
Blind Title Page
Abstract and Key Words
Introduction
Methods
Results
Discussion
Practical Applications
References
Acknowledgements
Figure Legends
Figures
Tables

Manuscript Submission Checklist

Cover Letter
Completed Copyright Assignment Form
Original Manuscript, including IRB reference and references to all figures.
Figures, in a single powerpoint presentation if possible.

Terminology and Units of Measurement

Per the *JSCR* Editorial Board and to promote consistency and clarity of communication among all scientific journals authors should use standard terms generally acceptable to the field of exercise science and sports science. Along with the American College of Sports Medicine's Medicine and Science ins Sport and Exercise, the *JSCR* Editorial Board endorses the use of the following terms and units.

The units of measurement shall be Système International d'Unités (SI). Permitted exceptions to SI are heart rate—beats per min; blood pressure—mm Hg; gas pressure—mm Hg. Authors should refer to the *British Medical Journal* (1:1334 – 1336, 1978) and the *Annals of Internal Medicine* (106:114 – 129, 1987) for the proper method to express other units or abbreviations. When expressing units, please locate the multiplication symbol midway between lines to avoid confusion with periods; e.g., $\mathrm{mL{\cdot}min^{-1{\cdot}kg-1.}}$

The basic and derived units most commonly used in reporting research in this Journal include the following:

mass—gram (g) or kilogram (kg); force—newton (N); distance—meter (m), kilometer (km); temperature—degree Celsius (°C); energy, heat, work —joule (J) or kilojoule (kJ); power—watt (W); torque—newton-meter (N·m); frequency —hertz (Hz); pressure—pascal (Pa); time—second (s), minute (min), hour (h); volume—liter (L), milliliter (mL); and amount of a particular substance—mole (mol), millimole (mmol).

Selected conversion factors:

1 N = 0.102 kg (force);

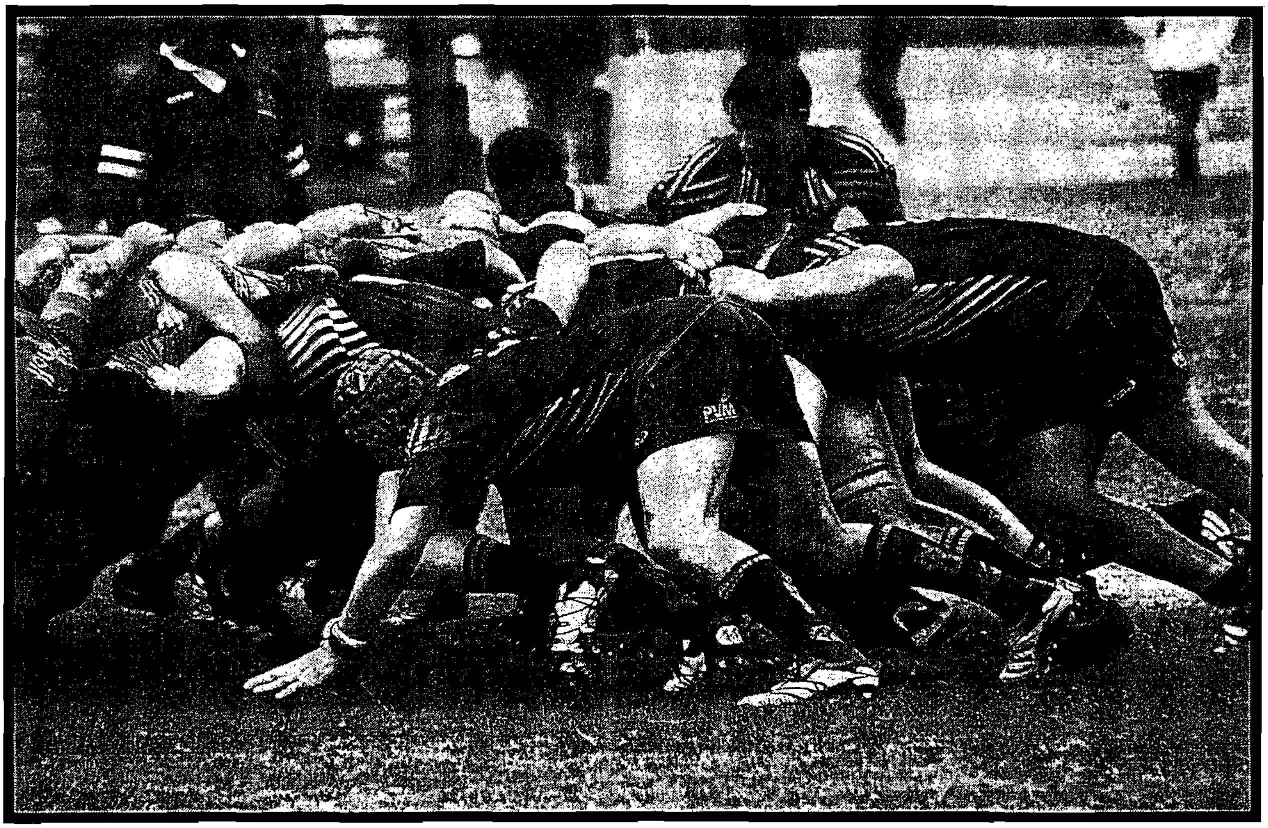
1 J = 1 N·m = 0.000239 kcal = 0.102 kg·m;

1 kJ = 1000 N·m = 0.239 kcal = 102 kg·m;

1 W = 1 J·s-1 = 6.118 kg·m·min-1.

APPENDIX C

EXAMPLE OF AN ARTICLE: THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH



EFFECTS OF A SHORT-TERM AQUATIC RESISTANCE PROGRAM ON STRENGTH AND BODY COMPOSITION IN FIT YOUNG MEN

JUAN C. COLADO,[1] VICTOR TELLA,[1] N. TRAVIS TRIPLETT,[2,3] AND LUIS M. GONZÁLEZ[1]

[1]Department of Physical Education and Sports, University of Valencia, Valencia, Spain; [2]Neuromuscular Laboratory, Department of Health, Leisure and Exercise Science, Appalachian State University, Boone, North Carolina; and [3]Invited Researcher, University of Valencia, Valencia, Spain

ABSTRACT

Colado, JC, Tella, V, Triplett, NT, and González, LM. Effects of a short-term aquatic resistance program on strength and body composition in fit young men. *J Strength Cond Res* 23(2): 549–559, 2009—This study was designed to analyze the effects of a short-term periodized aquatic resistance program (PARP) on upper-limb maximum strength, leg muscular power, and body composition (BC) in fit young men. Twenty subjects (21.2 ± 1.17 years) were randomly assigned to an exercise or control group; 12 subjects completed the study. The aquatic exercise group (AEG; $n = 7$) participated in an 8-week supervised program of 3 $d \cdot wk^{-1}$, and the control group (CG; $n = 5$) maintained their regular activities. The PARP consisted of a total-body resistance exercise workout using aquatic devices that increased drag force, with a cadence of movement controlled and adjusted individually for each exercise and subject. The volume and intensity of the program were increased progressively. Submaximal tests were carried out to determine the change in upper-limb maximum strength, as well as a squat-jump test to determine the change in leg muscular power. Four skinfold sites, 6 circumference sites, body weight, and stature were used to determine changes in BC. A significant increase in upper-limb maximum strength and leg muscular power was observed for the AEG. A significant increase also was noted in the circumference and muscular area of the arm, and there were significant decreases in pectoral and abdominal skinfolds. Nevertheless, the circumference, muscular area, and local fat of the lower limbs did not change. There were no significant changes in any variables in the CG. These results indicate that the PARP produces significant improvements in muscular strength, power, and fat-free mass and, thus, seems to be a very effective form of resistance exercise.

KEY WORDS drag force, monitored cadence of movement, periodized

INTRODUCTION

Both the number of physical conditioning activities carried out in water and the number of those exercising have significantly increased in the United States and Europe in recent decades. The physiological and articular benefits offered by the specific properties of this medium (7,38) may have promoted this increase. These activities have traditionally been aimed at and prescribed for those populations with some kind of disability. However, they are currently used both to improve the physical condition of healthy individuals who regularly take part in recreational training (9) and as a complement to improve the performance of athletes (5,16,25,27,33). Although the physiological responses, effects, and benefits offered by performing aerobic exercises in water are well known (8,15), studies are lacking on the potential effects of a program of resistance exercises in water (32). The absence of methodological criteria with which to control resistance objectively and progressively while performing these exercises (30,31) may be one of the reasons for this, and as a result this type of training has not been recommended by academic professionals or used by practitioners.

In general terms, the same program design recommendations should be followed for the specific application of strength training programs in water (31,36). Therefore, to *design a strength training program in the aquatic medium,* studies (6,7,9,10,12,17,23,28,30–32,36,38) have recommended that it is essential to achieve the combined control of i) the pace of the movement, ii) the size of the aquatic devices that increase the drag force, iii) the length of the lever of the limb being exercised, iv) the hydrodynamic position of the segment mobilized and the aquatic devices used, and v) the

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Address correspondence to Juan C. Colado, juancolado@uv.es.

23(2)/549–559

Journal of Strength and Conditioning Research

performance of a targeted number of repetitions based on the desired goal. In addition, it should be pointed out that in all cases the individuals exercising carry out the movements with the aquatic devices at a pace determined by a cadence of beats per minute that has been previously identified on the basis of the predicted targeted number of repetitions. It has been shown that the workload in water is always similar as long as the movement is performed at the same pace and under the same exercise conditions (7,12). Thus, to increase the resistance offered by the water, either the pace per minute must be increased or the area of the aquatic device must be increased (7). Therefore, objective criteria exist with which to quantify the progressive increase in the "load" or resistance, marked by the proposed pace per minute and the aquatic device used (7). The moment when neither the pace nor correct performance can be maintained defines when muscular actions are inadequate for the stimulus (29).

No scientific studies have examined the basic aspects of the design of resistance programs in combination with the use of adequate aquatic devices and the performance of movements according to a previously evaluated pace. Although several studies have confirmed the positive adaptations caused by aquatic resistance exercises (3,37,39), many of them display methodological shortcomings when it comes to controlling the resistance generated by the exercises both immediately and in the long term, as well as usually being applied to untrained middle-aged or older subjects with whom it is easier to cause certain adaptations in the early stages of strength training programs. Therefore, to analyze the effects that an aquatic resistance program can have on fit young men regarding maximum strength, muscular power, and body composition (BC), a randomized and supervised study was carried out for which a method was designed to adapt and control exercise intensity objectively. The hypothesis of the current study was that aquatic resistance training can generate positive neuromuscular adaptations in fit men if the resistance applied to the training movements is controlled by a specific cadence of movement for each exercise and subject according to the targeted number of repetitions initially prescribed.

METHODS

Experimental Approach to the Problem

In accordance with the methodology proposed by Kraemer et al. (23) for using elastic devices for strength training, in this study a specific cadence of movement using the same aquatic device to increase drag force was used to complete an 8- to 12-repetition maximum (RM) range with a 10-repetition target. To this end, a cadence of movement was identified for each subject in the aquatic exercise group (AEG) that allowed the subject to achieve the amount of resistance needed to maintain the targeted number of repetitions (RM zone ± 2 rep) while using good technique. The subjects trained using an acoustic metronome throughout the training program, with each individually following the initially identified cadence of movement for each exercise. Whenever necessary, greater resistance was provided by using a faster cadence of movement to maintain the targeted number of repetitions. At least 1 trained monitor was always present to corroborate the correct application of this methodology. Muscle function and BC were tested before and after the resistance training program to determine its effects. All measurements and practical procedures were always carried out by the same researchers, all of whom had experience with this kind of trial. All subjects were continually encouraged, and the laboratory conditions were always the same. Pre- and posttests were filmed, and the film was then checked to ensure the validity of the procedures followed. The study was approved by a research commission and by the Department of Physical Education and Sports from the University of Valencia (Spain).

Subjects

Twenty men volunteers from third-year students at the Faculty of the Sciences of Physical Activity and Sports at the University of Valencia (Spain) were randomly assigned into a control group (CG; 8 subjects) and an AEG (12 subjects), with no significant differences ($p > 0.05$) in any intergroup baseline measurement. All subjects were physically active as they performed 5.08 ± 1.5 d·wk^{-1} of varied physical training at moderate intensity for at least 20 minutes, and all had done so for at least 6 months before the study. They did not normally perform resistance exercises on dry land, and they never had performed aquatic resistance exercises. All subjects signed an agreement by which they committed themselves, for the duration of the study, not to carry out any specific physical activity for strength training in their free time, to maintain their habitual lifestyle and eating habits, and not to take performance-enhancing substances (after prior corroboration that they never had taken these substances). The subjects did not suffer any cardiovascular, neuromuscular, orthopedic, or psychological disorders. All subjects were informed of the nature of the study before volunteering to take part in it. To evaluate any possible interference with the training program followed in the study, and to better understand certain results obtained, each subject was supplied with a diary in which he listed the type of physical activity he had carried out during the day, his diet, his rest periods, and his feelings during the aquatic resistance training sessions. Finally, after the usual withdrawals and eliminations associated with any unremunerated experimental study, the final make-up of the groups was as follows: a) AEG: $n = 7$, 21 ± 1 years, 173.96 ± 4.97 cm, 73.43 ± 7.97 kg; b) CG: $n = 5$, 21.4 ± 1.34 years, 178.12 ± 4.08 cm, 76.38 ± 5.03 kg.

Body Composition

All measurements were carried out by the same fully trained individual under identical environmental conditions using exactly the same instruments. A Harpenden skinfold caliper was used to measure skinfolds, and the average of 2 trials was used except in the case in which the measurements differed by more than 2.0 mm. In this case, a third measurement was obtained, and the mean value was used. The skinfolds

measured were those of the right-hand side of the chest, abdomen, and thigh, following the usual protocol (18). In addition, a skinfold was taken from the brachial triceps region of the right arm for later analysis. Body density was calculated (21), and the value was used to determine body fat percentage by applying the Siri formula (35) for Caucasian men; subsequently, fat-free mass was determined. In addition, the circumferences of the relaxed right arm, the internal and thoracic region at shoulder height at maximum inspiration, the relaxed hip, and the upper thigh were measured. We also measured fasting body weight and height using the spinal column extension method and normal procedures for these measurements (18). Finally, the muscle area of the arm and thigh were determined by using the above measurements and applying the formulas used by Huygens et al. (20).

Procedures

It was scrupulously ensured that the correct range and technique were used for each exercise during the tests. All subjects were required to perform a standardized warm-up. Two measurement sessions with 48 hours of separation between them were carried out for both the initial and final tests, and there were 72 hours separating the final training session from the first posttest evaluation. The best result for each variable measured was taken for analysis. The intraclass correlation coefficient was calculated from the measurements of the pre- and posttests of the control group. For the anthropometric and strength variables, the intraclass correlation coefficient values for our protocols ranged between 0.87 and 0.98 and between 0.82 and 0.87, respectively.

Maximum Strength. The exercises chosen for the dry-land evaluation involved the same muscle groups and working angles exercised during the periodized aquatic resistance program (PARP) in as similar a fashion as possible. The exercises used and the order of evaluation were always the same, which prevented any possible interference with performance that could be a result of the order in which the exercises were carried out. The order was as follows: a) vertical row, b) horizontal bench press, c) horizontal bench row, d) arm lateral raise, and e) squat-jump. Previously calibrated standard materials were used, consisting of bars with diameters of 2.5 cm and weights of 11 kg, dumbbells with diameters of 2.5 cm and weights of 2.5 kg, weight plates with standard features, collars, and standard supports. Subjects were familiarized with each exercise, and their technique was checked before the performance of each test. A submaximal test only allowing a maximum of 6 repetitions until muscular failure with correct technique was used (14). A submaximal test was used because a large number of muscle groups were evaluated by means of different tests, and it was necessary to the quality and validity of the tests to minimize fatigue of the subjects. If a subject exceeded the number of repetitions, he rested and then tried again with a higher load. The Brzycki formula (4) was used to calculate maximal strength from the submaximal repetitions.

Power. To identify the evolution of lower-limb muscle power, the static vertical jump or squat-jump test was used because it also exclusively assesses the concentric muscle action that characterized the PARP used in this study. It was performed using the recommendations of Lehmkuhl et al. (24). The muscular power of each vertical jump was estimated by applying the prediction equation of Sayers et al. (34).

Periodized Aquatic Resistance Training Program

Exercises. Because the subjects were not used to aquatic resistance exercises, they were taught the correct technique for performing them before starting the training program. The researchers explained the exercises to the group, and each subject then carried them out under supervision. The criteria for correct technical performance were those described by Colado (9), and the exercises are described in Table 1. The temperature of the water in the swimming pool where the training program took place was 28 ± 1° C, and the depth of immersion was always such as to allow the exercises to be carried out in a technically correct fashion. Standard materials were used during the training program. For example, the gloves had a projected area of 293 cm^2, the fins had a projected area of 430 cm^2, and the boards had a projected area of 874 cm^2. Noodles were used to maintain the horizontal flotation position in the exercises training the abdominal musculature.

Resistance Identification. A Wittner metronome and a digital audio editing program were used to record a compact disc with 12 tracks corresponding to different paces and ranging from 46 beats per minute to 102 beats per minute. Each of the tracks was thoroughly checked to guarantee that they did not contain alterations to the preset pace. The subjects initially used the aquatic devices to carry out the basic exercises prescribed at a pace determined by a cadence of beats per minute chosen on the basis of pilot tests and the prior experience of the researchers. This meant that the subjects had to match their movements to the individual beats of the tracks recorded on the compact disc. Those subjects who were not able to generate enough resistance from the water to reach muscle failure with the preset number of repetitions at the pace initially planned and without varying their technique took a rest period and then increased the pace by choosing the next track. Similarly, the subjects for whom the pace was too difficult to reach the prescribed number of repetitions chose the previous track after the rest period. This allowed them to obtain the initial "load" after identifying the track offering the optimal pace to be used by each subject for each of the exercises. From then on, the "load" was adjusted to the aquatic movement by changing the track. The subjects repeated the process after resting for 2 hours to ensure that the track chosen for each exercise was correct. This test was carried out 48 hours after having carried out the dry-land pretests to determine maximum strength and muscular power. Table 1 also shows the beats per minute (pace) most commonly used for each of the basic training program exercises.

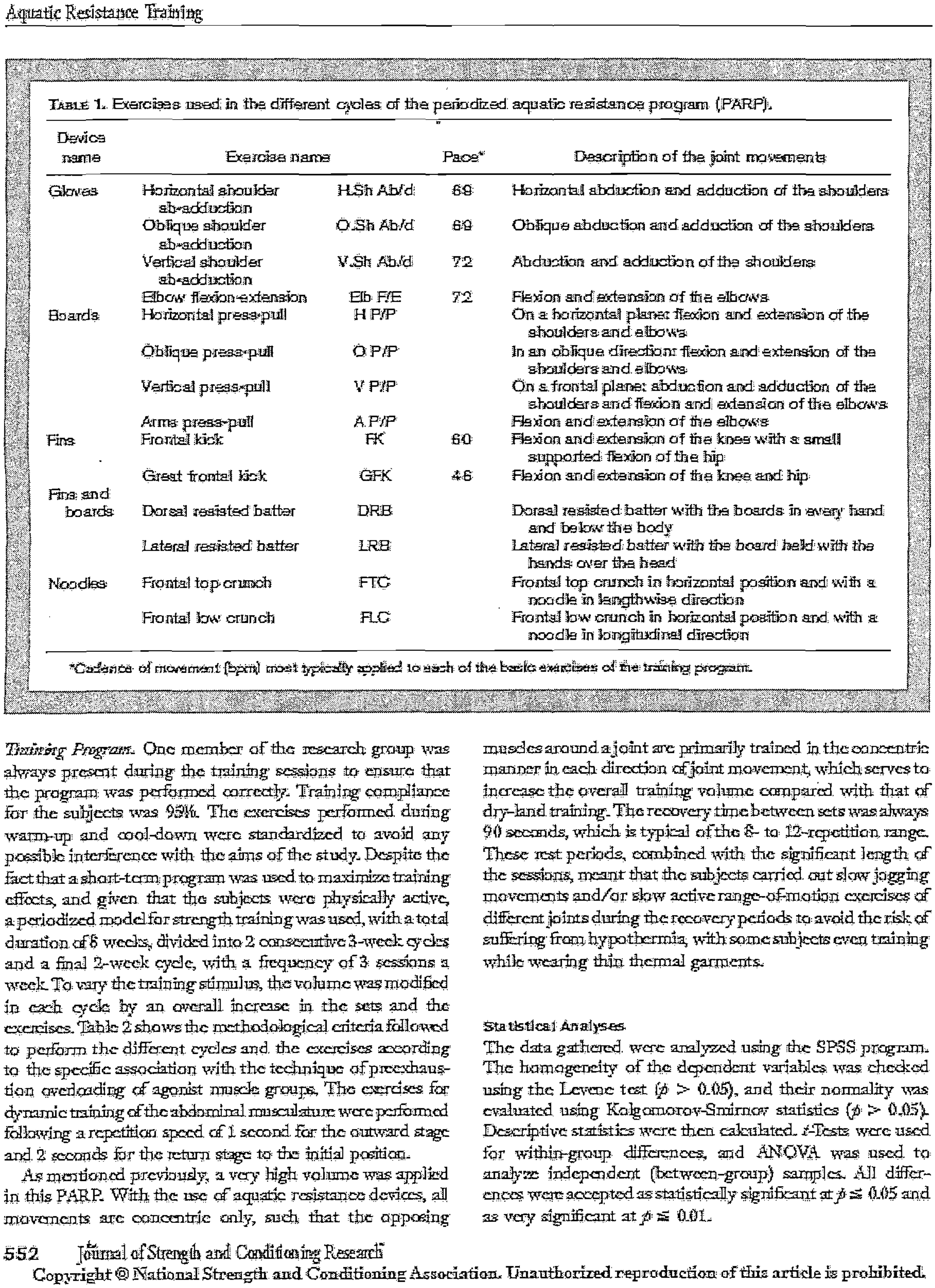

TABLE 1. Exercises used in the different cycles of the periodized aquatic resistance program (PARP).

Device name	Exercise name		Pace*	Description of the joint movements
Gloves	Horizontal shoulder ab-adduction	H.Sh Ab/d	69	Horizontal abduction and adduction of the shoulders
	Oblique shoulder ab-adduction	O.Sh Ab/d	69	Oblique abduction and adduction of the shoulders
	Vertical shoulder ab-adduction	V.Sh Ab/d	72	Abduction and adduction of the shoulders
	Elbow flexion-extension	Elb F/E	72	Flexion and extension of the elbows
Boards	Horizontal press-pull	H P/P		On a horizontal plane: flexion and extension of the shoulders and elbows
	Oblique press-pull	O P/P		In an oblique direction: flexion and extension of the shoulders and elbows
	Vertical press-pull	V P/P		On a frontal plane: abduction and adduction of the shoulders and flexion and extension of the elbows
	Arms press-pull	A P/P		Flexion and extension of the elbows
Fins	Frontal kick	FK	60	Flexion and extension of the knee with a small supported flexion of the hip
	Great frontal kick	GFK	46	Flexion and extension of the knee and hip
Fins and boards	Dorsal resisted batter	DRB		Dorsal resisted batter with the boards in every hand and below the body
	Lateral resisted batter	LRB		*Lateral resisted batter with the board held with the* hands over the head
Noodles	Frontal top crunch	FTC		Frontal top crunch in horizontal position and with a noodle in lengthwise direction
	Frontal low crunch	FLC		Frontal low crunch in horizontal position and with a noodle in longitudinal direction

*Cadence of movement (bpm) most typically applied to each of the basic exercises of the training program.

Training Program. One member of the research group was always present during the training sessions to ensure that the program was performed correctly. Training compliance for the subjects was 95%. The exercises performed during warm-up and cool-down were standardized to avoid any possible interference with the aims of the study. Despite the fact that a short-term program was used to maximize training effects, and given that the subjects were physically active, a periodized model for strength training was used, with a total duration of 8 weeks, divided into 2 consecutive 3-week cycles and a final 2-week cycle, with a frequency of 3 sessions a week. To vary the training stimulus, the volume was modified in each cycle by an overall increase in the sets and the exercises. Table 2 shows the methodological criteria followed to perform the different cycles and the exercises according to the specific association with the technique of preexhaustion overloading of agonist muscle groups. The exercises for dynamic training of the abdominal musculature were performed following a repetition speed of 1 second for the outward stage and 2 seconds for the return stage to the initial position.

As mentioned previously, a very high volume was applied in this PARP. With the use of aquatic resistance devices, all movements are concentric only, such that the opposing muscles around a joint are primarily trained in the concentric manner in each direction of joint movement, which serves to increase the overall training volume compared with that of dry-land training. The recovery time between sets was always 90 seconds, which is typical of the 8- to 12-repetition range. These rest periods, combined with the significant length of the sessions, meant that the subjects carried out slow jogging movements and/or slow active range-of-motion exercises of different joints during the recovery periods to avoid the risk of suffering from hypothermia, with some subjects even training while wearing thin thermal garments.

Statistical Analyses

The data gathered were analyzed using the SPSS program. The homogeneity of the dependent variables was checked using the Levene test ($p > 0.05$), and their normality was evaluated using Kolgomorov-Smirnov statistics ($p > 0.05$). Descriptive statistics were then calculated. t-Tests were used for within-group differences, and ANOVA was used to analyze independent (between-group) samples. All differences were accepted as statistically significant at $p \leq 0.05$ and as very significant at $p \leq 0.01$.

TABLE 2. Periodized aquatic resistance program (PARP) followed in the study.

Cycle number		Exercises and workout order	Sets per exercise	Repetitions per set 1	2	3
1	1ª	Horizontal shoulder ab-adduction	3	8–12		
	2ª	Oblique shoulder ab-adduction	3	8–12		
	3ª	Vertical shoulder ab-adduction	3	8–12		
	4ª	Elbow flexion-extension	5	8–12		
	5ª	Frontal kick	5	8–12		
	6ª	Great frontal kick	5	8–12		
	7ª	Frontal top crunch	4	15		
2	1ª	(1) Oblique shoulder ab-adduction + (2) oblique press-pull	3	8–12	15	
	2ª	(1) Vertical shoulder ab-adduction + (2) vertical press-pull	3	8–12	15	
	3ª	(1) Horizontal shoulder ab-adduction + (2) horizontal press-pull	3	8–12	15	
	4ª	(1) Elbow flexion-extension + (2) arms press-pull	5	8–12	15	
	5ª	(1) Great frontal kick + (2) lateral resisted batter	5	8–12	15	
	6ª	(1) Frontal kick + (2) dorsal resisted batter	5	8–12	15	
	7ª	*(1) Frontal low crunch + (2) frontal top crunch*	4	15	15	
3	1ª	(1) Vertical shoulder ab-adduction + (2) vertical press-pull + (3) vertical shoulder ab-adduction	4	8–12	15	8–12
	2ª	*(1) Horizontal shoulder ab-adduction + (2) horizontal* press-pull + (3) horizontal shoulder ab-adduction	4	8–12	15	8–12
	3ª	(1) Elbow flexion-extension + (2) arms press-pull + (3) elbow flexion-extension	5	8–12	15	8–12
	4ª	(1) Frontal kick + (2) dorsal resisted batter + (3) frontal kick	5	8–12	15	8–12
	5ª	(1) Great frontal kick + (2) lateral resisted batter + (3) great frontal kick	5	8–12	15	8–12
	6ª	(1) Frontal top crunch + (2) frontal low crunch + (3) frontal top crunch	5	15	15	15

Rest interval between sets: 90 seconds.

RESULTS

Tables 3 and 4 show the effects caused by the PARP on muscular fitness and global BC, stating the baseline value and final absolute change after comparing the initial value with that obtained after the 8 weeks of training. Additionally, *Figures 1 and 2 show* the individual values of the AEG for the variables indicated.

The PARP led to significant improvements in both the maximum strength of the upper limbs and in the power of the lower limbs (Table 3). The PARP also led to significant increases in fat-free mass (Table 4) and arm/hip circumference (Table 5). In addition, the PARP significantly reduced local fat in the abdominal and pectoral region (Table 5) together with overall fat mass (Table 4), there being a significantly positive correlation in the AEG between weight increase and reduction of body fat mass ($p \leq 0.01$). However, the PARP did not lead to any modification of lower-limb BC.

DISCUSSION

Except for the study carried out by Pöyhönen et al. (32) analyzing the effects caused by a PARP with movements performed with aquatic devices on the strength and BC of young, physically active women, there are no other scientific studies focusing on the effects that a total-body workout PARP using aquatic devices could have on other populations, especially where intensity is controlled objectively. Therefore, in the current investigation it was necessary to create a methodology that had been lacking up to now. The method used here to control intensity in aquatic strength training through joint control of the pace of movement and target number of repetitions is in agreement with current recommendations for controlling training against resistance (29). The results highlight the fact that the PARP developed was effective in increasing both strength and fat-free mass with only 8 weeks of training, despite the fact that there are aquatic devices available that are more appropriate because they are larger and more ergonomically designed than those used in the current investigation, and even though the subject attrition reduced the final statistical power, which is accounted for when making generalizations about the results obtained in this investigation.

The results provided by this study show a clear increase in the maximum strength of upper-limb muscle groups in young, healthy, physically fit men with an intermediate level of muscular fitness. Faced with the lack of equivalent studies in

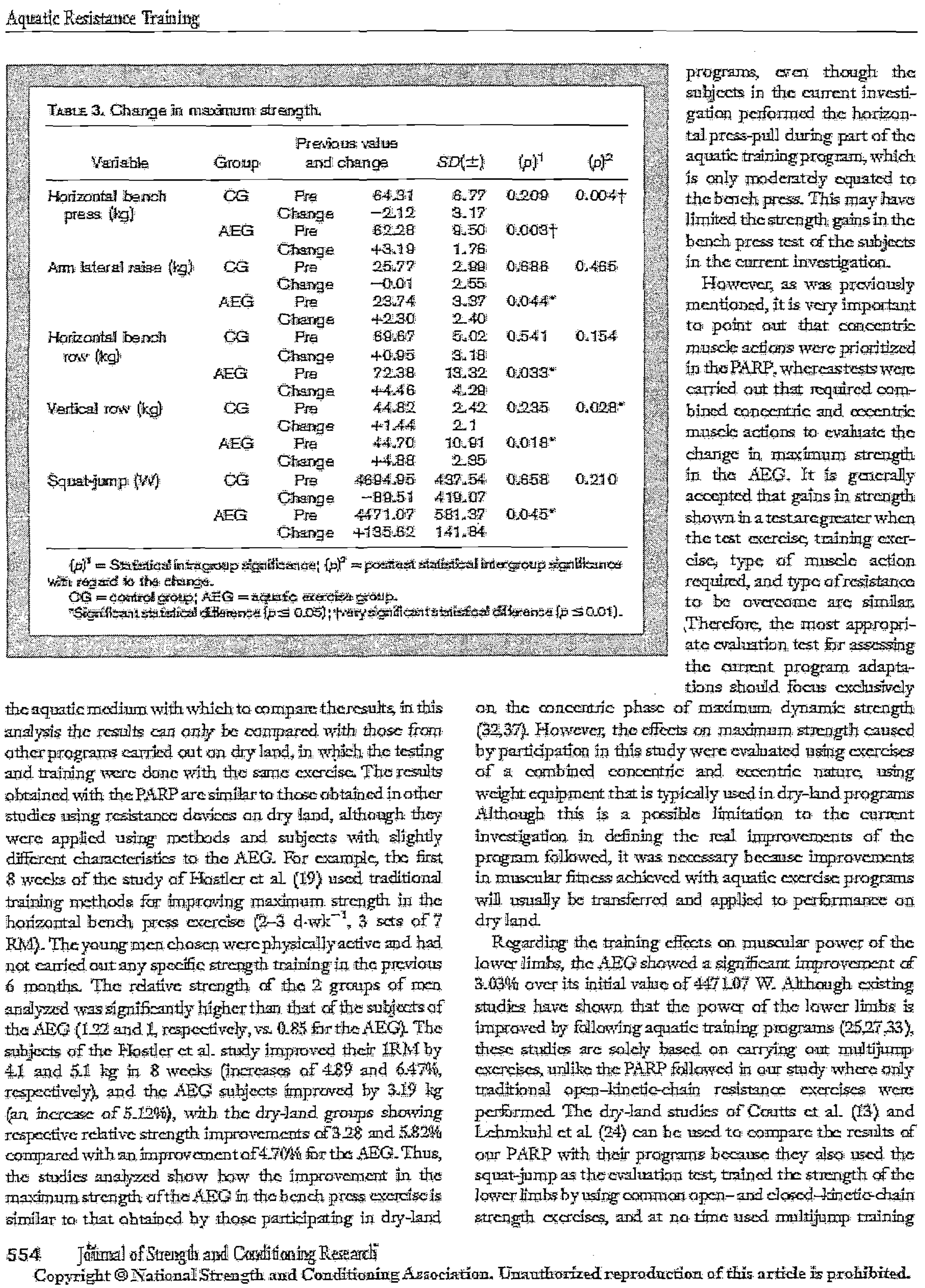

TABLE 3. Change in maximum strength.

Variable	Group	Previous value and change		$SD(\pm)$	$(p)^1$	$(p)^2$
Horizontal bench press (kg)	CG	Pre	64.31	6.77	0.209	0.004†
		Change	−2.12	3.17		
	AEG	Pre	62.28	9.50	0.003†	
		Change	+3.19	1.76		
Arm lateral raise (kg)	CG	Pre	25.77	2.99	0.686	0.465
		Change	−0.01	2.55		
	AEG	Pre	23.74	3.37	0.044*	
		Change	+2.30	2.40		
Horizontal bench row (kg)	CG	Pre	69.67	5.02	0.541	0.154
		Change	+0.95	3.18		
	AEG	Pre	72.38	13.32	0.033*	
		Change	+4.46	4.29		
Vertical row (kg)	CG	Pre	44.82	2.42	0.235	0.028*
		Change	+1.44	2.1		
	AEG	Pre	44.70	10.91	0.018*	
		Change	+4.88	2.95		
Squat-jump (W)	CG	Pre	4694.95	437.54	0.658	0.210
		Change	−89.51	419.07		
	AEG	Pre	4471.07	581.37	0.045*	
		Change	+135.62	141.84		

$(p)^1$ = Statistical intragroup significance; $(p)^2$ = posttest statistical intergroup significance with regard to the change.

CG = control group; AEG = aquatic exercise group.

*Significant statistical difference ($p \leq 0.05$); †very significant statistical difference ($p \leq 0.01$).

the aquatic medium with which to compare the results, in this analysis the results can only be compared with those from other programs carried out on dry land, in which the testing and training were done with the same exercise. The results obtained with the PARP are similar to those obtained in other studies using resistance devices on dry land, although they were applied using methods and subjects with slightly different characteristics to the AEG. For example, the first 8 weeks of the study of Hostler et al. (19) used traditional training methods for improving maximum strength in the horizontal bench press exercise (2–3 d·wk^{-1}, 3 sets of 7 RM). The young men chosen were physically active and had not carried out any specific strength training in the previous 6 months. The relative strength of the 2 groups of men analyzed was significantly higher than that of the subjects of the AEG (1.22 and 1, respectively, vs. 0.85 for the AEG). The subjects of the Hostler et al. study improved their 1RM by 4.1 and 5.1 kg in 8 weeks (increases of 4.89 and 6.47%, respectively), and the AEG subjects improved by 3.19 kg (an increase of 5.12%), with the dry-land groups showing respective relative strength improvements of 3.28 and 5.82% compared with an improvement of 4.70% for the AEG. Thus, the studies analyzed show how the improvement in the maximum strength of the AEG in the bench press exercise is similar to that obtained by those participating in dry-land programs, even though the subjects in the current investigation performed the horizontal press-pull during part of the aquatic training program, which is only moderately equated to the bench press. This may have limited the strength gains in the bench press test of the subjects in the current investigation.

However, as was previously mentioned, it is very important to point out that concentric muscle actions were prioritized in the PARP, whereas tests were carried out that required combined concentric and eccentric muscle actions to evaluate the change in maximum strength in the AEG. It is generally accepted that gains in strength shown in a test are greater when the test exercise, training exercise, type of muscle action required, and type of resistance to be overcome are similar. Therefore, the most appropriate evaluation test for assessing the current program adaptations should focus exclusively on the concentric phase of maximum dynamic strength (32,37). However, the effects on maximum strength caused by participation in this study were evaluated using exercises of a combined concentric and eccentric nature, using weight equipment that is typically used in dry-land programs. Although this is a possible limitation to the current investigation in defining the real improvements of the program followed, it was necessary because improvements in muscular fitness achieved with aquatic exercise programs will usually be transferred and applied to performance on dry land.

Regarding the training effects on muscular power of the lower limbs, the AEG showed a significant improvement of 3.03% over its initial value of 4471.07 W. Although existing studies have shown that the power of the lower limbs is improved by following aquatic training programs (25,27,33), these studies are solely based on carrying out multijump exercises, unlike the PARP followed in our study where only traditional open–kinetic-chain resistance exercises were performed. The dry-land studies of Coutts et al. (13) and Lehmkuhl et al. (24) can be used to compare the results of our PARP with their programs because they also used the squat-jump as the evaluation test, trained the strength of the lower limbs by using common open- and closed-kinetic-chain strength exercises, and at no time used multijump training

TABLE 4. Change in overall body composition.

Variable	Group	Previous value and change		$SD(\pm)$	$(p)^1$	$(p)^2$
Fat-free mass (kg)	CG	Pre	69.58	3.03	0.043*	0.000†
		Change	−1.42	0.48		
	AEG	Pre	66.01	7.53	0.000†	
		Change	+1.28	0.47		
Percentage of body fat (%)	CG	Pre	8.78	3.24	0.875	0.092
		Change	+0.12	1.59		
	AEG	Pre	10.13	2.25	0.019*	
		Change	−1.32	1.10		
Fat mass (kg)	CG	Pre	6.80	2.90	0.893	0.194
		Change	−0.02	1.44		
	AEG	Pre	7.42	1.71	0.023*	
		Change	−0.91	0.79		
Body weight(kg)	CG	Pre	76.38	5.03	0.112	0.029*
		Change	−1.44	1.59		
	AEG	Pre	73.43	7.98	0.374	
		Change	+0.37	0.88		

$(p)^1$ = Statistical intragroup significance; $(p)^2$ = posttest statistical intergroup significance with regard to the change.
CG = control group; AEG = aquatic exercise group.
*Significant statistical difference ($p \leq 0.05$); †very significant statistical difference ($p \leq 0.01$).

resources. The 2 groups of subjects in the Coutts et al. (13) study trained for the first 6 weeks at 3 d·wk^{-1}, with a total-body workout of 7 exercises including one for the lower limbs (back squat), carrying out multiple sets of 10–16 repetitions at an intensity of 55–73.5% 1RM, with a 1-minute rest interval. The load was modified when it was perceived as too heavy or too light. Applying the Sayers et al. (34) formula to the results of the study shows that 1 group improved its initial value of 4382.12 W by 2.8%, and the other group improved its initial value of 4575.64 W by 4.96%. The Lehmkuhl et al. (24) study used a combined sample of men and women athletes who were given performance-enhancing supplements. Their training program lasted 8 weeks and consisted of a total-body workout prioritizing maximum strength training for 3 d·wk^{-1} and using multiple sets. As before, if the Sayers et al. (34) formula is applied, it can be shown that the placebo group improved its initial jump value of 4642.22 W by 1.5%. As previously stated, the 3.0% improvement in lower-limb power by the AEG in the current study was significant, although there were no significant differences in power when compared with the CG. This can be explained by the use of nonspecific aquatic devices such as the fins. This material modified the movement pattern of the basic frontal kick and great frontal kick exercises, meaning that the subjects struck the bottom of the swimming pool as a result of the increased length of the limb caused by using this device. This made it difficult to carry out the exercise in technically correct fashion while stabilizing the body. One additional problem of this material used for the lower extremities was that it could have caused some ankle joint pain, and this fact could have limited the intensity, and maintained performance of the movements as the joint was subjected to significant stress. Another factor that could have had a negative effect was the type of test used, despite following the suggestions of previous studies (37) and the fact that the squat-jump really provided evaluation appropriate to the muscle action trained. However, the movement

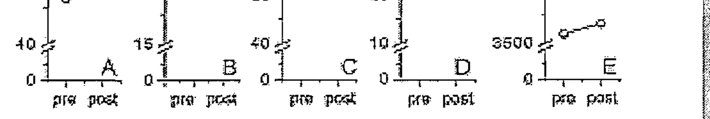

Figure 1. Individual values of the aquatic exercise group for maximum strength before and after 8 weeks of aquatic resistance training. From left to right, the panels represent: A) horizontal bench press (kg), B) arm lateral raise (kg), C) horizontal bench row (kg), D) vertical row (kg), and E) squat-jump (W). The significant differences between the pre- and posttests are indicated by *($p \leq 0.05$) and **($p \leq 0.01$).

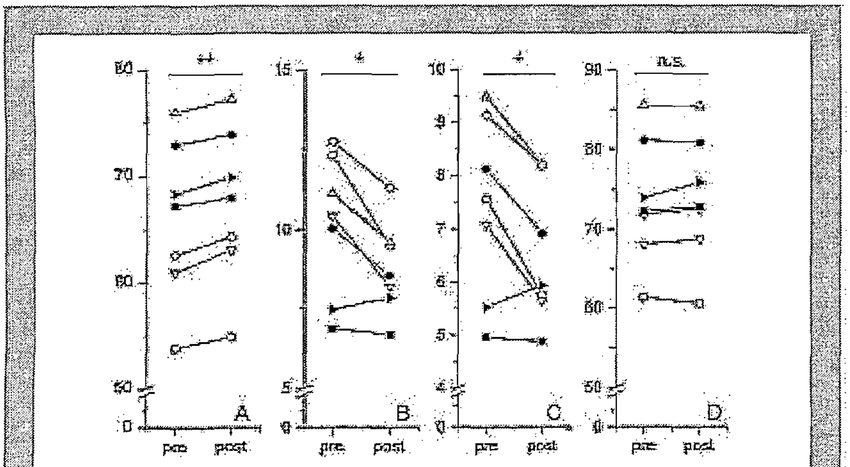

Figure 2. Individual values of the aquatic exercise group for overall body composition before and after 8 weeks of aquatic resistance training. From left to right, the panels represent A) fat-free mass (kg), B) percentage of body fat (%), C) fat mass (kg), and D) body weight (kg). The significant differences between the pre- and posttests are indicated by *($p \le 0.05$) and **($p \le 0.01$). n.s. = no significant difference.

pattern and the type of strength trained showed significant differences. These limiting factors were not present in the Pöyhönen et al. (32) study because Hydro-tone boots were used. These devices do not prevent correct execution of the exercise and do not overload the ankle joint. They also have a greater surface area that allows them to generate greater drag force. The leg extension test used by Pöyhönen et al. (32) was also better suited to the movement pattern trained. It is therefore likely that the limitations of the present investigation contributed to the lack of intergroup differences and the absence of change in the BC of the thigh segment. Thus, there is a need to carry out further studies in which these factors are taken into account, allowing future PARPs to be designed and evaluated more precisely.

One other important factor that should be highlighted is the fact that no relevant eccentric muscle actions have appeared in PARPs carried out using aquatic devices (31,32), which has created questions as to whether aquatic resistance programs can result in increases in strength and muscle mass of young, healthy, physically active subjects. However, physiological adaptations should result whenever the magnitude of muscular stress generated by the muscle action is greater than the normal level of stress to which the muscle group is subjected. The results of the current study support the statement that those PARPs using aquatic devices that prioritize concentric muscle action are effective in increasing both strength and fat-free mass. The fact that this kind of program was based on single-joint movements has possibly favored the very early gains in fat-free mass (32). Despite the fact that dietary modification as a basic factor for increasing fat-free mass was not manipulated while the PARP was being carried out, it should be noted that this kind of PARP did include typical program variables aimed at favoring muscle hypertrophy, such as the rest interval and the number of repetitions performed, the large number of sets per muscle group, the use of preexhaustion methods, the weekly training frequency, and the anabolic environment usually created by programs combining these aspects that also involve many large muscle groups.

Although the diet was not manipulated, the subjects agreed not to change their dietary practices and filled in daily questionnaires during the duration of the study to reduce any confounding effects with the PARP, as was the case with previous studies (37). These were checked every week to ensure that their habits before starting the study had not changed. Thus, the PARP applied led to a significant improvement of 1.285 kg of fat-free mass in only 8 weeks. This increase is even more significant considering that there was a significant reduction in physical activity (outside of the PARP in the AEG) during the course of the semester, which would normally lead to a reduction in fat-free mass, as was seen in the CG. In general terms, the improvements of the AEG are in line with those obtained in other dry-land programs following a similar methodology, obviously excepting the specific aquatic applications. It has been reported that fat-free mass increases by about 2.0 kg after 10–16 weeks of total-body resistance training (2). In another study, Mazzetti et al. (26) submitted young trained men to a classical linear periodized resistance training program emphasizing strength and hypertrophy phases for 12 weeks. In this study, the initial *68.22 kg of fat-free mass in the supervised group increased by* 1.38 kg—an improvement of 2.02% that is very similar to the 1.95% increase in the AEG studied here.

Despite the small reduction in the body fat percentage of the AEG, which is within the error range associated with the determination of body fat via skinfold methods (26), the results also suggest that the PARP applied was significantly effective in the reduction of body fat, despite not being designed for this purpose. The PARP involved extra expenditure of calories that, because it was not compensated for by an increase in the calories provided by the daily diet, caused a negative balance that led to a slight reduction in the fat mass of subjects with very low percentages of body fat. These results are therefore very positive because the PARP created a stimulus that both increased muscle mass and favored an overall reduction in fat—more specifically, that

TABLE 5. Change in body composition by segments.

Variable	Group	Previous value and change		SD (±)	$(p)^1$	$(p)^2$
Arm circumference (cm)	CG	Pre	30.48	1.81	0.142	0.000†
		Change	−0.10	0.12		
	AEG	Pre	30.03	2.18	0.000†	
		Change	+1.33	0.22		
Arm skinfold (mm)	CG	Pre	7.92	2.23	0.288	0.589
		Change	−0.56	1.02		
	AEG	Pre	10.63	4.56	0.095	
		Change	−0.94	1.26		
Arm muscular area (cm2)	CG	Pre	52.48	6.27	0.524	0.000†
		Change	+0.37	1.19		
	AEG	Pre	47.11	6.97	0.000†	
		Change	+5.49	1.99		
Thigh circumference (cm)	CG	Pre	60.48	2.66	0.181	0.71
		Change	−1.12	1.55		
	AEG	Pre	59.57	4.39	0.286	
		Change	+0.64	1.45		
Thigh skinfold (mm)	CG	Pre	11.88	2.85	0.542	0.294
		Change	+1.00	3.36		
	AEG	Pre	12.06	4.53	0.856	
		Change	−0.57	1.51		
Thigh muscular area (cm2)	CG	Pre	291.53	25.28	0.185	0.71
		Change	−10.65	14.89		
	AEG	Pre	283.72	41.92	0.278	
		Change	+6.24	13.84		
Thoracic internal circumference (cm)	CG	Pre	102.88	8.59	0.269	0.948
		Change	−0.90	1.57		
	AEG	Pre	100.84	5.37	0.121	
		Change	−0.96	1.40		
Thoracic external circumference (cm)	CG	Pre	119.20	3.66	0.533	0.880
		Change	−1.12	3.68		
	AEG	Pre	117.64	6.74	0.413	
		Change	−0.84	2.54		
Pectoral skinfold (mm)	CG	Pre	7.04	2.38	0.102	0.113
		Change	−0.52	0.50		
	AEG	Pre	8.77	3.44	0.039*	
		Change	−1.51	1.14		
Waist circumference (cm)	CG	Pre	83.88	3.89	0.004†	0.013†
		Change	−2.56	0.89		
	AEG	Pre	82.60	3.07	0.398	
		Change	−0.54	1.24		
Abdominal skinfold (mm)	CG	Pre	13.32	6.72	0.964	0.052*
		Change	−0.04	1.86		
	AEG	Pre	15.97	4.42	0.009†	
		Change	−2.17	1.50		
Hip circumference (cm)	CG	Pre	100.06	5.25	0.345	0.040*
		Change	−1.78	3.21		
	AEG	Pre	96.49	4.20	0.049*	
		Change	+1.51	1.63		

$(p)^1$ = Statistical intragroup significance; $(p)^2$ = posttest statistical intergroup significance with regard to the change.

*Significant statistical difference ($p \leq 0.05$); †very significant statistical difference ($p \leq 0.01$).

CG = control group; AEG = aquatic exercise group.

located in the pectoral and abdominal region (13.59%)—in fit subjects with excellent BC who only trained at a frequency of 3 d·wk^{-1}. Colado et al. (11) observed that aquatic resistance exercises using aquatic devices showed a certain tendency towards creating greater cardiovascular and metabolic response than dry-land resistance exercises with elastic bands, something possibly caused by the continuous participation of concentric muscle actions and, possibly, by the greater muscular demands made on stabilizing muscles in the aquatic medium. The PARP also used a progressive overload method based on increasing volume by grouping exercises that not only increased the total involvement of the number of muscle groups but also increased the duration of the effort and the number of muscle actions per session. In typical dry-land training, the load is constant for both the eccentric and concentric phases of movement. Conversely, with PARP and aquatic devices, the muscle actions are predominantly concentric for all movements, which may actually result in a higher growth hormone response (22). Therefore, this hormonal response could have a positive effect on improving BC, given the role played by growth hormone in the mobilization of fatty acids for use as an energy substrate, and it could be one of the causes underlying the results regarding the improvements in BC among the AEG. However, specific studies should be carried out to confirm this.

Body composition did not change equally in the upper and lower body, with no significant changes in BC seen in the lower body among the AEG. It is possible that the local training volume applied was too low when compared with that applied to the upper limbs. It is also possible that more time than that used in this program is needed to achieve muscle adaptations in the lower limbs, this not being the case for the upper limbs (1).

Nevertheless, despite the positive effects that can be provided by training programs that prioritize concentric muscle actions, we should be cautious with regard to the fact that eccentric actions do not play a major role in PARPs using aquatic devices, which are typical of sport and of daily life and are usually combined with concentric actions in many motor situations. Thus, it should be recommended that any overall neuromuscular conditioning program should include dry-land exercises that demand such actions for those taking part in a PARP. However, Colado (9) suggests that the fact that eccentric actions are minimized and training is carried out using muscle pairs (agonist/antagonist) could favor a reduction in delayed muscle pain, less risk of injury, greater caloric consumption, and reduced training time. These factors would increase adherence to the programs, routines for functional pairs that are easier to balance, and, as has been shown in this study, fat-free mass and strength.

An important contribution of the current investigation is that it offers a practical solution to one of the main drawbacks of strength training in the aquatic medium, which is control over the intensity of work (7,31) and, consequently, the possibility of objectively quantifying the resistance used. Prior methods were dependent on the subjective criteria of those exercising, who had to perform the exercises to a high speed depending on their effort perception (32,37); such methods therefore offered little control. Through quantification of the pace of movement per minute, with adjustments to a specific targeted number of repetitions according to the specific needs of each exercise and each subject, control of the intensity applied to each set, exercise, and training session could be maintained at all times. This method has provided tangible, objective, and practical criteria with which to monitor aquatic resistance exercises. Finally, it is very important to point out that quantification of the "load" for strength training in water using the methodology proposed here could allow the individual to target any particular program goal (hypertrophy, strength, muscle endurance, power). In conclusion, the present results indicate that a PARP with a cadence of movement monitored and adjusted individually for each exercise and subject using a metronome produces significant improvements in muscular strength, power, and fat-free mass and, thus, seems to be a very effective form of resistance exercise.

PRACTICAL APPLICATIONS

As well as being an effective training method for increasing maximum strength and fat-free mass, the aquatic resistance program has a positive effect on reducing body fat. As with dry-land exercises, these effects appear when the correct, progressive program design is established, meaning that the resistance offered by the water in each of the sets and exercises must be controlled. In the aquatic medium, progressive and well-adapted increases of the "load" or resistance can be applied as long as the subjects use aquatic devices with which they already have been evaluated to find a pace of movement per minute for each exercise that allows them to perform a certain number of repetitions at the initially prescribed perceived intensity. However, for this resource to be valid, we also must ensure that the subjects always maintain the same arm and lever length and the same position of the segments and the aquatic devices that increase the drag force. Therefore, if similar findings are made, we are witnessing a new future for strength training in such different fields as rehabilitation, sports performance, health, and aesthetics.

ACKNOWLEDGMENTS

The authors thank Dr. Carlos Pablos for his support and guidance in the completion of this investigation.

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EFFECTS OF A SHORT-TERM AQUATIC RESISTANCE PROGRAM ON STRENGTH AND BODY COMPOSITION IN FIT YOUNG MEN

JUAN C. COLADO,[1] VICTOR TELLA,[1] N. TRAVIS TRIPLETT,[2,3] AND LUIS M. GONZÁLEZ[1]

[1]*Department of Physical Education and Sports, University of Valencia, Valencia, Spain;* [2]*Neuromuscular Laboratory, Department of Health, Leisure and Exercise Science, Appalachian State University, Boone, North Carolina; and* [3]*Invited Researcher, University of Valencia, Valencia, Spain*

ABSTRACT

Colado, JC, Tella, V, Triplett, NT, and González, LM. Effects of a short-term aquatic resistance program on strength and body composition in fit young men. *J Strength Cond Res* 23(2): 549–559, 2009—This study was designed to analyze the effects of a short-term periodized aquatic resistance program (PARP) on upper-limb maximum strength, leg muscular power, and body composition (BC) in fit young men. Twenty subjects (21.2 ± 1.17 years) were randomly assigned to an exercise or control group; 12 subjects completed the study. The aquatic exercise group (AEG; $n = 7$) participated in an 8-week supervised program of 3 d·wk^{-1}, and the control group (CG; $n = 5$) maintained their regular activities. The PARP consisted of a total-body resistance exercise workout using aquatic devices that increased drag force, with a cadence of movement controlled and adjusted individually for each exercise and subject. The volume and intensity of the program were increased progressively. Submaximal tests were carried out to determine the change in upper-limb maximum strength, as well as a squat-jump test to determine the change in leg muscular power. Four skinfold sites, 6 circumference sites, body weight, and stature were used to determine changes in BC. A significant increase in upper-limb maximum strength and leg muscular power was observed for the AEG. A significant increase also was noted in the circumference and muscular area of the arm, and there were significant decreases in pectoral and abdominal skinfolds. Nevertheless, the circumference, muscular area, and local fat of the lower limbs did not change. There were no significant changes in any variables in the CG. These results indicate that the PARP produces significant improvements in muscular strength, power, and fat-free mass and, thus, seems to be a very effective form of resistance exercise.

KEY WORDS drag force, monitored cadence of movement, periodized

INTRODUCTION

Both the number of physical conditioning activities carried out in water and the number of those exercising have significantly increased in the United States and Europe in recent decades. The physiological and articular benefits offered by the specific properties of this medium (7,38) may have promoted this increase. These activities have traditionally been aimed at and prescribed for those populations with some kind of disability. However, they are currently used both to improve the physical condition of healthy individuals who regularly take part in recreational training (9) and as a complement to improve the performance of athletes (5,16,25,27,33). Although the physiological responses, effects, and benefits offered by performing aerobic exercises in water are well known (8,15), studies are lacking on the potential effects of a program of resistance exercises in water (32). The absence of methodological criteria with which to control resistance objectively and progressively while performing these exercises (30,31) may be one of the reasons for this, and as a result this type of training has not been recommended by academic professionals or used by practitioners.

In general terms, the same program design recommendations should be followed for the specific application of strength training programs in water (31,36). Therefore, to design a strength training program in the aquatic medium, studies (6,7,9,10,12,17,23,28,30–32,36,38) have recommended that it is essential to achieve the combined control of i) the pace of the movement, ii) the size of the aquatic devices that increase the drag force, iii) the length of the lever of the limb being exercised, iv) the hydrodynamic position of the segment mobilized and the aquatic devices used, and v) the

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Address correspondence to Juan C. Colado, juan.colado@uv.es.

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performance of a targeted number of repetitions based on the desired goal. In addition, it should be pointed out that in all cases the individuals exercising carry out the movements with the aquatic devices at a pace determined by a cadence of beats per minute that has been previously identified on the basis of the predicted targeted number of repetitions. It has been shown that the workload in water is always similar as long as the movement is performed at the same pace and under the same exercise conditions (7,12). Thus, to increase the resistance offered by the water, either the pace per minute must be increased or the area of the aquatic device must be increased (7). Therefore, objective criteria exist with which to quantify the progressive increase in the "load" or resistance, marked by the proposed pace per minute and the aquatic device used (7). The moment when neither the pace nor correct performance can be maintained defines when muscular actions are inadequate for the stimulus (29).

No scientific studies have examined the basic aspects of the design of resistance programs in combination with the use of adequate aquatic devices and the performance of movements according to a previously evaluated pace. Although several studies have confirmed the positive adaptations caused by aquatic resistance exercises (3,37,39), many of them display methodological shortcomings when it comes to controlling the resistance generated by the exercises both immediately and in the long term, as well as usually being applied to untrained middle-aged or older subjects with whom it is easier to cause certain adaptations in the early stages of strength training programs. Therefore, to analyze the effects that an aquatic resistance program can have on fit young men regarding maximum strength, muscular power, and body composition (BC), a randomized and supervised study was carried out for which a method was designed to adapt and control exercise intensity objectively. The hypothesis of the current study was that aquatic resistance training can generate positive neuromuscular adaptations in fit men if the resistance applied to the training movements is controlled by a specific cadence of movement for each exercise and subject according to the targeted number of repetitions initially prescribed.

METHODS

Experimental Approach to the Problem

In accordance with the methodology proposed by Kraemer et al. (23) for using elastic devices for strength training, in this study a specific cadence of movement using the same aquatic device to increase drag force was used to complete an 8- to 12-repetition maximum (RM) range with a 10-repetition target. To this end, a cadence of movement was identified for each subject in the aquatic exercise group (AEG) that allowed the subject to achieve the amount of resistance needed to maintain the targeted number of repetitions (RM zone ± 2 rep) while using good technique. The subjects trained using an acoustic metronome throughout the training program, with each individually following the initially identified cadence of movement for each exercise. Whenever necessary, greater resistance was provided by using a faster cadence of movement to maintain the targeted number of repetitions. At least 1 trained monitor was always present to corroborate the correct application of this methodology. Muscle function and BC were tested before and after the resistance training program to determine its effects. All measurements and practical procedures were always carried out by the same researchers, all of whom had experience with this kind of trial. All subjects were continually encouraged, and the laboratory conditions were always the same. Pre- and posttests were filmed, and the film was then checked to ensure the validity of the procedures followed. The study was approved by a research commission and by the Department of Physical Education and Sports from the University of Valencia (Spain).

Subjects

Twenty men volunteers from third-year students at the Faculty of the Sciences of Physical Activity and Sports at the University of Valencia (Spain) were randomly assigned into a control group (CG; 8 subjects) and an AEG (12 subjects), with no significant differences ($p > 0.05$) in any intergroup baseline measurement. All subjects were physically active as they performed 5.08 ± 1.5 $\text{d}\cdot\text{wk}^{-1}$ of varied physical training at moderate intensity for at least 20 minutes, and all had done so for at least 6 months before the study. They did not normally perform resistance exercises on dry land, and they never had performed aquatic resistance exercises. All subjects signed an agreement by which they committed themselves, for the duration of the study, not to carry out any specific physical activity for strength training in their free time, to maintain their habitual lifestyle and eating habits, and not to take performance-enhancing substances (after prior corroboration that they never had taken these substances). The subjects did not suffer any cardiovascular, neuromuscular, orthopedic, or psychological disorders. All subjects were informed of the nature of the study before volunteering to take part in it. To evaluate any possible interference with the training program followed in the study, and to better understand certain results obtained, each subject was supplied with a diary in which he listed the type of physical activity he had carried out during the day, his diet, his rest periods, and his feelings during the aquatic resistance training sessions. Finally, after the usual withdrawals and eliminations associated with any unremunerated experimental study, the final make-up of the groups was as follows: a) AEG: $n = 7$, 21 ± 1 years, 173.96 ± 4.97 cm, 73.43 ± 7.97 kg; b) CG: $n = 5$, 21.4 ± 1.34 years, 178.12 ± 4.08 cm, 76.38 ± 5.03 kg.

Body Composition

All measurements were carried out by the same fully trained individual under identical environmental conditions using exactly the same instruments. A Harpenden skinfold caliper was used to measure skinfolds, and the average of 2 trials was used except in the case in which the measurements differed by more than 2.0 mm. In this case, a third measurement was obtained, and the mean value was used. The skinfolds measured were those of the right-hand side of the chest, abdomen, and thigh, following the usual protocol (18). In addition, a skinfold was taken from the brachial triceps region of the right arm for later analysis. Body density was calculated (21), and the value was used to determine body fat percentage by applying the Siri formula (35) for Caucasian men; subsequently, fat-free mass was determined. In addition, the circumferences of the relaxed right arm, the internal and thoracic region at shoulder height at maximum inspiration, the relaxed hip, and the upper thigh were measured. We also measured fasting body weight and height using the spinal column extension method and normal procedures for these measurements (18). Finally, the muscle area of the arm and thigh were determined by using the above measurements and applying the formulas used by Huygens et al. (20).

Procedures

It was scrupulously ensured that the correct range and technique were used for each exercise during the tests. All subjects were required to perform a standardized warm-up. Two measurement sessions with 48 hours of separation between them were carried out for both the initial and final tests, and there were 72 hours separating the final training session from the first posttest evaluation. The best result for each variable measured was taken for analysis. The intraclass correlation coefficient was calculated from the measurements of the pre- and posttests of the control group. For the anthropometric and strength variables, the intraclass correlation coefficient values for our protocols ranged between 0.87 and 0.98 and between 0.82 and 0.87, respectively.

Maximum Strength. The exercises chosen for the dry-land evaluation involved the same muscle groups and working angles exercised during the periodized aquatic resistance program (PARP) in as similar a fashion as possible. The exercises used and the order of evaluation were always the same, which prevented any possible interference with performance that could be a result of the order in which the exercises were carried out. The order was as follows: a) vertical row, b) horizontal bench press, c) horizontal bench row, d) arm lateral raise, and e) squat-jump. Previously calibrated standard materials were used, consisting of bars with diameters of2.5 cm and weights of11 kg, dumbbells with diameters of 2.5 cm and weights of 2.5 kg, weight plates with standard features, collars, and standard supports. Subjects were familiarized with each exercise, and their technique was checked before the performance of each test. A submaximal test only allowing a maximum of 6 repetitions until muscular failure with correct technique was used (14). A submaximal test was used because a large number of muscle groups were evaluated by means of different tests, and it was necessary to the quality and validity of the tests to minimize fatigue of the subjects. If a subject exceeded the number of repetitions, he rested and then tried again with a higher load. The Brzycki formula (4) was used to calculate maximal strength from the submaximal repetitions.

Power. To identify the evolution of lower-limb muscle power, the static vertical jump or squat-jump test was used because it also exclusively assesses the concentric muscle action that characterized the PARP used in this study. It was performed using the recommendations of Lehmkuhl et al. (24). The muscular power of each vertical jump was estimated by applying the prediction equation of Sayers et al. (34).

Periodized Aquatic Resistance Training Program

Exercises. Because the subjects were not used to aquatic resistance exercises, they were taught the correct technique for performing them before starting the training program. The researchers explained the exercises to the group, and each subject then carried them out under supervision. The criteria for correct technical performance were those described by Colado (9), and the exercises are described in Table 1. The temperature of the water in the swimming pool where the training program took place was 28 ± 1° C, and the depth of immersion was always such as to allow the exercises to be carried out in a technically correct fashion. Standard materials were used during the training program. For example, the gloves had a projected area of 293 cm^2, the fins had a projected area of 430 cm^2, and the boards had a projected area of 874 cm^2. Noodles were used to maintain the horizontal flotation position in the exercises training the abdominal musculature.

Resistance Identification. A Wittner metronome and a digital audio editing program were used to record a compact disc with 12 tracks corresponding to different paces and ranging from 46 beats per minute to 102 beats per minute. Each of the tracks was thoroughly checked to guarantee that they did not contain alterations to the preset pace. The subjects initially used the aquatic devices to carry out the basic exercises prescribed at a pace determined by a cadence of beats per minute chosen on the basis of pilot tests and the prior experience of the researchers. This meant that the subjects had to match their movements to the individual beats of the tracks recorded on the compact disc. Those subjects who were not able to generate enough resistance from the water to reach muscle failure with the preset number of repetitions at the pace initially planned and without varying their technique took a rest period and then increased the pace by choosing the next track. Similarly, the subjects for whom the pace was too difficult to reach the prescribed number of repetitions chose the previous track after the rest period. This allowed them to obtain the initial "load" after identifying the track offering the optimal pace to be used by each subject for each of the exercises. From then on, the "load" was adjusted to the aquatic movement by changing the track. The subjects repeated the process after resting for 2 hours to ensure that the track chosen for each exercise was correct. This test was carried out 48 hours after having carried out the dry-land pretests to determine maximum strength and muscular power. Table 1 also shows the beats per minute (pace) most commonly used for each of the basic training program exercises.

Table 1. Exercises used in the different cycles of the periodized aquatic resistance program (PARP).

Device name	Exercise name		Pace*	Description of the joint movements
Gloves	Horizontal shoulder ab-adduction	H.Sh Ab/d	69	Horizontal abduction and adduction of the shoulders
	Oblique shoulder ab-adduction	O.Sh Ab/d	69	Oblique abduction and adduction of the shoulders
	Vertical shoulder ab-adduction	V.Sh Ab/d	72	Abduction and adduction of the shoulders
	Elbow flexion-extension	Elb F/E	72	Flexion and extension of the elbows
Boards	Horizontal press-pull	H P/P		On a horizontal plane: flexion and extension of the shoulders and elbows
	Oblique press-pull	O P/P		In an oblique direction: flexion and extension of the shoulders and elbows
	Vertical press-pull	V P/P		On a frontal plane: abduction and adduction of the shoulders and flexion and extension of the elbows
	Arms press-pull	A P/P		Flexion and extension of the elbows
Fins	Frontal kick	FK	60	Flexion and extension of the knee with a small supported flexion of the hip
	Great frontal kick	GFK	46	Flexion and extension of the knee and hip
Fins and boards	Dorsal resisted batter	DRB		Dorsal resisted batter with the boards in every hand and below the body
	Lateral resisted batter	LRB		Lateral resisted batter with the board held with the hands over the head
Noodles	Frontal top crunch	FTC		Frontal top crunch in horizontal position and with a noodle in lengthwise direction
	Frontal low crunch	FLC		Frontal low crunch in horizontal position and with a noodle in longitudinal direction

*Cadence of movement (bpm) most typically applied to each of the basic exercises of the training program.

Training Program. One member of the research group was always present during the training sessions to ensure that the program was performed correctly. Training compliance for the subjects was 95%. The exercises performed during warm-up and cool-down were standardized to avoid any possible interference with the aims of the study. Despite the fact that a short-term program was used to maximize training effects, and given that the subjects were physically active, a periodized model for strength training was used, with a total duration of 8 weeks, divided into 2 consecutive 3-week cycles and a final 2-week cycle, with a frequency of 3 sessions a week. To vary the training stimulus, the volume was modified in each cycle by an overall increase in the sets and the exercises. Table 2 shows the methodological criteria followed to perform the different cycles and the exercises according to the specific association with the technique of preexhaustion overloading of agonist muscle groups. The exercises for dynamic training of the abdominal musculature were performed following a repetition speed of 1 second for the outward stage and 2 seconds for the return stage to the initial position.

As mentioned previously, a very high volume was applied in this PARP. With the use of aquatic resistance devices, all movements are concentric only, such that the opposing muscles around a joint are primarily trained in the concentric manner in each direction of joint movement, which serves to increase the overall training volume compared with that of dry-land training. The recovery time between sets was always 90 seconds, which is typical of the 8- to 12-repetition range. These rest periods, combined with the significant length of the sessions, meant that the subjects carried out slow jogging movements and/or slow active range-of-motion exercises of different joints during the recovery periods to avoid the risk of suffering from hypothermia, with some subjects even training while wearing thin thermal garments.

Statistical Analyses

The data gathered were analyzed using the SPSS program. The homogeneity of the dependent variables was checked using the Levene test ($p > 0.05$), and their normality was evaluated using Kolgomorov-Smirnov statistics ($p > 0.05$). Descriptive statistics were then calculated. t-Tests were used for within-group differences, and ANOVA was used to analyze independent (between-group) samples. All differences were accepted as statistically significant at $p \leq 0.05$ and as very significant at $p \leq 0.01$.

Table 2. Periodized aquatic resistance program (PARP) followed in the study.

Cycle number		Exercises and workout order	Sets per exercise	Repetitions per set		
				1	2	3
1	1°	Horizontal shoulder ab-adduction	3	8–12		
	2°	Oblique shoulder ab-adduction	3	8–12		
	3°	Vertical shoulder ab-adduction	3	8–12		
	4°	Elbow flexion-extension	5	8–12		
	5°	Frontal kick	5	8–12		
	6°	Great frontal kick	5	8–12		
	7°	Frontal top crunch	4	15		
2	1°	(1) Oblique shoulder ab-adduction + (2) oblique press-pull	3	8–12	15	
	2°	(1) Vertical shoulder ab-adduction + (2) vertical press-pull	3	8–12	15	
	3°	(1) Horizontal shoulder ab-adduction + (2) horizontal press-pull	3	8–12	15	
	4°	(1) Elbow flexion-extension + (2) arms press-pull	5	8–12	15	
	5°	(1) Great frontal kick + (2) lateral resisted batter	5	8–12	15	
	6°	(1) Frontal kick + (2) dorsal resisted batter	5	8–12	15	
	7°	(1) Frontal low crunch + (2) frontal top crunch	4	15	15	
3	1°	(1) Vertical shoulder ab-adduction + (2) vertical press-pull + (3) vertical shoulder ab-adduction	4	8–12	15	8–12
	2°	(1) Horizontal shoulder ab-adduction + (2) horizontal press-pull + (3) horizontal shoulder ab-adduction	4	8–12	15	8–12
	3°	(1) Elbow flexion-extension + (2) arms press-pull + (3) elbow flexion-extension	5	8–12	15	8–12
	4°	(1) Frontal kick + (2) dorsal resisted batter + (3) frontal kick	5	8–12	15	8–12
	5°	(1) Great frontal kick + (2) lateral resisted batter + (3) great frontal kick	5	8–12	15	8–12
	6°	(1) Frontal top crunch + (2) frontal low crunch + (3) frontal top crunch	5	15	15	15

Rest interval between sets: 90 seconds.

RESULTS

Tables 3 and 4 show the effects caused by the PARP on muscular fitness and global BC, stating the baseline value and final absolute change after comparing the initial value with that obtained after the 8 weeks of training. Additionally, Figures 1 and 2 show the individual values of the AEG for the variables indicated.

The PARP led to significant improvements in both the maximum strength of the upper limbs and in the power of the lower limbs (Table 3). The PARP also led to significant increases in fat-free mass (Table 4) and arm/hip circumference (Table 5). In addition, the PARP significantly reduced local fat in the abdominal and pectoral region (Table 5) together with overall fat mass (Table 4), there being a significantly positive correlation in the AEG between weight increase and reduction of body fat mass ($p \leq 0.01$). However, the PARP did not lead to any modification of lower-limb BC.

DISCUSSION

Except for the study carried out by Pöyhönen et al. (32) analyzing the effects caused by a PARP with movements performed with aquatic devices on the strength and BC of young, physically active women, there are no other scientific studies focusing on the effects that a total-body workout PARP using aquatic devices could have on other populations, especially where intensity is controlled objectively. Therefore, in the current investigation it was necessary to create a methodology that had been lacking up to now. The method used here to control intensity in aquatic strength training through joint control of the pace of movement and target number of repetitions is in agreement with current recommendations for controlling training against resistance (29). The results highlight the fact that the PARP developed was effective in increasing both strength and fat-free mass with only 8 weeks of training, despite the fact that there are aquatic devices available that are more appropriate because they are larger and more ergonomically designed than those used in the current investigation, and even though the subject attrition reduced the final statistical power, which is accounted for when making generalizations about the results obtained in this investigation.

The results provided by this study show a clear increase in the maximum strength of upper-limb muscle groups in young, healthy, physically fit men with an intermediate level of muscular fitness. Faced with the lack of equivalent studies in

Table 3. Change in maximum strength.

Variable	Group	Previous value and change		*SD*(±)	$(p)^1$	$(p)^2$
Horizontal bench press (kg)	CG	Pre	64.31	6.77	0.209	0.004†
		Change	−2.12	3.17		
	AEG	Pre	62.28	9.50	0.003†	
		Change	+3.19	1.76		
Arm lateral raise (kg)	CG	Pre	25.77	2.99	0.686	0.465
		Change	−0.01	2.55		
	AEG	Pre	23.74	3.37	0.044*	
		Change	+2.30	2.40		
Horizontal bench row (kg)	CG	Pre	69.67	5.02	0.541	0.154
		Change	+0.95	3.18		
	AEG	Pre	72.38	13.32	0.033*	
		Change	+4.46	4.29		
Vertical row (kg)	CG	Pre	44.82	2.42	0.235	0.028*
		Change	+1.44	2.1		
	AEG	Pre	44.70	10.91	0.018*	
		Change	+4.88	2.35		
Squat-jump (W)	CG	Pre	4694.95	437.54	0.658	0.210
		Change	−89.51	419.07		
	AEG	Pre	4471.07	581.37	0.045*	
		Change	+135.62	141.84		

$(p)^1$ = Statistical intragroup significance; $(p)^2$ = posttest statistical intergroup significance with regard to the change.
CG = control group; AEG = aquatic exercise group.
*Significant statistical difference ($p \leq 0.05$); †very significant statistical difference ($p \leq 0.01$).

the aquatic medium with which to compare the results, in this analysis the results can only be compared with those from other programs carried out on dry land, in which the testing and training were done with the same exercise. The results obtained with the PARP are similar to those obtained in other studies using resistance devices on dry land, although they were applied using methods and subjects with slightly different characteristics to the AEG. For example, the first 8 weeks of the study of Hostler et al. (19) used traditional training methods for improving maximum strength in the horizontal bench press exercise (2–3 d·wk^{-1}, 3 sets of 7 RM). The young men chosen were physically active and had not carried out any specific strength training in the previous 6 months. The relative strength of the 2 groups of men analyzed was significantly higher than that of the subjects of the AEG (1.22 and 1, respectively, vs. 0.85 for the AEG). The subjects of the Hostler et al. study improved their 1RM by 4.1 and 5.1 kg in 8 weeks (increases of 4.89 and 6.47%, respectively), and the AEG subjects improved by 3.19 kg (an increase of 5.12%), with the dry-land groups showing respective relative strength improvements of 3.28 and 5.82% compared with an improvement of 4.70% for the AEG. Thus, the studies analyzed show how the improvement in the maximum strength of the AEG in the bench press exercise is similar to that obtained by those participating in dry-land programs, even though the subjects in the current investigation performed the horizontal press-pull during part of the aquatic training program, which is only moderately equated to the bench press. This may have limited the strength gains in the bench press test of the subjects in the current investigation.

However, as was previously mentioned, it is very important to point out that concentric muscle actions were prioritized in the PARP, whereas tests were carried out that required combined concentric and eccentric muscle actions to evaluate the change in maximum strength in the AEG. It is generally accepted that gains in strength shown in a test are greater when the test exercise, training exercise, type of muscle action required, and type of resistance to be overcome are similar. Therefore, the most appropriate evaluation test for assessing the current program adaptations should focus exclusively on the concentric phase of maximum dynamic strength (32,37). However, the effects on maximum strength caused by participation in this study were evaluated using exercises of a combined concentric and eccentric nature, using weight equipment that is typically used in dry-land programs Although this is a possible limitation to the current investigation in defining the real improvements of the program followed, it was necessary because improvements in muscular fitness achieved with aquatic exercise programs will usually be transferred and applied to performance on dry land.

Regarding the training effects on muscular power of the lower limbs, the AEG showed a significant improvement of 3.03% over its initial value of 4471.07 W. Although existing studies have shown that the power of the lower limbs is improved by following aquatic training programs (25,27,33), these studies are solely based on carrying out multijump exercises, unlike the PARP followed in our study where only traditional open–kinetic-chain resistance exercises were performed. The dry-land studies of Coutts et al. (13) and Lehmkuhl et al. (24) can be used to compare the results of our PARP with their programs because they also used the squat-jump as the evaluation test, trained the strength of the lower limbs by using common open– and closed–kinetic-chain strength exercises, and at no time used multijump training

Table 4. Change in overall body composition.

Variable	Group	Previous value and change		$SD(\pm)$	$(p)^1$	$(p)^2$
Fat-free mass (kg)	CG	Pre	69.58	3.03	0.043*	0.000†
		Change	−1.42	0.48		
	AEG	Pre	66.01	7.53	0.000†	
		Change	+1.28	0.47		
Percentage of body fat (%)	CG	Pre	8.78	3.24	0.875	0.092
		Change	+0.12	1.59		
	AEG	Pre	10.13	2.25	0.019*	
		Change	−1.32	1.10		
Fat mass (kg)	CG	Pre	6.80	2.90	0.893	0.194
		Change	−0.02	1.44		
	AEG	Pre	7.42	1.71	0.023*	
		Change	−0.91	0.79		
Body weight(kg)	CG	Pre	76.38	5.03	0.112	0.029*
		Change	−1.44	1.59		
	AEG	Pre	73.43	7.98	0.374	
		Change	+0.37	0.88		

$(p)^1$ = Statistical intragroup significance; $(p)^2$ = posttest statistical intergroup significance with regard to the change.
CG = control group; AEG = aquatic exercise group.
*Significant statistical difference ($p \leq 0.05$); †very significant statistical difference ($p \leq 0.01$).

resources. The 2 groups of subjects in the Coutts et al. (13) study trained for the first 6 weeks at 3 d·wk^{-1}, with a total-body workout of 7 exercises including one for the lower limbs (back squat), carrying out multiple sets of 10–16 repetitions at an intensity of 55–73.5% 1RM, with a 1-minute rest interval. The load was modified when it was perceived as too heavy or too light. Applying the Sayers et al. (34) formula to the results of the study shows that 1 group improved its initial value of 4382.12 W by 2.8%, and the other group improved its initial value of 4575.64 W by 4.96%. The Lehmkuhl et al. (24) study used a combined sample of men and women athletes who were given performance-enhancing supplements. Their training program lasted 8 weeks and consisted of a total-body workout prioritizing maximum strength training for 3 d·wk^{-1} and using multiple sets. As before, if the Sayers et al. (34) formula is applied, it can be shown that the placebo group improved its initial jump value of 4642.22 W by 1.5%. As previously stated, the 3.0% improvement in lower-limb power by the AEG in the current study was significant, although there were no significant differences in power when compared with the CG. This can be explained by the use of nonspecific aquatic devices such as the fins. This material modified the movement pattern of the basic frontal kick and great frontal kick exercises, meaning that the subjects struck the bottom of the swimming pool as a result of the increased length of the limb caused by using this device. This made it difficult to carry out the exercise in technically correct fashion while stabilizing the body. One additional problem of this material used for the lower extremities was that it could have caused some ankle joint pain, and this fact could have limited the intensity, and maintained performance of the movements as the joint was subjected to significant stress. Another factor that could have had a negative effect was the type of test used, despite following the suggestions of previous studies (37) and the fact that the squat-jump really provided evaluation appropriate to the muscle action trained. However, the movement

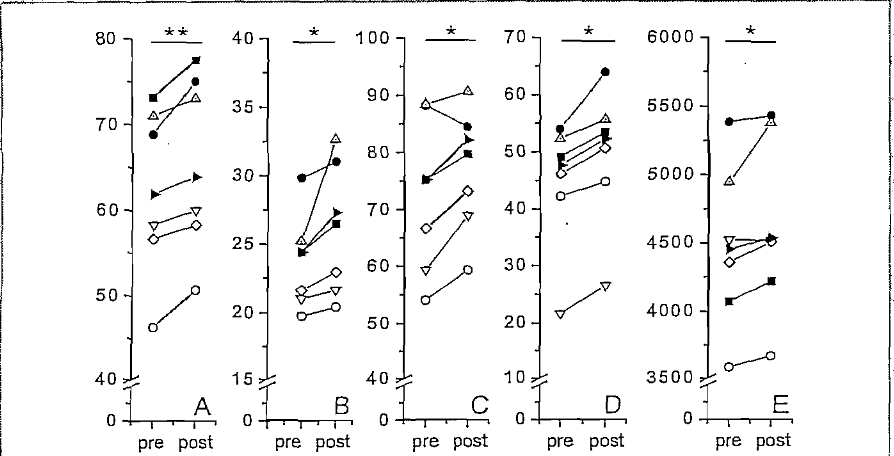

Figure 1. Individual values of the aquatic exercise group for maximum strength before and after 8 weeks of aquatic resistance training. From left to right, the panels represent A) horizontal bench press (kg), B) arm lateral raise (kg), C) horizontal bench row (kg), D) vertical row (kg), and E) squat-jump (W). The significant differences between the pre- and posttests are indicated by *($p \leq 0.05$) and **($p \leq 0.01$).

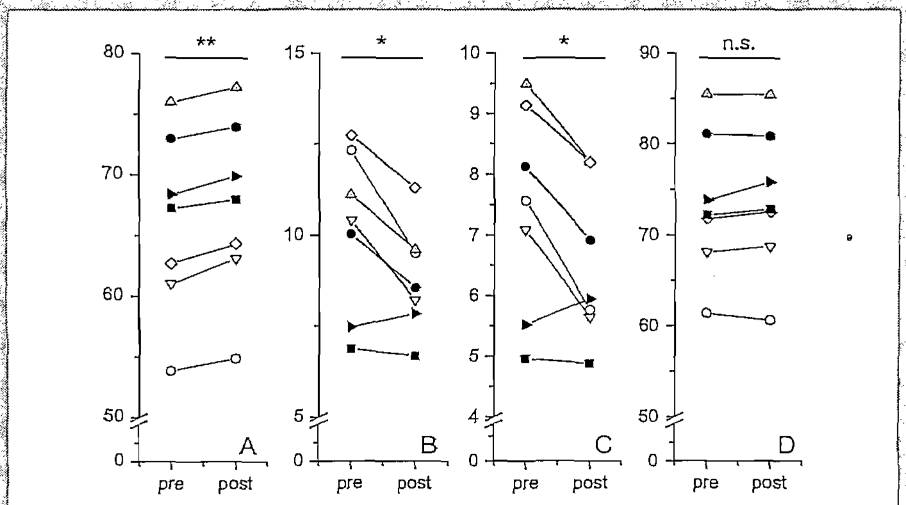

Figure 2. Individual values of the aquatic exercise group for overall body composition before and after 8 weeks of aquatic resistance training. From left to right, the panels represent A) fat-free mass (kg), B) percentage of body fat (%), C) fat mass (kg), and D) body weight (kg). The significant differences between the pre- and posttests are indicated by *($p \leq 0{,}05$) and **($p \leq 0.01$). n.s. = no significant difference.

pattern and the type of strength trained showed significant differences. These limiting factors were not present in the Pöyhönen et al. (32) study because Hydro-tone boots were used. These devices do not prevent correct execution of the exercise and do not overload the ankle joint. They also have a greater surface area that allows them to generate greater drag force. The leg extension test used by Pöyhönen et al. (32) was also better suited to the movement pattern trained. It is therefore likely that the limitations of the present investigation contributed to the lack of intergroup differences and the absence of change in the BC of the thigh segment. Thus, there is a need to carry out further studies in which these factors are taken into account, allowing future PARPs to be designed and evaluated more precisely.

One other important factor that should be highlighted is the fact that no relevant eccentric muscle actions have appeared in PARPs carried out using aquatic devices (31,32), which has created questions as to whether aquatic resistance programs can result in increases in strength and muscle mass of young, healthy, physically active subjects. However, physiological adaptations should result whenever the magnitude of muscular stress generated by the muscle action is greater than the normal level of stress to which the muscle group is subjected. The results of the current study support the statement that those PARPs using aquatic devices that prioritize concentric muscle action are effective in increasing both strength and fat-free mass. The fact that this kind of program was based on single-joint movements has possibly favored the very early gains in fat-free mass (32). Despite the fact that dietary modification as a basic factor for increasing fat-free mass was not manipulated while the PARP was being carried out, it should be noted that this kind of PARP did include typical program variables aimed at favoring muscle hypertrophy, such as the rest interval and the number of repetitions performed, the large number of sets per muscle group, the use of preexhaustion methods, the weekly training frequency, and the anabolic environment usually created by programs combining these aspects that also involve many large muscle groups.

Although the diet was not manipulated, the subjects agreed not to change their dietary practices and filled in daily questionnaires during the duration of the study to reduce any confounding effects with the PARP, as was the case with previous studies (37). These were checked every week to ensure that their habits before starting the study had not changed. Thus, the PARP applied led to a significant improvement of 1.285 kg of fat-free mass in only 8 weeks. This increase is even more significant considering that there was a significant reduction in physical activity (outside of the PARP in the AEG) during the course of the semester, which would normally lead to a reduction in fat-free mass, as was seen in the CG. In general terms, the improvements of the AEG are in line with those obtained in other dry-land programs following a similar methodology, obviously excepting the specific aquatic applications. It has been reported that fat-free mass increases by about 2.0 kg after 10–16 weeks of total-body resistance training (2). In another study, Mazzetti et al. (26) submitted young trained men to a classical linear periodized resistance training program emphasizing strength and hypertrophy phases for 12 weeks. In this study, the initial 68.22 kg of fat-free mass in the supervised group increased by 1.38 kg–an improvement of 2.02% that is very similar to the 1.95% increase in the AEG studied here.

Despite the small reduction in the body fat percentage of the AEG, which is within the error range associated with the determination of body fat via skinfold methods (26), the results also suggest that the PARP applied was significantly effective in the reduction of body fat, despite not being designed for this purpose. The PARP involved extra expenditure of calories that, because it was not compensated for by an increase in the calories provided by the daily diet, caused a negative balance that led to a slight reduction in the fat mass of subjects with very low percentages of body fat. These results are therefore very positive because the PARP created a stimulus that both increased muscle mass and favored an overall reduction in fat–more specifically, that

Table 5. Change in body composition by segments.

Variable	Group	Previous value and change		$SD(\pm)$	$(p)^1$	$(p)^2$
Arm circumference (cm)	CG	Pre	30.48	1.81	0.142	0.000†
		Change	−0.10	0.12		
	AEG	Pre	30.03	2.18	0.000†	
		Change	+1.33	0.22		
Arm skinfold (mm)	CG	Pre	7.92	2.23	0.288	0.589
		Change	−0.56	1.02		
	AEG	Pre	10.63	4.56	0.095	
		Change	−0.94	1.26		
Arm muscular area (cm2)	CG	Pre	52.48	6.27	0.524	0.000†
		Change	+0.37	1.19		
	AEG	Pre	47.11	6.97	0.000†	
		Change	+5.49	1.99		
Thigh circumference (cm)	CG	Pre	60.48	2.66	0.181	0.71
		Change	−1.12	1.55		
	AEG	Pre	59.57	4.39	0.286	
		Change	+0.64	1.45		
Thigh skinfold (mm)	CG	Pre	11.88	2.85	0.542	0.294
		Change	+1.00	3.36		
	AEG	Pre	12.06	4.53	0.356	
		Change	−0.57	1.51		
Thigh muscular area (cm2)	CG	Pre	291.53	25.28	0.185	0.71
		Change	−10.65	14.89		
	AEG	Pre	283.72	41.92	0.278	
		Change	+6.24	13.84		
Thoracic internal circumference (cm)	CG	Pre	102.88	3.59	0.269	0.948
		Change	−0.90	1.57		
	AEG	Pre	100.84	5.37	0.121	
		Change	−0.96	1.40		
Thoracic external circumference (cm)	CG	Pre	119.20	3.66	0.533	0.880
		Change	−1.12	3.68		
	AEG	Pre	117.64	6.74	0.413	
		Change	−0.84	2.54		
Pectoral skinfold (mm)	CG	Pre	7.04	2.38	0.102	0.113
		Change	−0.52	0.50		
	AEG	Pre	8.77	3.44	0.039*	
		Change	−1.51	1.14		
Waist circumference (cm)	CG	Pre	83.88	3.89	0.004†	0.013†
		Change	−2.56	0.99		
	AEG	Pre	82.60	3.07	0.398	
		Change	−0.54	1.24		
Abdominal skinfold (mm)	CG	Pre	13.32	6.72	0.964	0.052*
		Change	−0.04	1.86		
	AEG	Pre	15.97	4.42	0.009†	
		Change	−2.17	1.50		
Hip circumference (cm)	CG	Pre	100.06	5.25	0.345	0.040*
		Change	−1.78	3.21		
	AEG	Pre	96.49	4.20	0.049*	
		Change	+1.51	1.63		

$(p)^1$ = Statistical intragroup significance; $(p)^2$ = posttest statistical intergroup significance with regard to the change.

*Significant statistical difference ($p \leq 0.05$); †very significant statistical difference ($p \leq 0.01$).

CG = control group; AEG = aquatic exercise group.

located in the pectoral and abdominal region (13.59%)—in fit subjects with excellent BC who only trained at a frequency of 3 d·wk^{-1}. Colado et al. (11) observed that aquatic resistance exercises using aquatic devices showed a certain tendency towards creating greater cardiovascular and metabolic response than dry-land resistance exercises with elastic bands, something possibly caused by the continuous participation of concentric muscle actions and, possibly, by the greater muscular demands made on stabilizing muscles in the aquatic medium. The PARP also used a progressive overload method based on increasing volume by grouping exercises that not only increased the total involvement of the number of muscle groups but also increased the duration of the effort and the number of muscle actions per session. In typical dry-land training, the load is constant for both the eccentric and concentric phases of movement. Conversely, with PARP and aquatic devices, the muscle actions are predominantly concentric for all movements, which may actually result in a higher growth hormone response (22). Therefore, this hormonal response could have a positive effect on improving BC, given the role played by growth hormone in the mobilization of fatty acids for use as an energy substrate, and it could be one of the causes underlying the results regarding the improvements in BC among the AEG. However, specific studies should be carried out to confirm this.

Body composition did not change equally in the upper and lower body, with no significant changes in BC seen in the lower body among the AEG. It is possible that the local training volume applied was too low when compared with that applied to the upper limbs. It is also possible that more time than that used in this program is needed to achieve muscle adaptations in the lower limbs, this not being the case for the upper limbs (1).

Nevertheless, despite the positive effects that can be provided by training programs that prioritize concentric muscle actions, we should be cautious with regard to the fact that eccentric actions do not play a major role in PARPs using aquatic devices, which are typical of sport and of daily life and are usually combined with concentric actions in many motor situations. Thus, it should be recommended that any overall neuromuscular conditioning program should include dry-land exercises that demand such actions for those taking part in a PARP. However, Colado (9) suggests that the fact that eccentric actions are minimized and training is carried out using muscle pairs (agonist/antagonist) could favor a reduction in delayed muscle pain, less risk of injury, greater calorie consumption, and reduced training time. These factors would increase adherence to the programs, routines for functional pairs that are easier to balance, and, as has been shown in this study, fat-free mass and strength.

An important contribution of the current investigation is that it offers a practical solution to one of the main drawbacks of strength training in the aquatic medium, which is control over the intensity of work (7,31) and, consequently, the possibility of objectively quantifying the resistance used. Prior methods were dependent on the subjective criteria of those exercising, who had to perform the exercises to a high speed depending on their effort perception (32,37); such methods therefore offered little control. Through quantification of the pace of movement per minute, with adjustments to a specific targeted number of repetitions according to the specific needs of each exercise and each subject, control of the intensity applied to each set, exercise, and training session could be maintained at all times. This method has provided tangible, objective, and practical criteria with which to monitor aquatic resistance exercises. Finally, it is very important to point out that quantification of the "load" for strength training in water using the methodology proposed here could allow the individual to target any particular program goal (hypertrophy, strength, muscle endurance, power). In conclusion, the present results indicate that a PARP with a cadence of movement monitored and adjusted individually for each exercise and subject using a metronome produces significant improvements in muscular strength, power, and fat-free mass and, thus, seems to be a very effective form of resistance exercise.

Practical Applications

As well as being an effective training method for increasing maximum strength and fat-free mass, the aquatic resistance program has a positive effect on reducing body fat. As with dry-land exercises, these effects appear when the correct, progressive program design is established, meaning that the resistance offered by the water in each of the sets and exercises must be controlled. In the aquatic medium, progressive and well-adapted increases of the "load" or resistance can be applied as long as the subjects use aquatic devices with which they already have been evaluated to find a pace of movement per minute for each exercise that allows them to perform a certain number of repetitions at the initially prescribed perceived intensity. However, for this resource to be valid, we also must ensure that the subjects always maintain the same arm and lever length and the same position of the segments and the aquatic devices that increase the drag force. Therefore, if similar findings are made, we are witnessing a new future for strength training in such different fields as rehabilitation, sports performance, health, and aesthetics.

Acknowledgments

The authors thank Dr. Carlos Pablos for his support and guidance in the completion of this investigation.

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